COMPOSTING OF SOLID WASTE WITH SPECIAL EMPHASIS ON VERMICULTURE

MD. MAHMUDUL HAQUE

DEPARTMENT OF CIVIL ENGINEERING

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

DHAKA 1000, BANGLADESH

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by

Md. Mahmudul Haque
Student No. 100504135 (P)

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The World Bank
Agargaon, Sher-e-Bangla Nagar
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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Signature of the Candidate

Md. Mahmudul Haque

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LIST OF ABBREVIATIONS

BASA	Bangladesh Association for Social Advancement
CBO	Community Based Organization
DMDP	Dhaka Metropolitan Development Program
GHG	Green House Gas
IRR	Internal Rate of Return
MC	Moisture Content
MRF	Material Recovery Facilities
MSW	Municipal Solid Waste
NGO	Non Government Organization
NPV	Net Present Value
SWM	Solid Waste Management
US EPA	United States Environmental Protection Agency
WTE	Waste to Energy

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ABSTRACT

The composting process is currently conceived primarily as a waste management method to stabilize organic waste, such as manure, municipal biosolids, and organic urban wastes. Composting is a natural process whereby organic material decomposes into a dark nutrient-rich soil amendment .The stabilized end-product (compost) is widely used to improve soil structure, provide plant nutrients, and facilitate the revegetation of disturbed or eroded soil.

Vermicomposting uses earthworms to turn organic wastes into very high quality compost. The use of worms speeds up the process of decomposition to produce a richer end product. Vermicomposting is especially useful for processing food waste since the worms consume the material quickly and there are fewer problems with odor. Vermicompost consists mostly of worm casts (poop) plus some decayed organic matter

Characterization of MSW is important to evaluate its possible environmental impacts on nature as well as on society. The MSW can be characterized as the high content of organic matter which indicates that the MSW is superior for vermi composting in Bangladesh. From the study, it has been found that percentage of organic waste is more than 80% and most of them are vegetables and food waste.

The various controlling parameters of vermi composting are collected from the materials and digestion processes. Vermicomposting is carried out at relatively low temperatures (under 25 °C). It is vitally important to keep the temperature below 35 °C; otherwise the earthworms will be killed. Chemical analysis and microbial analysis also has been done to know the nutrient content and existence of pathogenic bacteria in the final compost. It is found that it is rich in nutrient and no pathogenic bacteria have been found. Vermi composting process is much faster than windrow composting process. Vermi compost can be ready within one month. Growth rate of worms are determined which shows that an initial stock of 1 kg of worms can become 9 kg after one year.

Finally the financial involvement for vermi composting plants are evaluated and found the economic feasibility of them.

CHAPTER 1
INTRODUCTION

1.1 GENERAL

MSW management in Bangladesh is in the primitive stage and needs modernization through innovative and appropriate approach for its proper management. MSW are generally poorly managed by the city authority through a very old system without bringing any necessary changes or developments. Therefore the information on characteristics is essential part for the selection of most appropriate system for storage and transport, evaluating equipment needs, determination of the potential for resource recovery, choice of a suitable method for disposal, sustainable management programs and proper planning. Characterization of MSW is also important to evaluate its possible environmental impacts on nature as well as on society. The per capita waste generation and percent composition of various waste components are the two most important types of data for decision-makers. This information is necessary in order to identify waste components to target for source reduction and recycling programs, and to allow technical professionals to design any waste facility such as material recovery facilities (MRF), waste-to-energy (WTE) projects, sanitary landfills, composting facilities, etc (Alamgir & Ahsan, 2007).

The MSW can be characterized as the high content of organic matter and good NPK values, which indicate that the MSW is superior for composting in Bangladesh. The potential of composting to turn domestic wastes and on-farm waste materials into a farm resource makes it an attractive proposition. Composting offers several benefits such as reduction of green house gas emission, enhanced soil fertility and soil health-thereby increased agricultural productivity, improved soil biodiversity; reduce ecological risks and a better environment.

Understanding how to make and use compost is in the public interest, as the problem of waste disposal climbs toward a crisis level. Landfills are brimming and new sites are not likely to be easily found. For this reason there is an interest in conserving existing landfill space and in developing alternative methods of dealing with waste. A bulk of the space in landfills is taken up with organic waste from yards and kitchens, just the type of materials that can be used in compost. With a small investment in time, it is possible to contribute to the solution to a community problem, while at the same time enriching the soil and improving the health of the plants on ones property.

A solid waste management system is an interrelated system of appropriate technologies and mechanisms involved in the generation, collection, storage, processing, transfer or transport and disposal of solid waste designed to reduce waste at the lowest possible cost. This should minimize the risk to the health of people and the environment as whole.

The present composting practices in Bangladesh mostly involve implementation of prototype small-scale composting plants in a few urban centers especially in the medium- and low- income communities particularly considering economy in context of Bangladesh environment. These include small-centralized windrow composting systems, composting plants using barrels and box composting and small scale vermi composting. This study is aimed to assess the process of composting of solid waste with special emphasis on vermiculture.

1.2 OBJECTIVE OF THE STUDY

Composting activity in Bangladesh is not new; traditional rural techniques have been in use for many years. But mega cities with a large amount of municipal solid waste and little processing space require different methods. The study is aimed to identify the management problems of solid waste and brings into discussion the recycle process of organic waste to composting.

1. Assessment of characteristics of solid for their sustainability in composting process.

2. Evaluation of environment conditions of vermi composting and composting without worm culture.
3. Assessment of nutrient content of compost obtained from different composting processes.
4. Assessment of economic viability of various composting processes.

1.3 OUTLINE OF METHODOLOGY

Initially extensive review of literature is carried out. Experimental work of this study is carried out at Vurulia, Gazipur. The quantitative analysis of solid waste is to be done to assess their suitability for composting process. Experimental composting plant is designed and constructed for vermi composting for evaluating environmental conditions of composting process. Compost samples are collected for bio-chemical analysis and nutrients content. Then financial feasibility analysis is to be done for the sustainability assessment of both the vermi composting and composting without worm culture.

1.4 ORGANIZATION OF THE THESIS

The thesis presents literature review, data analysis and findings of the study in six chapters and two annexure, as shown below. In addition, a bibliography of related publications has also been presented.

Chapter 1 includes general introduction, objectives and methodology of the study

Chapter 2 includes literature review covering details of composting, their various control parameters and microbiology of composting. Brief reviews of relevant literature are discussed.

Chapter 3 experimental works which are done in the thesis are described.

Chapter 4 presents the data collection and their analysis of various physical parameters from the selected compost samples collected. Compare the various chemical and microbial qualities of compost samples.

Chapter 5 presents the financial feasibility assessment of composting plant.

Chapter 6: presents a general discussion on the findings of the study identifies precise conclusions and provides a number of recommendations for future study.

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

Composting is a biological process carried out mainly under aerobic conditions in a matric phase environment. Matric phase is a soil science term and refers to an environment comprised of solids and water and air filled void spaces between solid particles. Composting systems are characterized by substrate densities sufficiently high and thermal conductivity's sufficiently low that the heat of metabolic activity causes the composting matrix to increase in temperature. Composting as a process is distinct from compost, a product. Composting has many applications beyond making compost. In practice, process management in composting is based on the control of chemical and physical factors such as nutrients, moisture, oxygen concentration, and heat management to control temperature. Composting systems are dynamic. In a composting pile, microbial activity can use up all the oxygen, raise the temperature to lethal limits, and evaporate away the moisture, which represses positive activity. Composting has some unique characteristics which make it particularly well suited to bioremediation. Composting ecosystems are complex and require knowledge and expertise in process management. Gradients of oxygen, pH, red ox potential, dissolved substrates and other factors can exist both within particles and on the macro level, all of which affects the ecological system. Temperature and moisture gradients are common at the macro level. Ecologically, the existence of three phases and various gradients within the composting environment means that composting environments offer a very broad and complex range of available niches.

The factors of high metabolic diversity, high metabolic rates, high oxygen availability, and increased substrate availability make composting ecosystems highly aggressive systems for biological decomposition of organic materials. Composting can also be viewed as an accelerated humification process, overcoming environmental stresses to the soil and increasing fertility by increasing soil organic matter. (Oldscollege, 2002)

Compost is partially decomposed organic matter. It is dark, crumbles easily, and has an earthy aroma. It is created by biological processes in which soil-inhabiting organisms break down plant tissue. The vast bulk of the decomposition work in compost is carried out by microorganisms including fungi, bacteria, and actinomycetes (organisms that resemble fungi but actually are filamentous bacteria). When decomposition is complete, compost has turned into a dark brown, powdery material called humus. The processes occurring in a compost pile are similar to those that break down organic matter in soil. However, decomposition occurs much more rapidly in the compost pile because the environment can be made ideal for the microbes to do their work. Physical characteristics of the compost ingredients, including moisture content and particle size, affect the rate at which composting occurs. Other physical considerations include the size and shape of the system, which affect the rate of aeration and the tendency of the compost to retain or dissipate the heat that is generated.

2.2 AEROBIC & ANAEROBIC COMPOSTING

Composting is the natural rotting of organic matter in a controlled environment. In aerobic composting, the organic matter is piled with temperatures left to rise rapidly to about 70 to 80 degrees. This active compost stage is followed by the curing stage. This is where the temperatures are decreased gradually. In anaerobic composting, oxygen levels are limited, thus microorganisms are allowed to produce methane and other substances. Unlike aerobic composting, anaerobic compost maintains both weeds and pathogens. Therefore, anaerobic composting takes longer than aerobic composting (Banks, 2008).

Anaerobic Composting

One advantage of anaerobic compost is that it is less labor intensive. Consequently, unlike aerobic compost, one does not need to turn the pile. All one does is pile the material, wet the pile, cover it and allow it to sit. The pile will usually be very smelly initially. However, after some time, the aerobic bacteria will use up all the oxygen and die off. This will reduce the odor. At this point, one needs to monitor the moisture level, so that too much gas does not accumulate. This type of compost will usually be dark and slimy. This is caused by the accumulation of nitrogen and organisms that do not require a lot of energy or nitrogen to survive. The nitrogen is converted to ammonia resulting, in the smelly end result. The high amounts of heat help speed up the entire decomposition process.

Aerobic Composting

Aerobic compost on the other hand requires large supplies of oxygen, more so in its initial stages. Limiting the oxygen supply results in slow decomposition. In addition, frequent aeration is essential to remove excess heat and gases that are trapped in the pile. To achieve good aeration, frequent turning of the heap is essential. The frequency of turning will determine how fast or slow the compost matures. Daily turning will ensure the entire process is complete in two weeks. If one needs the compost to mature gradually, one turn a month is adequate. When well done, both compost types are quite effective as natural forms of fertilization (Banks, 2008).

2.3 SOLID WASTE CHARACTERISTICS

The municipal solid waste in the urban centers of Bangladesh generates mainly from domestic, commercial and industrial sources. Solid waste is generated from all human activities in daily life. Kitchen garbage is the dominant part of domestic waste in Bangladesh. It is found from the characteristic analysis of solid waste particularly the domestic waste that it contains mostly organic wastes. So the huge quantity of organic waste (above 80% of total waste) can therefore be digested by aerobically to produce compost (Moqsud & Rahman, 2004).

Figure 2.1: The characteristics of domestic waste in Bangladesh, (Moqsud & Rahman, 2004).

In the major cities of Bangladesh, it is observed that the organic matter is usually the predominant component in the waste stream due to the type and habit of fresh food consumption. The overall socio-economic condition of the country is also very much responsible for the very high percentage of organic component. As shown in Table 2.1, a total of 7690 tons of waste generated daily from the six major cities as estimated in the year of 2005. The Dhaka city contributed the major portion as measured as 5340 tons which is the 69% of total waste generated in the six study cities. The Dhaka and Chittagong city contributed approximately 6655 tons, which is 87% of the said waste stream. The generation rates were ranged from 0.325 to 0.485 kg/cap/day, while the highest generation rate in Dhaka, lowest in Barisal and the average was 0.387 kg/capita/day for six major cities (Alamgir & Ahsan, 2007).

Table 2.1: Component weight of MSW generated in six major cities of Bangladesh,(Alamgir & Ahsan, 2007).

MSW composition	MSW generation (tons day^{-1})						All waste stream
	DCC	CCC	KCC	RCC	BCC	SCC	
Organic matter	3647	968	410	121	105	158	5409
Paper	571	130	49	15	9	18	792
Plastic	230	37	16	7	5	8	303
Textile and wood	118	28	7	3	2	5	163
Leather and rubber	75	13	3	2	1	1	95
Metal	107	29	6	2	2	2	148
Glass	37	13	3	2	1	2	58
Other	555	97	26	18	5	21	722
Total	5340	1315	520	170	130	215	7690
Population (million)	11.00	3.65	1.50	0.45	0.40	0.50	-
Per capita (kg day^{-1})	0.485	0.360	0.346	0.378	0.325	0.430	0.387*

Note: DCC=Dhaka city corporation. CCC=Chittagong city corporation. KCC=Khulna city corporation. RCC=Rajshahi city corporation. BCC=Barisal city corporation. SCC=Sylhet city corporation. *Weighted average.

As shown in Table 2.2, there is little variation in composition for different cities and the biodegradable fraction (organic matter) is normally very high as compared to the other fractions. Organic matter was ranged from 68 to 81% for the six cities, while paper and plastic were about 7 to 11% and 3 to 4%, respectively. Glass, leather and rubber were the smallest composition for all locations (Alamgir & Ahsan, 2007).

Table 2.2: Composition of MSW generated, (Alamgir & Ahsan, 2007).

MSW composition	MSW composition (in wet weight %)						All waste stream
	DCC	CCC	KCC	RCC	BCC	SCC	
Organic matter	68.3	73.6	78.9	71.1	81.1	73.5	74.4
Paper	10.7	9.9	9.5	8.9	7.2	8.6	9.1
Plastic	4.3	2.8	3.1	4.0	3.5	3.5	3.5
Textile and wood	2.2	2.1	1.3	1.9	1.9	2.1	1.9
Leather and rubber	1.4	1.0	0.5	1.1	0.1	0.6	0.8
Metal	2.0	2.2	1.1	1.1	1.2	1.1	1.5
Glass	0.7	1.0	0.5	1.1	0.5	0.7	0.8
Other	10.4	7.4	5.1	10.8	4.5	9.9	8.0
Total	100	100	100	100	100	100	100

The total solid waste generated is mainly organic with compare to small amount of inorganic. Among the organic waste the vegetables waste are dominant. The various types of solid waste generated are shown in Figure 2.2 and Table 2.3 (Moqsud, 2003).

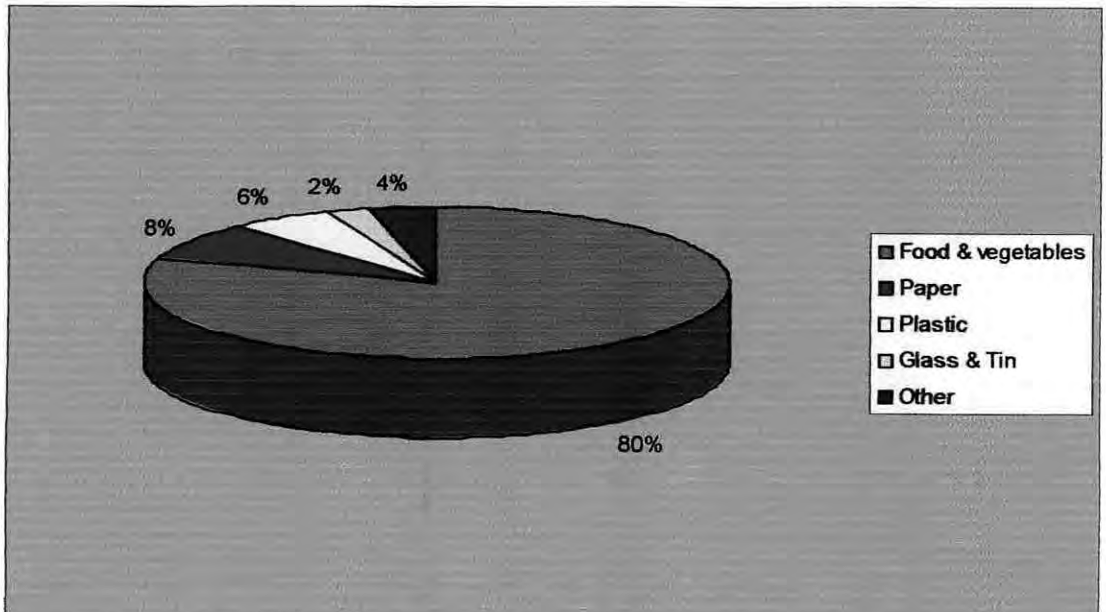

Figure 2.2: Characteristics Analysis of Municipal Solid Waste at Gazipur, (Moqsud, 2003).

Table 2.3: Physical Composition of Municipal Solid Waste at Gazipur (Moqsud, 2003).

Solid waste	Quantity by percent
Food & vegetables	80
Paper	8
Plastic	6
Glass & Tin	2
Other	4

Table 2.4 is a comparative analysis of solid waste characteristics of some developing and developed countries. The percentage of food wastes (organic matter) were 60-70 for the developing countries (Thailand & Egypt) which were a few folds higher than those of the developed countries (U.K & U.S.A). On the other hand, paper and cardboard were found to be higher in the solid wastes of the developed countries.

Table 2.4: Composition of Solid Waste in Developed and developing countries

	Thailand [b]	Egypt [c]	U.K [d]	U.S.A [e]
Food wastes (organic)	63.6	70	17.6	9
Paper and card board	8.2	10	36.9	40
Metals	2.1	4	8.9	9.5
Glass	3.5	2	9.1	8
Textiles	1.4	2	2.4	2
Plastics and rubber	17.3	1	1.1	7.5
Miscellaneous, incombustible	3.2	10	21.9	4
Miscellaneous, combustible	0.7	1	3.1	20
Bulk density, kg/L	0.28	-	0.16	0.18

[a] unit in % wet weight
[b] http://www.mnre.go.th
[c] Cook and Kalbermatten (1982)
[d] Department of Environment (1971)
[e] Tchobanoglous *et al.* (1993)

2.4 COMPOSTING BIOLOGY

Most of the organisms responsible for the transformation of the organic material are microbes. Some important groups of microorganisms are bacteria, actinomycetes, and fungi. The bacteria are responsible for the turnover of approximately 80-90% of the organic matter transformed. Bacteria grow faster and are better adapted to the low oxygen concentrations and high temperatures often found in the early stages of the composting process. Actinomycetes are a group of filamentous organisms that are often found in blue-grey powder-like colonies. Both actinomycetes and fungi are relatively slow growing organisms that are less tolerant of low oxygen concentrations and high temperatures compared to the bacteria. The microbial populations and the temperature in the compost often follow a specific pattern dictated by the degradation of compounds in the organic matter. The composting process can be divided into four phases (Poulsen, 2003).

The initial phase is the first period after initiation of the compost process where the temperature rises to about 50 °C over a period of a few days (Figure. 2.3). During this phase the population of especially bacteria increases rapidly and compounds that are easily degradable, such as sugars, starch, proteins and fats are degraded. Due to the rapid rate of degradation and oxygen consumption it is often difficult to provide enough oxygen for the biological processes and the compost will have a tendency to develop anaerobic pockets. Modest decreases in pH may be observed due to the production of organic acids by anaerobic organisms. The organisms active during the initial phase are mesophilic (optimal temperature 35 – 45 °C) and thermophilic (optimal temperature (55 – 60 °C) bacteria.

If the conditions in the composting material are well maintained the composting process will normally enter **the thermophilic phase** next. This phase involves especially thermophilic bacteria and also certain thermophilic actinomycetes and fungi. During this phase the temperature can exceed 70°C and temperatures as high as 80-85 °C have been observed during composting of sewage sludge. The pH usually increases to about 7.5 due to the destruction of the organic acids. Near the end of the thermophilic phase when the readily degradable organic material has been removed by the microorganism's only organic materials such as hemicelluloses, lignin, chitin, and similar compounds that are more difficult to degrade remain. The microbial activity especially concerning the bacteria begins to decrease and the temperature in the compost begins to fall. At this point the composting process is not yet finished and the compost is sometimes called raw compost (Poulsen, 2003).

Upon completion of the thermophilic phase the temperature decreases to levels where the mesophilic organisms have their optimum and the composting process enters **the mesophilic phase**. During this phase where the temperature ranges between 35 and 45 °C the more difficult-to-degrade components such as cellulose and lignin are decomposed. During the mesophilic phase several types of bacteria are still very active but it is especially the actinomycetes and fungi that are important during this phase. Actinomycetes and fungi are better adapted to utilize the more difficult degradable compounds compared to most of the bacteria. Some fungi can even produce penicillin that will kill some of the bacteria. The mesophilic phase can take up to several weeks to complete. At the end of the mesophilic phase the compost is often called finished compost.

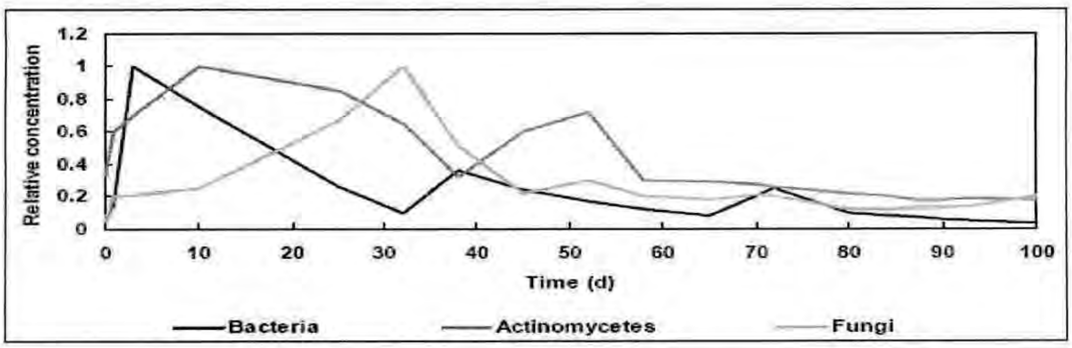

Figure 2.3(a): Top: Microbial succession during the composting process. Source Epstein (1997)

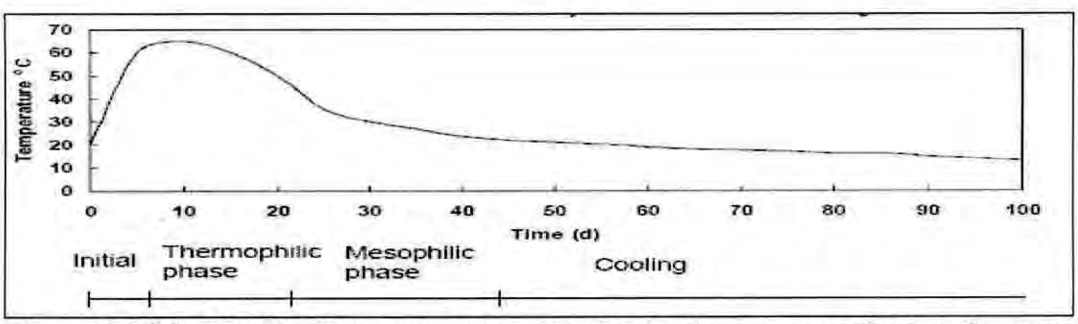

Figure 2.3(b): Idealized temperature variation in the compost during the course of the composting process (Epstein (1997)).

The final phase of the composting process is termed **the cooling phase**. During this phase the temperature slowly decreases to near ambient levels during a time span of several weeks. The microbial degradation of the organic material will be almost completed when entering the cooling phase and the rate of degradation will approach that of a natural soil. The organic matter remaining consists of very complex compounds with humus like structures that are difficult to degrade. The pH during this phase will normally stay relatively constant at about 8. Towards the end of the cooling phase higher organisms such as worms and insects will often colonize the compost. The compost is now termed mature compost and the structure of the organic matter in the compost will closely resemble that of humus.

Table 2.5: Temperature and time of exposure required fro destruction of some common pathogens and parasites. Source: Tchoubanoglous et al. (1993).

Organism	Inactivation requirements
Salmonella typhosa	Death within 30 min at 55-60°C and within 20 min at 60°C
Salmonella sp.	Death within 1 h at 55°C and within 15-20 min at 60°C
Shigella sp.	Death within 1 h at 55°C
Eschericia coli	Most die within 1 h at 55°C and within 15-20 min at 60°C
Entamoeba histolytica cysts	Death within a few min at 45°C and within a few seconds at 55°C
Taernia saginata	Death within a few min at 55°C
Trichinella spiralis larvae	Death within a few min at 55°C instant kill at 60°C
Brucella abortus or Br. Suis	Death within 3 min at 62-63°C and within 1h t 55°C
Micrococcus pyogenes	Death within 10 min at 50°C
Streptococcus pyogenes	Death within 10 min at 54°C
Myobacterium tuberculosis	Death within 15-20 min at 66°C or after momentary heating at 67°C
Corynebacterium diphteriae	Death within 45 min at 55°C
Necator americanus	Death within 50 min at 45°C
Ascaris lumbricoides eggs	Death within 1 h at 50°C

2.5 COMPOSTING METHODS

Commonly used composting methods are:

a) Windrow composting
b) Aerated static pile composting
c) In-Vessel composting
d) Vermi-Culture and Vermi composting.

2.5.1 Windrow composting

Turned Windrows

Windrow composting consists of placing the mixture of raw materials in long narrow piles or windrows which are agitated or turned on a regular basis. The turning operation mixes the composting materials and enhances passive aeration. Typically the windrows are initially from 3 feet high for dense materials like manures to 12 feet high for fluffy materials like leaves. The width varies from 10 to 20 feet. The equipment used for turning determines the size, shape, and spacing of the windrows. Bucket loaders with a long reach can build high windrows. Turning machines produce low, wide windrows (Rynk, 1992).

Windrows aerate primarily by natural or passive air movement. The rate of air exchange depends on the porosity of the windrow. Therefore, the size of a windrow that can be effectively aerated is determined by its porosity. A light fluffy windrow of leaves can be much larger than a wet dense windrow containing manure. If the windrow is too large, anaerobic zones occur near its centre which release odors when the windrow is turned. On the other hand, small windrows lose heat quickly and may not achieve temperatures high enough to evaporate moisture and kill pathogens and weed seeds. For small to moderate scale operations, turning can be accomplished with a front end loader or a bucket loader on a tractor. The loader simply lifts the materials from the windrow and spills them down again, mixing the materials and reforming the mixture into a loose windrow. The loader can exchange material from the bottom of the windrow with material on the top by forming a new windrow next to the old one. This needs to be done without driving onto the windrow in order to minimize compaction. Windrows turned with a bucket loader are often constructed in closely spaced pairs and then combined after the windrows shrink in size. If additional mixing of the materials is desired, a loader can also be used in combination with a manure spreader.

A number of specialized machines have been developed for turning windrows. These machines greatly reduce the time and labor involved, mix the materials thoroughly, and produce more uniform compost. Some of these machines are designed to attach to farm tractors or front-end loaders; others are self-propelled. A few machines also have the capability of loading trucks or wagons from the windrow (Rynk, 1992)

It is very important to maintain a schedule of turning. The frequency of turning depends on the rate of decomposition, the moisture content and porosity of the materials, and the desired composting time. Because the decomposition rate is greatest at the start of the process, the frequency of turning decreases as the windrow ages. Easily degradable or high nitrogen mixes may require daily turnings at the start of the process. As the process continues, the turning frequency can be reduced to a single turning per week.

By the end of the first week of composting, the windrow height diminishes appreciably and by the end of the second week it may be as low as 2 feet. It may be prudent to combine two windrows at this stage and continue the turning schedule as before. Consolidation of windrows is a good wintertime practice to retain the heat generated during composting. This is one of the advantages of windrow composting. It is a versatile system that can be adjusted to different conditions caused by seasonal changes.

With the windrow method, the active composting stage generally lasts three to nine weeks depending upon the nature of the materials and the frequency of turning. Eight weeks is a common period for manure composting operations. If three weeks is the goal, the windrow requires turning once or twice per day during the first week and every three to five days thereafter (Rynk, 1992).

Passively Aerated Windrows

The method, passively aerated windrow system, eliminates the need for turning by supplying air to the composting materials through perforated pipes embedded in each windrow. The pipe ends are open. Air flows into the pipes and through the windrow because of the chimney effect created as the hot gases rise upward out of the windrow.

The windrows should be 3-4 feet high, built on top of a base of straw, peat moss, or finished compost to absorb moisture and insulate the windrow. The covering layer of peat or compost also insulates the windrow; discourages flies; and helps to retain moisture, odor, and ammonia. The plastic pipe is similar to that used for septic system leach fields with two rows of 1/2-inch diameter holes drilled in the pipe. In many aerated pile applications, the pipe holes are oriented downward to minimize plugging and allow condensate to drain. However, some researchers recommend that the holes face upwards.

Windrows are generally formed by the procedures described for the aerated static pile method. Because the raw materials are not turned after the windrows are formed, they must be thoroughly mixed before they are placed in the windrow. Avoid compacting the mix of materials while constructing the windrow. Aeration pipes are placed on top of the peat/compost base. When the composting period is completed, the pipes are simply pulled out, and the base material is mixed with the compost (Rynk, 1992).

2.5.2 Aerated Static Pile

The aerated static pile method takes the piped aeration system a step further, using a blower to supply air to the composting materials. The blower provides direct control of the process and allows larger piles. No turning or agitation of the materials occurs once the pile is formed. When the pile has been properly formed and if the air supply is sufficient and the distribution is uniform, the active composting period will be completed in approximately three to five weeks.

With the aerated static pile technique, the raw material mixture is piled over a base of wood chips, chopped straw or other very porous material. The porous base material contains a perforated aeration pipe. The pipe is connected to a blower, which either pulls or pushes air through the pile.

The initial height of piles should be 5-8 feet high, depending on the material porosity, weather conditions, and the reach of the equipment used to build the pile. Extra height is advantageous in the wintertime to retain heat. It may be necessary to top off the pile with 6 inches of finished compost or bulking agent. The layer of finished compost protects the surface of the pile from drying, insulates it from heat loss, discourages flies, and filters ammonia and potential odors generated within the pile (Rynk, 1992).

Two forms of aerated static piles are common: individual piles and extended piles. Individual piles are long triangular piles with a width (10-16 feet, not including the cover) equal to about twice the pile height. The aeration pipe runs lengthwise beneath the ridge of the pile. Individual piles hold a single large batch of material or a few batches of roughly the same recipe and age (within three days, for example). Individual piles are practical when raw materials are available for composting at intervals rather than continuously. Since the pile does not receive additional turnings, the selection and initial mixing of raw materials are critical. Otherwise, poor air distribution and uneven composting occur. The pile must have good structure as well as to maintain porosity through the entire composting period. This generally requires a fairly stiff bulking agent such as straw or wood chips. Wood chips are commonly used for composting sewage sludge by this method. Because of their large size, wood chips pass through the process only partially composted. They are usually screened from the finished compost and reused as bulking agents for additional two or three cycles. Since straw decomposes over the composting period, a pile with straw as an amendment can gradually lose structure. This is partially compensated by the drying which takes place as composting proceeds. Other possible bulking agents and amendments for static pile composting include recycled compost, peat moss, corn cobs, crop residues, bark, leaves, shellfish shells, waste paper, and shredded tires. Uncomposted material like shredded tires and mollusc shells must eventually be screened from the compost and reused. To obtain good air distribution, manure or sludge must be thoroughly blended with the bulking agent before the pile is established (Rynk, 1992).

The required airflow rates and the choice of blowers and aeration pipe depend on how aeration is managed - that is, how the blower is controlled. The blower can be controlled in several different modes. It can be run continuously or intermittently. In the latter case, the control mechanism can be either a programmed time clock or a temperature sensor.

The airflow rates are based on the dry weight of the primary raw material, such as sludge or manure. They should take into account the presence of typical amendments like wood chips, straw, and compost. In practice, it may be necessary to adjust the timer cycle, pile size, or blower, to suit the specific conditions and materials (Rynk, 1992).

For static pile composting, the air can be supplied in two ways: a suction system with the air drawn through the pile or a pressure system with the blower pushing the air into the pile. Suction draws air into the pile from the outer surface and collects it in the aeration pipe. Since the exhaust air is contained in the discharge pipe, it can be easily filtered if odors are occurring during the composting process.

With positive pressure aeration, the exhaust air leaves the compost pile over the entire pile surface. Therefore, it is difficult to collect the air for odor treatment. If better odor control is desired, a thicker outer layer of compost can be used. Pressure aeration provides better airflow than suction aeration, largely because of the lack of an odor filter. The lower pressure loss results in greater airflow at the same blower power. Therefore, pressure systems can be more effective at cooling the pile and are preferred when temperature control is the overriding concern (Rynk, 1992).

2.5.3 In-Vessel composting

In-vessel composting refers to a group of methods which confine the composting materials within a building, container, or vessel. In-vessel methods rely on a variety of forced aeration and mechanical turning techniques to speed up the composting process. Many methods combine techniques from the windrow and aerated pile methods in an attempt to overcome the deficiencies and exploit the attributes of each method.

In-vessel composting is accomplished inside an enclosed container or vessel (Tchobanoglous, 1993). Every imaginable type of vessel has been used as a reactor in these systems, including vertical towers, horizontal rectangular and circular tanks, and circular rotating tanks. In-vessel composting systems can be divided into two major categories: plug flow and dynamic (agitated bed). In plug flow systems, the relationship between particles in the composting mass stays the same throughout the process, and the system operates on a first-in, first-out principle. In a dynamic system, the composting material is mixed mechanically during the processing.

Mechanical systems are designed to minimize odors and process time by controlling environmental conditions such as air-flow, temperature, and oxygen concentration. The popularity of in-vessel composting systems has increased in recent years. Reasons for this increased use are process and odor control, faster throughout, lower labor costs, and smaller area requirement. The detention time for in-vessel systems varies form 1 to 2 weeks, but virtually all systems employ a 4-12 weeks curing period after the active composting period.

2.5.4 VERMICULTURE AND VERMICOMPOSTING

Vermiculture is the culture of earthworms. The goal is to continually increase the number of worms in order to obtain a sustainable harvest. The worms are either used to expand a vermicomposting operation or sold to customers who use them for the same or other purposes.

Vermicomposting is the process by which worms 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.

These two processes are similar but different. If the goal is to produce vermicompost, then there should have maximum worm population density all of the time. If the goal is to produce worms, the population density should be kept low enough that reproductive rates are optimized (Munroe, no date).

2.6 METHODOLOGY OF VERMICOMPOSTING

Vermicomposting is much more complex than worms simply eating and excreting organic material. It is a highly complex chain of chemical, biochemical and biological interactions and reactions. The whole process is based on natural systems which have evolved over hundreds of millions of years. Worms play a vital role in creating the optimum conditions for the beneficial organisms to establish and reproduce. These 'good' organisms compete with and dominate the more harmful microbes. The waste is reduced in volume and increased in nutrient value.

It takes more than just the worms to make vermicompost. The worms eat, chew and churn up the waste. The other organisms which accompany them also break it down. A simplified description of the overall mechanism is described below:

1. The worms ingest organic matter, fungi, protozoa, algae, nematodes and bacteria. This is passed through the digestive tract. The majority of the bacteria and organic matter pass through undigested (although the organic matter has been ground into smaller particles). This forms the casting along with metabolite wastes such as ammonium, urea and proteins. The worms also secrete mucus, containing polysaccharides, proteins and other nitrogenous compounds. Through the action of eating food and excreting their casts, worms create "burrows" in the material. This in turn increases the available surface area and allows aeration.

2. There is an abundance of oxygen and nitrogenous compounds (urea, proteins and NH3) in the excreta (vermicast) and mucus secreted from the external tissues of the worms. Some bacteria require oxygen (aerobic bacteria) whereas some object to oxygen and prefer its absence (anaerobic bacteria). Anaerobic bacteria are responsible for the stench from stagnant drains, refuse sacks and landfill sites. With the aerobic conditions in vermicompost, aerobic microbiological growth increases. It is believed that the initial burst of microbiological activity mainly consists of

nitrogen fixing bacteria, nitrification bacteria, and to a lesser extent, aerobic bacteria. This is based upon previously established information that burrow walls have a high proportion of the total nitrogen fixing bacteria and that casts have higher concentrations of soluble salts and greater nitrifying power. Accompanying this microbiological growth is the breakdown of organic nitrogen compounds to ammonia and ammonium.

The good news is that the sweet smelling aerobic process overcomes the ugly smell of anaerobes. That is why worm compost piles (properly fed and maintained) smell so nice!

3. The whole process consumes organic matter and creates a ruffled surface in the burrow walls. The large surface area and improved aeration results in favorable conditions for obligate aerobes (such as Pseudomonas spp., Zoogloea spp., Micrococcus spp. and Achromobacter spp.). The continued growth of the microbiological population continues to increase the rate of decomposition of the material.

Air flows through the material more readily, minimizing the likelihood of anaerobic biochemical reactions occurring. This minimizes the formation of sulfide and ammonia gasses, odors that are typically present if anaerobic conditions are established. Objectionable odors disappear quickly, due to microorganisms associated with the vermicast

2.7 BASIC OF VERMICOMPOSTING

In short, vermicomposting involves setting up some type of container (hereafter called a bin); filling it with moist bedding materials; introducing worms and feeding them on a regular basis; monitoring the conditions in the bin; and adding food, water, and more bedding as the conditions warrant. It sounds simple and it basically is. However, worms are living creatures and attention does need to be paid to ensure that their living environment meets their needs.

2.7.1 Worm Bin

Bins can be made out just about anything, but they require drainage and air flow to be built in, so things like Styrofoam (very insulating, and may release toxins into the worms' environment) and metal (too conductive of heat and cold) are generally less desirable, and plastic requires more drainage than wood be it can't absorb moisture Most small bins can be grouped into three categories.

- **Non-continuous** bins are undivided containers that start with a layer of bedding materials -- shredded paper and the like -- that line the bottom. Worms are added and organic matter for composting is added in a layer above the bedding. Another layer is added on top of the organic matter and the worms will start to compost the organic matter and bedding. This type of bin popular because it is small and easy to build, but unfortunately they're more difficult to harvest because all the materials and worms must be emptied out when harvesting.
- **Continuous vertical flow** bins use a series of trays stacked on top of one another. The tray on the bottom, using something like chicken wire as the base, is filled first in the manner described above (bedding, worms, organic waste), but is not harvested when it is full. Instead, a thick layer of bedding is added on top and the tray above is used for adding organic material. When the worms finish composting the bottom tray, they head for more food and migrate to the tray above. When enough of the worms have migrated, the bottom tray can be collected with just a few straggling worms left behind (they can then go in the tray above). Because of the separate tray, these bins provide are easier to harvest.
- **Continuous horizontal flow** bins use a similar structure to the vertical flow, but line up the trays horizontally instead. The bin is usually horizontally longer than the vertical version is tall, and is divided in half, usually by a large gauge screen of chicken wire. One half is used until it becomes full, then the other half is filled with bedding and organic matter. Over time, the worms migrate to the side with the food and the compost can be collected. These bins are larger than a non-continuous system but still small enough to

be used indoors, with the added bonus of being easier to harvest (Dunn, 2007).

The main attributes of a good bin are that it keeps the light out, has a snug-fitting lid, provides for ventilation and drainage, and is big enough to handle the desired amount of food waste. The 18-gallon-sized bins can be started with 1,000 worms (1 pound) which, once acclimated, will process approximately one-half to one pound of waste a day.

2.7.2 Worm Bedding

Once the bin is made, bedding needs to be added. The bedding provides a moist home for the worms, provides the proper carbon-nitrogen balance, and covers the food waste to minimize odors. The bedding should be at least 6 inches deep after moistening. The bedding will be consumed along with the food waste to become vermicompost. Shredded paper is the most common worm bedding because it is readily available to most vermicomposters. While newspaper is usually used at homes, the white paper found in schools, offices, and institutions also makes an excellent bedding material. Glossy advertisements and magazines should be avoided. To turn paper into bedding, simply tear the paper into long one-inch-wide strips. If it is difficult to tear, try tearing in the other direction and it should be easier. Other common bedding materials include composted manure (not too fresh or hot) and shredded corrugated cardboard. As a general rule, fill the bin with dry bedding material and then dampen it to a point where it is thoroughly wet but not dripping wet. "As damp as a wrung-out sponge" is commonly used to describe the proper moisture level of the bedding. The worms can be harmed if the bedding is too dry or too wet. A 3 to 1 ratio (by weight) of water to bedding is a general guideline. A pint of water weighs approximately a pound.

2.7.3 Worm Adding

"Red wigglers" are the species of worm commonly used for vermicomposting. Also known as red worms and manure worms, red wigglers thrive in high-nutrient environments and like to live close to the surface. Place the worms on the bedding material and watch them burrow. Within ten minutes, they should all have disappeared into the bedding.

2.7.4 Feeding the Worms

Worms need a low-fat diet. This means no meat, no dairy and only minimal amounts of oily foods in the worm bin. Fruits, vegetables, coffee grounds, and grains are all welcome additions. Some foods decompose more slowly than others. It is best to chop up really large items and crush egg shells well to help the process along. Care should be taken to not overload the bin with acidic items.

Compost worms are big eaters. Under ideal conditions, they are able to consume in excess of their body weight each day, although the general rule-of-thumb is ½ of their body weight per day. They will eat almost anything organic, but they definitely prefer some foods to others. Manures are the most commonly used worm feedstock, with dairy and beef manures generally considered the best natural food for Eisenia.

Table 2.6 summarizes the most important attributes of some of the more common foods that could be used in an on-farm vermicomposting or vermiculture operation.

Table 2.6: Common Worm Feed Stocks

Food	Advantages	Disadvantages	Notes
Cattle manure	Good nutrition; natural food, therefore little adaptation req'd	Weed seeds make pre-composting necessary	All manures are partially decomposed and thus ready for consumption by worms
Poultry manure	High N content results in good nutrition and a high-value product	High protein levels can be dangerous to worms, so must be used in small quantities; major adaptation required for worms not used to this feedstock. May be pre-composted but not necessary if used cautiously (see	Some books (Gaddie & Douglas, 1975) suggest that poultry manure is not suitable for worms because it is so "hot"; however, research in Nova Scotia (Georg, 2004) has shown that worms can adapt if initial proportion of PM to bedding is 10% by volume or less.

		Notes)	
Sheep/Goat manure	Good nutrition	Require pre-composting (weed seeds); small particle size can lead to packing, necessitating extra bulking material	With right additives to increase C:N ratio, these manures are also good beddings
Hog manure	Good nutrition; produces excellent vermicompost	Usually in liquid form, therefore must be dewatered or used with large quantities of highly absorbent bedding	Scientists at Ohio State University found that vermicompost made with hog manure outperformed all other vermicomposts, as well as fertilizer.
Rabbit manure	N content second only to poultry manure, there-fore good nutrition; contains very good mix of vitamins & minerals; ideal earth-worm feed (Gaddie, 1975)	Must be leached prior to use because of high urine content; can overheat if quantities too large; availability usually not good	Many U.S. rabbit growers place earthworm beds under their rabbit hutches to catch the pellets as they drop through the wire mesh cage floors.
Fresh food scraps (e.g., peels, other food prep waste, leftovers, commercial food processing wastes)	Excellent nutrition, good moisture content, possibility of revenues from waste tipping fees	Extremely variable (depending on source); high N can result in overheating; meat & high-fat wastes can create anaerobic conditions and odours, attract pests, so should NOT be included without pre-composting	Some food wastes are much better than others: coffee grounds are excellent, as they are high in N, not greasy or smelly, and are attractive to worms; alternatively, root vegetables (e.g., potato culls) resist degradation and require a long time to be consumed.

Pre-composted food wastes	Good nutrition; partial decomposition makes digestion by worms easier and faster; can include meat and other greasy wastes; less tendency to overheat.	Nutrition less than with fresh food wastes (Frederickson et al, 1997).	Vermicomposting can speed the curing process for conventional composting operations while increasing value of end product (Georg, 2004; Frederickson, op. cit.)
Biosolids (human waste)	Excellent nutrition and excellent product; can be activated or non-activated sludge, septic sludge; possibility of waste management revenues	Heavy metal and/or chemical contamination (if from municipal sources); odour during application to beds (worms control fairly quickly); possibility of pathogen survival if process not complete	Vermitech Pty Ltd. in Australia has been very successful with this process, but they use automated systems; EPA-funded tests in Florida demonstrated that worms destroy human pathogens as well as does thermophillic composting (Eastman et al., 2000).
Seaweed	Good nutrition; results in excellent product, high in micronutrients and beneficial microbes	Salt must be rinsed off, as it is detrimental to worms; availability varies by region	Beef farmer in Antigonish, NS, producing certified organic vermicompost from cattle manure, bark, and seaweed.
Legume hays	Higher N content makes these good feed as well as reasonable bedding.	Moisture levels not as high as other feeds, requires more input and monitoring	Probably best to mix this feed with others, such as manures
Grains (e.g., feed mixtures for animals, such as chicken mash)	Excellent, balanced nutrition, easy to handle, no odour, can use organic grains for certified organic product	Higher value than most feeds, therefore expensive to use; low moisture content; some larger seeds hard to digest and slow to break down	Danger: Worms consume grains but cannot digest larger, tougher kernels; these are passed in castings and build up in bedding, resulting in sudden overheating

Corrugated cardboard (including waxed)	Excellent nutrition (due to high-protein glue used to hold layers together); worms like this material; possible revenue source from WM fees	Must be shredded (waxed variety) and/or soaked (non-waxed) prior to feeding	Some worm growers claim that corrugated cardboard stimulates worm reproduction
Fish, poultry offal; blood wastes; animal mortalities	High N content provides good nutrition; opportunity to turn problematic wastes into high-quality product	MUST be pre-composted until past thermophillic stage	Composting of offal, blood wastes, etc. is difficult and produces strong odours. Should only be done with in-vessel systems; much bulking required.

Source: Glenn Munroe, Manual of On-Farm Vermicomposting and Vermiculture

2.7.5 Placing the Food

The food waste should be placed under the bedding material or dug into the worm castings and not left on the surface. This will minimize the food's potential for odors and attractiveness to fruit flies. Add additional bedding when necessary. Rotate the burial of the food waste throughout the bin.

2.7.6 Other Things to Add to the Bin

Worms have gizzards and need a small amount of gritty material to help grind up the food waste. A handful of soil added to the bin will work. Before adding the soil, check to make sure that the area that the soil came from was not recently treated with pesticides. An even better source of grit is rock dust. Rock dust is ground up rocks. Many nurseries and garden stores sell bags of rock dust. It is rich in minerals and will help balance the acidity of the bin.

2.7.7 Harvesting

Light separation

Dump the finished material from the box onto a big piece of plastic (eg, an opened-out garbage bag) on the floor or on a table under a 100W light, or outside in the sun. Form it into eight or nine mounds. Worms are sensitive to light and immediately burrow beneath the surface. Wait a few minutes, and meanwhile put fresh bedding in the box.

A hand brush and dustpan are useful for this. Lightly brush the top off each mound until the worms are revealed, then wait for them to burrow deeper and do it again. Eventually you're left with a squirming mass of worms all trying to get under each other to avoid the light. Quickly put them in the new bedding in the box with a fresh supply of feed. This leaves with a rich harvest of worm castings and a lot of capsules, but the worms in the bin will soon replace them. Store the castings for a week or two before using them in the garden.

Sideways separation

Shift all the material in the box to one side and fill the other side with fresh bedding; put kitchen scraps and feed only in the fresh bedding side. In the next week or two the worms will migrate from the finished vermicompost into the fresh bedding. In the meantime the capsules will hatch and most of the hatchlings will also move across.

Vertical separation

Get a piece of nylon or mesh window screening a bit bigger than the surface of the box and lay it flat on the surface of the vermicompost. It should be big enough to flatten against the sides and leave some overlap at the top. Fill the box up with fresh bedding on top of the screen and continue feeding it with kitchen scraps. The worms will migrate up through the screen into the new bedding as the food runs out below.

When the top part is ready for harvesting, use the overlap to lift the screen from the box, vermicompost, worms and all. Set it aside and empty the box -- it will have a very high concentration of worm castings and few if any worms, hatchlings or capsules.

Dump the wormy material that was on top of the screen into the bottom of the box and put the screen back on top of it, with fresh bedding on top of the screen.

Check the condition of the screen each time you empty the box, and replace it before it gets rotten enough to rip just as you're removing it, spilling everything back into the box.

2.7.8 Screening

The vermicompost might need screening, especially if rough stuff has been used (sticks etc.) in the bedding that takes time to break down. A circular gardener's sieve with a 3/16" mesh will work best. With stainless steel mesh, the job will be much quicker, the worm castings won't stick to the mesh, and it won't rust.

This is also a good way of separating the worms from finished vermicompost, though capsules and hatchlings are lost.

2.8 CONTROLING PARAMETERS OF VERMICOMPOSTING

2.8.1 Moisture

The bedding used must be able to hold sufficient moisture if the worms are to have a livable environment. They breathe through their skins and moisture content in the bedding of less than 50% is dangerous. With the exception of extreme heat or cold, nothing will kill worms faster than a lack of adequate moisture.

The ideal moisture-content range for materials in conventional composting systems is 45-60% (Rink et al, 1992). In contrast, the ideal moisture-content range for vermicomposting or vermiculture processes is 70-90%. Within this broad range, researchers have found slightly different optimums: Dominguez and Edwards (1997) found the 80-90% range to be best, with 85% optimum, while Nova Scotia researchers found that 75-80% moisture contents produced the best growth and reproductive response (Georg, 2004). Both of these studies found that average worm weight increased with moisture content (among other variables), which suggests that vermiculture operations designed to produce live poultry feed or bait worms (where individual worm size matters) might want to keep moisture contents above 80%, while vermicomposting operations could operate in the less mucky 70-80% range.

2.8.2 Aeration

Worms are oxygen breathers and cannot survive anaerobic conditions (defined as the absence of oxygen). When factors such as high levels of grease in the feedstock or excessive moisture combined with poor aeration conspire to cut off oxygen supplies, areas of the worm bed, or even the entire system, can become anaerobic. This will kill the worms very quickly. Not only are the worms deprived of oxygen, they are also killed by toxic substances (e.g., ammonia) created by different sets of microbes that bloom under these conditions. This is one of the main reasons for not including meat or other greasy wastes in worm feedstock unless they have been pre-composted to break down the oils and fats.

Although composting worms O_2 requirements are essential, however, they are also relatively modest. Worms survive harsh winters inside windrows where all surfaces are frozen: they live on the oxygen available in the water trapped inside the windrow. Worms in commercial vermicomposting units can operate quite well in their well insulated homes as long as there are small cracks or openings for ventilation somewhere in the system. Nevertheless, they operate best when ventilation is good and the material they are living in is relatively porous and well aerated. In fact, they help themselves in this area by aerating their bedding by their movement through it. This can be one of the major benefits of vermicomposting: the lack of a need to turn the material, since the worms do that work for you. The trick is to provide them with bedding that is not too densely packed to prevent this movement.

2.8.3 Temperature Control

Controlling temperature to within the worms' tolerance is vital to both vermicomposting and vermiculture processes.

• **Low temperatures.** Eisenia can survive in temperatures as low as 0°C, but they don't reproduce at single-digit temperatures and they don't consume as much food. It is generally considered necessary to keep the temperatures above 10°C (minimum) and preferably 15 °C for vermicomposting efficiency and above 15 °C (minimum) and preferably 20 °C for productive vermiculture operations(Munroe, no date)

• **Effects of freezing.** Eisenia can survive having their bodies partially encased in frozen bedding and will only die when they are no longer able to consume food[8]. Moreover, tests at the Nova Scotia Agricultural College (NSAC) have confirmed that their cocoons survive extended periods of deep freezing and remain viable (Georg, 2004).

• **High temperatures.** Compost worms can survive temperatures in the mid-30s but prefer a range in the 20s (°C). Above 35°C will cause the worms to leave the area. If they cannot leave, they will quickly die. In general, warmer temperatures (above 20°C) stimulate reproduction (Munroe, no date).

• **Worm's response to temperature differentials.** Compost worms will redistribute themselves within piles, beds or windrows according to temperature gradients. In outdoor composting windrows in wintertime, where internal heat from decomposition is in contrast to frigid external temperatures, the worms will be found in a relatively narrow band at a depth where the temperature is close to optimum. They will also be found in much greater numbers on the south-facing side of windrows in the winter and on the opposite side in the summer.

2.8.4 pH.

Worms can survive in a pH range of 5 to 9 (Edwards, 1998). Most experts feel that the worms prefer a pH of 7 or slightly higher. Nova Scotia researchers found that the range of 7.5 to 8.0 was optimum (Georg, 2004). In general, the pH of worm beds tends to drop over time. If the food sources are alkaline, the effect is a moderating one, tending to neutral or slightly alkaline. If the food source or bedding is acidic (coffee grounds, peat moss) then the pH of the beds can drop well below 7. This can be a problem in terms of the development of pests such as mites. The pH can be adjusted upwards by adding calcium carbonate. In the rare case where they need to be adjusted downwards, acidic bedding such as peat moss can be introduced into the mix.

2.8.5 Carbon to Nitrogen Ratio

The C/N ratio plays an important role in the nutrient balance in a composting heap; this ratio tells us the amount of carbon available with respect to nitrogen for the composting microorganisms. The ideal C/N ratio for composting of Municipal solid waste generally falls in the range of 20:1 to 25:1 (Tchobanoglous et al., 1993). As stated by Gasser (1985) most municipal solid waste is high in C/N ratio. The initial carbon to nitrogen ratio of the incoming waste was in the range of 40- 47. This high ratio of the C/N ratio might be due to the presence of brown vegetation and plastics, which largely dominate the incoming waste stream. The other reason could be due to the absence of green leafy vegetable, which are high in nitrogen content. Carbon to Nitrogen ratio was actually meant to check the nutrient balance in the composting heap (Goluke, 1977). As reported by Basnayake (2002), the C/N Ratio becomes a good indicator for the stability of the compost. He further added that, the initial C/N Ratio of the material determines the critical level for C/N ratio when it reaches stability. So here this parameter was used to see the maturity of the compost, which in other words also reflects the stabilization of the mixed waste. Table 2.7 shows the nitrogen content and nominal C/N ratios of selected compostable materials (dry basis)

Table 2.7: C/N Ratio of Different Matters

Material	Percen N	C/N ration
Fruit wastes	1.52	34.80

Mixed slaughterhouse waste	7.0-10.0	2.00
Potato tops	1.50	25.00
Cow manure	1.70	18.00
Horse manure	2.30	25.00
Pig manure	3.75	20.00
Poultry manure	6.30	15.00
Sheep manure	3.75	22.00
Digested activated sludge	1.88	15.70
Raw activated sludge	5.60	6.30
Lumber mill wastes	0.13	170.00
Saw dust	0.10	200-500
Wheat straw	0.30	128.00
Wood	0.07	723.00
Mixed paper	0.25	173.00
Newsprint	0.05	983.00
Brown paper	0.01	4490.00
Trade magazines	0.07	470.00
Junk mail	0.17	223.00
Grass clippings	2.15	20.10

(Source: Spoken solid, 1996)

2.8.6 Salt content

Worms are very sensitive to salts, preferring salt contents less than 0.5% (Gunadi et al., 2002). If saltwater seaweed is used as a feed (and worms do like all forms of seaweed), then it should be rinsed first to wash off the salt left on the surface. Similarly, many types of manure have high soluble salt contents (up to 8%). This is not usually a problem when the manure is used as a feed, because the material is usually applied on top, where the worms can avoid it until the salts are leached out over time by watering or precipitation. If manures are to be used as bedding, they can be leached first to reduce the salt content. This is done by simply running water through the material for a period of time (Gaddie, 1975). If the manures are pre-composted outdoors, salts will not be a problem.

2.8.7 Urine content

Gaddie and Douglas (1975) state: "If the manure is from animals raised or fed off in concrete lots, it will contain excessive urine because the urine cannot drain off into the ground. This manure should be leached before use to remove the urine. Excessive urine will build up dangerous gases in the bedding. The same fact is true of rabbit manure where the manure is dropped on concrete or in pans below the cages."

2.9 PROJECTING VERMICOMPOST OUTPUTS

In the world of conventional composting, the rule-of-thumb is that one ton of inputs results in one cubic yard of compost, the weight of which varies with moisture content but is typically about ½ ton. In other words, 50% of the mass is lost, mostly as moisture and CO_2. Some N is lost as ammonia, but if the process is well managed the N loss is minimized (Rink et al, 1992). Of course, the final weight and volume of product varies with original feedstock, bulking agent used, etc., but the above rule-of-thumb is a handy way to quickly calculate output.

Vermicomposting is a bit more variable. This is because there is more variation in how the process is carried out. In composting, mixtures of high-N and high-C materials are made at the start and nothing is added to the mix thereafter. C:N ratios are calculated at the beginning and these fall as C is lost during the process in greater proportion than is N. In vermicomposting or vermiculture operations, the high-C materials are used as bedding, while the high-N materials are generally feed stocks. Although similar processes are taking place in the bed (including conventional composting due to the action of micro-organisms), some systems encourage the addition over the course of the process of greater amounts of N relative to C than would be the case with conventional composting. This is because the feeds are added to the surface of the pile or windrow incrementally, rather than mixed in at the beginning. Since some high-N materials (e.g., fresh food wastes) can be higher in initial water content than high-C bedding materials, weight losses during the vermicomposting process can be higher. In one flow-through system for vermicomposting fresh food wastes tested in Nova Scotia, the total system output was about 10% of the inputs by weight. Another factor reducing final output quantities in vermicomposting is the amount of material converted into worm biomass. This material is largely lost to the final product because most of the worms are removed from the product prior to completion of the process. Alternatively, vermicomposting processes can also allow for higher amounts of overall C to be processed. For instance, shredded paper and cardboard can be converted into vermicompost with the addition of as little as 5% poultry manure, by volume (Georg, 2004). The result of this process is a product weight closer to 50% of the initial input weight.

In general, outputs from vermicomposting processes can vary from about 10% to closer to 50% of the original weight of the inputs. This will vary with the nature of the inputs and the system used. The greater the proportion of high-C inputs to high-N inputs, the greater will be the weight of final output as a proportion of input weight.

Table 2.8: Vermicompost/Feed ratio

	Mushroom waste	Shredded paper	Total Feed	Vermicompost harvested	Vermicompost/ Feed
	105	79	184	110	
	154	80	234	123	
	60	191	251	150	**0.6**
Sub total	319	350	669	383	
	83	83	166	102	
	148	86	234	149	
	56	193	249	124	**0.6**
Sub total	287	362	649	375	
	151	76	227	124	
	151	100	251	208	
	60	211	271	148	**0.6**
Sub total	362	387	749	480	

Source: (Fuente & Gordillo, no date)

2.10 WORM FACTS

2.10.1 Compost worms

There are an estimated 1800 species of earthworm worldwide (Edwards & Lofty, 1972). But Eisenia foetida is commonly known as (partial list only): the "compost worm", "manure worm", "redworm", and "red wiggler" This extremely tough and adaptable worm is indigenous to most parts of the world.

Three Types of Earthworm

Anecic (Greek for "out of the earth") – these are burrowing worms that come to the surface at night to drag food down into their permanent burrows deep within the mineral layers of the soil. Example: the Canadian Night crawler.

Endogeic (Greek for "within the earth") – these are also burrowing worms but their burrows are typically more shallow and they feed on the organic matter already in the soil, so they come to the surface only rarely.

Epigeic (Greek for "upon the earth") – these worms live in the surface litter and feed on decaying organic matter. They do not have permanent burrows. These "decomposers" are the type of worm used in vermicomposting

(Card et al., 2004).

E. foetida can handle a wide temperature range (between 0 and 35oC) and can actually survive for some time almost completely encased in frozen organic material (as long as it can continue to take in nourishment). Its cocoons (eggs) have been shown to remain viable after having been frozen for several weeks. In addition, it can take a lot of handling and rough treatment. Perhaps most importantly, like most if not all litter-dwelling worms, the compost worm has the capacity for very rapid reproduction. This is an evolutionary necessity for a creature whose natural environment is extremely changeable and hazardous and whose natural supplies of food are of the "boom or bust" variety. All of these characteristics make E. foetida the natural choice for those who wish to do their vermicomposting outdoors, year-round, in climates with harsh winter conditions.

Figure 2.4: E. foetida - the compost worm

2.10.2 Reproduction

Redworms are hermaphrodites, equipped with both male and female organs. Redworms reproduce by joining together with mucus produced at the clitellum's, a round band around the midsection. Each worm has both ovaries and testes. When the worms join, sperm passes from each worm to the other's sperm storage sac. As the mucus hardens, a cocoon forms. As the worms back out of the cocoon, eggs and sperm are deposited into the cocoon. The cocoon seals itself, fertilization takes place inside the cocoon, and within a few weeks two or more baby worms hatch out of the cocoon. Redworms take approximately four to six weeks to mature between hatching and commencing reproduction. When temperature, moisture, and food are favorable, a mature redworm can mate and produce two to three cocoons per week. Cocoons look like tiny, brownish lemons. After hatching out of the cocoon, baby worms appear small and transparent.

2.10.3 Respiration

Unlike humans, worms have no lungs. Worms respire through the entire surface of their bodies. Oxygen dissolves in the moisture on the worms' body. Oxygen then passes into the body and the bloodstream. Worms need enough moisture to keep their skins wet, but not enough to drown them. Worms are not aquatic animals, but some species can live under water if there is enough oxygen dissolved in the water. Without moisture, however, the worms will die.

2.10.4 Ingestion

A worm can consume about one-half of its weight each day. A worm weighing 1 gram might eat 1/2 gram of food in one day. The bedding in the worm bin disappears as it, in addition to the food, is consumed and converted to castings.

2.10.5 Digestion

Microorganisms such as bacteria and fungi aid worms, which do not have teeth, by breaking down pieces of food. Bacteria act as digesters, and fungi break down cellulose. A redworm's mouth has a small sensitive pad of flesh, called the prostomium that protrudes above its mouth and stretches out to sense suitable food particles. Worms have a muscular gizzard, which functions similarly to that of birds. Small grains of sand and mineral particles lodge in this gizzard. Muscular contractions compress these hard materials against each other and the food, mix it with some fluid, and grind it into smaller particles. Undigested matter such as soil will pass through the worm's long intestine. The tiny, dark colored masses the worms deposit are called worm castings. Other names for worm castings are worm manure or worm feces. Castings contain thousands of bacteria, humus, and many nutrients that help plants to grow.

2.10.6 Locomotion

Worms move by contracting and relaxing their muscles in waves, alternating between circular and long muscles. Contraction of the circular muscles forces the worm's body forward. Then the long muscles contract, drawing the tail end of the worm towards the skinny front end. When the long muscles contract, the circular muscles relax, causing the worm to become thick. To keep from skidding during movement, tiny bristles called setae act as brakes to hold part of the worm's body against the surface. The worm moves forward and backward in similar ways.

2.10.7 Other Worm Facts

Most worms probably live and die within the same year, although they can live longer. Redworms have no eyes and cannot see but they use light-sensitive skin cells, concentrated at the front end of their bodies, to sense light and move away from it. Although worms are very prolific, they will automatically keep their numbers in check in a worm box. Contrary to folklore, if a worm is cut in half, both halves do not regenerate. A worm can replace a limited number of front or hind segments, but only if it still has middle.

2.10.8 Calculating Rates of Reproduction

Epigeic worms such as E. f0etida do reproduce very quickly, given good to ideal conditions. Compost worm populations can be expected to double every 60 to 90 days, but only if the following conditions are met:

- Adequate food (must be continuous supply of nutritious food)
- Well aerated bedding with moisture content between 70 and 90%;
- Temperatures maintained between 15 and 30°C;
- Initial stocking densities greater than 2.5 kg/m2 (0.5 lb/ft2) but not more

than

5 Kg/m2 (1.0 lb/ft2).

Stocking density refers to the initial weight of worm biomass per unit area of bedding. For instance, if you started with 5 kg of worms and put them in a bin with a surface area of 2 m2, then your initial stocking density would be 2.5 kg/m2. Starting with a population density less than this will delay the onset of rapid reproduction and, at very low densities, may even stop it completely. It seems that worms need a certain density in order to have a reasonable chance of running into each other and reproducing frequently. At lower densities, they just don't find each other as often as the typical worm grower would like.

On the other hand, densities higher than 5 kg/m2 begin to slow the reproductive urge, as competition for food and space increase. While it is possible to get worm densities up to as much as 20 kg/m2 or 4 lbs per square foot (Edwards, 1999), the most common densities for vermicomposting are between 5 and 10 kg/m2 (1 to 2 lbs per ft2). Worm growers tend to stock at 5 kg/m2 (Bogdanov, 1996) and "split the beds" when the density has doubled, assuming that the optimum densities for reproduction have by that point been surpassed.

If the above guidelines are followed, a grower can expect a doubling in worm biomass about every 60 days. Theoretically, this means that an initial stock of 10 kg of worms can become 640 kg after one year and about 40 tones after two years. In practice, this is difficult to achieve, though not impossible. For instance, American Resource Recovery, a recycling firm in northern California, started with 50 pounds of earthworms. In four years, they had enough to cover over 70 acres of windrows, within which the worms convert huge quantities of sludge from a cardboard recycling plant into worm castings (VermiCo, 2004).

2.11 PESTS AND DISEASES

Compost worms are not subject to diseases caused by micro-organisms, but they are subject to predation by certain animals and insects (red mites are the worst) and to a disease known as "sour crop" caused by environmental conditions. The following is a brief overview of the most common pests and diseases likely to be experienced in vermicomposting

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• **Moles.** Earthworms are moles' natural food, so if a mole gets access to your worm bed, you can lose a lot of worms very quickly (Gaddie, op. cit.). This is usually only a problem when using windrows or other open-air systems in fields. It can be prevented by putting some form of barrier, such as wire mesh, paving, or a good layer of clay, under the windrow.

• **Birds.** They are not usually a major problem, but if they discover your beds they will come around regularly and help themselves to some of your workforce. Putting a windrow cover of some type over the material will eliminate this problem. These covers are also useful for retaining moisture and preventing too much leaching during rainfall events. Old carpet can be used for this purpose and is very effective.

• **Centipedes.** These insects eat compost worms and their cocoons. Fortunately, they do not seem to multiply to a great extent within worm beds or windrows, so damage is usually light. If they do become a problem, one method suggested for reducing their numbers is to heavily wet (but not quite flood) the worm beds. The water forces centipedes and other insect pests (but not the worms) to the surface, where they can be destroyed by means of a hand-held propane torch or something similar (Gaddie, op. cit.; Sherman, 1997).

• **Ants.** These insects are more of a problem because they consume the feed meant for the worms (Myers, 1969). Ants are particularly attracted to sugar, so avoiding sweet feeds in the worm beds reduces this problem to a minor one. Keeping the bedding above pH 7 also helps.

• **Mites.** There are a number of different types of mites that appear in vermiculture and vermicomposting operations, but only one type is a serious problem: red mites. White and brown mites compete with worms for food and can thus have some economic impact, but red mites are parasitic on earthworms. They suck blood or body fluid from worms and they can also suck fluid from cocoons (Sherman, 1997). The best prevention for red mites is to make sure that the pH stays at neutral or above. This can be done by keeping the moisture levels below 85% and through the addition of calcium carbonate, as required.

•**Sour crop or protein poisoning.** This "disease" is actually the result of too much protein in the bedding. This happens when the worms are overfed. Protein builds up in the bedding and produces acids and gases as it decays (Gaddie, op. cit.). According to Myers (1969): "when you see a worm with a swollen clitellum or see one crawling aimlessly around on top of the bedding, you can just bet on sour crop and act accordingly, but fast". Her recommended solution is a "massive dose of one of the mycins, such as farmers give to chicken or cattle". Farmers wishing to avoid these or similar antibiotics should work to prevent sour crop by not overfeeding and by monitoring and adjusting pH on a regular basis. Keeping the pH at neutral or above will preclude the need for these measures.

2.12 AN OVERVIEW OF VERMICOMPOSTING SYSTEMS

2.12.1 Basic Types of Systems

There are three basic types of vermicomposting systems of interest to farmers: windrows, beds or bins, and flow-through reactors. Each type has a number of variants. Windrows and bins can be either batch or continuous-flow systems, while all flow-through systems, as the name suggests, are of the continuous-flow variety.

Batch vs Continuous-Flow Systems: Batch systems are ones in which the bedding and food are mixed, the worms added, and nothing more is done (except by the worms!) until the process is complete. Continuous-flow systems are ones in which worms are placed bedding, whereupon feed and new bedding aradded incrementally on a regular basis.

2.12.2 Windrows

Windrow vermicomposting can be carried out in a number of different ways. The three most common are described here.

2.12.2.1 Static pile windrows (batch)

Static pile windrows are simply piles of mixed bedding and feed (or bedding with feed layered on top) that are inoculated with worms and allowed to stand until the processing is complete. These piles are usually elongated in a windrow style but can also be squares, rectangles, or any other shape that makes sense for the person building them. They should not exceed one meter in height (before settling). Care must be taken to provide a good environment for the worms, so the selection of bedding type and amount is important. After the bedding was supplemented with large quantities of hay and silage, increasing the porosity of the windrows, worm reproduction took off.

Figure 2.5: Vermicomposting windrows of shredded cardboard and manure

2.12.2.2 Top-fed windrows (continuous flow)

Top-fed windrows are similar to the windrows described above, except that they are not mixed and placed as a batch, but are set up as a continuous-flow operation. This means that the bedding is placed first, then inoculated with worms, and then covered repeatedly with thin (less than 10 cm) layers of food. The worms tend to consume the food at the food/bedding interface, and then drop their castings near the bottom

of the windrow. A layered windrow is created over time, with the finished product on the bottom, partially consumed bedding in the middle, and the fresher food on top. Layers of new bedding should be added periodically to replace the bedding material gradually consumed by the worms.
The major disadvantages to this system are related to the winter conditions experienced in Canada. Unlike the batch windrows described above, these windrows require continuous feeding and are difficult if not impossible to operate in the winter. In addition, if windrow covers are used, they must be removed and replaced every time the worms are fed, creating extra work for the operator. The advantages of top-feeding have mainly to do with the greater control the operator has over the worms' environment: since the food is added on a regular basis, the operator can easily assess conditions at the same time and modify such things as feeding rate, pH, moisture content, etc., as required. This tends to result in a higher-efficiency system with greater worm production and reproduction.

Harvesting is usually accomplished by removing the top 10-20 cm first, usually with a front-end loader or tractor outfitted with a bucket (Bogdanov, 1996). This material will contain most of the worms and it can be used to seed the next windrow. The remaining material will be mostly vermicompost, with some unprocessed bedding. This can be used as is or screened, with unfinished material put back into the process. This is essentially the system used by North America's largest vermicomposting facility, a 77-acre operation run by American Resource Recovery in northern California that processes 300 tons of paper wastes per day (VermiCo, 2004).

2.12.2.3 Wedges (continuous flow)

The vermicomposting wedge is an interesting variation on the top-fed windrow. An initial stock of worms in bedding is placed inside a corral-type structure (3-sided) 15 of no more than three feet or one meter in height. The sides of the corral can be concrete, wood, or even bales of hay or straw. Fresh material is added on a regular feeding schedule through the open side, usually by bucket loader. The worms follow the fresh food over time, leaving the processed material behind. When the material has reached the open end of the corral, the finished material is harvested by removing the back of the corral and scooping the material out with a loader. A 4th side is then put in place and the direction is reversed.

Using this system, the worms do not need to be separated from the vermicompost and the process can be continued indefinitely. During the coldest months, a layer of insulating hay or straw can be placed over the active part of the wedges. The corrals can be any width at all, the only constraint being access to the interior of the piles for monitoring and corrective actions, such as adjustment of moisture content or pH level. A corral width of about 6 feet, with space between adequate for foot travel, would be ideal. The ideal length will depend on the material being processed, the size of the worm population, and other factors affecting processing times.

The sides of the corrals can be made of any material at all, although insulating value is a consideration. Hay or straw bales will gradually break down over time and be consumed by the worms; as a bale loses its structural integrity, however, it can be added to the contents of the wedge and replaced with a fresh one.

Operating the wedge system over the winter is challenging, though not impossible. The regular addition of fresh manure to the operating face can create enough heat to produce a "temperate zone" behind the face within which the worms will continue to thrive and reproduce. Another option would be to load up the face with fresh manure in late autumn, cover all of material with a thick layer of straw, and uncover and begin operations again in the spring.

2.12.3 Beds or Bins

2.12.3.1 Top-fed beds (continuous flow)

A top-fed bed works like a top-fed windrow. The main difference is that the bed, unlike a windrow, is contained within four walls and (usually) a floor, and is protected to some degree from the elements, often within an unheated building such as a barn. The beds can be built with insulated sides, or bales of straw can be used to insulate them in the winter. If the bins are fairly large, they are sheltered from the wind and precipitation, and the feedstock is reasonably high in nitrogen, the only insulation required may be an insulating "pillow" or layer on top. These can be as simple as bags or bales of straw. Harvesting vermicompost can be most easily accomplished by taking advantage of horizontal migration. The beds can be built with metal screen separating the different beds. To harvest, the operator simply stops feeding one of the beds for several weeks, allowing the worms' time to finish that material and then migrate to the other beds in search of fresh feed. The "cured" bed is then emptied and refilled with bedding, after which feeding is resumed. This is repeated on a regular rotating basis. If the beds are large enough, they can be emptied with a tractor instead of by hand.

These beds have the advantage of being more contained than windrows, and thus more controllable in terms of environmental conditions. The main disadvantage to this system is the extra cost of building and maintaining the beds, as well as the cost of shelter

2.12.3.2 Stacked bins (batch or continuous flow)

One of the major disadvantages of the bed or bin system is the amount of surface area required. While this is also true of the windrow and wedge systems, they are outdoors, where space is not as expensive as it is under cover. Growing worms indoors or even within an unheated shelter is an expensive proposition if nothing is done to address this issue.

Stacked bins address the issue of space by adding the vertical dimension to vermicomposting. The bins must be small enough to be lifted, either by hand or with a forklift, when they are full of wet material. They can be fed continuously, but this involves handling them on a regular basis (Beetz, 1999). The more economical route to take is to use a batch process, where the material is pre-mixed and placed in the bin, worms are added, and the bin is stacked for a pre-determined length of time and then emptied. This method is used by a number of professional vermicompost producers in North America.

In an experiment carried out by the author in Nova Scotia in 2003-04 (Georg, 2004), cattle manure was mixed in a 1:2 ratio by volume with shredded cardboard, placed in stacked bins that were 1.2 m (4 ft) square and either 30 cm (12 in.) or 45 cm (18 in.) in depth .Each bin was inoculated with 2.27 kg (5 lbs) of worms. The bins were stacked in an unheated building in December and harvested in June, approximately 6 months later. The bins were constructed of 5/8" particle-board and were stacked together within an 8' by 8' framework of 4' by 8' sheets of particle board covered with rigid foam insulation rated at R2. The top was covered by one thickness of standard pink fiberglass insulation covered on both sides by sheet plastic. The material did not freeze over the winter, as the decomposing manure brought temperatures within the bins into the 30 to 40°C range for the first month or so[17] and then kept them well above freezing for the balance of the winter.

Figure. 2.6: The framework for the stacked bins

All of the material was completely processed after six months and the worm populations had increased by a factor of 3. Some of the bins had contained aged manure (at least one year), while the others had fresh manure (two weeks). The bins with the fresh manure experienced a 4-fold increase in worm-biomass increase (a doubling period of 3 months), while the aged manure doubled its worm biomass. The vermicompost in all bins was mature and rich. .

The main disadvantage of the stacked-bin system is the initial cost of set-up. It requires an unheated shelter, bins, a way to mix the bedding and feed, and equipment to stack the bins, such as a forklift. On a smaller scale, of course, this could all be done by hand. Another disadvantage arises when it comes time to harvest. As with the batch windrow systems, the worms are mixed in with the product and need to be separated. That requires either a harvester or another step in the process, where the material is piled so that the worms can migrate into new material.

2.12.4 Flows-Through Reactors

The flow-through concept was developed by Dr. Clive Edwards and colleagues in England in the 1980s. It has since been adopted and modified by several companies, including Oregon Soil Corporation of Portland, Oregon, and the Pacific Garden Company, based in Washington and Pennsylvania. The latter company was started in the last few years by Dr. Scott Subler, a former colleague of Clive Edwards at Ohio State University. A variation of this system is also used by Vermitech, an Australian company that has built three biosolids processing facilities in that country over the past five years (Fox, 2001). The system operates as follows. The worms live in a raised box, usually rectangular and not more than three meters in width. Material is added to the top, and product is removed through a grid at the bottom, usually by means of a hydraulically driven breaker bar. The term "flow-through" refers to the fact that the worms are never disturbed in their beds – the material goes in the top, flows through the reactor (and the worms' guts), and comes out the bottom (E. fetida tends to eat at the surface and drop castings near the bottom of the bedding). The method for pushing the materials out the bottom is usually a set of hydraulically powered "breaker bars" that move along the bottom grate, loosening the material so that it falls through. Clive Edwards has stated that a "properly managed" flow-through unit of approximately 1000 ft2 surface area can process 2 to 3 tones per day of organic waste (Bogdanov, 1996).

2.12.5 Vermiculture Systems

Vermiculture focuses on the production of worms, rather than vermicompost. As mentioned earlier, growing worms efficiently requires a somewhat different set of conditions than vermicomposting. The most basic differences are as follows:

- **Population density.** Worm growers usually keep their beds at a density between 5 and 10 kg/m2 (1 to2 lbs/ft2). This ensures a high reproductive rate. Efficient vermicomposting operations would start at 10 kg/m2 and try for even higher densities (although windrows and other low-tech systems will have those high densities only in certain areas, where environmental conditions are closest to optimum, well-managed flow-through systems would operate at these levels or higher throughout the bed).
- **Type of system.** Vermiculture operators usually select systems that give them greater control over the environmental conditions. This means beds or stacked bins as opposed to windrows or wedges. The flow-through reactor could be used for vermiculture, but is generally used for vermicomposting because of its high capital cost and its efficiency in producing vermicompost. Worms can be harvested sustainably from a flow-through system, but doing so will decrease the vermicomposting efficiency.
- **Harvesting methods.** Vermiculture systems require special techniques for harvesting worms, since the systems usually favored by vermicomposting operators (e.g., vertical and horizontal migration into new bedding) only separate the worms from the finished material.

2.12.6 Methods of Harvesting Worms

2.12.6.1 General

Worm harvesting is usually carried out in order to sell the worms rather than to start new worm beds. Expanding the operation (new beds) can be accomplished by splitting the beds that is, removing a portion of the bed to start a new one and replacing the material with new bedding and feed. When worms are sold, however, they are usually separated, weighed, and then transported in a relatively sterile medium, such as peat moss. To accomplish this, the worms must first be separated from the bedding and vermicompost. There are three basic categories of methods used by growers to harvest worms: manual, migration, and mechanical (Bogdanov, 1996). Each of these is described in more detail in the sections that follow.

2.12.6.2 Manual Methods

Manual methods are the ones used by hobbyists and smaller-scale growers, particularly those who sell worms to the home-vermicomposting or bait market. In essence, manual harvesting involves hand-sorting, or picking the worms directly from the compost by hand. This process can be facilitated by taking advantage of the fact that worms avoid light. If material containing worms is dumped in a pile on a flat surface with a light above, the worms will quickly dive below the surface. The harvester can then remove a layer of compost, stopping when worms become visible again. This process is repeated several times until there is nothing left on the table except a huddled mass of worms under a thin covering of compost. These worms can then be quickly scooped into a container, weighed, and prepared for delivery.
There are several minor variations and/or enhancements on this method, such as using a container instead of a flat surface, or making several piles at once, so that the person harvesting can move from one to another, returning to the first one in time to remove the next layer of compost. They are all labour-intensive, however, and only make sense if the operation is small and the value of the worms is high .

2.12.6.3 Self-Harvesting (Migration) Methods

These methods, like some of the methods used in vermicomposting, are based on the worms' tendency to migrate to new regions, either to find new food or to avoid undesirable conditions, such as dryness or light. Unlike the manual methods described above, however, they often make use of simple mechanisms, such as screens or onion bags.
The screen method is very common and easy to use. A box is constructed with a screen bottom. The mesh is usually ¼", although 1/8" can be used as well

(Bogdanov, 1996). There are two different approaches. The downward-migration system is similar to the manual system, in that the worms are forced downward by strong light. The difference with the screen system is that the worms go down through the screen into a prepared, pre-weighed container of moist peat moss. Once the worms have all gone through, the compost in the box is removed and a new batch of worm-rich compost is put in. The process is repeated until the box with the peat moss has reached the desired weight. Like the manual method, this system can be set up in a number of locations at once, so that the worm harvester can move from one box to the next, with no time wasted waiting for the worms to migrate.
The upward-migration system is similar, except that the box with the mesh bottom is placed directly on the worm bed. It has been filled with a few centimeters of damp peat moss and then sprinkled with a food attractive to worms, such as chicken mash, coffee grounds, or fresh cattle manure. The box is removed and weighed after visual inspection indicates that sufficient worms have moved up into the material. This system is used extensively in Cuba, with the difference that large onion bags are used instead of boxes (Cracas, 2000). The advantage of this system is that the worm beds are not disturbed. The main disadvantage is that the harvested worms are in material that contains a fair amount of unprocessed food, making the material messier and opening up the possibility of heating inside the package if the worms are shipped. The latter problem can be avoided by removing any obvious food and allowing a bit of time for the worms to consume what is left before packaging.

2.13 THE VALUE OF VERMICOMPOST

Vermicompost, like conventional compost, provides many benefits to agricultural soil, including increased ability to retain moisture, better nutrient-holding capacity, better soil structure and higher levels of microbial activity. A search of the literature, however, indicates that vermicompost may be superior to conventional aerobic compost in a number of areas. These include the following.

• **Level of plant-available nutrients**. Atiyeh et al. (2000) found that compost was higher in ammonium, while vermicompost tended to be higher in nitrates, which is the more plant-available form of nitrogen. Similarly, work at NSAC by Hammermeister et al. (2004) indicated that "Vermicomposted manure has higher N availability than conventionally composted manure on a weight basis". The latter study also showed that the supply rate of several nutrients, including P, K, S and Mg, were increased by vermicomposting as compared with conventional composting. These results are typical of what other researchers have found (Short et al., 1999; Saradha, 1997, Sudha and Kapoor, 2000). It appears that the process of vermicomposting tends to result in higher levels of plant-availability of most nutrients than does the conventional composting process. Table 2.9 and Table 2.10 shows the chemical characteristics of garden compost and vermi compost.

Table2.9: Chemical characteristics of garden compost and vermicompost

Parameter*	Garden compost[1]	Vermicompost[2]
pH	7.80	6.80
EC (mmhos/cm)**	3.60	11.70
Total Kjeldahl nitrogen(%)***	0.80	1.94
Nitrate nitrogen (ppm)****	156.50	902.20
Phosphorous (%)	0.35	0.47
Potassium (%)	0.48	0.70
Calcium (%)	2.27	4.40
Sodium (%)	< .01	0.02
Magnesium (%)	0.57	0.46
Iron (ppm)	11690.00	7563.00
Zinc (ppm)	128.00	278.00
Manganese (ppm)	414.00	475.00
Copper (ppm)	17.00	27.00
Boron (ppm)	25.00	34.00
Aluminum (ppm)	7380.00	7012.00

[1]Albuquerque sample [2]Tijeras sample

*Units- ppm=parts per million mmhos/cm=millimhos per centimeter

** EC = electrical conductivity is a measure (millimhos per centimeter) of the relative salinity of soil or the amount of soluble salts it contains.

*** Kjeldahl nitrogen = is a measure of the total percentage of nitrogen in the sample including that in the organic matter.

**** Nitrate nitrogen = that nitrogen in the sample that is immediately available for plant uptake by the roots.

Source: Dickerson, 1994

Table2.10: Chemical characteristics of farm yard manure and vermicompost

Nutrient	Vermicompost	Farm Yard Manure
N(%)	1.6	0.5
PO(%)	0.7	0.2
KO(%)	0.8	0.5
Ca(%)	0.5	0.9
Mg(%)	0.2	0.2
Fe(ppm)	175.0	146.5
Mn(ppm)	96.5	69.0
Zn(ppm)	24.5	14.5
Cu(ppm)	5.0	2.8

Soruce: ***Punjab State Council for Science and Technology, Chandigarh***

Table 2.11 present the comparative study of nutrient component of different compost samples at Gazipur area.

Table2.11: Comparison of nutrient content of different compost samples

Parameter	Vermi compost (a)	Static pile compost (b)	Barrel compost ©
Nitrogen (N) (%)	1.71	2.06	1.22
Phosphorus (P) (%)	0.59	0.56	0.58
Potassium (K) (%)	1.19	1.94	0.88
Sulphur(S) (%)	1.18	1.18	0.28
(a)=BASA, 2006 (b)=BASA, 2006 (C)=Moqsud (2003)			

The NPK content of he vermicompost prepared from vegetable waste and cowdung has also shown a maximum increase when compared with the compost prepared using individual constituents. The cow dung influenced the rate of vermicomposition and increased the amount of macronutrients in the vermicompost. 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. Hence, it is clear that the mixture of vegetable waste and cow dung is suitable for the production of higher quality vermicompost when compared with the subjecting the same components individually. Table 2.12 present the Comparison of the nutrients in the different treatments of vermicompost (Amsath & Sukumaran, 2008).

Table2.12: Nutrient values of vermicompost (values are given in percentage)

Treatment	pH	N	P	K
Soil + Earthworm (T1)	**7.5**	**1.45**	**0.57**	**1.98**
Soil + Earthworm + Cow dung (T2)	**7.9**	**1.62**	**1.2**	**2.65**
Soil + Earthworm + Vegetable waste (T3)	**8**	**1.5**	**1.1**	**3.26**
Soil + Earthworm + Cow dung + Vegetable waste (T4)	**8.3**	**1.76**	**1.6**	**4.98**

• **Level of beneficial microorganisms.** It is widely believed that vermicompost greatly exceeds conventional compost with respect to levels of beneficial microbial activity. Much of the work on this subject has been done at Ohio State University, led by Dr. Clive Edwards (Subler et al., 1998). In an interview (Edwards, 1999), he stated that vermicompost may be as much as 1000 times as microbial active as conventional compost, although that Figure is not always achieved.

• **Ability to stimulate plant growth.** Many researchers have found that vermicompost stimulates further plant growth even when the plants are already receiving optimal nutrition. Atiyeh at al (2002) conducted an extensive review of the literature with regard to this phenomenon. The authors stated that: "These investigations have demonstrated consistently that vermicomposted organic wastes have beneficial effects on plant growth independent of nutritional transformations and availability. Whether they are used as soil additives or as components of horticultural soil less media, vermicomposts have consistently improved seed germination, enhanced seedling growth and development, and increased plant productivity much more than would be possible from the mere conversion of mineral nutrients into more plant-available forms." Moreover, the authors go on to state a finding that others have also reported (Arancon, 2004), that maximum benefit from vermicompost is obtained when it constitutes between 10 and 40% of the growing medium. It appears that levels of vermicompost higher than 40% do not increase benefit and may even result in decreased growth or yield.

Ability to suppress disease: There has been considerable anecdotal evidence in recent years regarding the ability of vermicompost to protect plants against various diseases. The theory behind this claim is that the high levels of beneficial microorganisms in vermicompost protect plants by out-competing pathogens for available resources, while also blocking their access to plant roots by occupying all the available sites.

Summary: The Value of Vermicompost

In Argentina, farmers who use vermicompost consider it to be seven times richer than compost, so that only one seventh of the quantity is required (Pajon, no date). Growers in Australia and India report similar findings (Vermitech, 2004; Bogdanov, 2004). The literature is fairly consistent in reporting benefits from the use of vermicompost ranging from increased growth and yield to disease suppression and even possible insect repellency.

2.14 ENVIRONMENTAL RISKS AND BENEFITS

2.14.1 Worms and the Environment

Aristotle called worms the "intestines of the earth" and Charles Darwin wrote a book on worms and their activities, in which he stated that there may not be any other creature that has played so important a role in the history of life on earth (Bogdanov, 1996). There can be little doubt that humankind's relationship with worms is vital and needs to be nurtured and expanded. The following sections touch on some of the most important areas in which our natural environment can be preserved and sustained through a partnership with these engines of the soil.

2.14.2 Water Quality Issues

One of the early concerns with vermicomposting was that this process, because it did not reach the high temperatures of conventional composting, did not destroy potentially dangerous pathogens. In recent years, however, strong evidence has surfaced that worms do indeed destroy pathogens, although the manner in which this occurs is still unknown. The best information in this regard comes from Florida, where the Orange County Environmental Protection Division carried out a study to assess the ability of the vermicomposting process to meet Class A standards for biosolids stabilization. The results of this study showed that vermicomposting could indeed be used as a method for destroying pathogens, with a success rate equal to conventional composting (Eastman, 1999; Eastman et al, 2000). More recently, Dr. Elaine Ingham has found in her research that worms living in pathogen-rich material, when dissected, show no evidence of pathogens beyond the first five millimeters of their gut. In other words, something inside the worm destroys the pathogens, leaving the castings pathogen-free (Appelhof, 2003).

These findings have implications that go beyond the protection of water quality during vermicomposting, although that is important in itself. They also suggest that:

Vermicompost spread on farm land will not result in pathogen contamination of ground or surface waters, having pasturelands seeded and re-seeded with E. fetida cocoons (as they would be if vermicompost were routinely applied) could help to prevent water contamination by pathogens, since fresh manure dropped by grazing animals will be quickly colonized by compost worms.

In addition, vermicompost, like conventional compost, binds nutrients well, both in the bodies of microorganisms and through their actions. This means less nutrient run-off. This is an extremely important environmental benefit of both composting and vermicomposting. Nutrient run-off from agricultural land is a major environmental problem worldwide, with eutropication of surface waters as its principal manifestation.

Finally, there appears to be some potential in using compost worms as part of natural filtration systems. This work is still in its infancy, but seems to have some potential.

2.14.3 Climate Change Factors

Climate change is one of the most serious and pressing environmental problems of our time. Farms are a significant contributor to climate change, largely through the release of carbon from soils and the generation of methane gas from livestock and their manure. Both composting and vermicomposting address these issues.

One of the principal benefits of both composting and vermicomposting occurs through carbon sequestration. This is the process of locking carbon up in organic matter and organisms within the soil. Because composts of all types are stable, more carbon is retained in the soil than would be if raw manure or inorganic fertilizer were applied. Soils worldwide have been gradually depleted of carbon through the use of non-organic farming systems. The consistent application of compost or vermicompost gradually raises the level of carbon in the soil. Although carbon is constantly leaving the soil as more is being sequestered, the use of composts can increase the equilibrium level, effectively removing large amounts of carbon permanently from the atmosphere.

The composting process itself is thought to be neutral with respect to greenhouse gas generation. The United States Environmental Protection Agency (US EPA) assessed the GHG impact of composting yard wastes a few years ago as part of a larger assessment of recycling and climate change. Their findings were that the composting process results in the same level of GHG emissions as if the materials were allowed to decay naturally, as on the forest floor. The EPA study acknowledged the potential gains from other factors, such as those discussed below, but did not include them in their analyses.

Other researchers (Paul et al, 2002) have pointed out that the GHG benefits from composting do not come from the process itself, but from the avoided processes at both the front and back ends. Front-end savings occur when the organic material, such as manure on farms, is not stored under anaerobic conditions or spread raw on farmers fields, both of which result in high emissions of methane and or nitrous oxide. The back-end savings result from the displacement of commercial fertilizer by the compost, since the production and transport of fertilizer over long distances result in high levels of GHG emissions. Unfortunately, these benefits have not as yet been systematically quantified.

The potential advantages of composting described above also apply to vermicomposting. In theory, however, vermicomposting should provide some potentially significant advantages over composting with respect to GHG emissions. First, the vermicomposting process does not require manual or mechanical turning, as the worms aerate the material as they move through it. This should result in fewer anaerobic areas within the piles, reducing methane emissions from the process. It also reduces the amount of fuel used by farm equipment or compost turners. Second, vermicompost's increased effectiveness (5 to 7 times) relative to compost in promoting plant growth and increasing yield, implies that five to seven times as much fertilizer could be displaced per unit of vermicompost, decreasing the GHG emissions proportionately. Finally, analysis of vermicompost samples has shown generally higher levels of nitrogen than analysis of compost samples made from similar feedstock. This implies that the process is more efficient at retaining nitrogen, probably because of the greater numbers of microorganisms present in the process. This in turn implies that less nitrous oxide is generated and/or released during the process. Since N_2O is 310 times as potent a GHG as CO_2, this could be a significant benefit.

2.14.4 Below-Ground Biodiversity

Biodiversity is declining rapidly worldwide, so much so that some scientists fear that we are heading for a mass extinction event similar to several that have occurred in Earth's ancient past. These events require millions of years to reverse once they occur, so it is vital to prevent that occurrence.

Earthworms have an extremely important role to play in counteracting the loss of biodiversity. Worms increase the numbers and types of microbes in the soil by creating conditions under which these creatures can thrive and multiply. The earthworm gut has been described as a little "bacteria factory", spewing out many times more microbes than the worm ingests. By adding vermicompost and cocoons to a farm's soil, you are enriching that soil's microbial community tremendously. This below-ground biodiversity is the basis for increased biodiversity above ground, as the soil creatures and the plants that they help to grow are the basis of the entire food chain. The United Nations Environment Program (UNEP) has acknowledged the importance of below-ground biodiversity as a key to sustainable agriculture, above-ground biodiversity, and the overall economy.

2.15 VERMICOMPOSTING IN OTHER COUNTRIES

Farmers around the world have started to grow worms and produce vermicompost in rapidly increasing numbers. Warmer climes have tended to predominate so far, with India and Cuba being the leaders to date. Vermicomposting centers are numerous in Cuba and vermicompost has been the largest single input used to replace the commercial fertilizer that became difficult or even impossible to import after the collapse of the Soviet Union (Cracas, 2000). In India, an estimated 200,000 farmers practice vermicomposting and one network of 10,000 farmers produces 50,000 metric tones of vermicompost every month. In the past decade, farmers in Australia and the West Coast of the U.S. have started to use vermicompost in greater quantities, fuelling the development of vermicomposting industries in those regions. At the same time, scientists at several Universities in the U.S., Canada, India, Australia, and South Africa have started to document the benefits associated with the use of vermicompost, providing facts and Figures to support the observations of those who have used the material.

Large-scale worm farms are found in many states, including California, Rhode Island, Washington, and Oregon. Worms even compost the food waste produced at the Seattle Kingdome stadium. Vermicomposting is also being used to help solve North Carolina's hog waste problems and many rabbit breeders are utilizing vermicomposting to turn their rabbit manure into vermicompost to be used in their and others' gardens.

CHAPTER 3

EXPERIMENTAL WORKS

3.1 INTODUCTION

This chapter describes the working procedure of the various stages of thesis and also the experimental set up of vermi composting. The various parameters of vermi composting and aerobic composting are observed. The nutrient analysis of compost samples is also performed. Data has been collected also from the beneficiary level to evaluate the efficiency of vermi composting.

3.2 EXPERIMENTAL SET UP OF COMPSOTING PLANT

To investigate the physical parameter and nutrient parameter three small size rectangular boxes is set in BASA Waste Management Plant in Gazipur. The boxes were made of wood. Length, width and height of the box are 3ft, 2ft and 1ft respectively. The boxes are open in the top, in the bottom there is some minimum opening to pass the leach ate. Boxes are placed in a tin shed room to avoid direct sunlight.

Figure: 3.1 Setup a small scale vermin composting plant

3.3 COMPOSTING PROCESS

Kitchen wastes and cow dung are collected. Wastes are sorted and keep it under sunlight for seven days to make dry with 50 to 60% moisture content. New cow dung needs to be fermented in natural way for 10 to 15 days. New cow dung can not be used directly otherwise all worms will be died. After completion of fermentation process of kitchens waste and cow dung, both components are mixed thoroughly. Then 20 kg of mixture placed in a wooden box. Only 20 kg of cow dung is placed in another wooden box. And only 20 kg of kitchen waste is placed in the last box. Then approximately 1 kg of worms are placed in each box. All the boxes are kept under the shelter to avoid direct sun light and rain drops. One piece of cloths is used to cover the boxes to make the boxes are dark inside. Because worms like to stay in dark place. Then the regular observations of various parameters are taken during composting. The bedding is kept moist to enable the worms to breathe. When bedding dries out, small amount of water are sprayed on it. After 20-25 days, worm castings are found (soil-like material that has moved through the worms' digestive tracts).

Figure: 3.2 Vermicompost after screening & maturation.

3.4 TEMPERATURE VARIATION DURING COMPOSTING

Temperature is raised during composting as heat is generated. The temperature is measured with a thermometer (range 0^0 to100^0) regularly during composting by inserting the thermometer in the middle portion for 10 minutes in the wooden box. It is observed that the temperature rises from the initial day, after one week it becomes to reduce and after two to three weeks it becomes constant.

3.5 MOISTURE CONTENT

The moisture content is another important parameter for composting. The variation of moisture content has been determined by comparing the initial water in the compost to the initial total weight of the compost. To determine the moisture content the sample is placed in the oven at 85 degree Celsius for 24 hrs (Jackson, 1973). It is expressed as percentage. The result of moisture content variation is shown in chapter four. The moisture content is determined by using following formula (Jackson, 1973).

$$M.C = 100 \times \frac{\text{Initial water in the sample}}{\text{Initial weight of the sample}}$$

3.6 CHEMICAL ANALYSIS OF COMPOST

To determine the nutrient content of the compost sample, the standard methods for chemical analysis is adopted (Jackson, 73). Nitrogen content is determined as total Nitrogen by Kjeldhal's method. Phosphorus is measured as Phosphorus penta oxide and Potassium as Potassium oxide from various compost samples following the standard methods for chemical analysis of compost.

3.7 MICROBIAL ANALYSIS OF COMPOST

All microbial analysis has been done form the final product of compost samples and the results are expressed as colony forming unit per gram (c.f.u/gm). The standard methods for microbial analysis are followed to determine various presences of bacteria in the compost samples. 0.5 gm of compost is diluted in 50 ml of normal saline water and mix several times. The pathogenic bacteria and fecal coliform are tested from final compost sample for public health concern as the farmers use the compost in the field.

3.8 GROWTH RATE DETERMINATION

Growth rate of the earthworms in different waste was determined by comparing the rate of the worms to the breeding unit set-up in the first part of the study. The growth rate here is defined as the quotient of the difference obtained from the initial total wt of worms and the total wt of living worms at the end of the study divided by the experimental time period. This is further simplified by this relationship,

$$R = (N2 - N1)/T$$

Where,
R = Growth rate
N1 = Total wt of initial worms
N2 = Total wt of living worms by the end of time T
T = Time period of the experiment in days.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

Results of the experimental works and some findings from literature of vermi composting and other composting process are presented in this chapter; also some comparison has been presented with vermi composting and other composting process. The change of various physical parameters during composting is observed and collected. The variation of the data of different samples are shown and compared in this chapter. Also some surveys have been done in the beneficiary level to obtain some field information about vermi composting. It is also presented in this chapter.

The characteristics of solid waste of Gazipur are studied and also compared various types of waste. After completing the composting process the ready samples are experimented both for chemical and microbial analysis to assess the feasibility of compost as a fertilizer.

4.2 CHARACTERISTICS OF SOLID WASTE

It is manifest from the Table 4.1 that the characteristic of solid waste at Gazipur is mainly organic, which is around 82-86%, whereas percentage of inorganic waste is around 14-18%. Among the organic waste the Kitchen garbage are dominant, which is around 80-90% as shown in Table 4.1, mainly comprises of vegetables wastes, potato and onion tops, cooked and uncooked foods, fruits scraps etc are shown in Figure 4.1. The various types of solid waste generated are presented in the Figure 4.2.

Table 4.1: Characteristics of solid waste at Gazipur.

No	Total waste(Kg)	Organic waste(Kg)	Inorganic waste(Kg)	% of organic waste	% of inorganic waste
Sample 1	20	16.5	3.5	82.50	17.50
Sample 2	20	17.2	2.8	86.00	14.00
Sample 3	20	16.3	3.7	81.50	18.50

Kitchen waste(kg)	% of kitchen waste to organic waste
14.70	89.09
16.00	93.02
13.80	84.66

Figure 4.1: Municipal solid waste at Gazipur

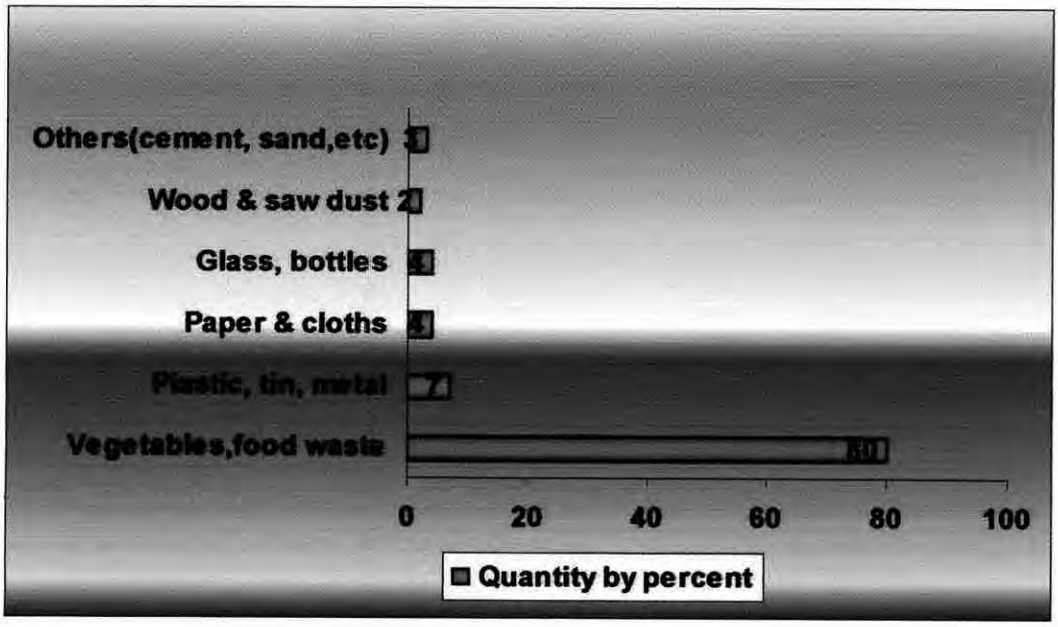

Figure 4.2: Characteristics analysis of Municipal solid waste at Gazipur

This analysis is harmonious with the study conducted by Moqsud & Rahman (2004), Alamgir & Ahsan (2007), Moqsud(2003) and the result presented in the Table 2.4.Figure 2.1 presents the study conducted by Moqsud & Rahman (2004), in which organic waste is found 84% of the total waste and kitchen waste is found around 90% in respect of characteristics of domestic solid waste in Bangladesh. From the study Alamgir & Ahsan, (2007), physical component of MSW in Bangladesh are found to be Kitchen waste (74.4%), paper (9.1%), plastic (3.5%), textile and wood (1.9%), leather and rubber (0.8%), metal (1.5%), glass (0.8%) and other waste (8.0%), in which total organic waste is found 86%. According to study conducted by Moqsud(2003), in that study organic waste is found around 85 % and kitchen waste is around 90% of the organic waste, physical composition of municipal solid waste at Gazipur are presented in the Figure 2.2 and Table 2.3. From the above studies, it can be summarized that organic waste is around 85% of the total municipal waste and kitchen waste is around 90% of the organic waste in Bangladesh.

4.3 TEMPERATURE VARIATION OF COMPOSTING PROCESS

The temperature variation during vermi composting is shown in the Figure 4.3. It is shown that the temperature is high in the initial day and it becomes lower from the following day. Within some days it becomes constant. There are three samples, only kitchen waste is taken in Box 1, sample 2 is 50% kitchen waste and 50% cow dung and sample 3 is only cow dung has been taken in Box 2 and Box 3 respectively.. From the experiment it shows that in the Box 1, temperature rises so high in the first day and temperature was above 40^0 for the following two days that the worm couldn't survive, all are dead after 3 to 4 days. For the box no 2 and box no 3, temperature was found 20^0 at an average.

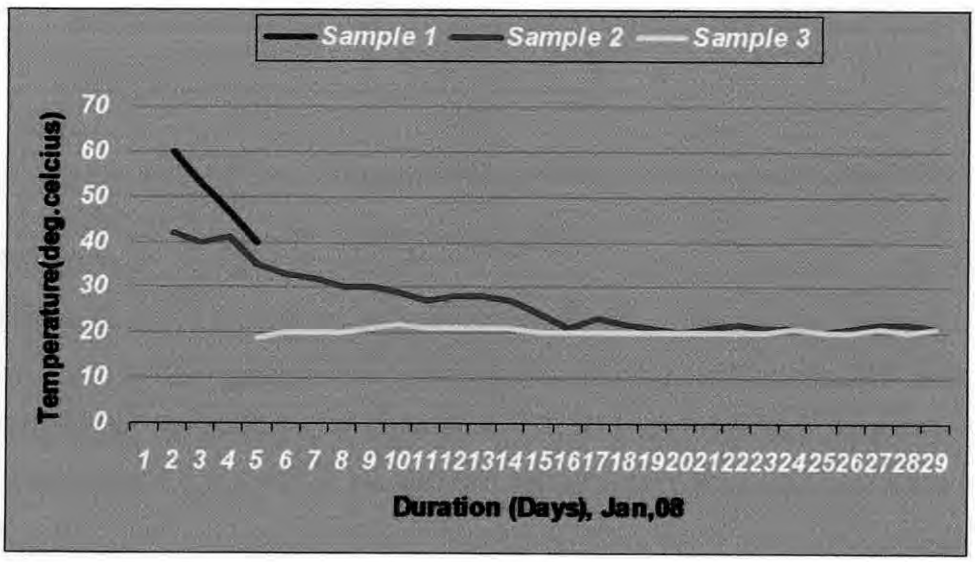

Figure 4.3: Temperature variation during composting.

This observation is consistent with literature in which it has been found that it is necessary to keep the temperatures above 10°C (minimum) and preferably 15 °C for vermicomposting efficiency. Also compost worms can survive temperatures in the mid-30s but prefer a range in the 20s (°C). Above 35°C they will quickly die. Our experimental results are in line with them.

Temperature data was taken of the five samples from the beneficiary level on a same day, data was taken from five different houses that are producing vermicompost. It has been found that temperature is almost same of the five samples which are around 26^0C, presented in the Figure 4.4.

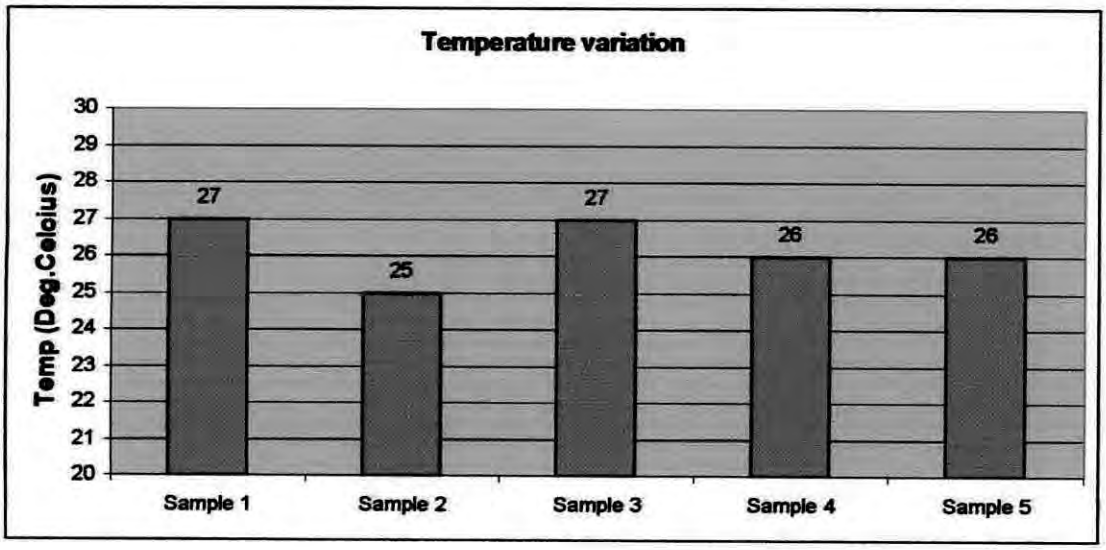

Figure 4.4: Temperature variation of 5 samples during composting.

Temperature is very important factor for the worms which need to be controlled. Worms can not survive more than 40^0C. BASA is doing vermicomposting at their plant for the four years, at the same time they motivated some local women to start. BASA and the local peoples are using different techniques to control temperature during summer and winter period. One of them is, putting the worm bin inside the shade to avoid direct sunlight and rain drops. They are putting the container inside a room that has a roof and outside wall is made of jute mat and straw; some of the portion is kept open by which air can flow. One piece of jute mat is placed over the container to make the inside dark. If the temperature rises high, then they put some wet straw on the container. Sometimes small amount of water are sprinkled over the wastes in the box. In the winter season, when temperature drops, they put some dry straw on the boxes to maintain the temperature.

4.4 MOISTURE CONTENT VARIATION DURING COMPOSTING

Figure 4.5 shows the moisture content variation of 5 samples, from this result it has been found that average moisture content is around 68-75%. Worms breathe through their skins and therefore must have a moist environment in which to live. If a worm's skin dries out, it dies. According to literature, optimum moisture content range is 75-80%.

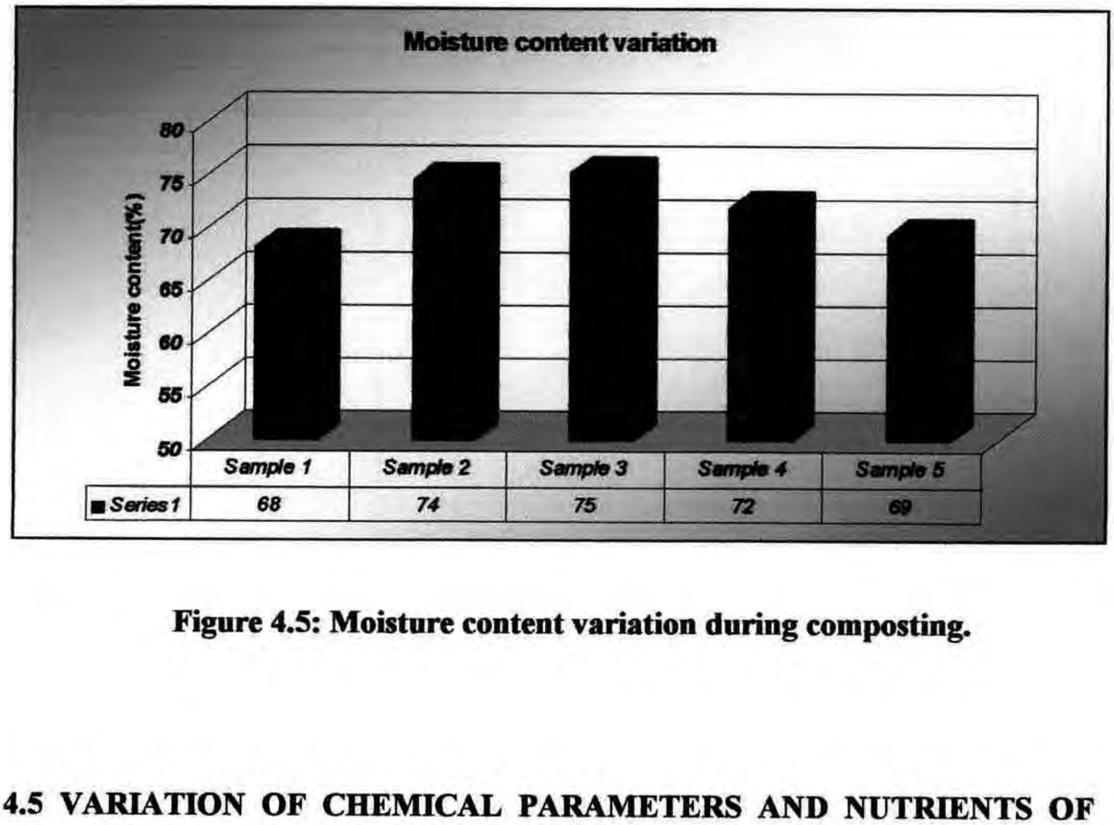

Figure 4.5: Moisture content variation during composting.

4.5 VARIATION OF CHEMICAL PARAMETERS AND NUTRIENTS OF COMPOST SAMPLES

Table 4.2 shows the nutrient analyses of field samples of vermi compost. From these results, it is found that nitrogen and phosphorus content are higher in compost obtained from vegetable waste with the use of cow dung. Nitrogen content is found 0.525% and 0.532% for compost sample of cow dung only and vegetable waste mixed with cow dung respectively. And phosphorous content is found 0.55% and 1.06 % in similar way.

Table4.2: Chemical characteristics of vermicompost

Parameter(s)	Concentration(vermi compost,100% cow dung)	Concentration(vermi compost,50% cow dung + kitchen waste)
Total nitrogen (%)	0.525	0.532
Phosphorous (%)	0.55	1.06

The cow dung increased the amount of macronutrients in the vermicompost Hence, it is clear that the mixture of vegetable waste and cow dung is suitable for the production of higher quality vermicompost when compared with the subjecting the same components individually. This result is supported by the study (Amsath & Sukumaran, 2008), in which nitrogen content is found 1.62% for compost sample of cow dung and1.76% for compost sample of vegetable waste mixed with cow dung, presented in the Table 2.12.

According to (Spoken solid, 1996), nitrogen content for fruit wastes, potato tops is around 1.52 % and for cow manure it is 1.7 %, which is presented in the Table 2.7. So from this data, we can find the nitrogen content for 50% vegetable waste mixed with 50 % cow dung, which is 0.5*1.52+.5*1.7=1.61%. It is lower than the nitrogen value of cow manure alone. This result is adversary with the experimental findings presented in the Table 4.2 and the study conducted by (Amsath & Sukumaran, 2008). This requires further experimental verification.

Nutrient value comparison also has been done with the sample of vermi compost and windrow compost. It is presented in the Table 4.3. It is found that nutrient value is lower in vermi compost sample than windrow compost sample, nitrogen value is found 0.532% in vermi compost sample whereas 1.4% is found in windrow compost sample which is 2.5 time higher. Potassium content is also found higher in windrow compost sample which is 1.51%, whereas for vermi compost sample it is 0.79% only.

Table4.3: Nutrient value comparison between vermi compost and windrow compost.

Parameter(s)	Vermi compost	Windrow compost
Nitrogen, N (%)	0.532	1.4
Phosphorous, P (%)	1.06	1.01
Potassium, K (%)	0.79	1.51

This analysis is supported by the study conducted by BASA, in which nitrogen content is found 1.71% in vermi compost sample and 2.06% in windrow compost sample, this 1.2% higher than vermi compost sample, which is presented in the Table 2.11. Potassium content is also higher in windrow compost sample which is 1.94%, and for vermi compost sample it is 1.19%.

From the Table 2.10, it is found that nutrient value is higher in vermin compost than normal compost. N, P, K content is 1.94%, 0.47%, 0.70% respectively in vermi compost sample, but for the normal compost it is found 0.8%, 0.35% and 0.48%. But our experimental analysis didn't match with this where window compost is found higher in nutrient than vermi compost.

However, nitrification and denitrification processes are more likely when substrate contains a higher portion of green waste. The amount of total nitrogen and plant available nitrogen in compost is a consequence of waste composition and of composting conditions

4.6 PATHOGEN REDUCTION IN VERMICOMPOSTING

The farmers use compost as a fertilizer in the agricultural field. So it is necessary to see that the compost might not contaminate them. . The result of microbial analysis for vermi compost sample and windrow compost sample is presented in the Table 4.11. So far no pathogenic bacteria are found in vermi compost sample as pathogenic bacteria are reliably killed in the worms' gut. Similar results have been found for windrow compost sample since the composting temperature is more than the survival limit of temperature for bacteria. Again when the layering of compost for maturation is done in the open sun light then the other harmful bacteria are destroyed. All tests are of microbial analysis are performed in the standard methods of testing from ready sample. For vermi compost, sample is collected after separating the worms from the compost sample and doing maturation for 3-4 days. For windrow compost, sample is also collected after maturation for one week.

Table4.4: Result of Microbial analysis of Compost sample

Sample	E.Coli c.f.u/g	Total Coliform c.f.u/g	Fecal Coliform c.f.u/g
Vermi compost	Nil	400	Nil
Windrow compost	Nil	2500	Nil

However, since high temperature are not part of the earthworm cast production process disease suppressing microorganisms that may be present in this material survives in the absence of heat, need to be further investigated. Also there might be a chance of presence of ovo-worm ascariasis in the compost sample, which is very important to find out. Because compost must be safe for the farmers, plant and soil. Due to unavailability of testing facility, the presence of this ascariasis couldn't be verified.

4.7 WEIGHT REDUCTION AND COMPOSTING TIME IN VERMICOMPOSTING

From the experiment it has been found that final product is around 55% of the waste sample in weight basis. From 20 kg sample of waste, 11 kg vermi compost has been produced, which is 55%. This result is supported by the study (Fuente & Gordillo, no date), in which vermicompost/feed ratio is found 0.6, presented in the Figure 2.8, that means if 100 kg food waste is harvested, and then 60 kg vermi compost would be achieved. Also from survey in the beneficiary level among 5 houses that produces vermi compost, similar observation has been found.

From the experimental analysis, it has been found that compost sample has been ready within one month. 20 kg waste sample was taken in a box, 27, 28^{th} day soil like materials have been found all over the box, then worms were separated in 29^{th} day, the sample is then spread in the sunlight for maturation for two days. However composting time is dependent on optimum environmental condition for composting, like temperature (20^{0}C), moisture content (70-80%), etc; it is also dependent on number of worms being added in the bin. Whereas windrow composting took almost two and half months to be harvested including maturation. 300 kg waste was taken in a pile form to be composted.

4.8 WORM GROWTH RATE DETERMINATION

Table 4.5 shows the growth rates of worms under two different feeds in one composting cycle. The growth rate of the worms in the vegetable waste mixed cow dung has been found 7.93gm worms/day whereas the growth rate of the worms in the cow dung has been found 7.24 gm worms / day. Initially 1 kg worm was added for each 20 kg sample. After 29^{th} day, worms have been separated from the compost sample. From the analysis it has been found that wt of worm after composting becomes 1.2 times [(1230+1210)/ (1000+1000)] of initial wt of worm after one month.

Table 4.5: Growth rates of worms under two different feeds

Sample	Time (days)	Feed	Initial worm wt.(gm)	Final worm wt.(gm)	Growth rate (worms/day)
sample 1	29	Vegetable waste + cow dung	1000	1230	7.93
sample 2	29	Cow dung	1000	1210	7.24

4.9 WORM FOODS

From the survey at the beneficiary level of few houses that produce vermi compost, it has been found that meats, fish, bones, eggs, dairy products and other oily foods should be avoided. These foods will cause odors and attract unwanted insects. Garlic, salt, vinegar, and spicy leftovers should not be added, nor should large quantities of onions. These foods may hurt the worms.

Do Feed Worms:	Don't Feed Them
• Vegetable Scraps	• Meat
• Grains	• Fish
• Fruit Rinds and Peels	• Cheese
• Breads	• Oily Foods
• Coffee Grounds, filters	• Butter
• Tea bags	• Pet Wastes

4.10 COMMON PROBLEMS AND SOLUTIONS

Following problems and solution have been found during the survey in the vermi composting process.

The most common problem is unpleasant, strong odors which are caused by lack of oxygen in the compost due to overloading with food waste so that the food sits around too long, and the bin contents become too wet. The solution is to stop adding food waste until the worms and micro-organisms have broken down what food is in there, and to gently stir up the entire contents to allow more air in. There may be non-compostables present such as meat, pet feces, or greasy food. These should be removed. Drainage holes are needed to be checked to ensure that they are not blocked. If necessary, more holes should be drilled. Worms will drown if their surroundings become too wet.

Worms have been known to crawl out of the bedding and onto the sides and lid if conditions are wrong for them. This can happen if there are a lot of citrus peels and other acidic foods present in the bin. They can be adjusted by adding a little garden lime and cutting down on acidic wastes.

Fruit flies can be an occasional nuisance. They can be discouraged by always burying the food waste and not overloading. One solution is to keep a plastic sheet or piece of old carpet or sacking on the surface of the compost in the bin.

Worms might be died to several causes. It may be that they are not getting enough food, which means food (wastes) should be buried into the bedding. They may be too dry; in which cases moisten the box should be done until it is slightly damp. They may be too wet, in which case bedding should be added. The worms may be too hot, in which case bin should be kept in the shade.

4.11 EVALUATING ENVIRONMENTAL CONDITIONS & ACCEPTABILITY OF VERMICOMPOSTING

Questionnaire survey has been done at the beneficiary level at Faocal village in Gazipur District to find out what people think or feel about vermicomposting and vermicompost and to evaluate environmental factors. Survey was conducted with 5 (Five) families out of 9 (Nine) who are doing vermicomposting at their land.

Table 4.6 show the response of the families. From which it has been found that, all of them who are doing vermicomposting found this beneficial for them. 80% participants said that they can sale their compost to the local villagers, BASA and buyers coming from different zones. Sometimes they also use this compost at their land to produce vegetables. Only 20% respondent told about the difficulty of selling compost. She claimed that buyers always go to known faces to buy the compost.

100% respondents said that they didn't face any adverse environmental impact due to vermicomposting. In case of odor problem, 100% response was negative; they didn't get any odor problem with vermicomposting set up. In terms of disease spreading and increase of insect attack, their responses were also negative; they didn't suffer any diseases like (e.g. diarrhoea) due to this set up at their land.

Table 4.6: Questionnaire survey response of the families

SN	Items	Response of the 5 families out of 9, who are doing vermicomposting: Yes	No
1	Is it beneficial for you?	100%	
2	Any significant expenditure?		100%
3	Any incident of worm dying?	20%	80%
4	Any objectionable odor?		100%
5	Is increase of insect around the environment found during vermicomposting?		100%
6	Anyone of your family has suffered from diseases like (e.g. diarrhoea) for this setup?		100%
7	Can you sale all of your compost?	80%	20%
8	Will you continue if BASA left?	100%	
9	Do you think other people should start this?	100%	
10	Overall impression, is it good for your family?	100%	

One of the questions was, if BASA left then will they continue with this or not? 100% response was positive, they found this as an additional income source, and also they recommend that all the village women should start this.

According to BASA, vermicomposting is a profitable set up, everyone should start doing this. Because it will help the village women financially, also wastes are processed by this method. Also vermicompost is good for soil conditioner. But they found that people are not aware of this process. They are trying to promote it, but due to small set up, it is not possible for them to spread to many peoples. Govt should take initiative to spread the news about vermicomposting and vermicompost. If the advantages and profitability of the vermicomposting is being advertised then big entrepreneurs will come to invest their money. This will be beneficial for all of the parties, in one way they will get profit and in parallel it will help the environment by minimizing solid waste.

CHAPTER 5

FINANCIAL FEASIBILITY STUDY OF COMPOSTING PROJECT

5.1 INTRODUCTION

Financial aspects include the impact of services on financial activities, cost-effectiveness of solid waste management system, macro-economic dimensions of resource use and conservation and income generation, employment generation.

Sustainability of any project depends on many factors such as potential of the system to achieve its goal, acceptability of the project to the beneficiaries of the project with respect to their satisfaction compared to other existing system, most of all, the economic viability of the project or of the system itself.

Some issues need to be investigated for financial feasibility analysis of the community based solid waste management. First, the cost of extracting recyclable materials from domestic solid waste that is left over tokays. This issue deals with matters relating to supply side of composting, using the decentralized approach. Second, the amount of compost that can be sold in the market at the prices that cover the production costs and provided a normal rate of profit. This deals with demand side of compost. Thirdly and finally, the intangible benefits (i.e. social and environmental effects above and beyond private cost and benefits).

Financial feasibility analysis of the community based solid waste management practices is done. Two analyses has been done, one is done in beneficiary level in which village women are involved in composting process. Another analysis is done using the collected data and considering large scale composting plant.

Finally, it should be noted that there are many different ways of operating vermicomposting systems and operational criteria will depend heavily on the required outputs and the commercial aims and objectives underpinning the process.

The system which was evaluated placed most emphasis on waste management and maximizing waste processing rates with less focus on maximizing the production and harvesting of worms. Hence, the following preliminary evaluation should be viewed as an analysis of a very specific system of vermicomposting, operating in a particular way and subject to various research constraints.

5.2 FINANCIAL EVALUATION

Table 5.1 & Table 5.2 shows the fixed cost & operational cost involvement of the vermi composting plant. Earning per year and economic analysis of the plant are presented in the Table 5.3 and Table 5.4 respectively.

Assumptions

1	970 sft area, 36 no of box, wooden box size (6ft*3ft*1ft)
2	Project life 5 yrs
3	Rate of return 60 % from waste (by weight).
4	One complete cycle 30 days
5	waste per box is 140 kg, total waste =140*36=5040 kg
6	9 lb worm per box, 1000 worms are 1 lb
7	Surplus worms are expected to be 4 times of initial worm in a year.

Table 5.1: Fixed Cost involved in composting plant (life of project 5 yrs)

SN	Item Description	Unit	Quantity	Unit rate(TK)	Total cost(TK)
1	Construction of composting shed with drainage facility of 520 sft	sft	520	400	208000

2	Worms	Kg	162	1500	243000
3	Wooden box (6ft*3ft*1ft)	Nos	36	2000	72000
4	Arrangement for putting boxes in vertical and horizontal rows	Nos	1	50000	50000
5	Construction cost of Office & toilet facility of 100 sft	sft	100	700	70000
6	Cost of 2 vans, equipment cost for composting	Nos	2	15000	30000
6	Miscellaneous cost	unit	1	30000	30000

Total	**703000**

Table 5.2: Operational cost (per year) of the composting plant

SN	Item Description	Unit	Quantity	Unit rate(TK)	Total cost(Tk)
1	Cowdung	Kg	8640	0.5	4320
2	Rent of Land of for the project	Month	12	12000	144000
3	Salary of 1 Plant Manager	Month	12	7000	84000
4	Salary of 2 Worker	Month	12	3000	36000

5	Salary of two waste collectors	Month	12	2000	24000
6	Salary of van drivers	Month	12	2000	24000
7	O & M cost (30% of construction cost of shed)	Nos	1	62400	62400

Total	**378720**

Table 5.3: Earning (per year) of the composting plant

SN	Item Description	Unit	Quantity	Unit rate(TK)	Total cost(TK)
1	Compost	Kg	36288	7	254016
2	Charge for house to house waste collection service	Nos	6000	10	60000
3	Worms	Kg	648	1500	972000

Total	**1286016**

Table 5.4: Economic analysis of the project of the composting plant (plant life 5 yrs)

Year	Cost stream	Benefit stream	PW@16%		PW@65%		PW@140%	
			Cost	Benefit	Cost	Benefit	Cost	Benefit
0	703000		703000		703000		703000	
1	378720	1286016	326483	1108634	229527	779404	157800	535840
2	378720	1286016	281451	955719	139107	472366	65750	223267

3	378720	1286016	242630	823896	84308	286282	27396	93028
4	378720	1286016	209164	710255	51095	173504	11415	38762
5	378720	1286016	180314	612289	30967	105154	4756	16151
Total	2596600	6430080	1943040	4210794	1238005	1816710	970117	907047

Cost benefit ratio at discount rate 16%, net present value and internal rate or return of the vermi composting plant are shown in the table 5.5.

Table 5.5: Summary

Therefore B/C ratio @ 16%	**2.17**	
NPV @ 0%	3833480	
NPV @ 16%	2267754	
NPV @ 65%	578706	
NPV @ 140%	-63070	
IRR= 65% + (140%-65%)*578706/(578706+63070) = **133%**		

Financial involvement in vermi composting plant in beneficiary level are presented in the Table 5.6, Table 5.7, Table 5.8, Table 5.9 & Table 5.10, where fixed cost and operating cost are shown in Table 5.6 & Table 5.7. Income and economic analysis of the project are presented in the Table 5.8 & 5.9.

Table 5.6: Fixed Cost (life of project 5 yrs)

SN	Item Description	Unit	Quantity	Unit rate(TK)	Total cost(TK)
1	Small house (15ft*10ft*7ft),	Nos	1	18000	18000
2	Worms	Kg	3	1500	4500

3	Container made of hard soil (diameter 36inch and depth 15 inch)	Nos	9	300	2700
3	Other cost	unit	1	5000	5000

Total	**30200**

Table 5.7 Operational cost per month

SN	Item Description	Unit	Quantity	Unit rate(TK)	Total cost(Tk)
1	Cow dung	Kg	800	0.5	400
2	Kitchen waste	Kg	300	1	300
3	Leaves & straw	Kg	30	1	30
4	Transportation	unit	1	200	200
5	Maintenance cost	unit	1	450	450
5	Labor	hr	40	25	1000

Total	**2380**

Table 5.8 Income per month

SN	Item Description	Unit	Quantity	Unit rate(TK)	Total cost(TK)
1	Compost	Kg	500	7	3500
2	Worms	Kg	1	1500	1500

Total	**5000**

Table 5.9 Economic analysis of the project of the composting plant (plant life 5 yrs)

Year	Cost stream	Benefit stream	PW@16%		PW@65%		PW@105%	
			Cost	Benefit	Cost	Benefit	Cost	Benefit
0	30200		30200		30200		30200	
1	28560	60000	24621	51724	17309	36364	13932	29268
2	28560	60000	21225	44590	10490	22039	6796	14277
3	28560	60000	18297	38439	6358	13357	3315	6964
4	28560	60000	15773	33137	3853	8095	1617	3397
5	28560	60000	13598	28567	2335	4906	789	1657
Total	173000	300000	123714	196458	70546	84760	56649	55565

Cost benefit ratio at discount rate 16%, net present value and internal rate or return of the vermi composting plant at beneficiary level are shown in the table 5.10.

Table 5.10 Summary of vermi composting plant in beneficiary level

Therefore B/C ration @ 16%	**1.59**
NPV @ 0%	127000
NPV @ 16%	72744
NPV @ 65%	14214
NPV @ 105%	-1084
IRR= 65% + (105%-65%)*14214/(14214+1084) = **102%**	

Table 5.5 and Table 5.10 shows that the cost benefit ratio at discount factor 16% is 2.31 for large scale project and for plant in beneficiary level it is 1.59 at the same discount factor. Also net present value is positive for both projects at discount factor 16%. The internal rate of return is much attractive for the large scale projects. It is found 136% and 102% for large scale project and beneficiary plant respectively.

From the analysis it has been found that a major portion of cost of fixed cost come from worms and wooden boxes. From the Table 5.11, it has been found that, it is around 50% for large scale production and around 25% for small scale production. But in normal composting like windrow composting worms are not needed. That's why the initial cost is lower than the vermi composting plant. Finally we can say that more start up financial resource is required for vermi composting which is an average (52+24)/2=38% of fixed cost.

Table 5.11: % of worm related cost on fixed cost

	Fixed cost	Worm cost	Container with fixation cost	Total of worm associated cost	Percentage (%)
Large scale project	703000	243000	122000	365000	**52**
Small scale project	30200	4500	2700	7200	**24**

CHAPTER 6

CONCLUSIONS AND RECOMMENDATION

6.1 CONCLUSION

Findings of the study as presented in the previous chapters are summarized bellow:

1. Characteristics of solid waste generated at Gazipur are mainly organic, which is around 82-86%, whereas percentage of inorganic waste is around 14-18%. Among the organic waste the Kitchen garbage are dominant, which is around 80-90%, mainly comprises of vegetables wastes, potato and onion tops, cooked and uncooked foods, fruits scraps etc.

2. Worm can't survive the temperature above 40° C. Favorable temperature for worms are around 20° C. Temperature is very important factor for worms which need to be controlled. There are different ways to control the high temperature which are putting the container under shade, placing jute mat over the container, placing the wet straw over the wastes in the box, sprinkle little amount of water.

3. Moisture content is also an important factor for vermicomposting. From the result, it has been found that average moisture content is around 68-75%. Worms breathe through their skins and therefore must have a moist environment in which to live

3. Nitrogen and phosphorus values are found higher in compost obtained from vegetable waste mixed with cow dung than the compost obtained from cow dung only. Nitrogen content is found 0.525% and 0.532% for compost sample of cow dung only and vegetable waste mixed with cow dung respectively. And phosphorous content is found 0.55% and 1.06 % for the same samples. But this result dissent with the theoretical study, in which nitrogen value is found higher in compost sample

obtained from cow dung only which is 1.7% than the compost generated from vegetables waste mixed with cow dung which is 1.61%. This requires further experimental verification.

4. It is found that nutrient value is lower in vermi compost sample than windrow compost sample; nitrogen value is found 0.532% in vermi compost sample whereas 1.4% is found in windrow compost sample which is 2.5 times higher. Potassium content is also found higher in windrow compost sample which is 1.51%, whereas for vermi compost samples it is 0.79% only. This result contradicts with the result reported in literature where vermi compost is found superior in terms of nutrient than windrow compost. Therefore this requires further experimental verification.

5. From the microbial analysis of vermi and windrow compost samples after maturation, it is observed that the compost samples are safe for the farmers to use in the field as no pathogenic bacteria are found for matured compost samples. However this requires further experimental verification regarding the presence of ovo-worm ascariasis.

6. In vermi composting process, final product (vermi compost) is around 55% of the waste sample in weight basis.

7. Vermicomposting is much faster than regular composting. Vermi compost can be ready in one month whereas normally it might take 2-3 months for windrow composting process including maturation.

8. The growth rate of the worms in the vegetable waste with cow dung has been found 7.93gm worms/day whereas the growth rate of the worms in the cow dung has been 7.24 gm worms / day.

9. From the questionnaire survey, it has been found that vermicomposting has the popularity and acceptability in the beneficiary level. But to attract the big

entrepreneur to do the vermicomposting at large scale, awareness program should be implemented. Advertisement of vermicomposting and vermicompost are required to make it popular.

10. Vermicomposting requires more start-up resources in terms of financial condition than windrow composting process. This initial higher cost is generated from the cost of worms and worm bins. The cost is approximately 38% higher.

11. Detail financial feasibility study for large scale vermicomposting plants and in the plant at beneficiary level show that both are commercially viable and sustainable as cost benefit ratio at discount factor 16% is 2.17 for large scale project and for plant in beneficiary level it is 1.59.

6.2 RECOMMENDATION FOR FURTHER STUDY

1. Comparison of variations in C/N ratios over the period of vermi composting and organic composting can be studied.
2. Comparison of effect of vermi compost and other fertilizers on plant growth can be studied.
3. In this experiment, wooden worm bin has been used. Different types of bins like plastic, metal can used to determine the effect on composting process.
4. Rate of production of worms can be studied.
5. Effect of pH and moisture content variation need to be studied.
6. Microbial analysis for other pathogenic bacteria (Salmonella sp., Shigella sp., etc) can be studied.
7. Presence of ovo-worm ascariasis in the compost samples need to be studied.

REFERENCES

Alamgir, M. & Ahsan, A. (2007), "Characterization of MSW and nutrient contents of organic component in Bangladesh", EJEAFChe, ISSN: 1573-4377

Amsath. A & Sukumaran .M (2008), "Vermicomposting of vegetable wastes using cow dung", ISSN: 0973-4945; CODEN ECJHAO, E-Journal of Chemistry, Vol. 5, No.4, pp. 810-813.

Appelhof, M. (2003), "Notable Bits". In WormEzine, Vol 2(5). May. Available at http://www.wormwoman.com; access on 11/10/2008.

Arancon, N. (2004), "An Interview with Dr. Norman Arancon". In Casting Call, 9(2), August.

Atiyeh, R.M, S. Subler, C.A. Edwards, G. bachman, J.D. Metzger, and W. Shuster. (2000), "Effects of vermicomposs and composts on plan growth inhorticultural container media and soil". In Pedo biologia, 44, pp. 579-590.

Banks, S. (2008), "Anaerobic versus Aerobic compost" In Bright Hub, December,2008.

Basnayake, B.F.A (2002), Aerobic Digestion of Municipal Solid Waste with and without Accelerator Agents-A Live Project Study Including Agro Applications.

Beetz, A. (1999), "Worms for Composting (Vermicomposting)." ATTRA-National Sustainable Agriculture Information Service, Livestock Technical Note, June, 1999.

Bogdanov, P. (1996), Commercial Vermiculture: How to Build a Thriving Business in Redworms. VermiCo Press, Oregon. 83 pp.

Bogdanov, P. (2004), "The Single Largest Producer o Vermicompost in the World". In Casting Call. 9(3). October.

Card, A.B., Anderson, J.V and Davis, J.G (2004), "Vermicomposting Horse Manure". Colorado State University Cooperative Extension no. 1.224. Available at http://www.ext.colostate.edu/pubs/livestk/01224.html; access on 11/10/2008

Cracas, P. (2000), "Vermicomposting Cuban Syle", in Worm Digest, Issue #25.

Dominguez, J. and Edwards, C.A (1997), "Effects of Socking Rate and Moisture Content on the Growth and Maturation of Eisenia andrei (Oliogochaeta) in Pig Manure". In Soil Biol Biochem Vol 29, #3, 4, pp 743-6.

Dunn, C. (2007), "Green Basics: Vermicompost" in Treehugger, February.

Eastman, Bruce R. (1999), "Achieving Pathogen Stabilization Using Vermicomposting". In BioCycle. November. Page 62.

Eastman, Bruce R., Philip N. Kane, Clive A. Edwards, Linda Trytek, Bintoro Gundadi, Andrea L. Stermer, Jacquelyn R. Mobley. (2000), "The Effectiveness of Vermiculture in Human Pathogen Reduction for USEPA Biosolids Stabilization",Orange County, Florida: Environmental Protection Division.

Edwards, C.A. (1998), "The Use of Earhworms in the Breakdown and Management of Organic Wases". In: Edwards, C.A. (ed) Earthworm Ecology. St. Lucie Press, Boca Raton, pp. 327-354.

Edwards, C.A. (1999,. "Interview with Dr. Clive Edwards". In: Casting Call; Peter Bogdanov, Ed., VermiCo, Merlin, Oregon. 4(1), June Issue.

Edwards, C.A. and Lofty, J.R (1972), "Biology of Earthworms". London: Chapman and Hall Ltd. 283 pp.

Ed.Rynk, R. (1992), "On-farm composting". Natural Resource, Agriculture, and Engineering Service, Cooperative Extension, Ithaka, New York

Epstein, E. (1997), "The science of composting". Technomic Publishing company, Inc. Lancaster, Basel.

Frederickson, J; Kevin, R; Butt, Richard M. and Daniel,C. (1997), "Combining Vermiculturewith Traditional Green Waste Composting Systems". In Soil Biol. Biochem., 29 (3/4), pp 725-730.

Fuente, M & Gordillo, R.M, No Date. "Mid-Scale On-Farm Vermicompost Production" UCCE Santa Clara County.

Fox, D, (2001), The Worm tha Earned". In New Scientist, September 15, 2001, pp. 32-34.

Gaddie, R.E. (Sr.) and Douglas, D.E (1975), Earthworms for Ecology and Profit. Volume 1: Scientific Earthworm Farming. Bookworm Publishing Company, Cal. 180 pp.

Georg (2004), Feasibility of Developing the Organic and Transitional Farm Market for Processing Municipal and Farm Organic Wastes Using Large-Scale Vermicomposting. Good Earth Organic Resources Group, Halifax, Nova Scotia.

Glenn Munroe. No Date. "Manual of On Farm Vermicomposting and Vermiculture". Organic Agriculture Centre of Canada

Goluke, C.G., (1977). Biological Reclamation of Solid Wastes, Rodale Press, Emmaus, PA. ISBN 0-87857-158-2.

Gunadi, B, Charles,B and Edwards, C.A (2002), "The growth and fecundity of Eisenia fetida (Savigny) in cattle solids pre-composted for different periods". In Pedobiologia 46, 15-23.

Hammermeister, A.M., Warman, P.R.; Jeliazkova, E.A. and Martin, R.C. (2004), "Nutrient supply and lettucegrowth in response to vermicomposed and composted catle manure". Submitted to Bioresource Technology, Dec, 2004.

Moqsud, M.A. (2003), "A Study on Composting of Solid Waste", M, Sc. Engg. Thesis, Department of Civil Engineering, BUET, Dhaka.

Moqsud, M.A (2003), "The Composting Barrel-a new way to solve the organic solid waste management problem in urban areas". Paper in Projukti, October-2003, Institute of Engineers, Bangladesh

Moqsud, M.A (2004), "Biochemical quality of compost from kitchen garbage of Bangladesh", Paper accepted for publication in the 19th International conference of Solid Waste Management and Technology, USA

Moqsud, M.A and Rahman, M.H. (2004), "Biochemical Quality of Compost from Kitchen Garbage in Bangladesh", Environmental Informatics Archives, Volume 2 (2004), 635-640

Muthukumaravel, K. Amsath, A. & Sukumaran, M. (2008). "Vermicomposting of Vegetable Wastes Using Cow Dung", E-Journal of Chemistry, ISSN: 0973-4945; Vol. 5, No.4, pp. 810-813.

Myers, R. (1969), The ABCs of the Earthworm Business. Shields Publications, Eagle River, Wisconsin, USA. 64 pp.

Pajon, S. No Date. "The Worm's Turn – Argentina". Intermediate Technology Development Group (ITDG), Case Study Series 4.

Paul, J. W., Claudia, W.R., Andrew, T., Ron, F. and Alpine, M.M (2002), "Composting as a Strategy toreduce Greenhouse GasEmissions". 14 pp. Available on ManureNet Website: http://res2.agr.ca/initiatives/manurenet, access on 11/10/2008.

Poulsen, T. G (2003), "Aerobic Composting", Solid waste management, Aalborg University, June 2003.

Rahman, M.H. (1993), "Waste Management in Greater Dhaka City", The International Journal of Environmental Education & Information. UK, Vol-12, No.2

Rahman, M.H. (1993), "Recycling of solid waste in Bangladesh", The International Journal of Environmental Education & Information. UK, Vol-12, No.4

Rink, Robert (Editor) (1992), Authors: Maarten van de Kamp, George B. Wilson, Mark E. Singley, Tom L. Richard, John J. Kolega, Francis R. Gouin, Lucien Laliberty, Jr., David Kay, D.W. Murphy, Harry A. J. Hoitink, W.F. Brinton. On-Farm Composting Handbook. Natural Resource, Agriculture, and Engineering Service (NRAES-54), Ithaca, NY.

Rynk, Ed. R. (1992) "On-farm composting" Natural Resource, Agriculture, and Engineering Service, Cooperative Extension, Ithaka, New York

Saradha, T. (1997), "The culture of earthworms in the mixture of pond soil and leaf litter and analysis of vermifertilizer". J. Ecobiology, 9(3), pp. 185-188.

Sherman, R. (1997), "Controlling Mite Pess in Earthworm Beds". North Carolina Cooperative Extension Service, Raleigh, NC,

Short, J.C.P., Frederickson, J and Morris, R.M. (1999). "Evaluation of tradiional windrow-compostingand vermicomposting for the stabilization of waste paper sludge (WPS)." In Diaz Cosin, D.J., Jesus, J.B., and Trogo, D. (Eds), 6th International Symposium on Earthworm Ecology, Vigo, Spain, 1998. Pedobiologia. 1999. 43(6), pp. 735-743.

Spoken Solid: Regional Solid Waste System (1996), "www.solidwaste.org/combenft.htm", access 10/12/2008

Subler, S, Edwards,C and Metzger, J. (1998). "Comparing Vermicomposts and Composts". In BioCycle, July. Pp. 63-66.

Sudha, B. and Kapoor, K.K. (2000). "Vemicomposting of crop residues and cattle dung with Eisenia foetida". In Bioresource Technology, 73. pp. 95-98.

Tchobanoglous, G., Theisen, H and Vigil, S., (1993). Integrated Solid Waste Management, 'Engineering Principles and Management Issues' McGraw – Hill, Inc. New York. ISBN 0-07-06-3237-5.

VermiCo. (2004), http://www.vermico.com.,access on 15/1/2008

Vermitech. (2004), http://www.vermitech.com, access on 15/1/2008

Oldscollege.(2002), www.oldscollege.ab.ca/schools/ocsi/CTC/pdf/, access on 30/11/2008.

APENDIX A

Table A.1: Result of questionnaire survey (Family 1)

		Family 1	
SN	Items	Yes	No
1	Is it beneficial for you?	√	
2	Any significant expenditure?		√
3	Any incident of worm dying?		√
4	Any objectionable odor?		√
5	Is increase of insect around the environment found during vermicomposting?		√
6	Anyone of your family has suffered from diseases like (diarhoea) for this setup?		√
7	Can you sale all of your compost?	√	
8	Will you continue if BASA left?	√	
9	Do you think other people should start this?	√	
10	Overall impression, is it good for your family?	√	

Table A.2: Result of questionnaire survey (Family 2)

		Family 2	
SN	Items	Yes	No
1	Is it beneficial for you?	√	
2	Any significant expenditure?		√
3	Any incident of worm dying?		√

4	Any objectionable odor?		√
5	Is increase of insect around the environment found during vermicomposting?		√
6	Anyone of your family has suffered from diseases like (diarhoea) for this setup?		√
7	Can you sale all of your compost?	√	
8	Will you continue if BASA left?	√	
9	Do you think other people should start this?	√	
10	Overall impression, is it good for your family?	√	

Table A.3: Result of questionnaire survey (Family 3)

		Family 3	
SN	**Items**	**Yes**	**No**
1	Is it beneficial for you?	√	
2	Any significant expenditure?		√
3	Any incident of worm dying?	√	
4	Any objectionable odor?		√
5	Is increase of insect around the environment found during vermicomposting?		√
6	Anyone of your family have suffered from diseases like (diarhoea) for this setup?		√
7	Can you sale all of your compost?	√	
8	Will you continue if BASA left?	√	
9	Do you think other people should start this?	√	
10	Overall impression, is it good for your family?	√	

Table A.4: Temperature data

Date	Sample 1	Sample 2	Sample 3
1/1/2008	60	42	
2/1/2008	53	40	
3/1/2008	47	41	
4/1/2008	40	35	19
5/1/2008		33	20
6/1/2008		32	20
7/1/2008		30	20
8/1/2008		30	21
9/1/2008		29	22
10/1/2008		27	21
11/1/2008		28	21
12/1/2008		28	21
13/1/2008		27	21
14/1/2008		24	20
15/1/2008		21	20
16/1/2008		23	20
17/1/2008		22	20
18/1/2008		21	20
19/1/2008		20	20
20/1/2008		21	20
21/1/2008		22	20
22/2/2008		21	20
23/1/2008		21	21
24/1/2008		20	20
25/1/2008		21	20
26/1/2008		22	21
27/1/2008		22	20
28/1/2008		21	21

APENDIX B

Figure B 1: A sample house for vermicomposting at Gazipur

Figure B 2: A sample house for vermicomposting at Gazipur

Figure B 3: A container for vermicomposting

Figure B 4: Worms are in the container

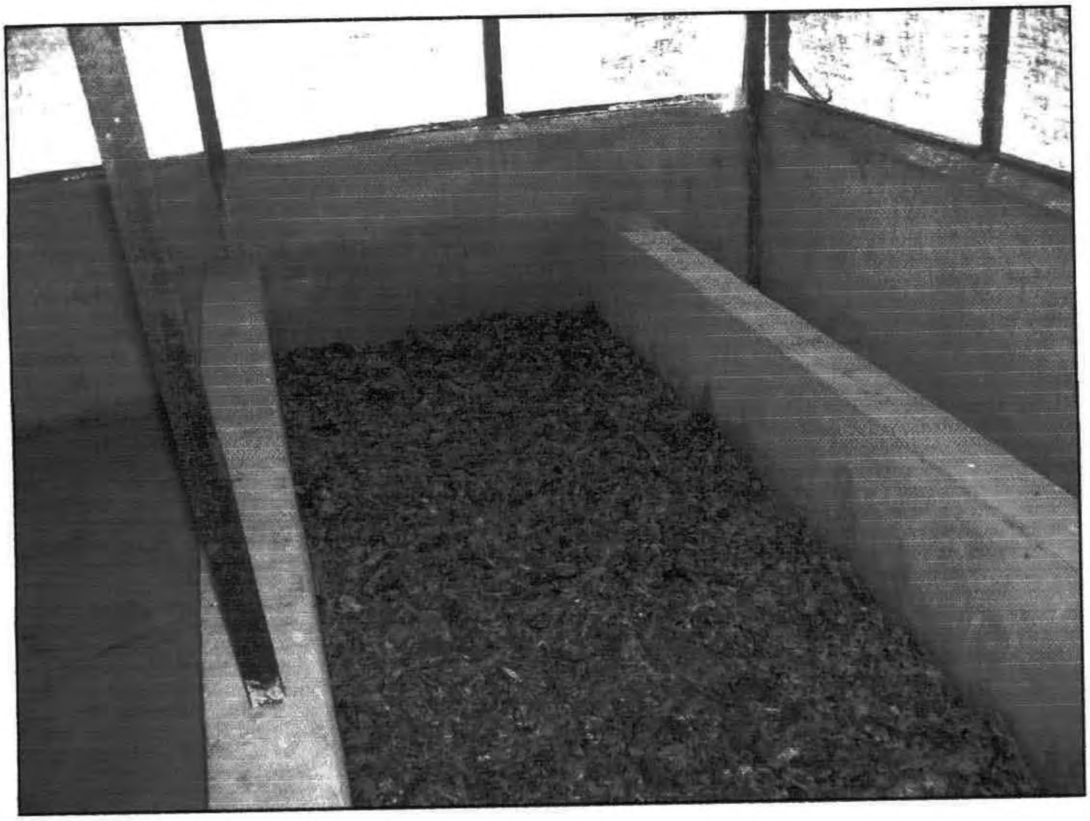

Figure B 5: Vermicomposting plant developed by BASA at Gazipur

Figure B 6: Vermicomposting plant developed by BASA at Gazipur

Figure B 7: Aerobic composting plant prepared & maintained by BASA at Gazipur

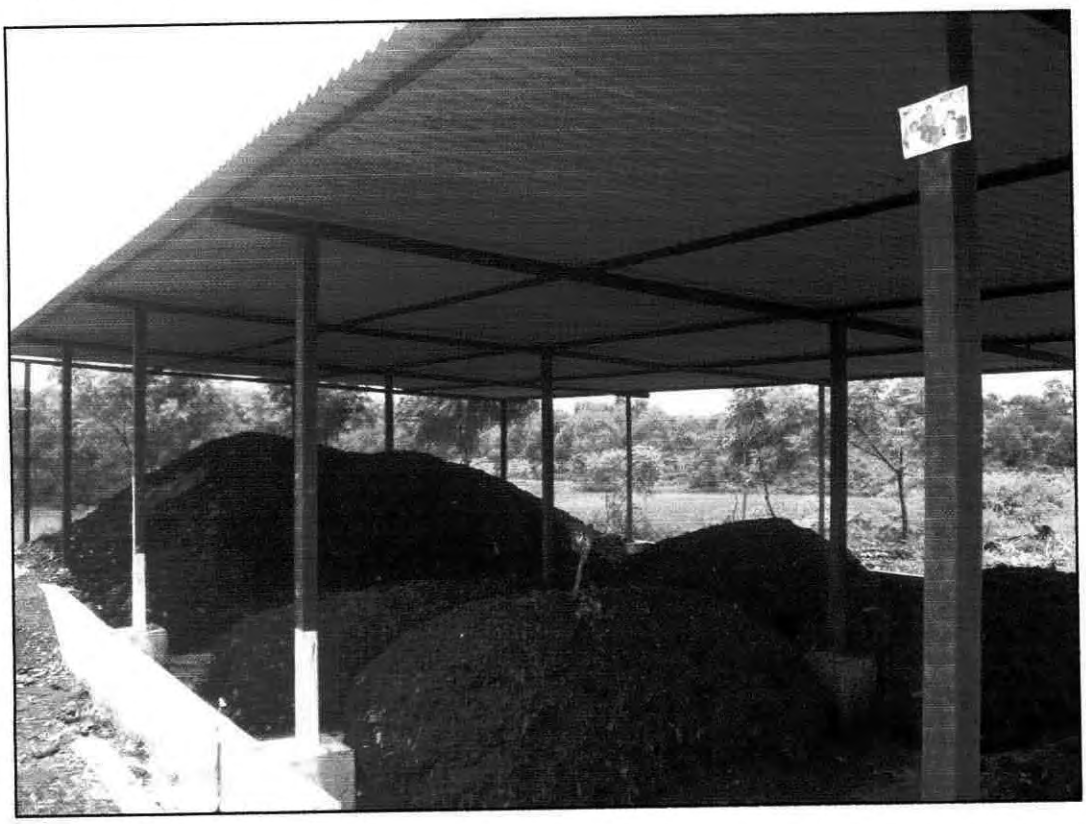

Figure B 8: Aerobic composting plant prepared & maintained by BASA at Gazipur

Figure B 9: Screening of waste at site

Figure B 10: A small van for collection of waste

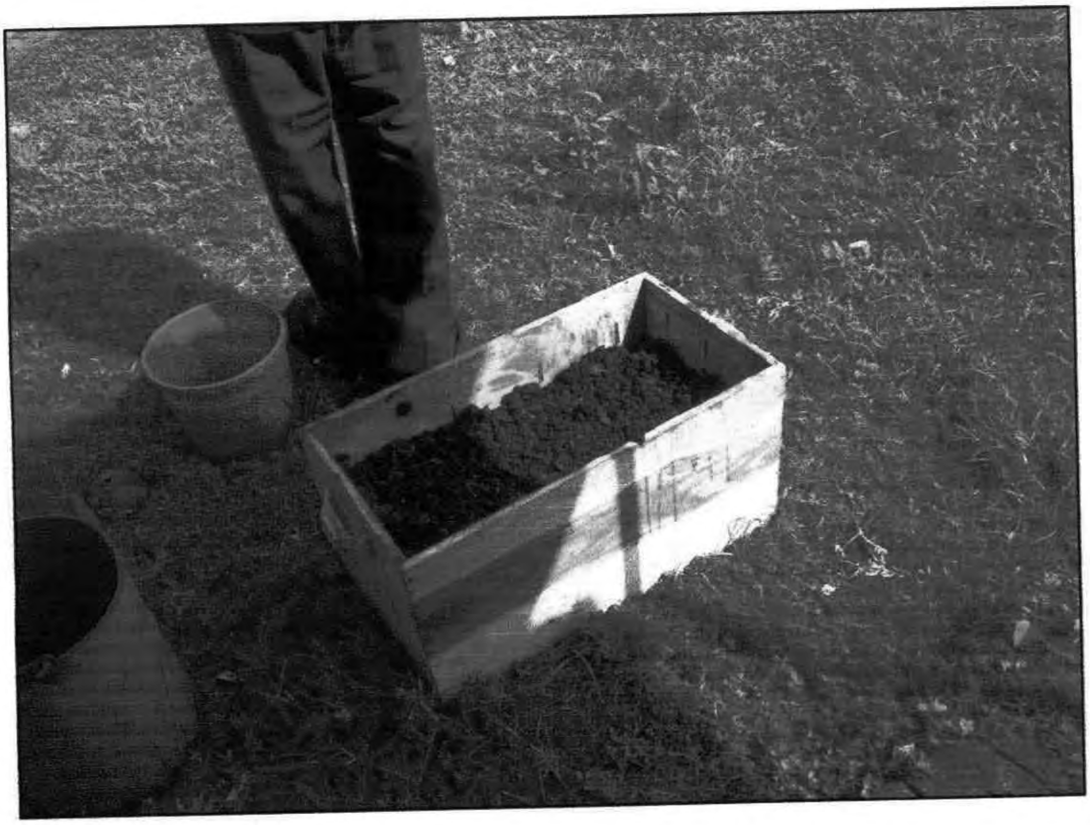

Figure B 11: Experimental set-up of vermi composting

Figure B 12: Experimental set-up of vermicomposting

Figure B 13: Matured vermicompost

Figure B 14: Workers at the site.