TRANSFORMATION OF ORGANIC SOLID WASTE INTO NUTRIENT RICH COMPOST USING EARTHWORM

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EXAMINATION ROLL NO. MS-080704

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The Author

ABSTRUCT

Household and farm yard solid wastes are mainly from domestic and agricultural recedes containing recyclable substances, compostable organic matter and others. With rapid increase in population and manifold increase of agricultural productivity, the generation of household solid wastes and agricultural by products has increased several folds during last few years. Disposal of solid wastes can be done by methods like land filling, incineration, recycling, conversion into biogas, disposal into sea and composting. Vermicomposting is one of the recycling technologies which will improve the quality of the products. The present study aims to find out the possibility of utilization of household and agricultural organic wastes for vermiculture. Earthworm *E. fetida* cultured in charies containing soil alone (control - T1), cow dung and saw dust (T2), cow dung , saw dust and green leaves (T3), cow dung, waste paper, saw dust, kitchen garbage and green leaves (T4), cow dung, waste paper, saw dust, kitchen garbage, green leaves and water hyacinth (T5) and cow dung, waste paper, saw dust, kitchen garbage, green leaves, water hyacinth and rice straw(T6) for 80 days. Nutrient values were determined from the compost and compared with that of the control. From these results, it was found that *E. fetida* is able to use the used materials as feed stock and mineralize them into nutrient rich compost. At the same time the study shows that increased use of organic household and agricultural waste for vermicomposting increases the proportion of both plant macro (N, P, K) and micro nutrient (S, Cu , Zn) in the output worm casting (vermicompost).

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ACCRONIMS

ABBREVIATED FORM	ELABORATE FORM
BRRI	BANGLADESH RICE RESEARCH INSTITUTE
CFT	CUBIC FEET
C/N	CARBON NITROGEN RATIO
C: N	CARBON NITROGEN RATIO
CO_2	CARBON DI OXIDE
Cu	COPPER
E. foetida	Eisenia foetida
HYV	HIGH YIELDING VARIETY
Kg	KILO GRAM
MOA	MINISTRY OF AGRICULTURE
NPK	NITROGEN PHOSPHORUS POTASSIUM
OSW	ORGANIC SOLID WASTE
O_2	OXYGEN
RI	RESPIRATION INDEX
SRDI	SOIL RESOURCE DEVELOPMENT INSTITUTE
WHO	WORLD HEALTH ORGANIZATION
Zn	ZINK

INTRODUCTION

1.1 Introduction

Bangladesh is located in a huge delta formed by the Ganges, Brahmaputra, and Meghna having alluvial soil. The economy of the country is still agrarian although industrialization is going on rapidly. But the agriculture is the basic support for livelihood of majority of the population. High population growth offset the increased agricultural production, thereby exacerbating the food deficit and poverty. About 8.7 million ha of land are cultivated in Bangladesh of which around 65% is in crop production (MOA 2011). However, since the population is increasing, increases in food production is a challenge. Intensive and extensive cultivation increases crop yield in the short term, but it costs to the natural environment and a decrease in yield in long term. Dependency on chemical fertilizers, pesticides, irrigation, and high yielding plants has been increasing , degrading the soil quality. In 2008- 09, high yielding varieties covered more than 72 percent of the total cultivable land area in Bangladesh at present it covers the area of 80% (BRRI 2012). Therefore, a large amount of fertilizer is being used to cultivate high yielding varieties (HYV) and consequently the demand of chemical fertilizers follows an increasing trend. Similarly HYV, cropping intensity also influences fertilizer application over the years. A decline in land productivity has been caused by intensive cropping, indiscriminate use of fertilizers, and continued use of irrigation and removal of bio-mass from agricultural fields.

Soil is the supplier of plant nutrients. Nutrient content in soil are rapidly becoming unbalanced due to continuous cropping and unplanned cropping pattern. A limited number of nutrients are applied as chemical fertilizers to get rapid return or high yield. As a result, continuous changes are taking place in the soil fertility condition due to nutrient deficit and increasing toxicity status. In Bangladesh most of the soil other than peat soil has less than

1% organic matter. A good soil should have 2.5 to 5% organic matter. It influences the physical, chemical, and biological properties of the soil. It also improves soil structure, water holding capacity and aeration. In a ward organic matter of soil is called the store house of available plant nutrient. It also serves food and energy for beneficial organisms like earthworm, *Rhizobium, Azotobacter* etc.

Organic matter in soil is continuously undergoing changes and need to replenish constantly to maintain soil productivity. In Bangladesh the major source of organic matter include animal dung and urine, crop residues, household waste, farmyard manure, municipal waste, green manure, agro industrial waste. Organic waste like kitchen waste discharged vegetable parts, which are normally thrown out to nearby ditches in the homestead area in Bangladesh. Earthworm generally inhibits in the ditches or in the field or open land where residues of plants or fallen leaves of plants or non decomposed matters are available. Using earthworm to convert these wastes into compost is called vermi-composting. Among the different sources of organic fertilizers vermin-compost is significant in maintaining and enhancing soil fertility, keeping healthy environment and conserving resources for sustainable agriculture. Vermi-compost is a wonderful eco friendly organic fertilizer that has good potential in perspective to soil condition of Bangladesh if compliance is maintained for organic compost production and trading. In this study the researcher intended to utilize different organic waste for producing nutrient rich vermicompost using specific earthworm species (*E. fetida*).

1.2 Objectives of the study

The Objectives of the study are

1. To study the suitability of recycling different organic waste, agricultural residues and other byproducts as feed for *E. fetida.*

2. To study the changes in physico-chemical properties, of the final output by using different organic waste in different population of *E. fetida*.

3. Please add cost effectiveness for your study

Literature Review

LITERATURE REVIEW

2. Vermicomposting

Vermicomposting is a simple biotechnological process of composting, in which certain species of earthworms are used to enhance the process of waste conversion and produce a better end product. Vermicomposting differs from composting in several ways (Gandhi et al. 1997). It is a mesophilic process, utilizing microorganisms and earthworms that are active at 10–32°C (not ambient temperature but temperature within the pile of moist organic material). The process is faster than composting; because the material passes through the earthworm gut, a significant but not yet fully understood transformation takes place, whereby the resulting earthworm castings (worm manure) are rich in microbial activity and plant growth regulators, and fortified with pest repellence attributes as well! In short, earthworms, through a type of biological alchemy, are capable of transforming garbage into 'gold' (Tara, C., 2003).

2. 1 Biology of earthworms

The earthworm is a tube shaped segmented invertebrate. Its body holds its shape because it's full of a liquid called coelomic fluid found between the body wall and the alimentary canal. If one were to view a cross section of the worm body it would resemble a target, with the center representing the internal organs and the outer circle representing the body wall.

Earthworm has a long, cylindrical body with a pointed head. In some species the posterior end is slightly flattened, while in others the body is cylindrical throughout. Rings that surround the moist, soft body allow the earthworm to twist and turn, especially since it has no backbone. With no true legs, bristles (setae) on the body move back and forth, allowing the earthworm to crawl. Earthworm breathes through its body surface. Detailed morphological and anatomical description of different species of earthworms is available in Aiyyar and Ananthakrishnan (1993). Food is ingested through the mouth into a bag like structure referred to as crop. In some species a distinct crop is absent. Later the food passes through the gizzard, where ingested stones grind it up. After passing through the intestine for digestion, what's left is eliminated as castings.

2.2. Classification of earthworm

Kingdom : Animalia

Phylum : Annelida

Class : Oligochaeta

Order : Opisthopora

Family : Lumbricidae

Genus : A large number of genera exist

Species : A large number of species under each genus exist

According to their feeding habits, earthworms are classified into detritivores and geophagous (Ismail, 1997). Detritivores earthworms feed near the soil surface. They feed mainly on the plant litter and other plant debris in the soil. These earthworms comprise the epigeic and the anecic forms. Geophagous worms, feeding deeper beneath the surface and ingest large quantities of organically rich soil. These are generally called as humus feeders and comprise of endogeic earthworms.

Epigeic earthworms are surface dwellers serving as efficient agents in fragmentation of organic matters on the soil surface. The Anecics feed on the organic matter mixed with soil and live deep in soil and make permanent burrows. Endogeic earthworms live within the soil surface and derive their nutrition from the organically rich soil they ingest. The distribution of earthworm in the soil is influenced by several factors like soil texture, temperature, moisture, pH, inorganic salts and the organic matter (Govindan, 1998)

Earthworms are also classified based on their occupying level in the soil and the feeding behavior as shown in Figure 1 (Ismail, 1997). The Anecic types burrow deep in the soil but come to the surface at night to forage for freshly decaying residues.

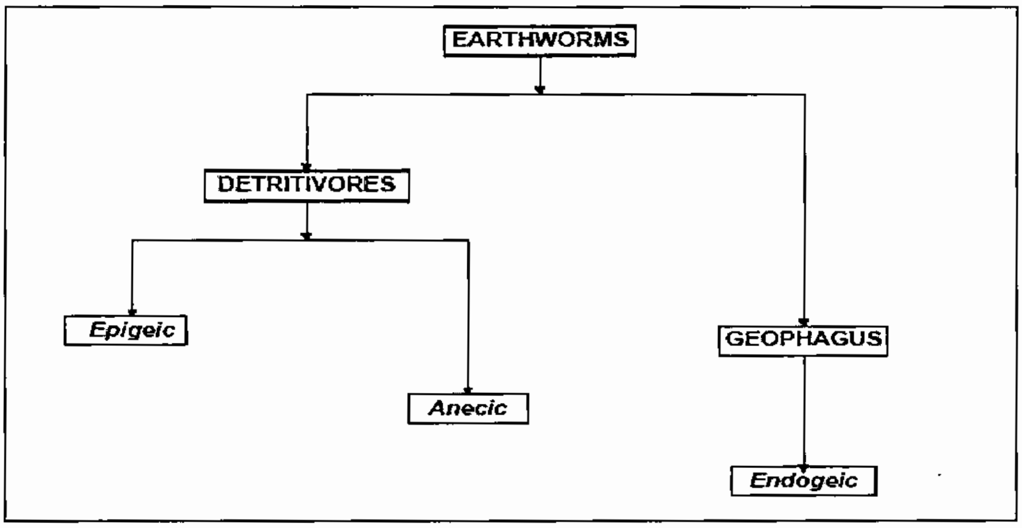


Figure 1. Classification of earthworms (adapted from Ismail, 1997)

2.3 Types of Earthworms

Ronald and Donald (1977b) have described the six common types of earthworms found in Europe. These are:

1. The native night crawler, or *Lumbricus terrestris*
2. The common field worm, or *Helodrilus caliginosus*
3. The green worm, or *Helodrilus chloroticus*
4. The manure worm, or *Eisenia foetida*
5. The slim earthworm, or *Diplocardia verrucusa*
6. The redworm or *Lumbricus rubellus*.

The most common types of earthworms used for vermicomposting are banded worms (*Eisenia fetida*) and redworms or red wigglers (*Lumbricus rubellus*). Often found in aged manure piles, they generally have alternating red and buff-colored stripes. They are not to be confused with the common garden or field earthworm (*Allolobophora caliginosa*) and other species.

2.4 Reproduction

Earthworms that are sexually mature have a prominent band around their body, which is called as the Clitellum. This is usually visible around 8 - 12 weeks of age. During copulation, the worms will join together at the clitellum (sometimes for quite a long period of time). Reproductive material is exchanged. When the worms separate, a ring of mucus material forms at the clitellum of each worm. This process is known as copulation. The worm will then wriggle backwards, and the mucus ring slips off over the head. The ring seals, forming a 'capsule' (also called an 'egg'). All the necessary reproductive material is sealed inside. The worm capsule, when first deposited is soft and milky white. This quickly hardens and turns a light lemon color. The capsule goes through various color changes through different toning of yellow, then to a rusty brown color. Capsules are almost ready to hatch when they are the rusty color. The capsule is about the size of a grape seed, but size is related to the size of the worm, with larger worms producing larger capsules. Capsules generally take an average of 1 month to hatch but depending on conditions can take more or less. Worm capsules have been known to survive drought conditions for 12 months or more, hatching when conditions become suitable again. They can even survive in the digestive systems of birds and animals. Each capsule can produce up to 20 baby worms, but the average survival is about 4.

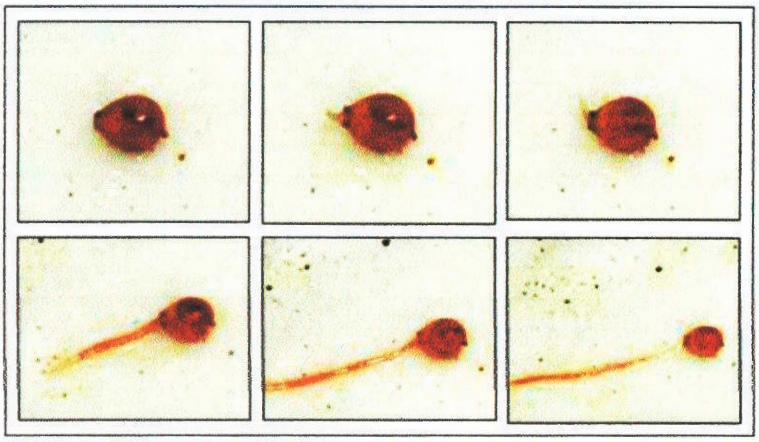


Figure 2. Earthworms hatchling, emerging from cocoon.

2.5 VERMICOMPOSTING PROCESS

2.5.1 Development of vermicomposting research

The role of earthworms has been recognized since the end of the 19th century regarding the breakdown of organic matter and release of nutrients (Edwards, 2007). Darwin's publication, '*Formation of vegetable mould through the action of worms with observations on their habits*', published in 1881, is known as the first research to mention earthworms (Feller *et al.*, 2003). During the last decade of the 20th century, more research focused on the ecology and biology of earthworms and the different uses of earthworms. Starting from only six publications in the period 1870-1889, there are now over 5000 publications dealing with earthworms (Feller *et al.*, 2003; Zhenjun, 2004). Edwards (2007) roughly divided the 130-year development of earthworm ecological research into four stages focusing on: (i) Morphology and ecological habits (1881-1949) (ii) Natural earthworm ecology (1950-1969) (iii) Vermiculture and utilization for humans (1970-1992) (iv) Bioactive proteins from earthworms and vermicomposting (after 1992). Since 1970, due to the proven success of vermicomposting, this method and other similar treatments using earthworms to produce valuable soil-like additives and proteins for animal feed from organic matter have been expanded rapidly (Edwards & Bohlen, 1996). The increase in researchers' interest in vermicomposting accompanied the interests of commercial organizations (Edwards, 2007).

Recently, vermicomposting has been discussed as a key step in sustainable OSW management. In developed countries, a variety of vermicomposting studies have been conducted in England (Gunadi & Edwards, 2003; Gunadi *et al.*, 2002; Morgan, 2004); Germany (Elmitwalli & Otterpohl, 2007; Ernst *et al.*, 2008), Spain (Aira and Domínguez, 2008; Elvira *et al.*, 1997; Monroy *et al.*, 2009) and the USA (Arancon *et al.*, 2008; Edwards, 2007; Hartenstein *et al.*, 1980). Researchers have also increasingly focused on this method for sustainable development in agriculture. For example, in China (Liu *et al.*, 2009; Zhenjun, 2004), India (Ghosh, 2004; Kale *et al.*, 1992; Yadav *et al.*, 2010), Vietnam (Fuchs *et al.*, 2005) and Brazil (Pereira *et al.*, 2009), considering it an efficient and sustainable alternative for local OSW treatment (Snel, 1999). Vermicomposting facilities for domestic and industrial applications are already commercially available in Canada, the USA, Italy, Japan and India. From a few-ton system started in Canada in 1970, there are now some processes with a capacity more than 2500 tons month^{-1}. Since 1978, the American Earthworm Company has operated a farm with ~500 tons capacity month^{-1}. The largest vermicomposting facility to date was built in California, the USA, in 1993 (Sherman-Huntoon, 2000). In this facility, about 22.5 tons of earthworms process 75 000 tons of material annually. Other examples are treatment facilities with ~2000 tons of sugarcane waste month^{-1} in India and ~3000 tons of OSWs month^{-1} in Japan (Ghosh, 2004).

2.5.2. Processes during vermicomposting

According to Ndegwa and Thomson (2000), vermicomposting can be divided into two main processes:

Physical and mechanical processes: Organic matter is aerated, mixed and homogenized by earthworms. In the case of composting, the process usually requires large tools/units that are associated with high cost. Vermicomposting avoids these operation costs (Ndegwa and Thomson, 2000; Ndegwa *et al.*, 2000).

Ecological and biochemical processes: Vermicomposting is a process with several interactions between earthworms and microorganisms. In the worm intestine (or gut), there are many biochemical processes among bacteria, protozoa, actinomycetes and fungi (Edwards & Fletcher, 1988). In addition, some digestive enzymes which are known as catalytic reagents for biochemical reactions exist in the worm gut (Atiyeh *et al.*, 2000).

2.5.3. Interaction between earthworms and microorganisms

The interactions between earthworms and microorganisms in soil and OSW materials seem to be of major importance in the degradation of organic matter and the release of mineralized nutrients (Aira *et al.*, 2007a; Edwards and Bohlen, 1996; Loh *et al.*, 2005). Edwards (2007) described earthworm-microbial community interactions in natural soils on three spatial scales: micro-, meso-, and macro-scale. Similar interactions can be expected in vermicomposting processes, but mainly at micro- and meso-scale, which are mentioned briefly below.

Micro-scale: This scale represents that of the worm's intestine, burrow lining or casts. At this scale, earthworm ecologists describe food preferences of earthworms, the fate of microorganisms in the intestines of earthworms, and the chemical and biological composition of casts and successful processes within them.

Meso-scale: This scale represents an integration of the drilosphere with surrounding matter. The term drilosphere was coined by Lavelle (1996) and the drilosphere includes five main components (Jouquet *et al.*, 2000): the internal micro-environment of the earthworm gut; the earthworm surface in contact with the soil; surface and belowground earthworm casts; middens; and burrows, galleries, or diapauses chambers. At meso-scale, ecologists consider the ways in which earthworm activity influences whole soil characteristics and functions, such as the distribution of microorganisms, soil respiration, microbial biomass, bacterial/fungal ratios, and the way these processes alter soil fertility and the incidence and severity of root diseases. These can be analyzed using microcosms or in small-scale field trials.

In the context of the current research, the importance of interactions at the micro- and meso-scale lies in the elimination of pathogenic microorganisms, particularly human pathogens (Edwards, 2007). However, almost nothing is known about the relative contribution of these interactions to the observed changes in microbial populations during the decomposition of organic matter (Monroy et al., 2009).

2.5.4. The role of earthworms in organic matter breakdown

The role of earthworms in mummification and breakdown of plant litter in natural soil has been known since the time of Darwin, but their potential to stabilize the organic refuse into useful components has been known only recently. Edwards (1998) reported five earthworm species *(D. veneta, E. eugeniae, P. excavatus* and *P.hawayana* and *E. fetida*) to be the most potential earthworms for breakdown of organic refuse. Generally most organic wastes can be broken down as such, except for those, which might need some degree of pretreatment prior to feeding.

Earthworms are highly adaptable to different types of organic waste, provided, the physical structure, pH and the salt concentration are not above the tolerance level (Seenappa, *et al.*, 1995). In most of the cases, the feedstock is thermophilically composted in windrows (turned twice weekly), for 15 to 30 days before being fed to earthworms. Extensive research on decomposition of animal manure viz. pig waste, cattle dung and poultry waste using earthworms has been done in the United Kingdom. The main emphasis of the research there has been the conversion of animal and vegetable wastes into useful materials and then harvesting earthworms from the waste on a commercial basis (Butt, 1999). In Wilson, North Carolina, more than five tons per week of swine manure solids is being vermicomposted. Temperature and moisture are controlled through the use of greenhouse curtains, shade cloth, fans, and an automatic mister. Castings are lifted and conveyed from the beds every other month by a retrofitted machine, and a harvester separates earthworms and eggs from the castings (NCSU, 1997). Earthworms convert the smelly organic matter into a dark, odourless, homogeneous material called castings or vermicast which is an ideal plant growth supplement. It is often referred to as 'Black Gold' by gardeners. Earthworms feed partly on the waste itself, but mostly on the microorganisms produced during decomposition. Their movement through the waste assists the break down and aeration of the material, providing ideal conditions for microbes to flourish, which in turn accelerates the decomposition rate of the organic matter. The waste entering the earthworm gut is subjected to biochemical break down by the enzymes secreted in the gut wall of the animal and by the microorganisms therein. The resulting product is colloidal humus that acts as a slow release fertilizer. The nutrients are easily available to plants, but resist leaching. The rate of decomposition also depends on the type of litter.

The role of earthworms in the breakdown of organic matter is attributed to three processes in the worm gut: interaction with gut microorganisms, digestive enzymes, and physical grinding. The latter two are discussed in more detail here.

The digestive system of different species, genera and families of worms differs in detail, but the worm gut has a common basic structure. Little information is available about the process of worm digestion and the quality of materials that pass through the worm gut (Edwards & Bohlen 1996). *E. fetida* appears to extract its nutrients from finely fragmented organic matter which is mixed with soil.

The digestive system of earthworms consists of a buccal cavity, pharynx, oesophagus, crop, gizzard and intestine. Feed adheres to mucus extruded by the buccal epithelium. Later, pressure in the wall of the buccal cavity is released which establishes a partial vacuum to transport materials through the crop, the gizzard and the intestine (Zhenjun, 2004). The time taken for food to pass through the worm gut can vary from 3-5 hours in the case of *E. fetida*, to 12-20 hours for *L. terrestris* (Edwards, 2007). Laverack (1968) observed that there are commonly six types of digestive enzymes in the worm gut (protease, lipase, amylase, lichenase, cellulase and chitinase). However, a variety of other enzymes have also been reported depending on species (Edwards & Fletcher, 1988). There is an increase in the absorption of nutrients along the length of the worm gut. The posterior gut, with its characteristic peritrophic membrane, appears to be a major zone of absorption (Edwards & Fletcher, 1988).

2.5.4.1 Fragmentation and breakdown

The rate of organic matter breakdown depends mainly on the type of litter. Very soft plant and animal residues may be decomposed by the soil micro-flora. Together plant leaves, stems and root material do not break down easily; they are first disintegrated by the soil animals, including earthworms. Earthworms thus have an important role in this initial process of the organic matter cycle. Soils with few earthworms have a well-developed layer of un-decomposed organic matter lying on the soil surface. Many types of leaves are not acceptable to the earthworms when they first fall on the ground, but require a period of weathering before they become palatable. It is believed that this weathering leaches the water-soluble poly-phenols from the leaves (Edwards and Lofty, 1976). These tiny creatures are responsible for the translocation of the accumulated organic debris from the soil surface to the subsurface layers and during this process much of the organic materials are ingested, macerated and excreted. Earthworms are also known to contribute several kinds of nutrients in the form of nitrogenous wastes (Lakshmi and Vijayalakshmi, 2000).

2.5.4.2 Consumption and Humificaton

Earthworms are reported to consume more organic matter from the soil surface than all of the other smaller soil animals put together (Ronald and Donald, 1977a). The amount they turn over depends on the availability of total suitable organic matter. If the soil physical conditions are suitable, the abundance of earthworms increases until the food becomes a limiting factor. The smaller earthworms that feed on the litter produce cast that are almost entirely fragmented litter, whereas the larger species consume large proportion of soil, and there is less organic matter in their casts. The final process in organic matter decomposition is the humificaton, in which the large organic particles are converted into a complex amorphous colloid containing phenolic materials. Only about one fourth of the organic matter becomes converted to humus (Edwards and Lofty, 1976). The major contributions of earthworms are in breaking up of organic matter, combining it with soil particles and, enhancing microbial activity. They also mix the humified material into soil.

2.5.4.3 Nitrogen mineralization

Earthworms greatly increase the soil fertility, and part of this must be due to the increased amounts of mineralized nitrogen that they make available for the plant growth. There have been reports of increase in the amount of nitrogen in the soil in which the earthworms are reared (Edwards and Lofty, 1976). This may be due to the decay of the bodies of dead earthworms, which are rich in proteins. Govindan (1998) reported that earthworm body contains 65% protein, 14% fats, 14% carbohydrates and 3% ash. Similarly, Ronald and Donald (1977a) reported that 72% of the dry weight of an earthworm is protein and that the death of an earthworm will release up to 0.01 g of nitrate in the soil. Also, earthworms consume large amount of plant organic matter that contains considerable quantities of nitrogen, and much of this is returned to the soil in their excretions. Hand *et al.*, (1988) reported that nitrogen mineralization would be greater in the presence of earthworms and this mineral nitrogen is retained in nitrate form.

2.5.4.4 Effects on the C/N ratio

Plant roots in general cannot assimilate the mineral nitrogen unless the Carbon/Nitrogen (C/N) ratio is in the order of 20:1 or lower (Edwards and Lofty, 1976). Earthworms help to lower the C/N ratio of fresh organic matter during respiration (Ronald and Donald, 1977b). To assess the role of earthworm in lowering the C/N ratio, the consumption of the carbon must be measured, and this can be done approximately, by measuring the respiration. But the disadvantage of laboratory studies is that they do not always reflect the actual situation. Daniel and Karmegam (1999) conducted an experiment in vermicomposting using selected leaf litter and cow dung mixtures (1:1) and showed a substantial variation in the C/N ratio, Electrical conductivity, NPK (Nitrogen, Phosphorus, Potassium) and organic carbon compared to controls without earthworms. There was a remarkable reduction in C/N ratio of vermicompost than in the compost. Similar results were obtained on utilization of weeds (*B. diffusa, P. odorata, S. acuta* and *T. portulacastrum*) as substrate for vermicomposting (Daniel and Karmegam, 2000).

2.6 Break down of organic solid wastes

Different earthworm species exist in almost all regions of the world except those with extreme climates, such as deserts and glaciers. These species have quite different life cycles, behaviours and environmental requirements. They are classified into three major ecological categories based primarily on their feeding and burrowing strategies: epigeic, endogeic and anecic (Maboeta *et al.*, 1999; Zhenjun, 2004). Only epigeic earthworms seem to be relevant for vermicomposting (Edwards, 2007).

About 8000 species of earthworm worldwide have been described as epigeic from ~800 genera belonging to the order Oligochaetae. Of those, seven earthworm species are used in vermicomposting, namely *Eisenia fetida, Dendrobaena veneta, Dendrobaena rubida, Lumbricus rubellus, Perionyx excavatus, Eudrilus eugeniae* and *Pheretima elongata* (Edwards, 2007; Zhenjun, 2004). These species show good growth on organic wastes compared with other species (Edwards, 2007).

2.6.1 *Eisenia fetida*

Most studies of vermicomposting focus on the species *Eisenia fetida* (Reinecke *et al.*, 1992; Tripathi & Bhardwaj, 2004). It occurs worldwide and naturally colonises many organic solid wastes, e.g. garden waste and animal slurry (Gunadi *et al.*, 2003). *E. fetida* has a rapid growth rate, good temperature tolerance (up to 35^{0}C) and accepts a large range of moisture (60-90%) (Reinecke *et al.*, 1992). Moreover, *E. fetida* can be handled easily and it is tolerant to other species (Aira *et al.*, 2002; Gunadi *et al.*, 2003; Loehr *et al.*, 1985). Under optimal conditions, the life cycle of *E. fetida* ranges from 45 to 51 days (Domínguez & Edwards, 2004). The time for hatchlings to reach sexual maturity is in the range 21-30 days. Cocoon laying begins 48 hours after copulation and the rate of cocoon production ranges from 0.4 to 1.3 cocoon day-1. Hatching viability is around 80% and the incubation period of the *E.*

fetida cocoon varies from 18 to 26 days (Edwards, 2007). On average, approx. 2.5-3.8 young earthworms hatch out from an *E. fetida* cocoon depending on temperature. The maximum life expectancy of *E. fetida* is 4.5-5.0 years (Domínguez & Edwards, 2004), but the average survival rate is ~20 months at 18-28°C (Aira *et al.*, 2007b).

2.6.2 *Dendrobaena veneta*

Dendrobaena veneta has been reclassified by taxonomists into the genus and species instead of the older classification of *Eisenia* hortensis, and is commonly referred to as the European night-crawler (Edwards, 2007; Muyima *et al.*, 1994). Although *D. veneta* does not grow rapidly, the worms have been used widely in vermicomposting and vermiculture systems, especially in industrial-scale processes. Because of their large size, they can be handled easily (Fayolle *et al.*, 1997). With the advantage of larger size in comparison with the other species, *D. veneta* is also the earthworm species subjected to the most detailed ecological studies (Reinecke *et al.*, 1992). Reproduction, maturity rate and environmental requirements of this species were studied in the early 1990s (Loehr *et al.*, 1985; Viuoen *et al.*, 1992). *D. veneta* has a low reproduction rate and a slow maturity rate compared with other vermicomposting worms such as *E. fetida, P. excavatus* and *E. eugeniae* (Edwards, 2007).

D. veneta prefers temperatures in the range 9-30°C for vermicomposting (Fayolle *et al.*, 1997; Muyima *et al.*, 1994). Muyima *et al.* (1994) also reported that *D. veneta* performs better in high moisture conditions (65-85%) than other species for vermicomposting of materials with lower moisture content such as paper sludge. The life cycle of the species is quite long (100-250 days). About 65 days is the average time for this worm to reach sexual maturity (Fayolle *et al.*, 1997). The species produces ~0.28 cocoons day-1 but the hatchling viability is only 20%. The incubation period of *D. veneta* is ~42 days and its hatchling rate from a viable cocoon is approximately 1.1 earthworms (Edwards, 2007).

2.6.3 *Dendrobaena rubida*

Dendrobaena rubida is also suitable for vermiculture as well as for vermicomposting treatment, although it has not been commonly used (Elvira *et al.*, 1997a). This is a temperate species with a clear preference for organic soils, and it inhabits substrates such as decaying rotting wood and straw, pine litter and compost (Edwards, 2007). The life cycle of the species is completed in 75 days and its rapid maturation and high reproductive rate could make the worm suitable for vermicompost processing (Edwards, & Bohlen, 1996). *D. rubida* grows well in the range of 15-25^{0}C and needs 54 days to reach sexual maturity after hatching (Domínguez & Edwards, 2004). The rate of cocoon production is about 0.46 cocoons day-1 and the hatching viability is up to 75% (Elvira *et al.*, 1997a).

2.6.4 *Lumbricus rubellus*

Lumbricus rubellus is found in moist substrates, such as animal manure and sewage solids (Elvira *et al.*, 1997a). *L. rubellus* has a long maturation time and a low reproductive rate, which suggests that the species is not an ideal earthworm for vermicomposting, although its size, vigour and ability to survive in soils could make it interesting as fish bait or for soil improvement (Adi & Noor, 2009). Moreover, the species is not an opportunistic species with obligatory bi-parental reproduction which contributes to its low reproductive rates (Zhenjun, 2004). *L. rubellus* has a relatively long life cycle in the range of 120-170 days, with a slow growth rate and a long maturation time of 74-91 days (Edwards, 2007). Edwards (2007) also reported that the optimum temperature of this worm is 15-18^{0}C and the optimum moisture is 80-85%. The net reproductive rate is 0.05 hatchlings day−1 because of the low cocoon production rate of ~0.1 cocoons day−1, with only one hatchling emerging from each cocoon.

2.6.5 *Perionyx excavatus*

Perionyx excavatus is a tropical earthworm which has been widely used in vermiculture and belongs to the *Megascolecidae,* commonly found over a large area of tropical Asia and Australia (Khwairakpam & Bhargava, 2009; Maboeta *et al.*, 1999). This is an ideal species which can be used to break down organic wastes under high temperatures in tropical countries (Reinecke *et al.*, 1992). High moisture contents and adequate amounts of suitable organic material are required for populations of the *P. excavatus* to become fully established and to process organic wastes efficiently (Hallatt *et al.*, 1992). Under optimal conditions, the life cycle of *P. excavatus* takes 40-71 days from hatching to maturity (Maboeta *et al.*, 1999). This species prefers high temperatures (20-30^{0}C) with an optimum of 25^{0}C and may die at temperatures <9^{0}C (Loehr *et al.*, 1985). With about 90% hatching rate and 1.1 worms cocoon-1, the species has a high net reproductive rate from nearly 6.7 cocoons day-1 (Reinecke *et al.*, 1992).

2.6.6 *Eudrilus eugeniae*

Eudrilus eugeniae is the other of the two tropical species used commonly in vermicomposting (Domínguez *et al.*, 2001; Reinecke *et al.*, 1992). Belonging to the *Eudrilidae,* the earthworm is a native African species that lives in both soils and organic wastes. The species is large and grows rapidly and is relatively prolific when cultured (Loehr *et al.*, 1985). *E. eugeniae* could be considered an ideal species for vermicomposting because it is handled and harvested more easily than the others (Domínguez *et al.*, 2001). However, its disadvantage is that it has a relatively narrow temperature tolerance, from only 20 to 28^{0}C (Domínguez *et al.*, 2001).

E. eugeniae can be highly reproductive when living un ideal conditions (Kale *et al.*, 1992). The earthworm is capable of decomposing large quantities of organic wastes rapidly and incorporating them into the topsoil (Loehr *et al.*, 1985). *E. eugeniae* has a life cycle of 43-122 days depending mainly on temperature. The maximum life expectancy of the worm is up to three years (Edwards, 2007). The time requirement of *E. eugeniae* for maturity is 40 days and for cocoon incubation is ~16 days. The average number of hatchlings is 2.7 earthworms cocoon-1 (Domínguez & Edwards, 2004). Up to now, the species has been bred extensively in the United States for the fish-bait market, where it is known commonly as the African night-crawler (Khwairakpam & Bhargava, 2009).

2.6.7 *Pheretima elongata*

Pheretima elongata is a Megascolecid earthworm which has been tested for vermicomposting of OSW including household wastes and animal slurries (Kale *et al.*, 1992; Somani, 2008). The species is indigenous to India. Some Indian researchers have claimed that *P. elongata* is used for a commercially viable processing facility for the vermicomposting of eight tons of substrates per day (Edwards, 2007). Loehr *et al.* (1985) also reported that the species is well-suit to complete processes including vermicompost and reusable water production from sewage sludge, manure slurries and wastewater from food processing. *P. elongata* survives by dwelling deeply in low organic matter and tolerates in a temperature range from 19 to 30^{0}C (Somani, 2008). The duration of its reproductive life is longer than 200-400 days and the period of maturity from hatchling to adult seems to be in the range of 120-150 days (Domínguez & Edwards, 2004). The average time for cocoon production of *P. elongate* is ~20-24 weeks and its cocoon incubation period is 28-31 days. The incubation period of this species seems shorter than for the others but the number of worms hatchling is limited (1.0 worm cocoon-1).

2.7 Pre-treatment of OSW materials for vermicomposting

The main idea behind pre-treating fresh OSW materials is to keep a balance between three factors: the time of processing, the survival of earthworms and the possible decrease in the amount of food available for earthworm growth (Gunadi *et al.*, 2002). These authors also reported that the pre-treatments of OSW materials could have the benefit of eliminating human pathogens and weed seeds from vermicompost. However, several OSW materials may decrease in quality in terms of nutrient availability for earthworm growth when they are pre-treated for a long time. This may inhibit the rate of growth and number of cocoons and hatchlings produced by earthworms (Nair *et al.*, 2006).

Generally, the pre-treatment of feeding materials for vermicomposting includes two methods: thermophilic pre-composting to reduce toxic factors and mixing some different types of OSW materials together to achieve an acceptable feed (Gunadi *et al.*, 2002). The thermophilic pre-composting could make OSW materials more acceptable and cause less worm toxicity factors (e.g. excess heat, anaerobic gases and ammonia) and too low or high pH level (Frederickson, 1997). However, depending on the types of OSW materials, the optimal time of pre-composting differs.

Although the pre-composting process may reduce the amount of food available for the growth and reproduction of earthworms, the process should be adopted and adjusted as the first step of vermicomposting is to eliminate the earthworm toxicity factors in the feeding substrates and to be tolerated by different species (Frederickson *et al.*, 2007). Pathogen reduction is an additional benefit that can be obtained from the process (Gunadi *et al.*, 2002; Nair *et al.*, 2006). Another pre-treatment option is to mix two or more fresh OSW materials together.

This mixing has been used quite commonly for pre-treatment of vermicompost substrates, especially when the main waste cannot be accepted directly as feed by earthworms (Yadav & Garg, 2009). Several OSW materials such as paper-pulp mill sludge, filter cake, etc. have unsuitable properties for earthworm feeding but they can be ideal materials in a mixture with other OSW materials (Yadav & Garg, 2009). Normally, when mixing OSW materials, some types of green waste are mixed with animal residues (Somani, 2008). For examples, it is advisable to combine yard and garden wastes with other animal manures, such as pig or cow slurry (Somani, 2008). A huge amount of crop residues from farm activities such as roots, branches, vegetable and fruit peelings (containing much more cellulose compounds) and similar derivatives could be mixed with animal slurries which have a high N amount to make a favourable feed for earthworms (Bansal & Kapoor, 2000; Frederickson *et al.*, 2007). According to Sangwan *et al.* (2008), horse manure and spiked filter cake in a 1:1 ratio could become the favoured substrate for *E. fetida*.

Yadav & Garg (2009) made a summary of suitable OSW materials which could be mixed with some industrial wastes as a pre-treatment before using them as feed materials for vermicomposting by several earthworm species (Table 2.5). Yadav & Garg (2009) also reported that vermicomposting of food industry sludge could produce a lot of *E. fetida* biomass and that the substrate was converted to good quality vermicompost when it was mixed up to 30% with cow dung.

2.8 Vermicomposting practice

Vermicomposting practices vary from place to place and country to country. Literature on this aspect is readily available (Edwards and Lofty, 1976; Kale, 1998). A general account on Vermicomposting practice as applicable to many regions is summarized below.

2.8.1 Bedding Material

It is important to provide earthworms with an environment that is close to the moisture content of the earthworms themselves. Their body wall must be moist for respiration to occur. However, the bedding cannot be fully saturated, or the earthworms will suffocate. The required moisture content of approximately 75% should be maintained. The bedding should be damp, about the consistency of a damp sponge. Although there are a number of commercially available bedding materials made from things like coconut fiber or peat moss, newspaper and cardboard make a very suitable bedding material because it is readily available, provides excellent moisture retention, and preparation is relatively simple.

In general, materials needed for preparing the bedding are:

- Newspaper (black & white only) or shredded paper, it works as a carbon source or it also looks into the prevention of protein poisoning if so ever occurred.
- Garden soil (worms need the grit for digestion, but don't use potting soil because it may contain chemicals)
- Crushed eggshell that may serve as a source of calcium.
- Grits or pebbles for proper drainage, to be used in the bottom layer of the bed.

2.8.1.1 Bedding Preparation

For the bedding preparation, some shredded and soaked newspapers (as a source of cellulose and to retain adequate moisture), and some crushed eggshells (for calcium supply) are needed (Visvanathan et al, 2005). Garden soil and crushed eggshell are mixed well before putting them in the bin. Earthworms are placed in the bin along with bedding material. The worms will retract down in the bedding layer to avoid the light. With its lid open the bin is placed near a light for an hour to encourage the worms to move down into the new bedding material.

2.8.1.2 Feeding

Vegetable and fruit scraps, tea bags, eggshells, stale bread, and houseplant trimmings etc., are used as feed. Dairy products and slaughterhouse wastes are to be avoided during the initial stage, as these can attract undesirable insects and create malodour. Heavily salted foods are also to be avoided as they might trigger the migration of worms from the bin or their death. It is best to collect food scraps separately in a small bucket and feed the worms once or twice a week. Following this procedure, (Norbu, 2002) observed that partial burial of the food (in the vermin bed), not only removed the ants and other mites but also created a better environment for the worms to feed.

2.8.1.3. Ideal environment for earthworms

The following are the environmental conditions, which are vital and may affect the breeding, cocoon production and hatching of young earthworms.

2.8.1.3.1 Temperature

In Vermicomposting, temperatures are kept generally kept below 350C (Riggle and Holmes, 1994). Most worm species used in vermicomposting require moderate temperatures from (10-35°C). While tolerances and preferences vary from species to species, temperature requirements are generally similar. In general, earthworms tolerate cold and moist conditions far better than they can hot and dry conditions (Slocum, 2001).

2.8.1.3.2 Moisture

Earthworm requires plenty of moisture for growth and survival. They need generally moisture in the range 60 -75 %. The soil should not be too wet else it may create an anaerobic condition and drive the earthworms from the bed

(Ronald and Donald, 1977a). It is very important to moisten the dry bedding material before putting them in the bin, so that the overall moisture level is well balanced.

2.8.1.3.3. pH

Edward and Lofty (1976) and Chan and Mead (2003) have reported that earthworms are pH sensitive and generally most of them survive at pH ranging from 4.5 to 9. The alteration of pH in the wormbed is due to the fragmentation of the organic matter under a series of chemical reactions. As cited by Edwards and Bohlen, (1996) in Chan and Mead, (2003), the soil pH is a major factor limiting the abundance and distribution of earthworms.

2.8.1.3.4. Feed

The first step in starting a vermicomposting unit is to arrange for regular input of feed materials for the earthworms. These can be in the form of nitrogen rich material like goat manure cattle dung and pig manure. When the material with high carbon content is used with C/N ratio exceeding 40: 1, it is advisable to add nitrogen supplements to ensure effective decomposition. All organic matter should be added only as a limited layer as an excess of the former may generate heat (Ismail, 1997). Generally, 5-10 % of the feed is assimilated in the body of the earthworms and the rest are excreted in the form of a nutrient rich cast (Chanda *et al,* 2010).

2.9 OUTPUT PRODUCTS OF VERMICOMPOSTING

2.9.1 Nutrient content in vermicompost

Besides its use as an alternative to other sanitary forms of OSW management, vermicomposting treatment can reap other benefits, such as producing vermicompost that is a soil improver for agriculture (Suthar, 2010). Through the action of earthworms, nutrients may be more available in the vermicompost produced as compared to those in the parent material or in non-vermicomposted materials.

The main advantage of vermicompost over its parent material is its available nutrients and high level of organic matter humidification (Edwards, 2007). Edwards (2007) also reported that vermicompost can have positive effects on soil and its physico-mechanical properties. After application to soil of vermicompost as a balanced bio-fertiliser, crop yields can increase by up to 30-50%. Because of the close relationship between parent material and the final product, the type of fresh vermicomposting substrate determines the properties of the vermicompost. According to Edwards (2007), Ntot concentration in vermicompost of animal wastes varies within the range 1.8-3.0% of total dry matter, whereas Ptot and Ktot concentration are in the range of 0.2-2.7% (Table 2.6). Elemental contents in products can change through the activity of earthworms by the adding earthworm biomass such as mucus, excreta or dead bodies (Ernst *et al.*, 2008; Monroy *et al.*, 2009). Edwards (2007) also reported that earthworm activities in fresh materials resulted in the plant available nutrients in vermicompost being present in higher amounts compared with the same material un-treated (Table 2.7).

2.9.2. Maturity of vermicompost

The vermicompost is ready as soon as it is considered to be mature. Mature vermicompost contains acceptable concentrations of phytotoxic compounds or short-chain organic acids (Brewer & Sullivan, 2003). The maturity level of vermicompost is determined as an important parameter for vermicompost quality assessment. Respiration can be directly related to the metabolic activity of a microbial population in soils (Gómez *et al.*, 2006). It is used as a useful parameter of the microbial activity in compost. Microorganisms respire at higher rates in the presence of large amounts of bio-available organic matter while the respiration rate is lower if this type of material is less (Aira &

Domínguez, 2009). The respiration index (RI) defines the rate of O2 uptake or CO2 evolution of a sample under controlled conditions of the assays (Gómez *et al.*, 2006). Methods to determine RI are based on three mechanisms: (i) self-heating, (ii) CO_2 production and (iii) O_2 uptake (Adani *et al.*, 2001).

2.9.3. Pathogens in organic solid wastes and the reduction after vermicomposting

One of the most important goals for OSW management is pathogen reduction because of the health hazard they represent to human beings if they are not treated carefully (WHO, 2004). There are more than 120 different types of viruses and bacteria that may be excreted in human and animal faeces (Schönning & Stenström, 2004). At the least, consideration of bacteria such as *Salmonella, Escherichia coli* and *Enterococcus* spp. are generally important when evaluating microbial risks from various OSW sources, including human faeces, sludge and animal manures (Jönsson *et al.*, 2004; WHO, 2004).

Microorganisms present in fresh materials for vermicomposting often include many sanitation-related pathogens such as intestinal-faecal micro-flora, bacteria, protozoa, parasites and viruses (Liu *et al.*, 2009). Pathological findings indicate that many animals appear to harbour bacteria such as *Salmonella* app., *E. coli, Enterococcus* spp. and coliphages in the intestinal tract (Murry & Hinckley, 1992). Excreted in animal manures, they can survive for months in the soil, and then enter the food chain via groundwater, thereby causing human diseases (e. g. diarrhoea, typhoid). Many previous studies have mentioned that there are large numbers of pathogens, bacteria and viruses in OSW materials due to organic matter-rich substrates, especially animal and human excreta (Aria & Domiguez, 2008; Edwards, 2007.

2.9.4. Plant growth in vermicompost

The OSW materials can be an especially rich nutrient supply source for soil improvement. Dehydrated or composted products should be applied and mixed into the soil before cultivation starts (Somani, 2008). As a result, vermicompost of organic wastes supplies nutrients but also improves the physical structure and the water-holding capacity of the soil (Arancon *et al.*, 2008). There is some well-substantiated evidence that vermicompost can significantly promote the growth of plants. Faster growth of *Vinca rosea* and *Oryza sativa* was observed after addition of vermicompost to soils (Reddy & Ohkura, 2004). Germination testing is a parameter for plant media where plants are tested for their rates of growth in different types or ages of compost product.

Germination of plant seedlings tends to be significantly better in vermicompost than in other commercial plant growth media (e.g. Metro-Mix 360) (Atiyeh *et al.*, 2001). In addition, there is evidence that vermicompost added to plant media increases growth, flowering and fruiting of vegetables (Arancon *et al.*, 2008). For example, tomatoes showed the highest yield when Metro-Mix360 was mixed with 20% pig manure vermicompost. Some field crops also show an increase in vegetable growth at low application rates of vermicompost (Arancon *et al.*, 2008).

2.10 Methods to harvest earthworm and the vermicompost

Growth rate of earthworms is very fast and a mature adult can attain up to 1500 mg body weight and attain reproduction capability within 50-55 days of hatching from cocoon (The Hindu, 2002). Redworms daily consume organic matter at the rate equal to their body weight. On an average, one million worms weigh approximately one ton. One million worms doubling every two months can become 64 million worms at the end of one year. Organic waste after being eaten by the worms may yield half the weight in dry Vermicompost. Since the worms double their number at least every 60 days, potentially large quantity of worm bio mass will be available as pro-biotic food for animal, after the first year. Therefore, after one year of the process 64 million worms could consume approximately 64 tons organic waste daily and produces approximately 32 tons of Vermicompost per day. This production can be done on two acres of land. In large-scale windrow vermicomposting, mechanical harvesters are used. At the time when the height of the pile is more than 65 cm, irrigation is discontinued and the windrow allowed to partially dry. To draw the worms to the windrow surface, a layer of fresh feedstock is added and a brief irrigation is applied to moisten the outer layer. After five to seven days, a front-end loader is used to skim the top 10-cm of the windrow, removing with it approximately 80 % of the worms. A second feeding and loader pass can bring the worm harvest to 90 to 92 %. Population density is always estimated before harvest so that worms can be used to inoculate new windrows. For small-scale vermicomposting, windrows, reactors or any of the following methods (whichever is appropriate) may be adopted:

2.10.1 Migration Method / Side way separation

In the migration method, the bedding is moved to one side of the bin and the fresh bedding is placed on the empty side. The new feed is put into the side with the new bedding. Gradually the worms will migrate towards the fresh bedding. The old bedding is left for about a month to allow the new capsules to hatch. The compost is then removed and some more fresh bedding is added (Visvanathan *et al.*, 2005).

2.10.2 Light Retraction Method

In the Light retraction method, new bedding is prepared for the worms. The contents of the existing bin are emptied onto a sheet of plastic. The bedding is then piled into mounds (one large or several small ones, whichever is easier). A bright light is placed over the mounds or is exposed to sunlight. The worms quickly move away from the light source, burying down to the bottom of the pile. After 10 to 15 minutes, the top of the bedding is scraped off. This procedure is repeated till the worms huddle together at the bottom of the pile, with very little bedding material. The worms are then placed immediately into the new bedding (Visvanathan *et al.*, 2005).

2.10.3 Sifting method

A sifting method can also be used to harvest the worms. In this method, the worms and bedding are sifted through a coarse screen. Castings fall through the mesh, while the worms stay behind. The sifting is done quickly and with a gentle shaking, before the worms get a chance to wriggle down through the wire. There are also special harvesters available that work in a similar way. These are mainly used in large worm farms, where large amounts of worms need to be harvested quickly (Visvanathan *et al.*, 2005).

2.10.4 Using worm swag

When using the worm swag, harvesting becomes very easy, with virtually no lifting. The swag is opened at the bottom, and the castings squeezed out into a bucket. This is called a flow-through system, which means it is fed at the top and harvested at the bottom (Visvanathan *et al.*, 2005). Once the Swag is established, castings can be harvested on a weekly basis. Some flow-through systems will have a grate at the bottom to either rake the castings out, or wind a handle and the castings drop out the bottom into a tray.

2.10.5 Vertical separation

In this method three trays are used, as the first working tray becomes full, a new empty tray is simply put on top, and feeding begins in the new tray, as the worms will migrate upwards through the trays seeking food . A piece of nylon or mesh window screening, a bit bigger than the surface of the box is laid flat on the surface of the vermicompost. (big enough to flatten against the sides and some overlap at the top). The box is filled up with fresh bedding on top of the screen and feeding with kitchen scraps is continued. The worms migrate up through the screen into the new bedding as the food runs out below (Visvanathan *et al.*, 2005).

2.11 Vermicomposting for Bangladeshi Conditions

Most towns and cities in Bangladesh do not have proper waste management systems and untreated solid waste is generally dumped in landfills or on the roadsides and the liquid wastes are discharged into water bodies. It is seen from Figure 3 that a substantial portion (69% to 77%) of solid waste in the urban areas is compostable. Average compostable content of the waste is 74% with the remaining 26% being non-compostable. The large quantity of organic contents present in urban solid waste composition indicates the necessity for frequent collection and removal. This also indicates good potentials for recycling of organic waste for resource recovery (Enayetullah *et al.*, 2005). This can be put to productive use rather than being thrown into the bin from where it makes its way to over loaded landfills. These wastes can be considered as a resource to produce manure for the soil using vermicomposting technology.

2.11.1 Vermicomposting for Rural Development

Large quantity of potential agro-industrial wastes and byproducts are thrown out as wastes/underutilized by the local population since they are not aware of its importance. These waste materials can be utilized profitably by vermicomposting, which is a low cost and sustainable technology. Unemployed rural population can do this, as part time/ full time profession if they are aware of the technical knowhow to utilize the materials. Awareness about vermiculture and vermicomposting will motivate both the rural and urban people to start vermicomposting units, which can fetch regular income (http://www.krishisewa.com).

2.11.2 Revenue Generation through Vermiculture and Vermicomposting

Vermi technology can be made popular because it is a simple methodology with low investment and does not need sophisticated infrastructure. To process one ton of organic matter daily, it would require about 1500 sq meters of space with 6 workers. It would produce about 70 tons of earthworms casting annually. Innovative, interested and talented rural people can be successful entrepreneurs in vermicompost production and accruing profits will enhance their life style and income. They will be able to spend time usefully by getting job opportunities with the help of self-employment schemes (http://www.krishisewa.com).

Materials and Methods

MATERIALS AND METHODS

3.1 Materials

For the research purpose the following materials is used

- Cement charies with diameter approximately180 cm and depth 45 cm;
- Worm (*Eisenia foetida*) 100 worm/ cubic feet food stock;
- Waste raw materials (Cow dung, saw dust, kitchen garbage, green and dry leaves waste paper, hyacinth, paddy straw, etc);
- Plastic dram, thick heavy polythin paper for pre composting;
- pH meter, thermometer;
- Spade, construction pan, chopper, Mash/Sieve etc;
- Different chemicals (Sulfuric acid, Ammonium sulfate, potassium sulfate, boric acid, sodium carbonate, mercuric oxide, aqua-regia, hydrofluoric acid etc.) needed for chemical analysis of vermicompost.

Figure 3. Earthworm (*Eisenia foetida*) used for the study

3.2 Methodology

Vermicomposting process is a combination of four broad stages mentioned as

- Pre composting

- Adding worm to the feed stock
- Composting
- Harvesting

In case of small scale production these four steps can be clearly observed but in case of bulk production it is more or less a continuous process where each stage continues to support the next step of production.

3.2.1 Pre composting: Pre composting is the early stage of producing vermicompost. It is a very impotent step having impact on the quality of final product. All the waste material is collected from households, farm yard, local market, and from other neighboring sources of Sokhipur area under Gazipur District. After collection of waste material in this stage the organic wastes are separated. The cutable raw materials like straw, hyacinth, waste paper, green leaves were chopped into small pieces and all the raw material were mixed in specific proportion. By using different organic wastes and cow dung, six experiments were set up in cement charies.

Figure 4. Raw materials made ready for pre-composting

The proportion of raw materials and worms for the six treatments are presented in Table 1.

Table 1: Raw materials used for six experiments

Ingredients	Raw material in Treatment 1	Raw material in Treatment 2	Raw material in Treatment 3	Raw material in Treatment 4	Raw material in Treatment 5	Raw material in Treatment 6
Soil	*10 kg*	-	-	-	-	-
Cow dung	-	5 kg	5 kg	5 kg	5 kg	5 kg
Waste paper	-	-	-	1 kg	1 kg	1 kg
Saw dust	-	1kg	1kg	1 kg	1 kg	1 kg
Kitchen garbage	-	-	-	1 kg	1 kg	1 kg
Green leaves	-	-	1kg	1kg	1 kg	1 kg
Water hyacinth	-	-	-	-	1 kg	1 kg
Straw	-	-	-	-		1 kg
Water	-	As per required	As per required	As per required	As per required	As per required
Eisenia foetida	100 worm /cft waste	100 worm /cft waste	100 worm /cft waste	100 worm /cft waste	100 worm /cft waste	100 worm /cft waste

The first experiment in which only soil was used treated as control. The mixtures for other five experiments were then brought into 5 separate plastic drum. They were then subject to aerobic composting to initiate microbial activity and decomposed naturally. It took 10 -20 days for different organic matter to be decomposed. At the last stage of pre composting excess liquid (organic liquor) was drained away. The pre composted material then became ready to use as feed stock.

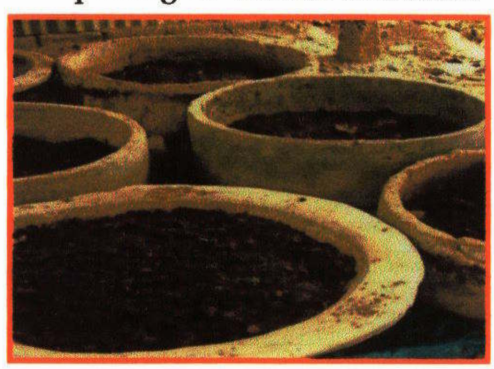


Figure: 5. Earthworm added to the feedstock

3.2.2 Adding worm to the feed stock:

For this research Cement charies were used. In this stage six separate charies are loosely filled with the feed stock. Then 100 worms per cubic feet feed stock was added on the surface of each chari and the charies were covered with wet gunny bag. All the charies were kept placed in a shade. Cool conditions were maintained for further steps of vermicomposting.

3.2.3 Composting: In this stage the worms began to eat the feed from the top and gradually went to the deeper part of the charies. For keeping suitable environment temperature and humidity of the feed stock were recorded and monitored time to time. Temperature was maintained between 20°C to 30°C. The humidity was also maintained in such a way that the feed stock becomes moist but not soaked by making small holes within feed stoke with stick and spraying water when necessary. The vermicompost was ready after about 2 months. The processed vermicompost was black to gray in color, light in weight and free from bad odor. At this stage the compost contain different stages of earthworm namely cocoons, juveniles and adults.

Figure: 6 Composting occur with the help of earthworm

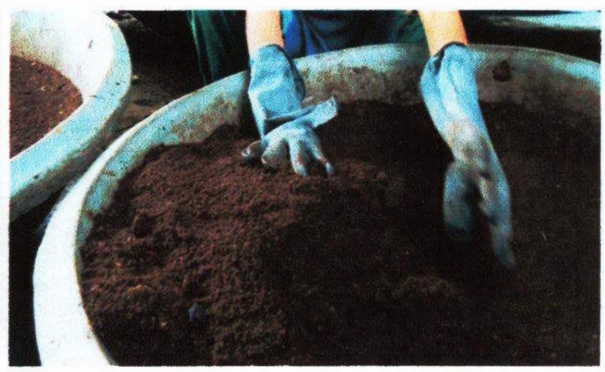


Figure: 7 Testing moisture content of composting feed stock

During the composting process the following precautions were maintained:

• Only plant-based materials such as grass, leaves or vegetable peelings has used for vermicompost.

• The earthworms were kept protected against birds, termites, ants and rats.

• Adequate moisture was maintained during the process because either stagnant water or lack of moisture could kill the earthworms.

• Temperature was also controlled by making provision for aeration.

3.2.4 Harvesting of Vermicompost: Within 40 to 60 days most of the feed stock was converted into worm casting. The compost was ready when the casting looks moderately loose and crumbly and the color of the compost is dark brown. When it turned dark and black, became granular, lightweight and humus-rich prior to 3 - 5 days of harvesting watering was stopped. This has forced about 80 per cent of the worms to the bottom of the charies.

Figure: 8 Harvesting vermicompost from the top of chari

In such situation vermicompost was collected gradually from the top part of the charies. Vermicompost of the bottom part was collected by using mash and after sieving the earthworm and the thick material was returned to the chari for the next cycle. Collected vermicompost was then heaped in a cold dry place and indirect sunlight was used to reduce the moisture content. The compost was then ready for physico-chemical analysis.

Figure: 9 Harvesting and separating the young earthworms

The whole process is of vermicomposting is depicted below through flow chart:

Collection of raw materials

⇩

Raw materials are made ready for pre composting

⇩

Pre composting of the raw materials

⇩

Collection of earth worm (*Eisenia foetida*)

⇩

Pre composted materials are placed in charies and addition of worms

⇩

Temperature and humidity were maintained favorable for the worms

⇩

Time was allowed for worm to eat all the feed stock

⇩

Harvesting of worm casting

⇩

The worm casting were dried up to certain stage

⇩

Packaging and storage of vermicompost

Figure: 10 Flow Diagram of the process of vermicomposting

3.3 Physicochemical analysis

After the harvesting of vermicompost, sample from each experiment was taken to the lab of Soil Resource Development Institute (SRDI, Dhaka) for physicochemical analysis. At that stage each sample was analyzed for different physicochemical attributes such as pH, organic carbon, total nitrogen, available phosphorus, potassium, C: N ratio and organic matter as per standard procedure.

The followings chemical parameters of each experiment outcome vermicompost were analyzed: Organic carbon was determined by dry combustion method (Nelson *et al*, 1996) total nitrogen was determined as per method of Micro-Kjeldahi method (Schuman *et al*, 1973). Available phosphorus was analyzed by employing spectophotpmetric Molybdovanadate method (Bartlett, E. M. and Lewis, D. H. , 1970), Potassium was determined by flame photometric method (Berry *et al*, 1946) and sulphur was measured by spectophotometric method. Measurement of micro nutrients like zinc, lead, nickel, cadmium and chromium was performed using Atomic Absorption Spectophotometric method (Hatch, W.R. Ott, W.L. 1968) and moisture content was measured by gravimetric method (Reynolds, S. G. 1970) and the pH of the composts was determined using glass electrode pH meter. All the above nutrients and C/N ratio were analyzed after 10 days of harvesting.

RESULTS AND DISCUSSION

4.1 Result

Vermicompost produced through six different experiments is analyzed in the laboratory of Soil Resource Development Institute, Farmgate, Dhaka. Results of the chemical analysis of the samples are presented in Table 2, 3 and 4.

Table: 2 Result of physical properties of different experimental vermicompost sample.

Variable	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6
Color	Dark gray	Dark brown	Dark brown	Dark brown	Dark brown	Dark brown
Physical condition	Non granular	Non granular	Non granular	Non granular	Non granular	Non granular
Odor	No foul odor	No foul odor	No foul odor	No foul odor	No foul odor	No foul odor
Moisture	27%	24%	33%	15%	13%	11%
pH	6.9	8.1	7.7	7.5	7.4	7.9

Analyzing the physical properties of the end product of six different treatments it is found that the colors of the experimental output are more or less similar color. The color ranges from dark brown to dark grey. Except the control treatment other treatment out puts are of dark brown color. They all are non granular and free from any foul odor. Moisture content of the end product varies significantly. Variation may

Figure: 11 Final product (vermicompost)

occur due to early harvesting, or for storing the harvested material inappropriately. pH of the end products are within a range of 7.4 to 8.1. Difference in pH may occur because of variation between treatments (different substrate use). The rate of bioconversion extent of different substrate varies resulting varied amount of CO_2 and organic acid production that caused different pH value for different end product. The vermicomposted material had greater nitrogen content.

Table 3. Proportion of different plant macronutrients in different experimental vermicompost sample.

Variable	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6
Organic Carbon	9.30%	19.60%	10.65%	15.73%	16.39%	17.68%
Total Nitrogen	0.52%	0.61%	0.42%	0.74%	0.90%	0.87%
(C:N)	17.8:1	32.1:1	25.3:1	21:01	18:01	20:01
Phosphorus	0.12%	0.33%	0.45%	0.58%	0.69%	0.85%
Potassium	0.16%	0.63%	0.92%	1.03%	1.15%	1.43%

The inoculation of worms in waste material considerably enhances the amount of N due to earthworm mediated nitrogen mineralization of wastes. An increased level of plant growth macronutrient is observed with the addition of new organic waste as feed stock. Especially the addition of cow dung , saw dust, kitchen garbage has increased the percentage of total nitrogen on the compost resulting a balanced Carbon Nitrogen ratio. It also suggested that the earthworm also enhances the nitrogen levels of the substrate by adding their excretory products, mucus, body fluid, enzymes and even through the decaying tissues of dead worms in vermicomposting sub-system (Suthar, 2007a). Similarly the use of water hyacinth and straw contributed in the increased percentage of Potassium and Phosphorus respectively.

Proportion of plant growth micronutrients (Sulphur, Copper and Zinc) are also found to increase within the finished product with the gradual increase of different organic waste material as feedstock of earthworm. The presence of some heavy metal is also observed but they are limited/ below to the standard acceptance level.

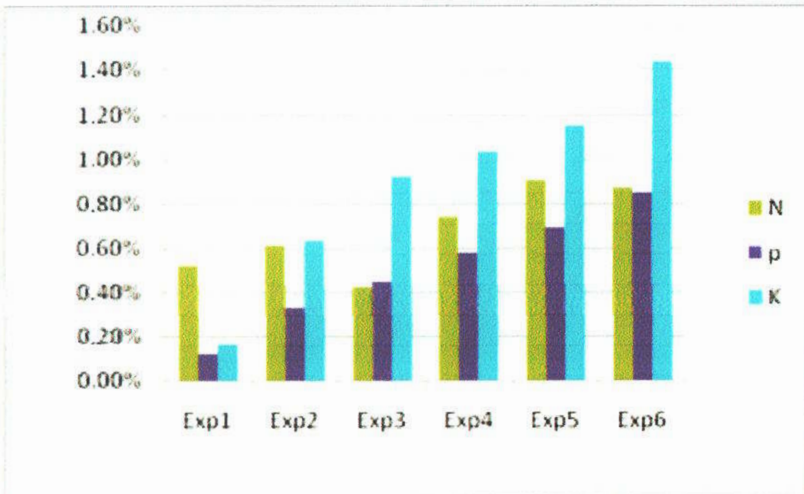
Table: 4 Proportion of different plant micronutrient in different experimental vermicompost sample

Variable	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6
Sulphur	0.010%	0.025%	0.070%	0.100%	0.170%	0.210%
Zinc	0.01%	0.03%	0.08%	0.04%	0.05%	0.07%
Copper	0.01%	0.0070%	0.0080%	0.0100%	0.0100%	0.0150%
Chromium	112.9ppm	85.2ppm	65.9ppm	33.53ppm	29.27ppm	31.53ppm
Cadmium	0.65ppm	0.60ppm	0.35ppm	1.50ppm	1.37ppm	1.81ppm
Lead	0.0ppm	0ppm	1.75ppm	12.12ppm	11.67ppm	11.19ppm
Nickel	50.05ppm	28.98ppm	50.28ppm	12.32ppm	17.04ppm	14.12ppm
Inert material	<1%	<1%	<1%	<1%	<1%	<1%

4.2 Discussion

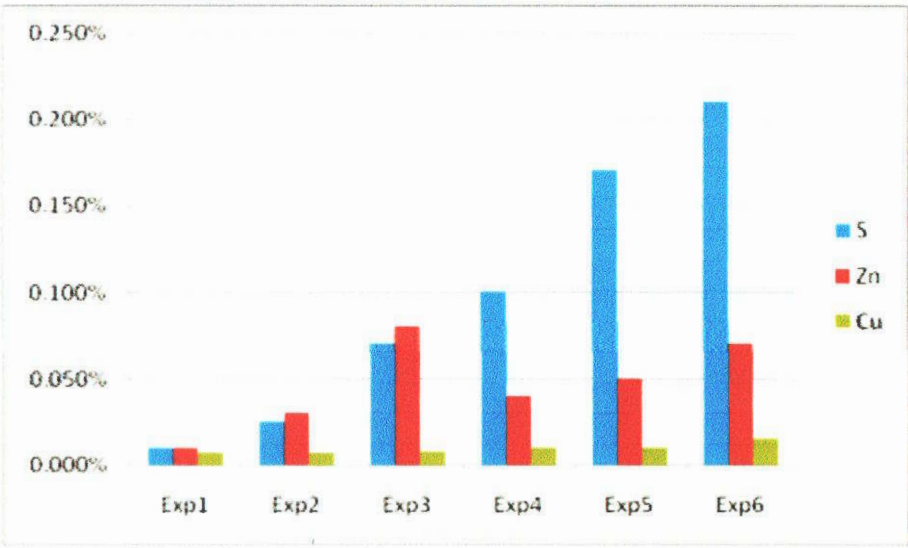
The pH value of output obtained from experiment 1 was 7.4. The pH value of vermicompost obtained from experiment 6 showed significant variation when compared to the control experiment. The overall increase of pH may be attributed to the decomposition of nitrogenous substrates resulting in the production of CO_2, ammonia and different organic acid. Ammonia which forms a large proportion of the nitrogenous matter was excreted by earthworms (Cohen and Lewis, 1949). Casts may cause a temporary rise in soil pH (Umamaheswari and Vijayalaksmi, 2003). From the results, it was clear that there was significant increase in the NPK content in the vermicompost.

The enhanced P level in ready vermicompost suggests phosphorous mineralization during vermicomposting process. Lee, (1992) suggests that the passage of organic matter through the gut of earthworm's results in phosphorus is converted to forms, which are more available to plants. The release of phosphorous in the available form is performed partly by earthworm gut phosphatases and further release of P might be attributed to the P-solubolizing microorganisms present in worm casts. Le Bayon and Binet, (2006) concluded that the impact produced by earthworm on P biogeochemical transformations in the soil depends on the close relationship between the properties of the organic P source and the specific burrowing behavior and food preferences of worms. Some previous studies also indicate enhanced potassium content in vermicompost by the end of the experiment (Suthar, 2007a). The results obtained in this study are similar to those by Delgado, et al., (1995), who demonstrated higher potassium concentration in the end product prepared from sewage sludge. The C:N ratio of the substrate material reflects the organic waste mineralization and stabilization during the process of composting or vermicomposting.



Graph 1: Graphical presentation of plant macronutrients (NPK) in different experiment

The present study supports the work of Lee (Lee E K 1985) who found that the earthworm casts contain more nitrogen, phosphorous and calcium. Esther Rani (Esther Rani et al 2007) found that the worm *Eisenia fetida* is capable of ingesting and excreting organic materials at a high rate. Gunathilagaraj and Ravignanam (Gunathilagaraj and Ravignanam 1996) reported that the macro and micronutrients in the vermicompost of semicultural wastes were more. Gaur (Gaur1982) found that the nutrients are richer in the earthworm casts. Lakshmi Bai and Vijayalakshmi (Bai L, and Vijayalakshmi, *2000*) have reported similar increase in NPK values on subjecting sugar factory filter press mud to vermicomposting. Muthukumaravel (1996) found that macronutrients NPK and micronutrients were more, that is also observed in case of Cu and Zn in the research.



Graph: 2 Graphical presentations of sulphur, zinc and copper found in different experimental output

Ravichandran et al (Ravichandran , Chandrasekaran and Christy 2001) observed more NPK in the compost than that in the initial soil. The NPK content of the vermicompost prepared from vegetable waste and cow dung has also shown a maximum increase when compared with the compost prepared using individual constituents. The cow dung influenced the rate of vermicomposting and increased the amount of macronutrients in the vermicompost (Muthukumaravel, 1996, Vasanthy et al, 2005). The increased nitrogen may be due to nitrogenous metabolic products of earthworms which are returned to the soil through casts, urine, muco-proteins and earthworm tissue (Umamaheswari and Vijayalaksmi 2003). Hence, it is clear that the mixture of different organic solid waste and cow dung is suitable for the production of higher quality vermicompost when compared with subjecting the same components individually. A the same time comparison between the end product of the first experiment and the sixth experiment clearly shows that vermicomposting of different organic waste yields nutrient rich organic fertilizer.

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