Handbook of Vermicomposting Technology

By

Dr.E.Sreenivasan

The Western India Plywoods Ltd

Handbook of Vermicomposting Technology

By

Dr.E.Sreenivasan

The Western India Plywoods Ltd

Dedicated

To

Late Mr.P.K.MOHAMED,
Former Managing Director,
The Western India Plywoods Ltd

&

Late Mr.K.P.KAMALUDDIN,
Former Chief General Manager,
The Western India Plywoods Ltd

Preface

This handbook explains a technology which is an alternative option to solid waste management systems, based on the application of earthworms and generally termed as vermicomposting. It also describes the various treatments with earthworms from agro-industrial wastes to domestic wastes. It also highlights the biology of these worms and how to maintain and prepare suitable bedding for this biological treatment of solid waste.

This book also provides basic information and vermicomposting experiences, should one be involved in vermicomposting or breeding of the worms. It is believed that this book would be useful to any person and government agencies involved in vermicomposting; industrial organizations, researchers, teachers as well as to students and other scholars.

I take this opportunity to thank Mr.P.K.Mayan Mohamed, The Managing Director, The Western India Plywoods Ltd (WIP), Kannur, Kerala for sponsoring this timely and interesting project. I also would like to extend my thanks to Mr.C.A.Gafoor, Mr.T.M.Bava, Mr.R.Balakrishnan, Mr.Jose Antony, General Managers of WIP and Mr.P.K.Mehaboob, Head, Marketing,WIP for their encouragement and support for this work.

I wish to thank Dr.R.N.Kumar, Dr.K.Raghunathan and Mr.M.Anilkumar, former Technical Managers of WIP, for encouraging me to work on this project. I also express my sincere gratitude to my friend Dr.P.Balakrishnan, former Microbiologist of WIP for initiating the work on vermicomposting of wood wastes in WIP and for introducing me to this fascinating area of research.

I am thankful to my colleagues in R&D Division of WIP, Mr.M.A.Gaffoor, Mr.K.Vijayaraghavan and Ms.K.B.Fouziya for their support and critical evaluation of this manuscript. Thanks are also due to Mr.P.Anilkumar, Mr.Mukesh ,Mr.K.V.Bharathan,Mr.Uthaman and Mr.P.K.Balakrishnan for their help during the course of writing this book.

Dr.E.Sreenivasan
Technical Manager, R&D
The Western India Plywoods Ltd,
Kannur, Kerala

CONTENTS

LIST OF TABLES

LIST OF FIGURES

No.	Title
1	Agro-industrial wastes for vermicomposting
2	Earthworms
3	Common species of Earthworms for vermicomposting
4	Earthworms: Copulation
5	Earthworms: Cocoons
6	Vermicomposting windrows
7	Vermicomposting tanks made of ordinary bricks in a semi-commercial unit
8	Cement rings used as Vermicomposting tanks
9	A view of a semi-commercial vermicomposting unit
10	Sample of commercially available EM solution
11	Common pests of vermibeds
12	Screening and separation operation
13	Vermicompost: Packing Operations and a Sample packet of 1Kg
14	Vermiwash-concentrated and diluted
15	Vermiwash collection
16	Vermicompost: Pellets
17	Field cultivation of vegetables using Vermicompost
18	Inauguration of Vegetable -harvest by Late Mr.P.K.Mohamed, Former Managing Director, WIP
19	Best Institution Award in the District for the Vegetable Development Project received by WIP, from Mr.K.P.Mohanan, Minister of Agriculture, Govt.of Kerala

CHAPTER 1

INTRODUCTION

Rapid industrialization, urbanization, and the ever-increasing population generate voluminous solid wastes. In recent years, disposal of organic wastes has caused serious environmental hazards and economic problems. Burning of organic wastes contributes tremendously to environmental pollution thus, leading to polluted air, water and land. This process also releases large amounts of carbon dioxide in the atmosphere, a main contributor to global warming together with dust particles. Burning also destroys the soil organic matter content, kills the microbial population and affects the physical properties of the soil. A substantial portion of this solid organic waste is non-toxic. On one hand tropical soils are deficient in all necessary plant nutrients and on the other hand huge quantities of such nutrients available in solid organic wastes. Treatment of solid organic wastes has therefore become an essential part of the waste management programmes almost all over the world. Existing methods to its treatment and disposal are rather expensive. Vermicomposting technology is one of the best options available at present for the treatment of organic wastes. The term vermicomposting is coined from the Latin word '*Vermis*' meaning the 'worms'. Vermicomposting refers to natural bioconversion of biodegradable garbage into high quality manure with the help of earthworms.

Earthworms play a key role in soil biology; they serve as versatile natural bioreactors to harness energy and destroy soil pathogens by feeding voraciously on all biodegradable refuse. They are nature's way of recycling organic nutrients from dead tissues back to living organisms. They have faithfully done their part to keep this cycle of life continuously moving for more than 20 million years. Ancient civilizations including Greece and Egypt were the pioneers in recognizing the role of these worms played in soil. Earthworms were considered as "sacred" by the Egyptian Pharaoh, Cleopatra who recognized the role played by worms in fertilizing the Nile Valley croplands. The role of earthworms in waste stabilization has been known for many years, especially in Southeast Asian and European countries. Attracted by the nature and activities of burrowing earthworms in soil, Charles Darwin carried out studies on the significance of their activities for over 39 years. He wrote this about these tiny creatures," It may be doubted whether there are many other animals in the world which have played so important a part in the history of the world." He also called them as unheralded soldiers of the land, in his last and final book "*The Formation of Vegetable Mould, Through the Action of Worms, With Observations of their Habits*" which reported how these organisms feed and convert organic materials (Darwin, C.,1881).

From then on, studies have been carried out to find out their role in maintaining the soil fertility and also in the degradation of the organic matter present in the soil. These works also included investigations into the possibility of utilizing earthworms for the break down of organic wastes such as animal wastes, vegetable wastes and municipal solid wastes (MSW). Earthworms convert a portion of the organic matter into worm biomass and respiration products, and expel the remaining partially stabilized matter as discrete material (castings). In this process, earthworms and the microorganisms act symbiotically to accelerate the decomposition of organic matter. The driving forces behind the introduction of vermiculture and other reuse processes, is the global recognition of the need to recover organic material and return this to the natural cycle.

Vermicomposting is generally defined as the aerobic decomposition of organic residues by exploiting the optimum biological activity of earthworms and micro-organisms. The process depends upon the earthworms to fragment, mix and promote microbial activity in the organic waste material. The earthworms ingest organic solids and convert a portion of it into earthworm biomass and respiration products and egest peat like material termed as vermicompost. As compared to the thermal composting, vermicomposting generates a product with lower mass, high humus content, processing time is lower, phytotoxicity is less likely, fertilizer value is usually greater, and an additional product (earthworms) which can have other uses is produced.

Organic waste materials which are biodegradable in nature may be used as substrates for the vermicomposting process, provided that the materials do not contain anything harmful to earthworms. For example, the byproducts of agro-industrial processing offer potential opportunities to be used as substrates for the earthworms and microorganisms. The agro-industrial wastes are huge source of plant nutrients and their disposal means the ultimate loss of the resourceful material. At present, these wastes are either grossly underutilized or completely unutilized due to in situ burning in the fields or land disposal to the surrounding areas. These individually and cumulatively agro-industrial wastes could effectively be tapped for resource recovery through vermicomposting technology for use in sustainable land restoration practices.

Some of the major agro-industrial wastes explored for vermicomposting are shown in Table.1and Fig.1

Table.1: Details of agro-industrial organic wastes for vermicomposting

No.	Sources	Types of wastes generated
1	Agricultural wastes	Rice husk, cereal residues, wheat bran, millet straw etc.
	Food processing waste	Canning industry waste, breweries waste, dairy industry waste, sugar industry waste press mud and trash, wine industry waste, oil industry waste- non edible oil seed cake, coffee pulp, cotton waste etc.
2	Wood processing waste	Wood chips, wood shavings, saw dust

3	Other industrial wastes	Fermentation waste, paper and cellulosic waste, tannery waste
4	Local organic products	Coco fiber dust, tea wastes, rice hulls etc.
5	Fruits and vegetable processing waste	Peels, rinds and unused pulp of fruits and vegetables

Fig.1: Agro-industrial wastes for vermicomposting

Coir waste

Saw dust

Sugarcane trash

Wood waste

CHAPTER 2
EARTHWORMS

The earthworm is a segmented invertebrate. Its body holds its tube-shape because it is full of a liquid called coelomic fluid found between the body wall and the alimentary canal. Earthworm has a long, cylindrical body with a pointed head (Padashetty,S.&Jadesh,M.,2014) (Fig.2). In some species the posterior end is slightly flattened, while in others the body is cylindrical throughout. Rings that surround the moist, soft body allow the earthworm to twist and turn, especially since it has no backbone. With no true legs, bristles (setae) on the body move back and forth, allowing the earthworm to crawl. Earthworm breathes through its body surface. Food is ingested through the mouth into a bag like structure referred to as crop. In some species a distinct crop is absent. Later the food passes through the gizzard, where ingested stones grind it up. After passing through the intestine for digestion, what's left is eliminated as castings.

Fig.2: Earthworms

Distribution

Earthworms are found all over the world, except in areas under constant snow and ice, mountain ranges, deserts and areas almost entirely lacking in soil and vegetation. Species which are widely distributed are called peregrine, whereas others termed as endemic do not spread successfully to other areas. (Ansari, A.A. and Ismail,S.A.,2012)

Factors affecting distribution

The distribution of earthworms in soil is affected by physical and chemical characters of the soil, such as temperature, pH, moisture, organic matter and soil texture. (Govindan,1998)

Temperature

The activity, metabolism, growth, respiration and reproduction of earthworms are all influenced greatly by temperature.

pH

pH is a vital factor that determines the distribution of earthworms as they are sensitive to the hydrogen ion concentration. pH and factors related to pH influence the distribution and abundance of earthworms in soil. Several workers have stated that most species of earthworms prefer soils with a neutral pH. There is a significant positive correlation between pH and the seasonal abundance of juveniles and young adults.

Moisture

Prevention of water loss is a major factor in earthworm survival as water constitutes 75-90% of the body weight of earthworms. However, they have considerable ability to survive adverse moisture conditions, either by moving to a region with more moisture or by means of aestivation. Availability of soil moisture determines earthworm activity as earthworm species have different moisture requirements in different regions of the world. Soil moisture also influences the number and biomass of earthworms.

Organic matter
The distribution of earthworms is greatly influenced by the distribution of organic matter. Soils that are poor in organic matter do not usually support large numbers of earthworms. Several workers have reported a strong positive correlation between earthworm number and biomass and the organic matter content of the soil (Ismail,1997).

Soil texture
Soil texture influences earthworm populations due to its effect on other properties, such as soil moisture relationships, nutrient status and cation exchange capacity, all of which have important influences on earthworm populations.

Classification
Earthworm belongs to *Annelida* phylum and to *Oligochaeta* class that comprises more than 1800 species; most of the species belong to *Lumbricidae* family, including the genera: *Dendrobaena, Eisenia and Lumbricus*. The classification of one of the species' of this family, *E. fetida* which is known as red worm, brandling worm, red wiggler worm is shown in Table**.**2.

Phylum	Annelida
Class	Oligochaeta
Subclass	Clitelata
Order	Haplotaxia
Suborder	Lumbricina
Super family	Lumbricoidea
Family	Lumbricidae
Subfamily	Lumbricinae
Genus and species	*Eisenia fetida*

Table.2: Taxonomic classification of *Eisenia fetida*

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

The morpho-ecological groupings relate to several factors including general size, shape and pigmentation, burrow construction, position in the soil profile, source of food and reproductive potential. The three groups of earthworms are:

1. Litter dwelling earthworms (*Epigeic* species)

There are several deeply pigmented or red species that normally live in the rotting litter or organic matter on the surface of soils. They grow and reproduce very prolifically compared with true soil dwelling earthworms.

Some of the species commonly used in vermicomposting are *Dendrobaena veneta* (blue nosed worm), *Eisenia fetida* (tiger or brandling worm)*, and Eisenia andrei* (red tiger worm) and *Eudrilus eugeniae*.

2. Topsoil dwelling earthworms (*Endogeic* species)

Just below the surface live another group of small earthworms, in the first few centimetres of topsoil. They improve soil structure in the root zone of plants and recycle dead organic matter. One notable species is *Allolobophora chlorotica* (green worm).

3. Deep burrowing earthworms (*Anecic* species)

Anecic species live deeper down in the soil profile in permanent vertical burrows that can be up to two metres long. They help create topsoil by dragging dead organic material from the soil surface down into their burrows, ingesting it along with soil and then egesting the mixture back on the surface as nutrient-rich earthworm casts. Species in this category are highly valued and have been successfully bred for land restoration projects. One beneficial species is *Lumbricus terrestris* (the lob worm).

The Anecic types burrow deep in the soil but come to the surface at night to forage for freshly decaying residues.

Basic Requirements

Earthworms need these basic things for vermicomposting:

1. Bedding: Bedding is any material that provides the worms with a relatively stable habitat. This habitat must have the following characteristics: ***High absorbency-*** 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. The bedding must be able to absorb and retain water fairly well if the worms are to thrive. ***Good bulking potential-*** If the material is too dense to begin with, or packs too tightly, then the flow of air is reduced or eliminated. Worms require oxygen to live, just as we do. Different materials affect the overall porosity of the bedding through a variety of factors, including the range of particle size and shape, the texture, and the strength and rigidity of its structure. ***Low protein and/or nitrogen content (high C:N ratio)-*** Although the worms do consume their bedding as it breaks down, it is very important that this be a slow process. High protein/nitrogen levels can result in rapid degradation and its associated heating, creating inhospitable, often fatal, conditions. Heating can occur safely in the food layers of the vermiculture or vermicomposting system, but not in the bedding.

2. Housing: Sheltered culturing of worms is recommended to protect the worms from excessive sunlight and rain. A low cost unit can be arranged in vacant cowsheds, poultry sheds, basements and back yards.

3. Containers: Bricks or cement tanks are to be constructed separated in half by a dividing wall.

4. Environmental conditions: The environmental conditions are vital and may affect the breeding, cocoon production and hatching of young earthworms.

a. Temperature

In vermicomposting, temperatures are kept generally kept below 35^{o}C. Most worm species used in vermicomposting require moderate temperatures from (10-35^{o}C).While tolerances and preferences vary from species to species, temperature requirements are generally similar. In general, earthworms tolerate cold and moist conditions far better than they can hot and dry conditions.

b. Moisture

Earthworm requires plenty of moisture for their growth and survival. They need moisture in the range 60–75 %. The soil should not be too wet else it may create an anaerobic condition and drive the earthworms from the bed (Ronald and Donald, 1977). It is very important to moisten the dry bedding material before putting them in the bin, so that the over all moisture level is well balanced.

c. pH

Earthworms are pH sensitive and generally most of them survive at pH ranging from 4.5 to 9. The alteration of pH in the worm bed is due to the fragmentation of the organic matter under a series of chemical reactions. The soil pH is a major factor limiting the abundance and distribution of earthworms.

Nutrition

- Earthworms obtain their nutrition from microorganisms, especially fungi and also nematodes
- The grinding action of earthworm's gizzard increases surface area of the organic matter and promotes microbial activity in organic wastes as they pass through earthworm guts
- Earthworm feeding favors aerobic microorganisms at the expense of anaerobic microbes
- Vermicomposts are very much more microbially-active than the parent organic wastes with diverse microbial communities

Species

The selection of species of earthworms for vermicomposting should focus on species where, consumption of organic biomass, rapid growth and reproduction is within short time span (Gunasegaran and Desai,1999).Some of the characteristics the earthworms for attaining the objectives of vermicomposting are detailed below:

1. Worms should be capable of inhabiting a wide range of organic materials
2. It should have high fecundity rate with short incubation period.
3. The period of interval from hatching to maturity should be very short.
4. It should have less vermistabilization (period of inactivity after initial inoculation to organic wastes).
5. Wide adaptability (tolerance) to environmental factors (capability to live in varying temperature and moisture conditions);
6. High growth rate, low incubation period, high reproduction and cocoon production rate;

7. High consumption, digestion and assimilation rate for organic matter decomposition;
8. Easy to culture.

The vermicompost produced using different species of earthworms show variation in nutrient composition. So, the selection of the suitable species for particular vermicomposting application is important. It is well established that epigeic species of earthworms are used widely for the purpose of vermicomposting of different organic wastes (Ismail,2005).A list of common earthworm species suitable for vermicomposting has been presented in Table.3

Table.3: List of some earthworm species suitable for vermicomposting

FAMILY	SPECIES
Lumbricidae	*Bimasto parvus* *Eisenia foetida* *Eisenia hortensis*
Megascolecidae	*Lampito mauritii* *Perionyx excavatus* *Metaphire anomala Polypheretima elongate*
Ocnerodrilidae	*Ocnerodrulus occidenalis*
Octaochaetidae	*Dichogaster bolaui* *Dichogaster saliens* *Romiella bishambari*
Eudrilidae	*Eudrilus euginae*
Moniligastridae	*Moniligaster perrieri*

(Source: Chattopadhyay, G.N., 2012)

Some of these species identified as most suitable for breaking down solid wastes are: *Eisenia fetida* (and the closely-related *E. andrei*), *Eudrilus eugeniae and Perionyx excavatus*.(Fig.3) These species are prolific breeders,maintaining a high reproduction rate under favorable, moisture and food availability. They show high metabolic activity and hence are particularly useful for vermicomposting.(Radhakrishnan,B. and Muraleedharan,N.,2010) Other species can also be used but these species are the commonest.

1 *Eisenia fetida*

Eisenia fetida, popularly known as red wriggler, red worm, tiger worm etc is perhaps the most widely used earthworm for vermicomposting. Mature individuals can attain up to 1.5 g body weight. Each mature worm on average produces one cocoon every third day and from each cocoon emerge from 1 to 3 individuals on hatching within 23 days. Average life of this worm is 1–2 years.

2 *Eudrilus eugeniae*

Eudrilus eugeniae commonly known as Night Crawler is a native of Equatorial West Africa. It is a fast growing species capable of accumulating body mass at the rate of 12 mg per day. A mature worm can attain body weight up to 4.3 g/individual. Maturity is attained over a period of 40 days, and, a week later, individuals commence cocoon production (on average one cocoon day−1). Its life span has been estimated from 1 to 3 years. The temperature tolerance of *the* species is lesser than that of *E. fetida*. This species is widely used as vermicomposting worm in tropical and sub-tropical regions.

3 *Perionyx excavatus*

This species is highly adaptable and can tolerate a wide range of moisture and composition of the waste materials. Average growth rate of *Perionyx excavatus* is 3.5 mg per day and body weight (maximum) 600 mg. Maturity is attained within 21–22 days and reproduction commences by 24th day, with 1 to 3 hatchlings per cocoon. This species is considered by many as best suited for vermicomposting in tropical climates.

The survival, growth, mortality, and reproduction of these species have been studied in detail in several laboratories, in a range of organic wastes, including pig, cattle, duck, turkey, poultry, potato, brewery, paper, and activated sewage sludge. All of the species tested could grow and survive in a wide range of different organic wastes, but some were much more prolific, others grew more rapidly, and yet others attained a large biomass quickly. Most organic wastes can be broken down by these worms, but some organic wastes (e.g. wood wastes) have to be pretreated in various ways to make them acceptable to the earthworms.

Fig.3: Common species of Earthworms for vermicomposting

Eisenia sp. *Eudrilus sp.* *Perionyx sp.*

Microbiology

Microorganisms live in the alimentary canal of earthworms in a complex, mutually beneficial inter-relationship (Ansari,A.A and Ismail,S.A., 2012). Recently some of these microbes were isolated and identified in the gut of *Eudrilus eugeniae* by Prabha,M.L.,*et al* (2014).The various types of bacteria isolated and identified were *Proteus mirabilis, Staphylococcus aureus, E.coli* and *Klebsiella* sp. and the fungi identified were *Aspergillus flavus*, *A. niger, A. ternus, Alternaria* sp. and *Pencillium* sp. Although these microorganisms are the same as those in the soils, the microbial population in earthworm casts is found to be much higher as compared with the surrounding soil. Earthworm casts usually have a greater population of fungi, actinomycetes and bacteria and higher enzyme activity than the surrounding soil. Microbial activity in earthworm casts may have an important effect on soil crumb structure by increasing the stability of the worm-cast-soil relative to that of the surrounding soil. Earthworms are very important in inoculating soils with microorganisms. Many microorganisms in the soil are in a dormant stage with low metabolic activity, awaiting suitable conditions like the earthworm gut or mucus to become active. Earthworms have been shown to increase the overall microbial respiration in soil, thereby enhancing microbial degradation of organic matter.

Microbial action

Earthworms make vermicompost by feeding on the waste. The other organisms which accompany them also assist in the complex process of breaking down the matter. The overall mechanism behind this is given below:

1. The organic matter, fungi, protozoa, algae, nematodes and bacteria ingested by earthworm is passed through its digestive tract. The majority of the bacteria and organic matter pass through undigested as ‘casting’ with metabolite wastes such as ammonium, urea and proteins.
2. During this, the worm also secretes mucus, containing polysaccharides, proteins and other nitrogenous compounds. Through feeding and excreting, worm creates a number of “burrows” in the material which helps in aeration.
3. Some bacteria require oxygen (aerobic) whereas some prefer its absence (anaerobic). Anaerobic bacteria are responsible for the stench from stagnant drains, landfill sites, etc. With the aerobic conditions in vermicompost, aerobic microbial growth increases. Accompanying this microbial growth is the breakdown of organic nitrogen compounds to ammonia and ammonium. The sweet smelling aerobic process overcomes the ugly smell of anaerobes. That is why worm compost piles (properly maintained) smell so nice.
4. The whole process consumes organic matter and creates a ruffled surface in the burrow walls resulting in favourable environment for obligate aerobes (such as *Pseudomonas spp*., *Zoogloea spp., Micrococcus spp., etc)*. The continued growth of the microbiological population continues to increase the rate of decomposition of the material.
5. Air flows through the material minimize the formation of sulfide and ammonia gases, odours that are typically present in anaerobic conditions. Objectionable odours disappear quickly, due to microorganisms associated with the vermicast.

Reproduction

Mature worms have a prominent band around their body, which is called as the clitellum. This is usually visible around 8-12 weeks of age. During copulation, the worms will join together at the clitellum (sometimes for quite a long period of time(Fig.4). Reproductive material is exchanged. When the worms separate, a ring of mucus material forms at the clitellum of each worm. This process is known as copulation. Sperm from the other worm is stored in sacs. As the mucus slides over the worm, it encases the sperm and eggs inside. After slipping free from the worm, both ends seal, forming a lemon-shape cocoon approximately 3.2 mm long (Fig.5).Two or more baby worms will hatch from one end of the cocoon in approximately 3 weeks. Baby worms are whitish to almost transparent and are 12 to 25 mm long.

Red worms take 4 to 6 weeks to become sexually mature.

Fig. 4: Earthworms:Copulation

Fig.5: Earthworms: Cocoons

Calculating Rates: Epigeic worms reproduce very rapidly and the worm populations double every 60 to 90 days, if the following conditions are provided:

1) Adequate food (continuous supply of nutritious food);
2) Well aerated bedding with moisture content between 70 and 90%;
3) Temperatures maintained between 15 and 30ºC;
4) Initial stocking densities greater than 2.5 kg/m^2 but not more than 5 kg/m^2

The term ‘stocking density’ refers to the weight (initial) of worm biomass per unit area of bedding. For instance, when we start with 5 kg of worms in a bin with a surface area of 2 m^2, the initial stocking density would be 2.5 kg/m^2. The onset of rapid reproduction will be delayed at very low densities, and may even stop it completely. It is clear that worms need a certain density in order to get a 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/m^2 begin to slow there productive urge, as competition for food and space increase. While it is possible to get worm densities up to as much as 20kg/m^2, the most common densities for vermicomposting are between 5 and 10 kg/m^2.Worm growers tend to stock at 5 kg/m^2 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 tonnes after two years.

The main barriers to achieving optimum rates of reproduction are:
Lack of knowledge and experience Growing worms is part science, part "green thumb". You need the knowledge, but you also need to do it to learn how to do it well.
Lack of dedicated resources Increasing worm populations requires paying attention to what is happening and responding accordingly. This takes time and effort. If the beds or windrows are neglected, the worms will likely survive, but the population will not increase at an optimum rate.

Life cycle and population
Earthworms are hermaphrodite, which means each worm is both male and female (Diaz Cosin, D.J., *et al,* 2011). However, each worm must still mate with another worm of its species in order to reproduce. During mating, any two adult worms can join together to fertilize each other's eggs. Fertilized egg contains in a mucous tube secreted by the clitellum that slips over its head and then into the soil through its mouth as an egg-case or cocoon. These cocoons are about the size of a match stick head and change color as the baby worms develop, starting out as pale yellow and when the hatchlings are ready to emerge, cocoons are reddish-brown.

Number of cocoons and hatchling period varies for each species and depend upon the environmental conditions (Table.4). The lifespan of the earthworm in the wild is not certain, but researchers estimate a normal lifespan of about 3 years. The earthworm population is self controlled and limited by available food, space, and environmental conditions.

Table.4: Comparison of Lifecycle and Growth of Different Earthworm Species

Earthworm Species	Biomass Production, g/wk	Average Reproduction Rate, worm/wk	Egg Maturation Period, d	Cocoon Hatching, d	Period to Attain Maturity, d	Mean Matur Weigl g
Eisenia fetida	0.68	10.4	85-49	32-73	53-76	0.55
Eudrilus eugeniae	5.76	6.7	43-12	13-27	32-95	4.3
Perionyx excavatus	6.3	29.4	44-71	16-21	28-56	1.3
Dendrobaena veneta	0.16	1.4	97-214	40-126	57-86	0.92

(*Source: Edwards, 1988)*

Multiplication

Earthworms can be multiplied in 1:1 mixture of cow dung and decaying leaves kept in a cement tank or wooden box or plastic bucket with proper drainage fa- cilities. The nucleus culture of the worms needs to be introduced into the above mixture at the rate of 50 worms per 10 kg of organic wastes properly mulched with dried grass or straw in a wet gunny bag. The unit should be kept in shade. Sufficient moisture level should be maintained by occasional sprinkling of water. Within 1-2 months, the worms multiply 300 times, which can be used for large-scale vermicomposting.

Suitability of municipal biosolids and cattle manure as substrates for vermicomposting was evaluated and reported that larger weights of newly hatched earthworms were obtained in substrate containing dry olive cake. In another study, maize straw was found to be the most suitable feed material compared to soybean (*Glycine max*) straw, wheat straw, chickpea (*Cicer arietinum*) straw and city refuse for the tropical epigeic earthworm, *Perionyx excavatus.*

CHAPTER 3

TREATMENT WITH EARTHWORMS

Earthworms for bioconversion

The potential of earthworms to stabilize the organic refuse into useful components has been known only recently. Mary Appelhof, the 'Worm Woman', with her experiments in the early 1970s, popularized the idea of using worms for waste conversion and brought it to the public's attention. In addition to this work, the publication of the "Proceedings of a Workshop on the Role of Earthworms in the Stabilization of Organic Residues" in 1981, 100 years after Darwin's study, was also responsible for the accelerated interest on the use of earthworms in breaking down organic wastes within and outside of the United States. Edwards (1998) reported five earthworm species *(D. veneta, E. eugeniae, P. excavatus* and*P.hawayana* and *E. fetida*) to be the most potential earthworms for breakdown of organic refuse. Generally most organic wastes can be broken down as such, except for those, which might need some pre-digestion prior to feeding. Earthworms are highly adaptable to different types of organic waste, provided, the physical structure, pH and the salt concentration are not above the tolerance level (Seenappa, *et al*, 1995). In most of the cases, the feedstock is thermophilically composted in windrows (turned twice weekly), for 15 to 30 days before being fed to earthworms.

Earthworms convert the smelly organic matter into a dark, odourless, homogeneous material called castings or vermicast which is an ideal plant growth supplement. It is often referred to as 'Black Gold' by gardeners. Earthworms feed partly on the waste itself, but mostly on the microorganisms produced during decomposition. Their movement through the waste assists the break down and aeration of the material, providing ideal conditions for microbes to flourish, which in turn accelerates the decomposition rate of the organic matter. The waste entering the earthworm gut is subjected to biochemical break down by the enzymes secreted in the gut wall of the animal and by the microorganisms therein. The resulting product is a colloidal humus that acts as a slow release fertilizer. The nutrients are easily available to plants, but resist leaching. The rate of decomposition also depends on the type of litter.

Fragmentation and breakdown

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

Consumption and Humification

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

Nitrogen mineralization

Earthworms greatly increase the soil fertility, and part of this must be due to the increased amounts of mineralized nitrogen that they make available for the plant growth. There have been reports of increase in the amount of nitrogen in the soil in which the earthworms are reared. This may be due to the decay of the bodies of dead earthworms, which are rich in proteins.

Govindan (1998) reported that earthworm body contains 65% protein, 14% fats, 14%carbohydrates and 3% ash. Similarly, Ronald and Donald (1977) reported that 72% of the dry weight of an earthworm is protein and that the death of an earthworm will release up to 0.01 g of nitrate in the soil. Also, earthworms consume large amount of plant organic matter that contains considerable quantities of nitrogen, and much of this is returned to the soil in their excretions.

Effects on the C/N ratio

Plant roots in general cannot assimilate the mineral nitrogen unless the Carbon/Nitrogen (C/N) ratio is in the order of 20:1 or lower. Earthworms help to lower the C/N ratio of fresh organic matter during respiration (Ronald and Donald, 1977b). To assess the role of earthworm in lowering the C/N ratio, the consumption of the carbon must be measured, and this can be done approximately, by measuring the respiration. But the disadvantage of laboratory studies is that they do not always reflect the actual situation. There was a remarkable reduction in C/N ratio of vermicompost than in the compost.

CHAPTER 4

VERMITECHNOLOGY IN WASTE MANAGEMENT

Open dumping is the prevailing method of solid waste disposal in many of the developing countries. It has become increasingly expensive and hazardous to the natural environment. Therefore, presently there is an urgent need to explore the potential of earthworms in waste management. For millennia, earthworms have been preparing soil for the colonization and evolution of plants. They have played a commendable role in agriculture. Their value in supporting the waste disposal and management systems is being realized by the day. Earthworms, in dense culture and in large quantities, can physically handle virtually any biological waste.

Vermitechnology, based on this inherent ability of earthworms has the capacity to handle large quantities of organic wastes and is seen as a viable industrial process capable of sustained commercial operation (Sharma, S., *et al*, 2005).The core of the system is the process bed in which millions of worms are regularly fed with organic waste and from which worm stabilized organic matter, referred to as vermicompost, is harvested.

Feeds for Vermitech systems

1. Animal manures

Use of animal manure as primary feed for earthworms is very common in vermitech systems. Cattle solids are the most suitable of all animal wastes for earthworm biomass increase. They usually do not have materials that deter the growth of earthworms. Cowdung slurry is a suitable substrate for vermicomposting, both when mixed with solid materials or on applying to the surface of bedding materials containing earthworms. Horse manure is also suitable for the growth of earthworms. (Manaf, L.A., et *al*, 2009) Horse manure contains 0.7 % of nitrogen, 4.38 % of protein and 60 % of organic matter, trace amounts of phosphoric acid and potassium oxide (Ronald and Donald, 1977) and can therefore be applied directly as feed. Waste from the piggeries is probably regarded as the most productive refuse for growing the earthworms. Poultry wastes are higher in protein content, nitrogen and in terms of phosphoric acid than any other animal manure. The fresh waste generated from the poultry farms contains significant amount of inorganic salts, and if used directly might threatened the survival of the worms (Edwards, 1988).These wastes have to be pretreated by composting, washing or simply by aging process to reduce the inorganic salt content and the heating potential.

2. Kitchen Waste and Urban waste

The residential and the commercial portion make up to about 50 to 70 percent of the total Municipal solid wastes (MSW) generated in a community. The solid waste so generated can be of two types:

A. Biodegradable or organic- kitchen waste, straw, hay, paper and animal excreta.
B. Non-biodegradable- ash, stone, cinders, plastics, rubber and metals.

The food waste from domestic households and restaurants and other yard waste are good for growth of earthworms (Gandhi M, et al,1997;Bharadwaj, A., 2010). Vegetable scraps from kitchen and other yard wastes provide ideal feed bed for growing earthworms. Earthworms digest municipal biosolids along with green mulch. About two thirds of this volume becomes vermicompost. (Giraddi, R.S., *et al,* 2008; Singha, R.P, 2011)

3. Paper pulp and card board solids

Paper and cardboard are excellent materials, both for feeding and for the bedding of earthworms due to their cellulose content. Earthworms convert cellulose into its food value faster than the proteins and other carbohydrates .These wastes do not need any special pretreatment and can be applied directly as a feed. In a recent work, Basheer, M and Agrawal,O.P.(2013) successfully utilized epigeic earthworm, *Eudrilus eugeniae* for the conversion of paper waste into vermicompost.

4. Compost and waste products

Spent mushroom compost is also a good medium to grow earthworms. It is low in plant nutrients. Brewery waste needs no modification, in terms of moisture and the worms can process it quickly.

5. Industrial Wastes

Wastes from the canning plant and potato chip or corn chip manufacturing unit are excellent food for worms. Wastes generated from vegetable oil factory are also suitable as feed (Kale, 1998). Wastes from logging and carpentry industries and sugar factories are also used as substrate to feed earthworms. When the earthworms are reared in the ratio of 1:1 sawdust and press mud, the cast generated shows 1.2 times more CFU (Colony Forming Units) than saw dust and 1.6 times more than the press mud (Parthasarathi,*et al*., 1999).Earthworms can partially detoxify wastes. The fly ash waste generated from the thermal power plants creates a major disposal problem due to its heavy metal content although it is supposed to be very rich in microbial biomass. It was found out that the organic waste, *sisal* green pulp, *Parthenium* and green grass cuttings admixed with 25% of fly-ash proved to be a potential valuable material for *E.fetida* biomass. The vermicompost so produced contains higher NPK content than the other available commercial manures. In some cases, earthworms are also used in the management of distillery waste containing wastes of malt, spent grain wash, yeast and molasses settled at the bottom of the lagoon. Seenappa, *et al*., (1995) observed that the total volume of cow dung leaf litter should be proportional to the total volume of distillery waste and press mud to have positive impact on the growth and production of worm biomass. Lakshmi and Vijayalakshmi (2000) reported that the filter press mud from the sugar factory could be used as a feed in the vermicomposting units. It is seen that after worms have worked on it, the press-mud is converted to nutrient rich manure and its physico-chemical features improved after vermicomposting. In 2011, Murali,M.,*et al* reported that coir wastes could be converted into vermicompost by utilizing *Eudrilus Eugeniae.* Studies by this author reported that chip wash residue, a kind of wood waste from wet-process hardboard factory could be converted into vermicompost by utilizing *E. eugeniae* (E.Sreenivasan, 2013a).

Other applications

1. In aquaculture

In aquaculture, the most common method of solid waste disposal is land spreading, which causes pollution of soil, surface and ground water bodies resulting in untimely death of aquatic organisms. Vermicomposting of such waste controls water and soil pollution, thereby ensuring better survivability and growth offish, prawn and other aquatic organisms within its natural habitat. The application of vermi-castings, which is a high-grade organic fertilizer to the aquaculture ponds, reduces the input cost and makes the aquaculture process more profitable. It also helps in combating the harmful effects against chemical fertilizer if so ever present in the receiving water.

Large-scale vermiculture has the potential of supplying earthworm meal as a substitute for fishmeal. (Pucher J, *et al*, 2014) Earthworm meal contains all the essential amino acids required in fish feed. The methionine and lysine availability is higher than that of the normal fishmeal. There is also an increasing demand for protein-rich raw materials in other animal-feed industry.

2. Vermifilter

Ground Water Recharge

Earthworm increases the hydraulic conductivity and natural aeration by granulating the clay particles. They also grind the silt and sand particles, increasing the total specific surface area, which enhances the ability to adsorb the organics and inorganics from the wastewater. This is ideal for dilute wastewater (such as sewage). Figure shows the vermifilter that could be used to recharge groundwater. The loading rate of wastewater is calculated as $2m^2/m^3$ of sewage. Earthworms ensure bio-sanitation and prevent sewage sickness through effective regeneration of adsorption ability with their bacterial farming along with their grazing act on surplus bacterial biomass (Bhawalkar, 1995).

Water recovery

It is possible to have single or multiple stage vermifilter depending on the strength of the wastewater and desired quality of renovated water. In principle, a single unit can produce any given purity of water by increasing the recyclable ratio, which reduces the organic loading. The first stage achieves roughing filtration and the second stage achieves polishing (Bhawalkar, 1995).

CHAPTER 5

VERMICOMPOSTING: BASIC PROCESS

The preparation of vermicompost involves five stages as shown inTable.5.The process takes place in the mesophilic temperature range (35–40◦C). The different phases during the process are as follows:

Initial pre-composting phase: The organic waste is pre-composted for about 15days before being fed to earthworms. During this phase, readily decomposable compounds are degraded and the potential volatile substances are eliminated which may be toxic to earthworms. Pre-composting the feedstock decreases the amount of energy contained within the material, so that heating doesn't take occur within the worm system. Feedstock which are pre-composted for 10-14 days retain sufficient nutrition for the worms, but not so much energy that they are able to generate heat (Nair, *et al*, 2006)

Mesophilic phase: The predigested waste material should be mixed with 30% cattle dung either by weight or volume. The mixed waste is placed into the tub / container up to brim. The moisture level should be maintained at 60%. If necessity arises, water should be sprinkled over the bed rather than pouring the water. Over this material, the selected earthworm is placed uniformly. For one-meter length, one-meter breadth and 0.5-meter height, 1 kg of worm (1000 Nos.) is required. During this phase, earthworms, through their characteristic functions of breaking up organic matter, combine it with the soil particles and enhance microbial activities and condition organic waste materials for the formation of organic manures.

Maturing and stabilization phase: In the vermicomposting process, the action of the earthworms is both physical/mechanical and biochemical. Physical participation in degrading the organic substances results in fragmentation, thereby increasing the surface area for further microbial colonization. Biochemical changes in organic matter decomposition are carried out through enzymatic digestion, enrichment by nitrogen excrement and transport of organic and inorganic material. The passage of material through the earthworm intestine rapidly converts the locked up minerals of nitrogen, potassium, phosphorus, calcium etc. into the forms that are much more soluble and available to plants than the parent material. This is made possible by various enzymes present in their gut as well as enzymes of certain type of ingested microorganisms, viz., proteases, lipases, amylases, cellulases, chitinases, etc which degrade the cellulosic and proteinaceous materials in organic waste. The earthworms seem to have developed mutualistic relationship with microorganisms ingested for decomposition of organic matter present in their food. Thus, the final quality of the vermicompost is the result of combined efforts taken by earthworms and the microorganisms.

Table.5: The steps involved in the process of vermicomposting

Step 1	Collection of wastes, shredding, mechanical separation of the metal, glass and ceramics and storage of organic wastes.

Step 2	Pre-digestion of organic wastes by heaping the material along with cattle dung slurry. This process partially digests the material and fit for earthworm consumption. Cattle dung and biogas slurry may be used after drying. Wet dung should not be used for vermicompost production.
Step 3	Preparation of vermibed. A concrete base is required to put the waste for vermicompost preparation. Loose soil will allow the earthworms to go into soil and also while watering; all the dissolvable nutrients go into the soil along with water.
Step 4	Collection of earthworm after vermicompost collection. Sieving the composted material to separate fully composted material. The partially composted material will be again put into vermicompost bed.
Step 5	Storing the vermicompost in proper place or room to maintain moisture and allow the beneficial microorganisms to grow.

Mechanism of Earthworm action

Earthworms promote the growth of 'beneficial decomposer aerobic bacteria' in waste biomass and also act as an aerator, grinder, crusher, chemical degrader and a biological stimulator. Earthworms host millions of decomposer (biodegrader) microbes in their gut. Edwards (1988) showed that the number of bacteria and 'actinomycetes' contained in the ingested material increased up to 1000 fold while passing through the gut. A population of worms numbering about 15,000 will in turn foster a microbial population in billions in short time. Under favourable conditions, earthworms and microorganisms act 'symbiotically and synergistically' to accelerate and enhance the decomposition of the organic matter in the waste.

It is the microorganisms which breaks down the cellulose in the food waste, grass clippings and the leaves from garden wastes.The waste feed materials ingested is finely ground (with the aid of stones in their muscular gizzard) into small particles to a size of 2-4 microns and passed on to the intestine for enzymatic actions. The gizzard and the intestine work as a 'bioreactor'; The worms secrete enzymes proteases, lipases, amylases, cellulases and chitinases in their gizzard and intestine which bring about rapid biochemical conversion of the cellulosic and the proteinaceous materials in the waste organics.The final process in vermiprocessing and degradation of organic matter is the 'humification' in which the large organic particles are converted into a complex amorphous colloid containing 'phenolic' materials. Only about one-fourth of the organic matter is converted into humus.

CHAPTER 6
VERMICOMPOSTING SYSTEMS

In general the following vermicomposting systems are used the world over, for volume reduction, extraction of organic load, cost and energy reduction and rapid processing. Any of these systems may be adopted for vermicomposting depending on the availability of space, nature of waste or bedding material, quantity of waste to be processed etc.

A.Windrow system

This system deals with construction of windrows under shade to avoid direct sunlight. This method involves spreading out a layer of worms and bedding on the floor or ground to start(Fig.6).The first layer of a new windrow should be 10 to 15cm high. Earthworms can be reared at a production nursery or rectangular boxes prior to their inoculation in the windrows. The worms feed from the bottom till the top of the bed. The windrow has to be monitored daily and when signs of surface feeding are noticed, another 7 to 10 cm layer of feedstock can be added.

Thick layers of feedstock are avoided because they impede oxygen penetration into the windrow. This can cause the worms to migrate to the upper surface before lower layers are thoroughly digested, creating anaerobic fermentation. The windrows are irrigated with center post sprinkler up to twice daily to maintain optimum moisture content of 80% throughout the windrow. Now the material on top is removed to start a new row, and the material on the bottom is vermicompost. The new row can be started in a new location. Or it can be moved longitudinally by about 20' by dumping the worm inhabited material past the end of the row, digging out some vermicompost, and then shuffling some more worms over.

One of the problems with this method is that it requires some digging by hand. If the windrow is wide enough, it might be possible to drive into the side of it with a loader to remove some material off the top. But the rest of it will have to be forked off by hand because the loader will merely push it over and off the opposite edge of the row. No matter how careful you are, material will roll down the sides when digging off the top, and it takes some care to make sure that material does not end up getting mixed in with the finished product.

Windrows work great in places where temperatures are just right most of the time. If the windrows are outside, they should ideally be under a shade structure on a slightly elevated concrete slab. If there is no shade structure, or if the shade structure does not shed rain, then compost covers need to be ready for use during heavy or frequent rain. Compost covers are heavy and awkward, usually requiring two or more people to handle. If there is no concrete, there still needs to be some type of impervious surface such as asphalt or certain types of clay.

Fig.6:Vermicomposting windrows

B. Wedge System

This is a modified windrow system and it maximizes space and simplifies harvesting because there is no need to separate worms from vermicompost. Organic wastes are applied in layers against a finished windrow at a 45^o angle. The piles can be constructed inside a structure or outdoors if they are covered with a tarpaulin or compost cover to prevent leaching of nutrients. A front-end loader is used to establish a windrow 1.2 to 3 m wide by whatever length is appropriate. Spreading a 30 to 45 cm layer of organic materials the length of one end of available space starts the windrow. Up to 0.45 kg of worms is added per square meter of windrow surface area. Subsequent layers of 5 to 7.5 cm of organics are added weekly and preferably more addition in colder seasons. After the windrow reaches two to three feet deep, worms in the first windrow will eventually migrate toward the fresh feed. Worms will continue to move laterally through the windrows. After two to six months, the first windrow and each subsequent pile can be harvested. A variation of this method uses a migrating windrow. Here a row can be started as a windrow or as a layer and then grown into a windrow. A loader is used to feed one side of the row, keeping it the same height and length, but making it wider. After a while, a loader is used to remove vermicompost from the side opposite the one being fed. Later, the finished compost is removed from that same side again. The row migrates laterally as it is being fed along one side and harvested along the other. At any time, the feeding and harvesting sides can be switched to change the migration direction.

C. Container System

a. Pits,Tanks and Cement rings

Pits made for vermicomposting are 1 m deep and 1.5 m wide. The length varies as required. Tanks made up of different materials such as normal bricks, hollow bricks, asbestos sheets and locally available rocks were evaluated for vermicompost preparation. Tanks can be constructed with the dimensions suitable for operations. Scientists at ICRISAT have evaluated tanks with dimensions of 1.5 m (5 feet) width, 4.5 m (15 feet) length and 0.9 m (3 feet) height. The commercial biodigester contains a partition wall with small holes to facilitate easy movement of earthworms from one tank to the other (Nagavallemma, *et al*, 2004)(Fig.7)

Fig.7: Vermicomposting tanks made of ordinary bricks in a semi-commercial unit

Vermicompost can also be prepared above the ground by using cement rings. The size of the cement ring should be 90 cm in diameter and 30 cm in height.

Fig.8: Cement rings used as Vermicomposting tanks

(Source: ICRISAT, Hyderabad, India)

b. Commercial model

The commercial model for vermicomposting consists of four chambers enclosed by a wall (1.5 m width, 4.5 m length and 0.9 m height). The walls are made up of different materials such as normal bricks, hollow bricks, asbestos sheets and locally available rocks. This model contains partition walls with small holes to facilitate easy movement of earthworms from one chamber to another. Providing an outlet at one corner of each chamber with as light slope facilitates collection of excess water, which is reused later or used as earthworm leachate on crop. The four components of a tank are filled with plant residues one after another. The first chamber is filled layer by layer along with cow dung and then earthworms are released. Then the second chamber is filled layer by layer. Once the contents in the first chamber are processed the earthworms move to chamber 2, which is already filled and ready for earthworms. This facilitates harvesting of decomposed material from the first chamber and also saves labor for harvesting and introducing earthworms. This technology reduces labour cost and saves water as well as time.

Fig.9: A view of a semi-commercial vermicomposting unit

c. Beds or Bins

1 Top-fed type

A top-fed bed works within four walls and (usually) a floor, often within a building. If the bins are fairly large, they are sheltered from the wind, 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. The reader should note that these beds were designed for vermiculture, rather than vermicomposting. Harvesting vermicompost can be most easily accomplished by taking advantage of horizontal migration. To harvest, the operator simply stops feeding one of the beds for several weeks, allowing the worm’s 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.

2. Stacked type

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 vermi- composting. 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. 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.

The initial cost of setting-up a stacked-bin system is high. It requires a 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.

D. Continuous Flow Systems

This system originally developed by Dr.Clive Edwards of the Rothamstead Agricultural Research Station is gaining popularity and has been adopted by many mid-scale operations. The efficiency savings offered by their continuous flow design increases with the amount of material processed.

This system design is now almost ubiquitous in commercial mid to large-scale vermicomposting systems. Each of these systems uses a relatively deep top-fed container, in which the composting mass sits upon a raised floor made from a widely spaced wire mesh. Worms are added to the system and food waste is added gradually, layered with bedding material. The system is continually fed until the bin is nearly full. The worms generally move upward through the feedstock/bedding layers and vermicompost is harvested from below by scraping or cutting a thin layer of finished material from just above the grill using a rake or a manually or hydraulically-operated blade.

Continuous flow systems offer several advantages to medium to large scale composting operations. They are relatively straightforward to construct and operate. They are labour-efficient in terms of operation and harvesting finished material. They avoid the need for expensive equipment associated with technical ‘in-vessel’ systems and the turning and screening of windrowed material. It should be noted that, despite the recent and increasing interest in this design, windrows are still the most common large-scale vermicomposting system in use. Continuous flow vermicomposting designs are arguably the most efficient systems available, in terms of time and labour savings. However, regardless of efficiency or ease of operation, there is no design that eliminates the need for careful monitoring and good system management, which may require considerable initial experimentation and familiarization.

Maintaining Continuous Flow

Continuous flow vermicomposting systems provide an ongoing flow of vermicompost that is easily removed from the system without disrupting the worm activity or requiring complex or time-consuming harvesting methods. Because of their operating efficiency, these system designs are becoming almost as popular as windrows for large-scale applications. However, like all vermicomposting systems, the continuous flow model poses several challenges.

In order to simplify some of the technical terminology, the worms most often used in vermicomposting are usually referred to as "surface feeders.”

They are generally presumed to only be active at or just below the surface. However, this is not always the case. Earthworms are oxygen breathing, moisture-loving animals that require organic material to be bacterially active before they eat it. In their natural environment, this is usually top few inches of soil or surface organic litter, such as leaves. In any system with a free flow of oxygen, monitored moisture level and abundant supply of decomposing organic material, earthworms may spread throughout the material unless the system is carefully managed. Earthworms may therefore be found anywhere within the continuous flow systems which meets their requirements.

One of the advantages to the continuous flow design is in the ease with which a continuous supply of vermicompost can be removed from the system. However, harvesting of the finished material should not begin until the system is nearly full of material. Many operators have found that, along with appropriate loading rates, a minimum depth of material in the system of between 12"-18" will help to ensure that few, if any, worms will be low in the bed and drop through, or fall out with the harvested vermicompost. Once fully charged, vermicompost then needs to be removed at a rate that maintains a relatively constant level of material in the system.

Feeding Rates

The precise loading rate (at which raw feedstock can be added to a worm bed to encourage the worms to concentrate at or near the surface) will vary depending on the feedstock being used, temperature, moisture levels and the density of the worm population. Proper loading rates require that new feedstock is not added until the majority of the previously added feedstock has been decomposed. Adding new feedstock too early means there can lead to a build-up of unprocessed material within lower layers. There will therefore be sufficient available food deeper within the container, instead of being concentrated immediately below the surface. The worms will then spread into all the available food areas. Worm movement in the lower levels of a flow-through system often causes vermicompost to drop through the mesh floor before it has been sufficiently decomposed. Also, when the system is harvested, worms remaining low in the material will fall through with the vermicompost and will either need to be separated using labour-intensive screening methods, or will be lost to the system. Most operators of continuous flow systems find that frequent additions of thin layers of feedstock (1"-2" deep spread across the surface) produce the best results. Feedstock is sometimes mixed with bulking agents like compost, shredded leaves, cardboard, paper or straw, or covered with an equally thin layer of these materials. Paper products are a preferred feedstock for earthworms, as they provide an easily accessible and digestible form of carbon.

Excessive Heating

Another of the challenges to any vermicomposting system, irrespective of size, is the potential for heating in the feedstock. Bacteria are the primary decomposers of raw organic matter and in oxygen rich system, water, carbon dioxide and heat are produced as a result of microbial activity. When raw material is added to the system, particularly in large volumes, the mass can support the activity of billions of bacteria. Bacterial activity can produce significant amounts of heat, which may be trapped within the system. Even a small volume of raw material can result in heating if it contains sufficient energy to support high levels of bacterial activity. This potential for heating complicates the assessment system loading rates. It should be recognized that a worm bed may contain thousands of different species of invertebrates and microorganisms, all of which playa vital role within the vermiculture ecosystem. The loading rate cannot therefore be based solely on the needs or capacity of a single organism in that system. Bacterial activity may have as much impact as the worm activity, as bacteria will have access to the feedstock first.

Overfeeding (in relation to the design capacity, the type of feedstock and/or the level of system activity) may generate sufficient heat to deter worm activity. Unless design modifications can be made, such as installing fans to remove excess heat, the loading rate will need to be decreased to a point where heating is not a problem, even if that means feeding less material than the worms are capable of processing.

CHAPTER 7

PROCESSING: TIME AND ACCELERATION

1. It is possible to get vermicompost in 5 to 6 weeks with high worm populations and frequent management; 2 to 3 months (60 to 90 days) under favourable conditions; but 4 to 6 months is a better estimate with minimal management of the worm beds.
2. With high volume flow through systems, it has been reported that a marker such as a coin placed on the surface of the bed will typically drop out the bottom of the bed in about 60 days.
3. With a high worm population, kitchen wastes or animal manure will be decomposed in 4 to 6 weeks. If the material is to be used in certified organic production systems, the required worm composting time for a batch system is four months (16 weeks).
4. Worm populations will clearly decline with no added feed for four months. Worms are extracted over a one month period. A low population of worms is left for up to one month prior to sieving the finished compost. This also allows time for additional worms to emerge from cocoons.

Maturity and Stability

Compost/vermicompost quality is assessed on the basis of its stability and maturity. Good compost would have the texture of moist loose soil homogeneous and aesthetic. The abundance of physical, chemical and biological changes occurred during aerobic or worm composting. Different parameters proposed to assess the maturity of the compost include the C/N ratios, water soluble carbon, cation ion exchange capacity, CO2 evaluation, NH4-N/NO3-N ratio, organic carbon content, and humus content. However, germination index (GI) measuring phototoxicity has been considered as a reliable parameter to quantify compost maturity. A coliform test gives indication of pathogen reduction.

Composting and Vermicomposting-A comparison

In contrast to composting, vermiculture has several distinct applications, with the potential to produce different grades of end product, depending on volume or time constraints:

1. The complete processing of organic wastes by this method produces the highest-grade end product, in the form of worm casts. These typically contain much higher concentrations of vital nutrients than standard composted material. Worm casts tend to be used as a high quality (and high value) soil conditioner within the horticultural sector, rather than as bulk compost or plant bedding material.
2. The partial processing of organic material, in order to accelerate the composting process or to provide a product of higher quality than standard compost.
3. Elimination of nuisance odours associated with the decay of organic matter, such as in forms of open air composting, which do not employ sealed ‘in-vessel’ equipment.
4. The energy requirements of vermicomposting are very small compared to the existing waste disposal systems and processing costs are negligible.
5. The breeding of worms. Although this is not of primary concern for a municipal composting installation, such a facility would require very large numbers of worms in

order to operate satisfactorily. The maintenance and increase of worm numbers is therefore necessary, in order to increase initial worm numbers as the facility expands.

Process acceleration

1. Using Organic nutrients and other additives.

Literature survey on this area of research showed that only very few reports were available on the successful use of organic nutrients or other additives for enhancing the vermicomposting process. A recent article by Parray,*et al*, 2014 reported the use of *Spirulina* and *Trichoderma* as probiotic and microbial inoculants during pre-decomposition period in order to get qualitative and quantitative improvement vermicomposting. Studies by Vasanthi,*et al,* 2011 recommended the use of an organic nutrient, *Jeevamirtham* (a preparation using cow dung, urine, jaggery and black gram flour) for vermicomposting to enhance the functioning of the earthworm and to increase fertilizer value of vermicompost

2. Using Effective Microorganisms(EM)

EM is a multi-culture of co-existing anaerobic and aerobic beneficial microorganisms. (Higa, 1991;Fig.10).The major groups of the microbes present in EM are:

- Lactic acid bacteria - *Lactobacillus plantarum*,*L. casei , Streptococcus lactis*.
- Photosynthetic bacteria - *Rhodopseudomonas palustrus, Rhodobacter spaeroides.*
- Yeasts - *Saccharomyces cerevisiae, Candida utilis.*
- Acitinomycetes - *Streptomyces albur, S.griseus.*
- Fermenting fungi - *Aspergillus oryzae, Mucor hiemalis.*

They are used directly in waste management programmes as they can grow and multiply in solid wastes and other residues under proper conditions and are capable of converting wastes into high-quality compost. Studies by the author in 2013 showed that EM can be used to convert different types of lignocellulosic residues from a large wood industrial complex into a reusable form (E.Sreenivasan, 2013b). Research works by this author, with the objective of enhancing the efficiency of the earthworm that is involved in the process of vermicomposting of wood waste, by fortifying the vermibed using an effective microbial suspension were successful during the initial trial. This work requires further experimentations to establish and recommend the utilization of Effective Microorganisms for enhanced functioning of the earthworms.

Fig.10: Sample of commercially available EM solution

CHAPTER 8

TROUBLE SHOOTING

Let us discuss some of the common problems you may experience while working with your vermicomposting systems and the solutions to deal with these issues here:

1. Temperature

Heat as well as cold cause many problems for vermicomposting. A red wiggler becomes inactive once the temperature of the bedding rises above 29^{o}C. This could be avoided by placing the bin under shade at all times, if placed outdoors during the warm seasons. Evaporative cooling of the moist bedding keeps the bin cooler than the air temperature, but may need to add more water during the summer. The greater danger of overheating the worms arises from heat produced within the bin, which could be reduced substantially by feeding small amount of food frequently rather than a bulky food at one time. In general, worms like cool weather. They are at their highest activity and reproductive levels as the weather cools in the fall and warms in the spring.

2. Aeration

It is important to construct the bin to allow adequate airflow. Holes may be drilled on the upper sidewall of the bins for air circulation. Holes drilled on the lid may allow water inside during the rainy season. The type of bedding used also influences air circulation. Coarser bedding such as chopped leaves allows more air to circulate than fine textured bedding such as peat moss or shredded paper. As the composting process progresses, the bedding becomes more finely textured. This can be alleviated to some extent by periodically adding fresh bedding. Other ways to promote aeration includes occasional fluffing of the bedding material, avoidance of deep bedding (a maximum of 30cm), over-feeding and over-watering.

3. Acidity (pH)

The decomposition of organic matter produces organic acids that lower the pH of the bedding soil. The best way to deal with this is to add several cups of ground limestone to the bedding and in the application of Zeolite in proper amount. Limestone will serve dual purpose - maintaining the acidity and acting as a source of calcium to the worms. Other products, which can 40 be used, are powdered limestone, dolomite limestone. Baking soda should be avoided because of its high sodium content.

4. Pests and Diseases

Vermicompost worms are not subject to diseases caused by microorganisms, 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. A brief overview of the most common pests (see Fig.11) and diseases is given below:

- **Ants.** These tiny insects are a real problem because they not only consume the feed meant for the worms but are also found to attack young worms causing serious injuries. Ants are particularly attracted to sugar, so avoiding sweet feeds in the worm beds reduces this problem to a minor one. Or constructing a waterchannel around the vermi-tank (at the bottom) will permanently solve the ant-problem.

- **Rodents.** Worms are a favorite natural food for many small animals like rats. So if a rat gets access to your worm bed, you can lose a lot of worms very quickly. Rats and mice can chew through plastic or wood easily, and don't need very much space to move through a surface. This is usually only a problem when using open-air systems in fields. It can be prevented by putting some form of barrier, by using wire mesh for the lids.

- **Birds.** They are not usually a major problem, but if they discover your vermibeds, they will come around regularly for the worms. Putting a lid over the tank or cover over the material in the open-air systems, 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.

Fig.11: Common pests of vermibeds

- **Sour crop.** This is reported to be the result of poisoning caused by having too much protein in the bedding. This happens only when the worms are overfed. Protein builds up in the bedding and produces acids and gases as it decays. Farmers wishing to prevent sour crop should work 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.

- **Mite Pests**. Insects are attracted to wormbeds due to its moist and organic environment. If the bedding is not properly maintained, acidity build up in the bedding soil may invite the mites as they are attracted towards an acidic, moist environment. Although small populations of mites thrive in all worm beds, they might create problems when present in excessive numbers. The mite populations at high level scan also cause worms to bury deep in their burrows without feeding.

White or Brown Mites

White or brown mites are not predaceous and tend to feed only on decaying or injured worms. However, during infestations, these mites can devour much of the food in earthworm beds, depriving earthworms from the nutrients.

Red Mites

These mites first appear as small white or gray clusters, resembling mould, which under magnification would reveal the clusters of juvenile red mites in various stages of development. The adult red mite is smaller than white or brown mites with bright red colour and an egg-shaped body with four pair of legs. The red mites are known to be parasitic on earthworms. It attaches to the worm and relishes its coelomic fluid. They are also capable consuming the cytoplasmic fluids from egg capsules.

Mite Prevalence and Prevention

Harmful buildup of mites can be prevented by taking proper care of worm beds. The conditions usually associated with high mite population are:

a. Excess water: Beds that are too wet create conditions that are more favorable to mites than to the worms. Excessive wetting of beds may be avoided by adjusting watering schedules, improving drainage, and turning bedding frequently.

b. Over feeding: Excess food can lead to an accumulation of fermented feed in worm beds and lower the pH of the beds. The feeding schedules may be adjusted and modified according to seasonal variations. The pH of beds should be maintained to neutral (pH: 7), using calcium carbonate as the buffering agent

c. High moisture content feed or fleshy feed: vegetables with high moisture content can attract high mite populations in worm beds. Use of such feed should be limited, and if still, high mite populations persist, this feed should be discontinued until mite populations are under control.

Mite Removal

Several methods have been suggested for removing mites from earthworm beds. However, any type of mite removal, physical or chemical, will only be temporary unless worm-bed management is altered to make conditions less favorable for mites. The following techniques range from low- to high-intensity measures.

* The worm beds should be exposed to sunlight for several hours, however one should make sure that the earthworms are not directly exposed to sunlight. The amount of water and feed should be reduced. This will further encourage the mites to leave the beds.

* Moistened newspapers or burlap (jute) bags may be placed on top of the

beds, and these can be removed as mites accumulate on them. This procedure may be repeated until mite populations are substantially reduced.

* Pieces of watermelon or potato slices may be placed on top of the worm beds. The peels could then be removed with the mites.

* The bed may be watered heavily without flooding. This will compel the mites to move up to the surface. The mites can then be scorched using a hand-held propane torch. This procedure may be repeated several times, at three-day intervals, if needed.

* Light sulphur dusting will kill the mites. Or bed may be wetted (as suggested above) and then the sulphur added directly to the mites. Sulphur should be applied at the rate of approximately 2 g per 0.93 square meter of bed. Sulphur will not harm the worms, but in time, it may increase the acidity of the bed. In the past, some chemical pesticides have been used in worm beds. However, due to their biomagnification, it is not advisable to use these chemical compounds. Although safer miticides do exist in the market they are not specifically made for the Vermibed.

5. Odour Problems

The problem of unpleasant odours is caused by lack of oxygen in the compost due to overloading of food waste, and when the bin contents become wet. The solution is to stop adding food waste until the worms and microorganisms have broken down the initial feed and to gently stir up the entire contents to promote aeration. The drainage holes may be checked for blocking. If the drainage is insufficient additional holes can be drilled. Worms have been known to crawl out of the bedding if conditions are not favorable for them. If this migration is not triggered by moisture content of the soil, then the bedding may be acidic. Avoid adding citrus peels and other acidic foods to the bedding as these might reduce the pH of the bedding soil. One can overcome this acidic medium by adding a little garden lime and cutting down on acidic wastes.

In limiting the malodours, one should

-Reduce the amount of food
-Stir the bin thoroughly, especially at the bottom
-Add paper if the bedding is soggy

And if odours still persist, the best solution may be to start over, using new bedding, a minimal amount of scraps.

CHAPTER 9

SEPARATION TECHNIQUES

Once vermicomposted, the volume of material will be much reduced, possibly down to 10% of its original volume. The finished material will brown and earthy-like and the original bedding will no longer recognizable. The vermicompost might require post-screening, especially if coarse green waste was incorporated into the bedding, as this takes longer to break down. This may be carried out manually on a pilot scale, but is identical to the screening and separation operation carried out using commercial, rotating screener. The worms are separated effectively from finished vermicompost, though cocoons and hatchlings are lost. If only the worm casts are required as a fertilizer, any of the following methods are appropriate. In order to separate and retain worms as well as casts, the light separation method or a wire mesh screen will be required. The methods described are best suited to Smaller-scale containerized systems or pilot operations designed to breed initial worm populations. Once the system is expanded, it will be necessary to use a commercial-scale mesh screener.

Light Separation

Earthworms are very sensitive to light and this separation method utilises this nature and the tendency to burrow beneath the surface in order to escape light sources. The finished material may be removed and spread onto a surface or else left *in situ*, but should be exposed to a light source. The worms will quickly burrow downwards, allowing the surface material to be removed. After repeating this operation, a thin layer of material remains, containing all of the worms. This should be added to the new bedding with a fresh supply of feed. This leaves a harvest of worm castings and un-hatched capsules. These capsules will be lost, as the hatchlings will not survive in garden soil, but the remaining worms quickly replace them. The castings should be stored for a week or two before use as a fertilizer.

Sideways Separation

The finished material is moved to one side, while the fresh bedding mixed with organic waste is placed alongside. During the following 7 to 14 days the worms will migrate from the finished vermicompost into the fresh bedding. The advantage of this method is that it allows the capsules to hatch in the meantime and most will also move across.

Vertical Separation

A nylon mesh screen slightly larger than the surface area of the container is placed onto the surface of the vermicompost. The screen should be large enough to flatten up the sides of the container overlap at the top. The container is filled with fresh bedding on top of the screen and fed with organic waste. The worms will migrate up through the screen into the new bedding as the food source below is depleted.

When the upper part is ready for harvesting, the screen, and the finished material containing the worms is lifted from the container. The remaining material in the lower part of the container will have a very high concentration of worm castings and few if any worms, hatchlings or capsules. Once this is removed, the worm-filled material that was on top of the screen is placed into the bottom of the container with fresh bedding on top of the screen.

Gradual Transfer

This simple method produces castings, but no extra worms. Continue feeding kitchen scraps into the container for up to four months. A second container should be started and primed with fresh bedding and a supply of worms from the first box. The first container continues until the second is full, by which time the first container will contain a very high proportion of fine castings, but very surviving few worms. To ensure there are enough worms for both containers, the second can be prepared about a month earlier, adding some worms to it every time the first container is fed.

Harvesting earthworm

After the vermicompost production, the earthworm present in the tub / small bed may be harvested by trapping method. In the vermibed, before harvesting the compost, small, fresh cow dung ball is made and inserted inside the bed in five or six places. After 24 hours, the cow dung ball is removed. All the worms will be adhered into the ball. Putting the cow dung ball in a bucket of water will separate this adhered worm. The collected worms will be used for next batch of composting.

Worm harvesting is usually carried out in order to sell the worms, rather

Fig.12: Screening and separation operation

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. Each of these is described in more detail in the sections that follow.

1. Manual Method: This is the method used in units engaged in selling worms and vermicompost on a small-scale to the local market. It 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.

2. Self-Harvesting or Migration Method: The tendency of worms to migrate to new regions, either to find new food or to avoid undesirable conditions, is utilized in this harvesting method. Unlike the manual methods described above, simple mechanisms such as screens are employed for the purpose.

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. 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. 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.

Packing and Storage

The vermicompost should be stored in a dark, cool place. It should have minimum 40% moisture. Sunlight should not fall over the compost. It will lead to loss of moisture and nutrient content. It is advocated that the harvested compost is openly stored rather than packed in over sac. Packing can be done at the time of selling. If it is stored in open place, periodical sprinkling of water may be done to maintain moisture level and also to maintain beneficial microbial population. If the necessity comes to store the material, laminated over sac is used for packing(Fig.13).This will minimize the moisture evaporation loss. Vermicompost can be stored for one year without loss of its quality, if the moisture is maintained at 40% level.

Characteristics of vermicompost

Vermicompost, a product of a non-thermophilic biodegradation of organic material through interactions between earthworms and microorganisms, is a peat like material with high porosity, aeration, drainage, water holding capacity and microbial activity. It contains all nutrients in plant available forms such as nitrates, phosphates, exchangeable calcium, soluble potassium etc and has large particular surface area that provides many microsites for microbial activity and for the strong retention of nutrients. The plant growth regulators and other plant growth influencing materials i.e. auxins, cytokinins, humic substances etc, produced by microorganisms have been reported from vermicompost(Sharma S, *et al,* 2005).The humic materials extracted from vermicomposts have been reported to produce auxin-like cell growth and nitrate metabolism of carrots (*Daucus carota*). However humic substances can occur naturally in mature animal manure, sewage sludge or paper-mill sludge but their amount and rates of production are increased dramatically by vermicomposting.

The nutrient level of vermicompost depends on the nature of the organicwaste used as food source for earthworms. It is found that a heterogeneous waste mix will have balanced level of nutrients than from any one particular waste. It contributes to the supply of micronutrients essential for the crops. Apart from this, the stimulatory effect of vermicompost for nutrient uptake, growth and yield of crops is linked to the secretions of earthworms and the associated microbes mixed with the cast.

Fig.13: Vermicompost-Packing Operations and a Sample packet of 1Kg

The nutrient status of vermicompost produced with different organic waste is shown in Table.6

Table.6: Chemical Composition of Vermicompost

No.	Nutrient	Composition
1	Organic carbon	9.5 – 17.98%
2	Nitrogen	0.5 – 1.50%
3	Phosphorous	0.1 – 0.30%
4	Potassium	0.15 – 0.56%
5	Sodium	0.06 – 0.30%
6	Calcium and Magnesium	22.67 to 47.60 mg/100g
7	Copper	2 – 9.50 mg kg-1
8	Iron	2 – 9.30 mg kg-1
9	Zinc	5.70 – 11.50 mg kg-1
10	Sulphur	128 – 548 mg kg-1

(*Source: Kale,1995*).

CHAPTER 10
VERMICOMPOST: QUANTITY & APPLICATION

Vermicompost can be used for all crops: agricultural, horticultural, ornamental and vegetables at any stage of the crop and in any amount as it is ‘completely safe’ for soils and crops in all amounts.

- For general field crops: Around 2–3 t per ha vermicompost is used by mixing with seed at the time of sowing or by row application when the seedlings are 12–15 cm in height. Normal irrigation is followed.
- For fruit trees: The amount of vermicompost ranges from 5 to 10 kg per tree depending on the age of the plant. For efficient application, a ring (15–18 cm deep) is made around the plant. A thin layer of dry cow dung and bone meal is spread along with 2–5 kg of vermicompost and water is sprayed on the surface after covering with soil.
- For vegetables: For raising seedlings to be transplanted, vermicompost at 1 t per ha is applied in the nursery bed. This results in healthy and vigorous seedlings. But for transplants, vermicompost at the rate of 400–500g per plant is applied initially at the time of planting and 45 days after planting (before irrigation).
- For flowers: Vermicompost is applied at 750–1000 kg per ha.
- For vegetable and flower crops vermicompost is applied around the base of the plant. It is then covered with soil and watered regularly.

Scientists at the Central Research Institute for Dryland Agriculture, Hyderabad, India have recommended the quantity and time of application of vermicompost which is given in Table.7 (CRIDA, 2009)

The Value of Vermicompost
Vermicompost 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. Literature survey shows that vermicompost is superior to conventional organic manures in a number of ways. These include:

- **Rich in humic acids and enzymes:** The growth responses of plants from vermicompost appears more like ‘hormone-induced activity’ associated with

Table.7: Recommended quantity and time of application of vermicompost in some crops

Crop	Quantity	Time of Application
1) Rice (Paddy)	1 ton/acre	After Transplanting
2) Maize (Corn)	1 ton/acre	Last Ploughing
3) Sugarcane	1.5 ton/acre	Last Ploughing
4) Groundnut	0.5 ton/acre	Last Ploughing

5) Sunflower	1.5 ton/acre	Last Ploughing
6) Chilli	1 ton/acre	Last Ploughing
7) Potato	1-1.5 ton/acre	Last Ploughing
8) Tomato	1-1.5 ton/acre	Last Ploughing
9) Brinjal	1-1.5 ton/acre	Last Ploughing
10)Okra	1-1.5 ton/acre	Last Ploughing
11)Cauliflowers	1-1.5 ton/acre	Last Ploughing
12)Cabbage	1-1.5 ton/acre	Last Ploughing
13)Garlic	1-1.5 ton/acre	Last Ploughing
14)Onion	1-1.5 ton/acre	Last Ploughing
15)Grape (Vineyards)	1 ton/acre	Summer time
16)Citrus	2 kg/tree	At planting time & before flowering
17)Pomegranate	2 kg/tree	At planting time & before flowering
18)Guava	2 kg/tree	At planting time & before flowering
19)Mango & Coconut	2 kg/tree	At planting time
	5 kg/tree	1-5 years old trees
	10 kg/tree	6-9 years old trees
	20 kg/tree	Trees older than 10 years
20)Cotton	1 ton/acre	Last Ploughing

(*Source: CRIDA (2009), Hyderabad, India)*

the high levels of humic acids and humates in vermicompost rather than boosted by high levels of plant-available nutrients. Vermicompost is alsorich in enzymes like amylase, lipase, cellulase and chitinase, which break down organic matter, improving soil nutrients and fertility. (Chaoui,H.I, *et al*, 2003; Tiwari, S.C, *et al*, 1989) They also increase some important soilenzymes like dehydrogenase, acid and alkaline phosphatases and urease. Urease plays a key role in nitrogen cycle as it hydrolyses urea and phosphatase bioconvert soil phosphorus into bio-available form for plants.

- **Free of pathogens and toxic chemicals:** Several studies have indicated that vermicomposting leads to greater reduction of pathogens after 3 months upon storage. Whereas,the samples which were subjected to only thermophilic composting, retained higher levels of pathogens even after 3 months. Studies have also found that earthworms effectively bioaccumulate or biodegrade several organic and inorganic chemicals including heavy metals, organochlorine pesticide and polycyclic aromatic hydrocarbons (PAHs) residues in the medium in which it inhabits.

- **Plant nutrient level**: Vermicompost contains nutrients in plant-available forms such as nitrates (N), phosphates (P), soluble potassium (K), & magnesium (Mg) and exchangeable phosphorus (P) and calcium (Ca). Vermicomposts have large particulate surface areas that provide many micro-sites for microbial activities and for the strong retention of nutrients.

- **Beneficial microbes:** Vermicompost is rich in microbial populations particularly fungi, bacteria and actinomycetes. Suhane (2007) found that the total bacterial count was more than 1010 per gram of vermicompost. It included *Actinomycetes, Azotobacter, Rhizobium, Nitrobacter* and phosphate solubilizing bacteria (PSB) which ranged from 102-106 per gm of vermicompost. The PSB has very significant role in making the essential nutrient phosphorus (P) bio-available for plant growth promotion. The microbial population in vermicompost prepared from cow dung and municipal solid wastes as substrates was in highest abundance. Application of lime in the substrate enhanced the population of all above mentioned microbes irrespective of the substrates used for vermicomposting. Plant growth promoting bacteria (PGPB) directly stimulates growth by nitrogen (N) fixation, solubilisation of nutrients and production of growth hormones. There is also evidence to demonstrate that microbes, including bacteria, fungi, actinomycetes, yeasts and algae, produce plant growth regulators (PGRs) such as auxins, gibberellins, cytokinins, ethylene and ascorbic acids in appreciable quantities.

- **Stimulate plant growth:** Vermicompost has 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 plant-available forms. Vermicompost contains growth promoting hormone auxins, cytokinins and flowering hormone gibberellins secreted by earthworms. In 2006, Arancon, *et al* attributed the growth promoting effect of vermicompost to humic acids present in it. 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. Paul and Metzger (2005) studied the impact of vermicompost on quality of vegetable transplants.

- **Suppress disease:** The ability of vermicompost to protect plants against various diseases comes from the high levels of beneficial microorganisms present in it. These microbes protect plants by out-competing pathogens for available resources, while also blocking their access to plant roots by occupying all the available sites. This analysis is based on the concept of the “soil food web”, a soil-ecology-based approach pioneered by Dr.Elaine Ingham of Corvallis, Oregon. This attribute of vermicompost was studied by Edwards and Arancon (2004) and reported that the effects of relatively small applications of commercially-produced vermicomposts suppressed the incidence of attacks by *Pythium* on cucumbers, *Rhizoctonia* on radishes in the greenhouse, and by *Verticillium* on strawberries and *Phomopsis* and *Sphaerotheca fulginae* on grapes in the field. The authors added that the pathogen suppression disappeared when the vermicompost was sterilized, indicating that the mechanism involved was microbial antagonism.

- **Repel pests:** Edwards and Arancon (2004) reported significant suppression of plant-parasitic nematodes in field trials with peppers, tomatoes, strawberries, and grapes. This is a relatively new area of research and further research is required, before vermicompost can be considered as an alternative to pesticides or alternative, non-toxic methods of pest control.

CHAPTER 11

BY-PRODUCTS AND VALUE-ADDED PRODUCTS

1. Vermiwash

In the vermicomposting process, the bed filled with organic wastes, bedding materials and earthworms is fitted with a drainage and collection system. Vermicomposting produces a leachate as a result of addition of moisture contents through the column of worm action. Draining of this water or leachate is important to prevent saturation of the vermicomposting unit and attraction of pests. The leachate so obtained is termed as vermiwash(Fig.14) It is beneficial in the sense that when collected it can be used as a liquid fertilizer as it contains large amounts of plant nutrients. It is a collection of excretory products and mucous secretion of the earthworms, along with the micronutrients from the organic molecules. This liquid partially comes from the body of earthworms (as worm's body contain plenty of water) and is rich in amino acids, vitamins, nutrients like nitrogen, potassium, magnesium, zinc, calcium, iron and copper and some growth hormones like auxins, cytokinins. It also contains plenty of nitrogen fixing and phosphate solubilizing bacteria (*Nitrosomonas, Nitrobacter and Actinomycetes*). Vermiwash, if collected properly, is clear and transparent, honey brown colored fluid. It should be noted; however, that plant bioassay test of vermiwash should be done prior to its use as foliar spray in order to explore the presence of pathogens and phytotoxic compounds. If used as fertilizer, the vermiwash is better diluted to avoid plant damage, but this automatically decreases its nutrient content so it has to be combined with other mineral fertilizers. Commercial formulations of liquid fertilizers are sometimes complemented with certain chemical compounds, such as polyoxyethylene tridecyl alcohol as dispersant and polyethylene nonylphenol as adherent, to increase nutrient availability for plants.

Vermiwash has great growth promoting (Suthar,S.,2010) as well as pest killing properties. Study by Giraddi, R.S.(2003) reported that weekly application of vermiwash increased radish yield by 7.3%. Another study also reported that both growth and yield of paddy increased with the application of vermiwash and vermicast extracts (Thangavel, P *et al*, 2003)

Fig.14 :Vermiwash-concentrated and diluted

Ansari, A.A. and Sukhraj, K. (2010) reported the effect of vermiwash and Vermicomposton soil parameters and productivity of okra (*Abelmoschus esculentus*). Recently Rekha G.S., *et al*

(2013) studied the influence of vermicompost and vermiwash on the growth and productivity of Black Gram (*Vigna mungo*).

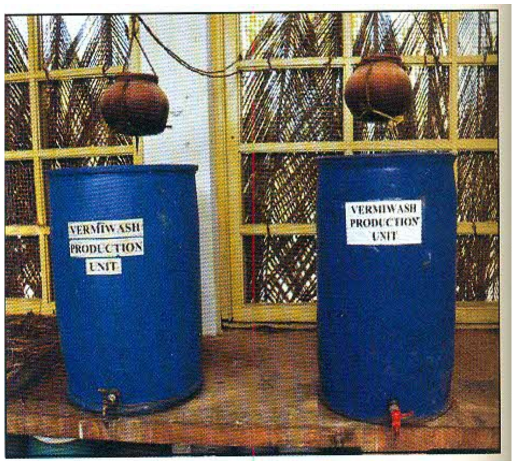
Farmers from Bihar in North India reported growth promoting and pesticidal properties of this liquid. They used it on brinjal and tomato with excellent results. The plants were healthy and bore bigger fruits with unique shine over it. Spray of vermiwash effectively controlled all incidences of pests and diseases significantly reduced the use of chemical pesticides and insecticides on vegetable crops and the products were significantly different from others with high market value. In order to evaluate its efficacy against thripsand mites for the management of ‘thrips’ (*Scirtothrips dorsalis*) and ‘Mites’ (*Polyphagotarsonemus latus*) on chilli vermiwash was used in three different dilutions e.g. 1:1, 1:2 and 1:4 by mixing with water both as ‘seedling dip’ treatment and ‘foliar spray’ (Saumaya, G *et al*,2007). Giraddi, R.S.(2003) also reported significantly lower pest population in chilli applied with vermiwash (soil drench 30 days after transplanting, and foliar spray at 60 and 75 days after transplanting) as compared to untreated crops. Suthar (2010) has reported hormone like substances in vermiwash. He studied its impact on seed germination, root and shoot length in *Cyamopsis tertagonoloba* and compared with urea solution (0.05%). Maximum germination was 90% on 50% vermiwash as compared to 61.7% in urea solution. Maximum root and shoot length was 8.65 cm & 12.42 cm on 100% vermiwash as compared to 5.87 and 7.73 on urea.

Preparation steps

The preparation of vermiwash involves the following steps:

1. Take a plastic container of about 50 liters capacity.
2. Make a hole at the bottom and fix a tap using a safety gauge.
3. Put a layer of broken bricks, pieces of stones having thickness of 10-15 cm in the container.
4. Over this layer put another layer of sand having thickness of 10-15 cm.
5. Then put a layer of partially decomposed cow dung having 30-45 cm thickness over it.
6. Then put another layer of soil having 2-3 thicknesses.
7. Then introduce 100-200 nos. of earthworms.
8. After that, a layer of paddy straw having 6 cm thickness is given.
9. Spray water regularly for a period of 7-8 days.
10. After 10 days the liquid vermiwash will be produced.
11. Hang one pot with a bottom hole over the container in such a way so that water falls drop by drop.
12. Every day 4-5 litres of water is to be poured in the hanging pot.
13. Keep another pot under the tap to collect the vermiwash.

A typical model for vermiwash collection is shown in Fig.15



(*Courtesy: CPCRI, Kasaragod, Kerala*)

Fig.15: Vermiwash collection

2. Vermicompost tea or Liquid Vermicompost Vermicompost tea is a type of compost tea derived from soaking vermicompost in water. It contains beneficial microbes that may also reduce or control diseases and improve soil health. Studies also indicate that the tea has a positive effect on suppressing plant-parasitic nematodes and arthropod pests (Edwards, C.A, *et al*, 2007). Vermicompost tea nutrients will vary based on the vermicompost source materials and the brewing techniques. Liquid Vermicompost can contain the three basic plant nutrients: nitrogen in the form of nitrate or ammonium ($N0_3$ and NH_4); phosphorus (P); and potassium (K). One analysis of this product brewed at a 1:10 ratio showed on average: nitrate (NO_3) at 77 ppm (parts per million); ammonium (NH_4) at 3.7 ppm; P at 18 ppm; and K at 186 ppm.

Preparation

Methods of producing aqueous extracts include:

- Passing water through vermicomposts
- Standing vermicomposts in water (1-7 days)
- Modifications of these methods

-Aeration

-Addition of other materials

-Addition of organic substrates

3.Vermimeal

Vermimeal or earthworm meal is a feed preparation consisting of processed earthworm biomass. It is a rich source of animal protein as well as essential amino acids, fats, vitamins, and minerals for livestock, birds and fish. About 5.5 kg of fresh earthworm biomass (18% dry matter) is needed to produce 1 kg of vermimeal. It can be packed in plastic bags and stored in a cool dry place out of direct sun for up to 3 months. Proximate analysis of an earthworm vermimeal in dry and pulverized form revealed the following composition; 68% crude protein, 9.57% fat, 11.05% nitrogen-free extract, and 9.07% ash. Numerous studies on different livestock animals, birds and fishes have shown excellent results of feeding the animals with vermimeal or earthworm meal. This is not surprising, considering that earthworms are a natural source of nutrition for birds and other animals in the wild.

4. Enriched Vermicompost

The enhancement of nutrients and beneficial microbial population in the vermicompost is yet another important evolving trend where the vermicompost is value added with nutrients and or microorganisms resulting in improved growth and yield of crop plants. “Enriched vermicompost” is a mixture of vermicompost, natural minerals and microorganisms. Not only does it contain additional nutrients, it also takes less time to produce than conventional vermicompost. Another benefit of the new compost is the ability to exchange ingredients and vary the concentrations of nutrients depending on the specific requirements of different plants and soils. To produce the fertilizer, vermicompost made from raw materials like farm manure and legume residues is mixed with natural minerals such as rock phosphate and mica powder. In 2011, a study on enriching vermicompost using iron and zinc and its effect on the growth and nutritional status of peach trees was reported by Hashemimajd, K and Jamaati-e-Somarin, S. Also included are microorganisms, such as *Aspergillus awamori* and *Trichoderma viride*, which are effective at providing and protecting fertilizers and help mineralize elements that are used by the crops. In 2012, Rajasekar,K. *et al* reported the possibility of enrichment of vermicompost with microbial inoculants (i.e.,biofertilizer organisms), *Azospirillum brasilense* and *Rhizobium leguminosarum*, optimization of inoculum level and time of inoculation during vermicomposting.

5. Pelleted Vermicompost

Vermicompost is an effective material for improving the physical and chemical conditions of soil. However, there are two factors that limit the application of this composted manure. The first problem is that vermicompost usually has high moisture content and a high volume per unit of weight. As a result, it is difficult and costly to transport. The second problem is that the quality of the vermicompost and its nutrient content are not constant. This also limits the efficient use of compost. The molding technology to manufacture compost in the easy-to-use pellet form is an effective solution to these problems.

A pellet making machine can be used to make composted manure into pellets of 0.5-1 cm in diameter. The machine designed in 2007 by Nitin K Tyagi of Meerut, Uttar Pradesh, India is manually operated, and consists of a hopper, flat moving belt, a die to form pellets and power transmission system. A single person can operate the machine. The principle used here involves mixing the vermicompost with suitable binder (molasses), putting the mixture in the hopper, carrying the compost using the conveyor belt on a flat bed in the form of a sheet and passing through pellet making die to generate a stream of pellets. Though the use of conveyor and die system to make conventional compost-pellets is well known (Zafari and Kianmehr, 2012) and in chemical and pharmaceutical industries, the deployment of this concept to create "vermicompost pellets" is novel in application. If pelleting is to be done without adding any other materials, it is important to control the moisture content of the compost and the rate at which the compost is supplied to the die part of the pelleting machine.

The dried pellets retain their form during storage and distribution, and have a volume only 60-90% of the raw compost. The pellets produced need less space to store and can be spread uniformly to the fields. In pellet form the release of the nutrients to the plants is slow and for a longer period(Fig.16).

Fig.16:Vermicompost: Pellets

CHAPTER 12

VERMICOMPOST: CUSTOMER-FEEDBACKS & FIELD EVALUATION

Organic farming using vermicompost in India

Vermicompost is the basic ingredient for successful organic farming. More than 85 per cent of organic crop cultivation in India depends on it. It has several advantages as an organic seedling growth medium: it is relatively high in nitrate, which can enhance seedling germination and stimulate seedling growth; it has high microbial activity that may protect against some pests; and it has little or no phytotoxicity. There have been several reports that vermicompost can induce excellent plant growth and enhance crop production. Recently, Dhanalakshmi.V., *et al* (2014) studied the impact of addition of vermicompost on growth of okra, brinjal and chilli and recorded the improvement in the yield of fruits.

In a recent review article, Sinha, K., *et al* (2010) reported that studies on the production of important vegetable crops like tomato (*Lycopersicum esculentus*), egg plant (*Solanum melangena*) and okra (*Abelmoschus esculentus*) have yielded very good results. In this review, they have also reported that farmers in India mainly in the States of Karanatka, Tamil Nadu, Gujarat, Maharashtra, Punjab, Harayana, Himachal Pradesh and Bihar are using vermicompost with very good profit. According to this report, farmers in a number of villages in Bihar (designated as ‘Bio-Village’) have completely switched over to organic farming by vermicompost and have given up the use of chemical fertilizers since 2005. The farmers were able to harvest three different crops in a year (reaping 2-3 times more harvest) due to their rapid growth and maturity, and reduced harvest cycle.

The important revelations by farmers about use of vermicompost recorded by the above research team are given below:

1) Reduced use of water for irrigation;
2) Reduced pest attack (by at least 75%) especially after spray of vermiwash (liquid drained during vermicomposting);
3) Reduced termite attack in farm soil especially where worms were in good population;
4) Reduced weed growth;
5) Faster rate of seed germination and rapid seedlings growth and development;
6) Greater numbers of fruits per plant (in vegetable crops) and greater numbers of seeds per ear (in cereal crops), heavier in weight-better in both, quantity and quality as compared to those grown on chemicals;
7) Fruits and vegetables had better taste and texture and could be safely stored up to 6-7 days, while those grown on chemicals could be kept at the most for 2-3 days;
8) Fodder growth was increased by nearly 50% @ 30 to 40 quintal/hectare; 9) Flower production (commercial floriculture) was increased by 30%-50% @ 15-20 quintal/hectare. Flower blooms were more colourful and bigger in size.

Field cultivation of vegetables using vermicompost in WIP

The major observations recorded by the author, during the project on Field cultivation of vegetables using vermicompost produced from wood wastes under the “Vegetable Development in Institutions Programme” in WIP supported by the Department of Agriculture, Government of Kerala in 2013-2014(Fig.17-19) are given below:

1) Reduced pest attack in the field;
2) Reduced weed growth;
3) Rapid growth and development of seedlings in the case of lady’s finger, green chilli and brinjal;
4) Better quality and number of fruits per plant especially in tomato and brinjal;
5) Better taste and texture of all vegetables;
6) Fast,luxurious growth of leafy vegetables like Red amaranth.

Fig.17: Field cultivation of vegetables using Vermicompost

Fig.18: Inauguration of vegetable-harvest by Late Mr.P.K.Mohamed, Former Managing Director, WIP

Fig.19: Best Institution Award in the District for the Vegetable Development Project received by WIP from Mr.K.P.Mohanan, Minister of Agriculture, Govt.of Kerala

CHAPTER 13

FUTURE PROSPECTS

Bioconversion of organic wastes utilizing earthworms into a beneficial product is an ecologically safe method in the field of waste management. The tiny creatures' ability to devour virtually any organic waste and excrete it as premium organic fertilizer is proving profitable for farmers and entrepreneurs. Keeping the environmental and economical aspects in mind, research and development activities on vermicomposting in developing countries need to be planned, propagated and commercialized. Future research works on this field could include the following:

1. Optimizing the vermicomposting process to achieve most efficient process outcome by changing important variables such as:
    - Variety of earthworm
    - Moisture content level
    - Thickness of the bedding layer
2. Studies on finding more new native species for vermicomposting
3. Accelerating the pre-digestion stage for reducing the time required for vermicomposting of lignocellulosic wastes and other hard materials by the following:
    - using treatment with various microbial cultures
    - using physical and/or mechanical methods
4. Develop the potential of vermicompost teas as an environmentally friendly alternative to 'chemical pest control'
5. Attempts to reduce the cost of commercial unit operations.
6. On-farm trials to achieve the following objectives:
    a. Study of quality, field performance and post-harvest quality of produce from seedlings grown in vermicompost-based media in organic production systems.
    b. Impact of vermicompost as an organic seedling medium on vegetable transplant health and pest tolerance.
    c. Enhance the efficiency and profitability of organic growers through increased vegetable yield and plant health on their farms using vermicompost.

CHAPTER 14

COMMERCIAL VERMICOMPOST UNIT-REQUIREMENTS

Land: For initiating a vermiculture production and extension unit, about 0.5-1 acre of land is required on which about 8 to 10 shacks sized 180-200sq.ft could be built. The land should have adequate water supply with watering facilities. Sub Marginal land could also be used. In case one does not own land, he or she could take apiece of land on lease for a 10 to 15 year period.

Building and/or Shed: For a commercial unit, one has to invest for an office; warehouses for raw material and finished goods, the infrastructure should have accommodation facilities for the manager and workers.

Shed: An open shed supported by pillars for the corners or a shed on top with bamboo rafters, wooden tie ups is needed to prevent the vermicompost bed from getting soaked from rain water or from wind. The shed should be designed with sufficient place for movement of labourers to do their work.

Vermi-beds: The vermibed should be 75cm-90cm in thickness with adequate drainage facilities to drain out excess water. The entire bed should be in uniform height to ensure equal production. The width of the bed should not be more than 1.5m so that the centre of the bed can be easily reached.

Seed Stock: Seeds are the primary requirement to start vermicomposting. Worms multiply within a period of 6 months to 1year, but to start the vermicompost bed should have about 350 worms per m3 to increase the worm population in about 2 to 3cycles with our affecting the production.

Roads, Paths & Fencing: The site needs adequate infrastructure with roads and paths for easy movement of workers, trolleys and wheel barrows to transport the raw materials to the bed & carry out the finished compost. The site should be fenced to prevent entry of animals or unwanted elements onto the site. The investment should be minimum for this purpose but these facilities are pivotal to ensure undisturbed production

Water Supply System: The vermicompost beds have to be kept moist with about 50% water content. Adequate water supply with well designed water distribution mechanism is mandatory. Drippers with nonstop water flow would be viable for continuous water supply and also helps in saving water. This may be a costly investment but reduces operational costs of manual watering and economical in the long run.

Machinery: A shredding machine to shred the raw material, wheel barrows and trolleys for transportation to and fro the site for loading & unloading of compost, aeration, for air drying, machinery for sieving, stitching and automatic packing.

Transport: Transport is required in order to shift raw materials to the site, especially if the source of the raw materials is far away from the unit. For a unit that produce about 1000 tones of compost per annum, a truck with the minimum capacity of 3-tonnes is required, smaller units can use smaller vehicles depending on their production. On-site vehicles, like trolleys are required to transport the raw material from the warehouses to the shacks. These expenses could be included in the project cost.

Furniture: A decent amount could be used to furnish the office which could also be used as a store house, spending on the basic requirements for an office and racks for storage.

Operational Costs: In the operational cost, some expenses are recurrent. These expenses include cost of raw materials, fuel & Transport costs, power, Insurance, repair & Maintenance, wages for labourers & staff salaries. The number of staff & workers hired should be according to the need of workers of each level of the production depending on the size of the unit. Manpower should be properly managed and used properly at all work points.

Extension Service: A vermicomposting unit could serve the vicinity by providing cultural material of desired species and train farmers and aspiring entrepreneurs who are interested in vermicomposting. Those who have the idea to set up commercial vermicomposting units too can get practical advice & culture material at reasonable prices from the existing units. These vermicomposting units could benefit from extension services unit by selling culture material and by consultancy. Units could also construct smaller, simpler models which could serve as demonstrations for farmers and give wide publicity & to popularize vermicomposting.

CHAPTER 15

CONCLUSION

Treatment of solid organic wastes is an essential part of the waste management programmes almost all over the world. Existing methods to the treatment and disposal of organic wastes are rather expensive. Vermicomposting is one of the best known technologies available at present for the proper handling of the organic wastes. It is the process of turning organic debris by earthworms into worm castings or vermicompost. This process of treating organic residuals represents an alternative approach in waste management and is compatible with sound environmental principles that value conservation of resources and sustainable practices.

Vermicomposting technology is known throughout the world and is one of the fastest growing sectors for recycling of organic wastes in waste management. In North America, Europe, Asia and African regions, and in several other countries earthworms are being used for various waste treatment options. They could help waste managers for minimizing waste input to landfills and saving precious groundwater resources. In addition, vermicomposting will be helpful for managing domestic solid waste problems and could stabilize wastes with low toxicity, pathogens and heavy metals. The solid waste management could successfully promote vermicomposting as a viable alternative for the disposal of solid wastes.

Vermicomposting in developing countries could prove to be useful in many instances. Some aspects of the process may be labour intensive when mechanized equipment such as front-end loaders, trommel screens, tractors, etc., are not available to handle large volumes of material. In areas where creation of low or semi-skilled jobs is considered advantageous, vermicomposting may supply an opportunity for employment. Where accumulation of food waste, paper, cardboard, agriculture waste, manures, and biosolids are problematical, composting and vermicomposting offer good potential to turn waste material into a valuable soil amendment.

Vermitechnology is a natural contributor for farming and gardening as the worm castings are very important to the fertility of the soil. The castings contain high amounts of nitrogen, potassium, phosphorus, calcium, and magnesium. Castings contain: 5 times the available nitrogen, 7 times the available potash, and 1½ times more calcium than found in good topsoil. Several researchers have demonstrated that earthworm castings have excellent aeration, porosity, structure, drainage, and moisture-holding capacity. The content of the earthworm castings, along with the natural tillage by the worms burrowing action, enhances the permeability of water in the soil. Worm castings can hold close to nine times their weight in water. “Vermiconversion,” or using earthworms to convert waste into soil additives, has been done on a relatively small scale for some time.

REFERENCES

Ansari,A.A. and Ismail,S.A.(2012): Earthworms and Vermiculture Biotechnology, Management of Organic Waste, Dr. Sunil Kumar (Ed.), InTech,Available from: http://www.intechopen.com/books/management-of-organic-waste/earthworms-and-vermiculture-biotechnology

Ansari,A.A. and Sukhraj,K.(2010): Effect of vermiwash and vermicompost on soil parameters and productivity of okra (*Abelmoschus esculentus*) in Guyana. *Pakistan Journal of Agricultural Research*, Vol. 23(3-4): 137-142

Arancon,N.Q., Edwards,C.A, Lee,S., Byrne,R.(2006): Effects of humic acids from vermicomposts on plant growth *European Journal of Soil Biology*,42:S65–S69

Bharadwaj,A.(2010):Management of Kitchen Waste Material through Vermicomposting, *Asian J. Exp. Biol. Sci., Vol. 1 (1):175-177*

Basheer, M. and Agrawal, O.P (2013): Management of paper waste by vermicomposting using epigeic earthworm, *Eudrilus eugeniae* in Gwalior, India *Int.J.Curr.Microbiol.App.Sci 2*(4): 42-47

Bhawalkar, U.S. (1995): ‘Vermiculture Ecotechnology’, Bhawalkar Earthworm Research Institute, Pune, India.pp.332

Buckerfield, J.C, Flavel, T.C, Lee, K.E. and Webster, K.A. (1999): Vermi- compost in solid and liquid forms as a plant growth promoter. *Pedobiologia*, 43(6):753-759.

CRIDA (2009): *Vermicompost from Waste*; Pub. Of Central Research Institute for Dryland Agriculture; Hyderabad, (Unit of Indian Council for Agricultural Research).

Chaoui,H.I, Zibilske,L.M. and Ohno,T.(2003): Effects of earthworms casts and compost on soil microbial activity and plant nutrient availability. *Soil Biology and Bio-chemistry*,35(2):295-302.

Chattopadhyay,G.N. (2012): Use of vermicomposting biotechnology for recycling organic wastes in agriculture. *International Journal of Recycling of Organic Waste in Agriculture*, 1(8):1-6

Darwin,C. (1881): The formation of vegetable mould through the action of worms, with observations on their habitats. Murray, London. pp.326

Dhanalakshmi.V, K. M. Remia, R. Shanmugapriyan and K. Shanthi (2014) Impact of addition of Vermicompost on Vegetable Plant Growth. *Int. Res. J. Biological Sci.* Vol. 3(12), 56-61

Diaz Cosin, D.J., Novo, M. and Fernandez, R. (2011): Reproduction of Earthworms: Sexual Selection and Parthenogenesis (Chapter 5) In: A. Karaca (ed.), *Biology of Earthworms*, Soil Biology 24, Springer-Verlag,Berlin Heidelberg

Edwards,C.A. (1988): Breakdown of animal, vegetable and industrial organic waste by earthworms. *Agric. Ecosyst. Environ,* 24: 21-31.

Edwards,C.A. (1998): Breakdown of animal, vegetable and industrial organic wastes by earthworms. In: *Earthworms in waste and environmental management*. Edwards, C.A., Neuhauser, F.(Eds). SPB Academic Publishing, The Hague, 21-31.

Edwards,C A. and Arancon, N. (2004): Vermicompost Suppress Plant Pests and Disease Attacks. *Rednova News*, http://www.rednova.com/display

Edwards,C.A., Arancon,N.Q., Emerson, E. and Pulliam,R.(2007): Suppressing plant parasitic nematodes and arthropod pests with vermicompost teas. *BioCycle*, 48(12):38-39.

Gandhi,M., Sangwan,V., Kapoor,K.K. and Dilbaghi,N. (1997): Composting of household wastes with and without earthworms. *Environment and Ecology* 15(2):432–434.

Giraddi,R.S. (2003): Method of extraction of earthworm wash: A plant promoter substance.*VIIth National Symposium on Soil Biology and Ecology*, Bangalore.

Giraddi,R.S., Patil,B.G., Lingaraju,P.S., Umapathy,A.N., Swamy,B.C. and Megalaman,I.R. (2008): Vermitechnology for Successful Management of Muncipal Wastes - A Joint Effort in South India *Karnataka J. Agric. Sci.,* 21(2): 284-286

Govindan,V.S.(1998): Vermiculture and Vermicomposting, Ecotechnology for pollution control and Environmental Management.pp.48-57

Gunasekaran,S. and Desai, S.(1999): Vermicomposting and Spectral Analysis of Vermicompost. *Asian.chem.Lett*. 3:231-232.

Hashemimajd,K. and Jamaati-e-Somarin, S. (2011): Investigating the effect of iron and zinc enriched vermicompost on growth and nutritional status of peach trees *Scientific Research and Essays,*Vol. 6(23):5004-5007

Higa,T.(1991): Effective microorganisms: A biotechnology for mankind. pp. 8-14. In: J.F. Parr, S.B.Hornick, and C.E. Whitman (ed.) Proceedings of First International Conference on Kyusei Nature Farming. USDA, Washington.D.C., USA

Ismail,S.A.(1997): Vermicology ‘Biology of earthworms’ Orient Longman Limited, Chennai, India. ISBN 81-250-10106.

Kale,R.D.(1998):Earthworm: Nature’s gift for utilization of organic wastes, ‘Earthworm Ecology’(ed)Edwards, C.A. St. Lucie Press New York. pp.355- 376.

Kale,R.D.(1998): Earthworm Cinderella of Organic Farming. Prism Book Pvt Ltd, Bangalore, India.pp.88.

Kale,R.D. and Sunitha,N.S.(1995):Efficiency of earthworm *E. eugeniae* in converting the solid waste from aromatic oil extraction units into vermicompost, *Journal IAEM*, Vol. 22, No. 1,267-269.

Lakshmi,B.L. and Vijayalakshmi,G.S. (2000): Vermicomposting of sugar factory filter press mud using African earthworm species *E. eugeniae, Pollution Research*,Vol.19, No.3:481-483.

Manaf,L.A, Jusoh, M.L.C, Yusoff,M.K, Hanidza,T., Ismail, T, Harun,R. & Juahir,H. (2009): Influences of Bedding Material in Vermicomposting
Process. *Journal of Biology* ,1(1): 81-91

Murali,M., Bharathiraja,A. and Neelanarayanan, P. (2011): Conversion of Coir Wastes (*Cocos nucifera*) Into Vermicompost by Utilizing *Eudrilus Eugeniae* and Its Nutritive Values. *Ind. J. Fundamental and Applied Life Sciences,* Vol. 1 (3): 80-83

Nagavallemma,K.P., Wani,S.P., Stephane,L., Padmaja,V.V., Vineela,C., Babu Rao, M. and Sahrawat,K.L.(2004):*Vermicomposting: Recycling wastes into valuable organic fertilizer. Global Theme on Agrecosystems* Report no.8.Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.pp.20.

Nair,J., Sekiozoic,V. Anda,M.(2006): Effect of pre-composting on vermicomposting of kitchen waste *Bioresource Technology ;* 97: 2091–2095

Padashetty,S. & Jadesh ,M. (2014): Earthworm distribution with special reference to physicochemical parameters in Aland and Chincholi regions, Gulbarga district, *Int. J. Res. Engg & Tech.*, Vol. 2,11:1-6

Parray, M.A, Wani, M.G., Rather, G.M. (2014): Stimulatory Influence of Some Additives on Vermicomposting by *Eudrilus Eugeniae International Journal of Engineering Science Invention,* Vol. 3,7: 01-04

Parthasarathi,K., Ranganathan,L.S., Thirumalai,M., Parameshwaran,P. (1999): Mono and polyculture vermicomposting press mud enhance macronutrients, *Asian J. Microbial Biotech & Env. Science*, Vol. 1:63-65.

Paul,L.C. and Metzger,J.D. (2005):Impact of vermicompost on vegetable transplant quality;*HortScience* :40(7):2020-2023

Prabha,M.L, Priya, M.S and Pavithra,R.(2014): Microorganisms in the gut of Earthworm
Eudrilus eugeniae, Int.J.Curr.Res.Chem.Pharma.Sci.1(3): 06-09

Pucher,J., Ngoc,T. N., Thi Hanh Yen ,T., Mayrhofer,R., El-Matbouli, M.,

Focken, U. (2014): Earthworm Meal as Fishmeal Replacement in Plant based Feeds for Common Carp in Semi-intensive Aquaculture in Rural Northern Vietnam, *Turk. J. Fish. Aquat. Sci*. 14: 557-56

Radhakrishnan,B. and Muraleedharan,N.(2010):A Monograph on Vermiculture and Vermicomposting in tea growing areas. A joint Publication from UPASI Tea Research Foundation, Coimbatore and National Tea Research Foundation, Kolkata, pp.76

Rajasekar,K., Daniel,T. and Karmegam,N. (2012): Microbial Enrichment of Vermicompost. *International Scholarly Research Network ISRN Soil Science* Vol 2012,Article ID 946079,pp.13

Rekha,G.S., Valivittan, K. and Kaleena, P.K. (2013): Studies on the Influence of Vermicompost and Vermiwash on the Growth and Productivity of Black Gram (*Vigna mungo*),*Adv. in Biol. Res.,*7(4):114-121

Ronald,E.G. and Donald, E.D. (1977): Earthworms for Ecology and Profit, Vol.1,'Scientific Earthworm Farming.' Bookworm Publishing Co., Ontario, California.

Saumaya, G., Giraddi, R. S. and Patil, R. H. (2007): Utility of vermiwash for the management of thrips and mites on chilli (*Capiscum annum*) amended with soil organics. *Karnataka J. Agriculture Sciences*, 20(3):657- 659.

Seenappa,C., Jagannatha, C. B., Kale, R. D.(1995): Conversion of distillery waste into organic manure using earthworms *E. eugeniae*, *Journal IAEM*, Vol. 22, No. 1:244-246

Sharma,S., Pradhan,K., Satya,S., Vasudevan,P. (2005): Potentiality of Earthworms for Waste Management and in Other Uses – A Review; *The J. American Science*, 1(1):4-16

Sinha,R.K., Agarwal,S., Chauhan,K., Valani,D.(2010):The wonders of earthworms & its vermicompost in farm production: Charles Darwin's 'friends of farmers', with potential to replace destructive chemical fertilizers from agriculture. *Agricultural Sciences* Vol.1, No.2:76-94

Singha,R.P., Singha,P., Araujoc,A.S.F., Ibrahim,A.H. and Sulaiman,B.O. (2011): Management of urban solid waste: Vermicomposting a sustainable option *Resources, Conservation and Recycling,* 55: 719–729

Sreenivasan, E.(2013a):Bioconversion of industrial wood wastes into vermicompost by utilizing African Night Crawlers (*Eudrilus eugeniae*). *Int.J.Adv. Engg.Tech*,IV/III/Jul-Sept.2013:19-20

Sreenivasan, E.(2013b):Evaluation of Effective Microorganisms Technology in industrial wood waste management.*Int.J.Adv.Engg.Tech*,IV/III/Jul-Sept.2013/21-22

Suhane,R.K.(2007):Vermicompost.Publication of Rajendra Agriculture University, Pusa, Bihar, India, pp.88

Suthar,S. (2010): Evidence of plant hormone-like substances in vermiwash: An ecologically safe option of synthetic chemicals for sustainable farming. *J. Ecological Engineering*, 36(8):1089-1092

Thangavel,P., Balagurunathan,R., Divakaran,J. and Prabhakaran,J.(2003):
Effect of vermiwash and vermicast extract on soil nutrient status, growth and yield of paddy. *Advances of Plant Sciences*, 16(1):187-190.

Tiwari, S.C., Tiwari, B.K. and Mishra, R.R. (1989): Microbial populations, enzyme activities and nitrogen, phosphorus, potassium enrichment in earthworm casts and in surrounding soil of a pineapple plantation. *J.Biological Fertility of Soils*, 8(1):178-182.

Vasanthi,K., Chairman, K., Michael, J.S., Kalirajan, A. and Singh, A.J.A.R.(2011): Enhancing Bioconversion Efficiency of the Earthworm *Eudrilus Eugeniae* (Kingberg) by Fortifying the Filtermud Vermibed using an Organic Nutrient *On Line Journal of Biological Sciences*,11(1):18-22

Zafari and Kianmehr (2012): Pellets from compost, *BioResources;*7(4): 4704-4714.