ISBN: 978-93-48620-26-2

Textbook of Vermiculture and Vermicomposting

Dr. Vaishali Badwaik

Bhumi Publishing, India
First Edition: February 2025

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Bhumi Publishing

March 2025

Title: Textbook of Vermiculture and Vermicomposting

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ISBN: 978-93-48620-26-2

Published by:

BHUMI PUBLISHING

Nigave Khalasa, Tal – Karveer, Dist – Kolhapur, Maharashtra, INDIA 416 207

E-mail: bhumipublishing@gmail.com

PREFACE

This textbook 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.

- Dr. Vaishali Badwaik

Dedicated to

Dr. R. G. Bhoyar Sir

Message from Dr R. G. Bhoyar Sir: Scan the QR code for Valuable insight for farmers for the benefits of use of vermicompost over the chemical fertilizer.

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Chapter 1
INTRODUCTION

Increase the use of biofertilizers and decrease the solid waste are the biggest challenges nowadays. Vermicomposting is solution for both. Earthworm digests waste in medium of cowdung with the help of aerobic and anaerobic microflora, transform it into value added product called as Vermicompost. Due to the increase solid waste, there is need of innovative technologies to minimize hazardous environmental impact and solid waste management. Vermiremediation is economical and sustainable technology to reduce solid waste and burden on landfills.

Solid waste production is accelerated by urbanisation, industrialisation and population growth. The disposal of organic wastes has resulted in significant environmental risks and financial difficulties in recent times. Burning organic wastes is a major source of environmental pollution, which contaminates the land, water and air. Along with dust particles, this process also releases significant amounts of carbon dioxide into the atmosphere, which is a major cause of global warming.

Burning also reduces the amount of organic matter in the soil, eliminates the microbial population and modifies the physical characteristics of the soil. There is a significant amount of non-toxic organic waste in this solid trash. While tropical soils lack many of the nutrients required by plants, solid organic wastes contain enormous amounts of these nutrients. Thus, in practically every waste management program in the world, the treatment of solid organic wastes has become a crucial component. The current methods for treating and disposing of it are fairly costly. One of the greatest solutions for treating organic wastes currently accessible is vermicomposting technology. The word "vermicomposting" comes from the Latin word "vermis" which means "worms" Vermicomposting refers to natural bioconversion of biodegradable garbage into high quality manure with the help of earthworms.

Earthworms are important to soil biology because by consuming an abundance of biodegradable waste, they act as adaptable natural bioreactors that capture energy and eliminate soil pathogens. They are how organic nutrients from decomposing tissues are recycled back into living things by nature. For a long time, earthworms have been recognised for their ability to stabilise trash, particularly in Southeast Asian and European nations.

Since then, research has been done to determine their function in both preserving soil fertility and causing the organic matter in the soil to decompose. These studies also looked into the viability of using earthworms to break down organic pollutants, including municipal solid wastes, animal wastes and vegetable wastes. Earthworms remove the partially stabilised substance as separate material (castings) and convert some of the organic stuff into worm biomass.

Earthworms and microbes work together in this process to hasten the breakdown of organic materials. The widespread realization of the need to recover organic waste and reintegrate it into the natural cycle is what propelled the development of vermiculture and other reuse techniques. The aerobic breakdown of organic wastes by taking advantage of earthworms' and microorganisms' peak biological activity is known as vermicomposting. The earthworms' ability to break up, combine and encourage microbial activity in the organic waste material is essential to the process. After consuming organic substances, the earthworms turn it into biomass resembles peat called as vermicompost. Vermicomposting produces a product with lower mass and higher humus content than thermal composting. It also takes less time to process, reduces the likelihood of phytotoxicity, increases the value of fertiliser and produces an additional product (earthworms) that can be used for other purposes.

As long as they don't include anything toxic to earthworms, organic waste items that naturally biodegrade can be utilised as substrates for the vermicomposting process. For instance, the byproducts of agro-industrial processes may be able to be utilised by microorganisms and earthworms as a source of food. The disposal of these enormously valuable plant-nutrient sources results in the eventual loss of valuable material agro-industrial wastes. Currently, these wastes are disposed of in the surrounding areas or burned in the fields, leaving them either terribly underutilised or altogether unutilised. By using vermicomposting technology, these separate and combined agro-industrial wastes could be efficiently recovered as resources for use in environmentally friendly land restoration techniques. Some agro industrial waste used in vermicomposting are agricultural waste, food processing waste, wood processing waste, paper and cellulosic waste, Fruits and vegetable processing waste.

Chapter 2

BIOLOGY OF EARTHWORMS

Terrestrial earthworm studied under phylum Annelid and Class Oligochaeta.

External Morphology

1. **Shape and Size**: The earthworm is a bilaterally symmetrical organism. Its body is elongated in a cylindrical shape, tapering at the front, broader at the rear and thickest just behind the anterior end. This structure makes it well-suited for burrowing. A fully grown earthworm typically reaches a length of about 150 mm and a width ranging from 3 to 5 mm.
2. **Colour**: The earthworm has a shiny deep brown or clay-like hue. Its dorsal surface is darker than the ventral side, with a visible dark median line running along the back, caused by the dorsal blood vessel visible through the skin. The brown coloration is due to the pigment porphyrin in the body wall, which helps shield the earthworm from intense light.
3. **Segmentation**: The earthworm's soft, bare body is divided into 100 to 120 similar segments known as *metameres* or *somites,* which lack parapodia. These segments are separated externally by distinct ring-like grooves and the external segmentation corresponds to the internal segmentation of the body.
4. **Head**: The earthworm does not have a distinct head or sensory organs like eyes, cirri, or tentacles. The first body segment at the anterior end is called the buccal segment or peristomium, which houses the terminal, crescent-shaped mouth. This segment extends into a fleshy lobe called the prostomium, which overhangs the mouth**.**
5. **Clitellum**: In mature earthworms, a prominent external feature is the clitellum, a thick, girdle-like band of glandular tissue that permanently encircles segments 14 to 16. The body is divided into peri-clitellar, clitellar and post-clitellar regions due to the clitellum presence. This glandular organ secretes mucus, albumen and forms an egg case or cocoon for the eggs.
6. **Setae**: In the middle of each segment, there is a ring of tiny, curved bristles called *setae* or *chaetae*, made from a nitrogenous organic substance known as chitin. Each segment contains about 80 to 120 setae, except for the peristomium, pygidium and clitellum, where they are absent. Each seta is housed in a small pit in the body wall, known as a setigerous or setal sac, which is formed by a single formative cell at the base of the sac. The setae are faint yellow in colour and have an elongated 'S' shape with a swollen middle part called the nodulus. Approximately one-third of each seta extends above the skin surface when the segment is contracted. The arrangement of numerous setae in a ring around each segment is referred to as the *perichaetine* arrangement, as seen in *Pheretima*. In a lumbricine or *octochaetine* arrangement, the setae are organized in two pairs on each side of each segment, as found in *Eutyphaeus* and the European earthworm, *Lumbricus*. (fig: 2.1)

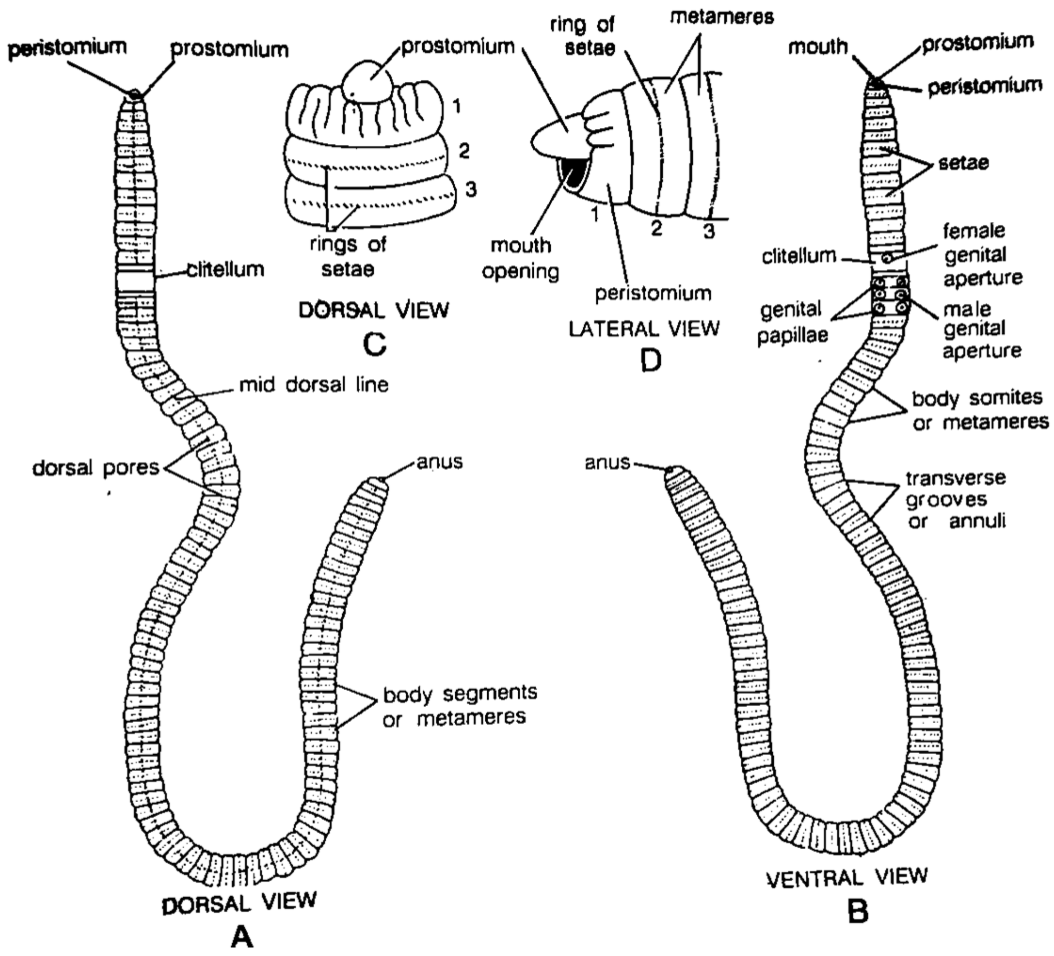

Fig. 2.1: *Pheretima posthuma*.

A-Entire worm in dorsal view. B-Entire worm in ventral view.

C-Anterior end in dorsal view. D-Anterior end in lateral view

7. **Apertures**: These include the following:
   a) **Mouth**: A crescent-shaped anterior opening, surrounded by the peristomium and overhung by the prostomium.
   b) **Anus**: A vertical, slit-like aperture located at the posterior end of the body.
   c) **Female Genital Pore**: A single median opening of the oviducts on the ventral surface of the 14th segment in the clitellar region.
   d) **Male Genital Pores**: A pair of crescent-shaped openings for the common prostatic and spermatic ducts, located on the ventral surface of the 18th segment, one on each side. Spermathecal Pores: Four pairs of openings for the spermathecae, found in the grooves between segments 5/6, 6/7, 7/8 and 8/9, one on each side in a ventro-lateral position.
   e) **Nephridiopores**: Numerous tiny openings of the integumentary nephridia scattered across the body, except on the first two segments.

f) **Dorsal Pores**: Small apertures of the coelomic chambers located mid-dorsally, one in each intersegmental groove starting from behind the 12th segment, except the last groove.

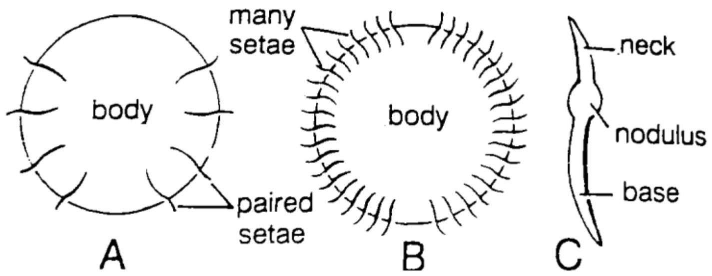

Fig.2.2: *Pheretima.* Diagrammatic representation of arrangement of setae in earthworms.
A-Lumbricine arrangement in *Lumbricus*.
B-Perichaetine arrangement in *Pheretima*. C-Parts of a single seta.

8. Genital Papillae: These are two pairs of prominent, rounded elevations, with one pair located in the 17th and the other in the 19th segment on the ventral surface. Each papilla has a shallow, cup-like depression at the top, which acts as a sucker during copulation. (fig: 2.1)

Body Wall

The body wall of the earthworm consists of a thin cuticle, an epidermis, a well-developed musculature and a coelomic epithelium or parietal peritoneum.

1. **Cuticle**: The cuticle is a flexible, non-cellular, finely striated layer secreted by the underlying epidermis. It provides elasticity and protection.
2. **Epidermis**: Located just beneath the cuticle, the epidermis is a single-layered structure made up of various cell types that perform different functions. The bulk of the epidermis is composed of columnar-shaped supporting cells. Gland cells include many mucous cells and a few albumen cells that are packed with secretory granules. Small, rounded or conical basal cells are found in the spaces between the inner ends of supporting cells and gland cells. Receptor cells are grouped together and have fine, hair-like processes extending from their outer ends. The epidermis rests on a thin basement membrane.

1. Muscles: The musculature is located beneath the epidermis and consists of two main layers. The outer layer is a thin layer of circular muscle fibres running around the body, while the inner layer is thicker and composed of longitudinal muscle fibres running along the body's length. The longitudinal muscle fibres are arranged in parallel bundles, separated by connective tissue and reinforced by collagen fibres. **Setal Musculature**: In addition to the primary muscle layers, two specific types of muscles are associated with the base of each setal sac that holds a seta. These include:

- A pair of **protractor muscles**, which extend outward to connect with the circular muscle layer.

- A single **retractor muscle**, which passes inward and connects with another thin circular muscle layer forming a ring beneath the longitudinal muscles, parallel to the ring of setae.

All of these muscle fibres are unstriped, long and spindle-shaped. According to K.N. Bahl (1926), the protractor muscles radiate outward to join the circular muscle layer. However, according to Vijay Kumar (1972), the protractor muscle fibres pass independently through both the longitudinal and circular muscle layers and attach distally to the basement membrane located beneath the epidermis.

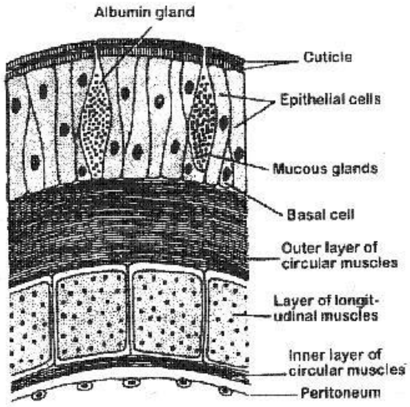

Fig. 2.3: *Pheretima*. T.S. of a portion of body wall.

4. Coelomic Epithelium:

Between the body wall musculature and the coelom lies a thin layer of coelomic epithelium, also known as the parietal peritoneum. This layer consists of flat cells that are mainly identifiable by their nuclei. (fig: 2.3)

Functions of the Body Wall:

1. Maintains body form due to its elasticity.
2. Provides protection against mechanical injuries.
3. Secretes mucus, which helps in plastering the internal walls of the burrow, keeps the body surface slimy and kills harmful bacteria.
4. Sensory epidermal cells respond to external stimuli.
5. Houses setae, which aid in locomotion.
6. Body wall musculature facilitates movement.
7. The moist and vascular body wall enables gaseous exchange.
8. Albumen secreted by clitellar glands provides nourishment to embryos developing inside cocoons.

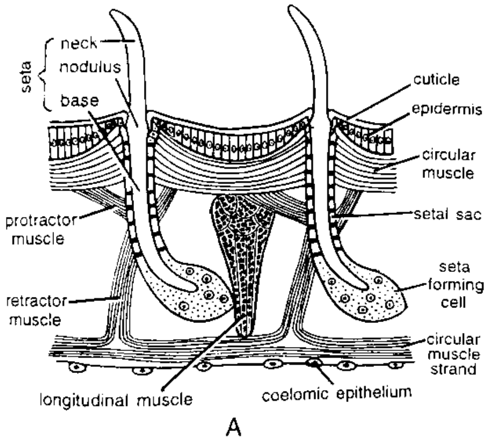

Fig. 2.4: ***Pheretima posthuma.*** **V.S. body wall through setal sacs showing setal musculature**

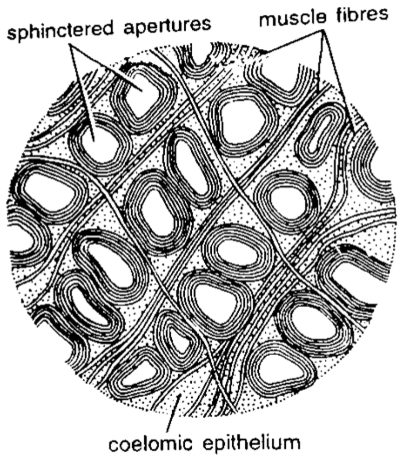

Fig. 2.5: ***Pheretima.*** **A part of intersegmental septum**

Coelom:

The body cavity of the earthworm is a true coelom, situated between the body wall and the alimentary canal. It is lined with coelomic epithelium, which is derived from the mesoderm.

1. **Septa**:

   The coelom of the earthworm is divided into a series of coelomic chambers by transverse intersegmental septa. Each septum consists of a thin layer of interwoven muscle fibres, covered on both sides by coelomic epithelium. There are no septa in the first four segments. The first septum, located between segments 4 and 5, is thin and membranous, while the next five septa are thick and muscular. These six septa are cone-shaped and run obliquely from the body wall to the gut wall. Only a single septum exists between segments 8 and 10, while the other is absent. The contraction of these cone-like septa increases pressure on the coelomic fluid, making the anterior segments of the body turgid and elongated, which aids in locomotion and burrowing. The first nine septa, up to the septum between segments 13/14, do not have perforations. The remaining septa, starting from the one between segments 14/15, are perforated with numerous sphinctered oval or circular openings, allowing adjacent coelomic chambers to remain connected.

2. **Coelomic Fluid**:

The coelom is filled with an alkaline, colourless or milky coelomic fluid that contains water, salts, some proteins and at least four types of coelomic corpuscles:

(a) **Phagocytes**: These are the largest and most numerous nucleated amoeboid corpuscles. Phagocytes have multiple surface folds, a deep concavity on one side and contain many ingested particles, such as bacteria.

(b) **Mucocytes**: These elongated cells have a broad, fan-like process attached to a narrow nucleated body.

(c) **Circular Nucleated Cells**: These rounded, nucleated cells resemble blood corpuscles and make up about 10% of the coelomic corpuscles. They have clear protoplasm and characteristic surface markings.

(d) **Chloragogen Cells**: Also known as yellow cells, chloragogen cells are small and star-shaped. They turn deep yellow when stained with iodine solution. These cells are believed to serve an excretory function, removing waste products from the coelomic fluid. (fig: 2.6)

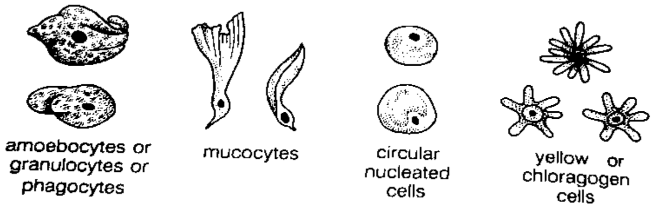

Fig. 2.6: *Pheretima.* Kinds of coelomic corpuscles

Functions of Coelomic Fluid:

1. Aids in locomotion by providing turgidity to the body.
2. Facilitates distribution of digested food through its circulation from one coelomic chamber to another.
3. By exuding through the dorsal pores, it keeps the body surface moist, aiding in respiration.
4. Destroys harmful bacteria and parasites present in the soil.
5. Acts as a protective, shock absorbing layer around the internal organs.
6. Chloragogen cells in the coelomic fluid help to remove excretory products from the body.
7. In some earthworms, the coelomic fluid contributes to luminescence.

Locomotion:

Movement in earthworms involves the body wall musculature and the setae. According to studies by Gray and Lissman (1938), the worm's movement is characterized by a sequence of extension, anchoring and contraction as it progresses. A wave of contraction starts at the anterior end and travels toward the posterior, first affecting the circular muscles, causing the body to elongate and become thinner. This is followed by another wave of contraction in the longitudinal muscles, which thickens and shortens the body. These alternating waves of contraction and relaxation continue in succession. Each wave of circular contraction pushes the affected segments forward, while the segments undergoing longitudinal contraction remain anchored to the ground by the protruded setae. During longitudinal contraction, the setae protrude to anchor the worm and they retract during circular contraction. This coordinated action allows the earthworm to travel a distance of approximately 25 cm per minute. If the direction of the muscle waves is reversed, the earthworm can crawl backward. Throughout locomotion, the coelomic fluid functions as a hydraulic skeleton. When the circular muscles contract, compressing the coelomic fluid, it stiffens the body and facilitates the relaxation of the longitudinal muscles. (fig: 2.7)

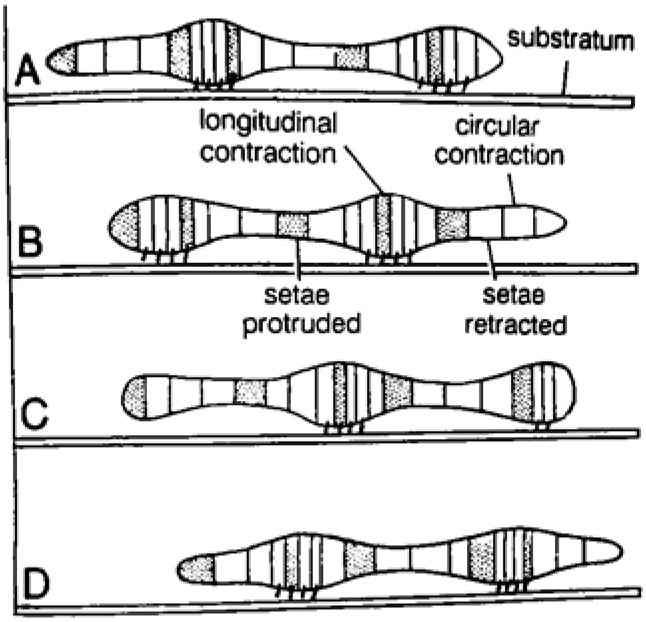

Fig. 2.7: *Pheretima.* Stages of locomotion

Physiology of Earthworm

Digestive System: Alimentary Canal

The alimentary canal of *Pheretima* is a complete and straight tube that runs the length of the body. It has two openings: the mouth at the anterior end and the anus at the posterior end. The canal is divided into functional regions, including the buccal chamber, pharynx, oesophagus, gizzard, stomach and intestine.

1. **Buccal Chamber:**

   The crescent shaped mouth located ventrally to the prostomium at the anterior end of the peristomium, opens into a short and narrow buccal chamber. This chamber extends up to the middle of the third segment and is lined with an epithelium that forms longitudinal folds.

2. **Pharynx:**

   The buccal chamber leads into a large, pear-shaped muscular pharynx that extends to the fourth segment. A nerve ring, located in a transverse groove between the buccal chamber and the pharynx, marks its anterior end. The pharyngeal cavity is flattened dorsoventrally because of the presence of a large glandular pharyngeal mass on its roof, which secretes saliva. The lateral walls of the pharynx fold inward, forming narrow horizontal shelves on each side. These shelves meet at both ends, dividing the pharyngeal cavity into two sections: a dorsal salivary chamber and a ventral conducting chamber. The salivary secretion, containing mucus and proteolytic enzymes, is released into the salivary chamber.

3. Oesophagus:

Located behind the pharynx, the oesophagus is a short, narrow, thin-walled tube that extends to the seventh segment.

4. Gizzard:

The oesophagus transforms into a prominent, oval, hard and thick-walled muscular organ known as the gizzard, located in the eighth segment. The gizzard's muscular wall is made up of circular muscle fibres and its interior is lined with a tough cuticle.

5. Stomach:

The gizzard is followed by the stomach, a short, narrow tube extending from the 9th to the 14th segments, with a sphincter at both ends. The stomach's walls are highly vascular, glandular and have internal transverse folds.

6. Intestine:

Following the stomach is the intestine, a long, wide and thin-walled tube that stretches from the 15th segment to the last. It has a beaded appearance due to circular constrictions that correspond to the body’s septa. The internal lining of the intestine is ciliated, folded, vascular and glandular.

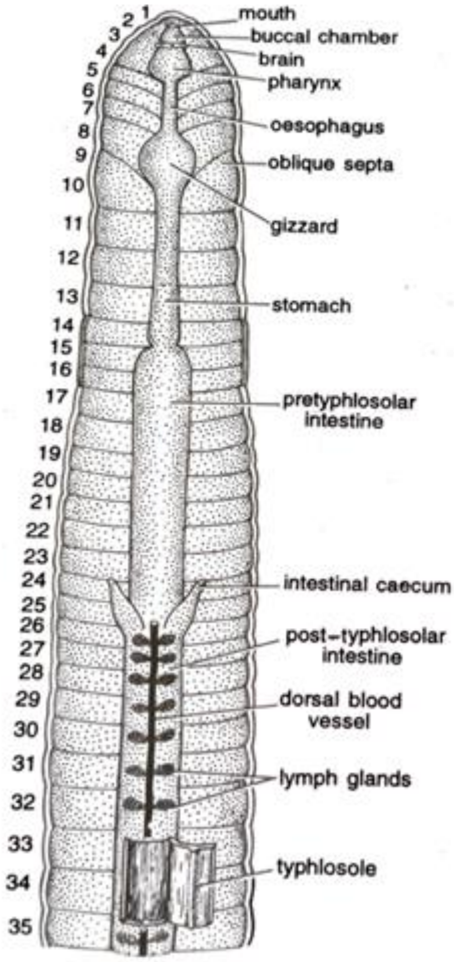

Fig.2.8: *Pheretima*. Dissection of alimentary canal

The intestine can be divided into three sections:

(a) Pre-typhlosolar Region:

The first section, known as the pre-typhlosolar region, is located between the 15th and 26th segments. Its inner walls have minute folds called villi and are highly vascular. Beginning from the 26th segment, a pair of forward-directed lateral structures emerge externally.

(b) Typhlosolar region: The second or middle part extends from the 27th segment to about 23-25 segments before the anus. This region is marked by a highly glandular and vascular longitudinal ridge, which develops as a median inward growth of the dorsal aspect of the intestinal cavity. This structure is referred to as the typhlosole.

(c) Post-typhlosolar region: The third or final part, also known as the rectum, consists of around 23-25 segments. Internally it is distinguished by longitudinal folds and opens to the exterior through a terminal anus. (fig: 2.8)

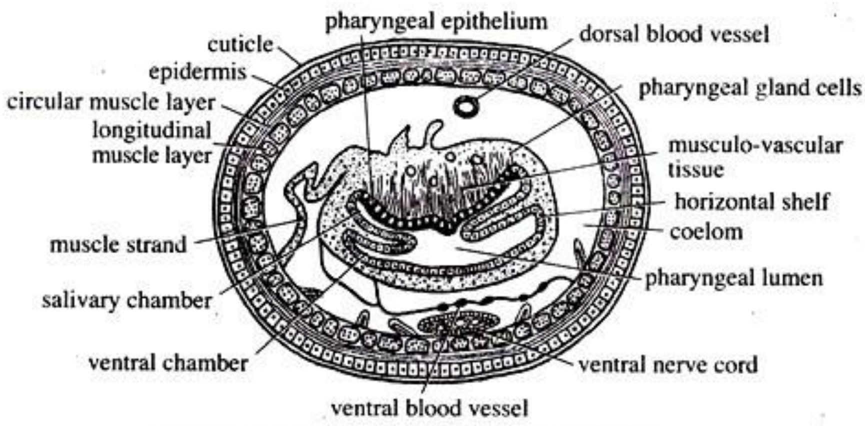

Fig. 2.9: ***Pheretima.*** **T.S. body through Pharynx**

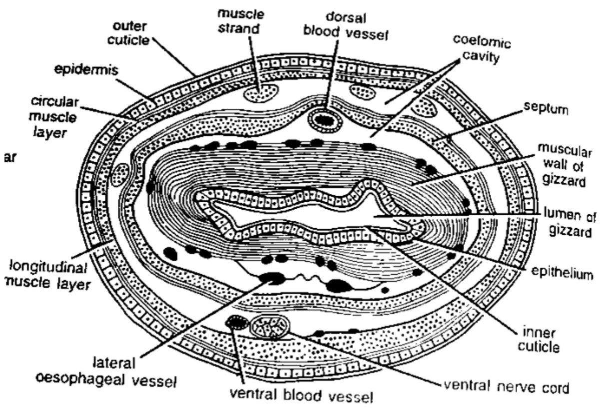

Fig. 2.10: ***Pheretima.*** **T.S. body through gizzard**

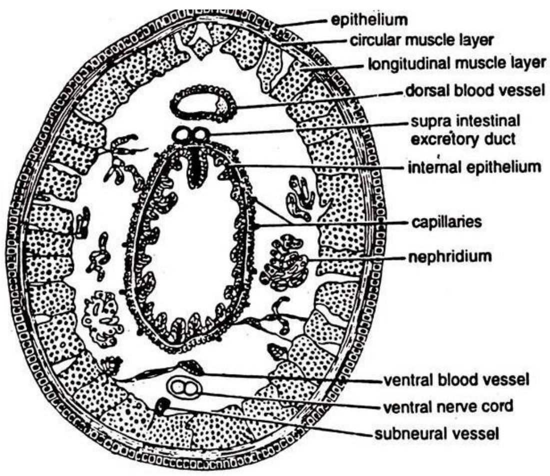

Fig. 2.11: ***Pheretima.*** **T.S. body through intestine (typhlosolar region)**

Histology of gut wall

The wall of the alimentary canal is composed of four successive layers:

1. **Peritoneum:** This is the outermost layer, made up of tall, narrow cells. On the surface of the intestine and stomach, some of these cells contain yellow refractile granules and are thus referred to as yellow or chloragogen cells. Their function remains a topic of debate, but they are believed to play a role in storing reserve food, deaminating proteins, forming urea from ammonia and excretion.
2. **Muscles:** Situated beneath the peritoneum, this layer includes an outer layer of longitudinal muscle fibres and an inner layer of circular muscle fibres. These muscles are well-developed in the pharynx and oesophagus but are less developed in the intestine. In the gizzard, the circular muscles are highly developed, while the longitudinal muscles are absent. These muscles are unstriped, meaning they are involuntary.

3. **Enteric epithelium:** Composed of a single row of columnar cells, this layer becomes ciliated in the roof of the pharynx, glandular in the stomach and both absorptive and glandular in the intestine. Internally, it forms folds in the oesophagus, stomach and intestine.
4. **Cuticle:** This thin lining is found in the buccal cavity while in the gizzard, it becomes a thicker lining. (fig: 2.10; 2.11)

Food and Feeding Mechanism

The earthworm primarily feeds on dead organic matter, particularly decaying vegetation mixed with soil. It ingests food by pumping soil into its mouth using the action of its pharynx. By pressing its mouth against the soil and employing the contractile sucking motion of its pharyngeal wall, the earthworm draws in soil fragments. It also directly feeds on leaves, grasses, seeds, algae and other organic materials. The buccal chamber aids in this sucking action and the pharynx's movements are assisted by muscle fibres extending from the pharynx to the body wall.

Physiology of Digestion: After ingestion, the food moves towards the posterior, with no digestion occurring in the buccal chamber. As the food passes through the ventral conducting chamber of the pharynx, it encounters a salivary secretion produced by glandular cells in the pharyngeal mass. This secretion contains mucin, which lubricates the food and a protease enzyme that digests proteins. The food then travels through the oesophagus into the gizzard, which functions as a grinding mechanism. The gizzard's muscular walls contract, causing the food to be rolled and ground against the internal cuticular lining. In the stomach, a chalky secretion from calciferous glands neutralizes the humic acids present in the soil. The intestine serves as the main site of digestion. Its walls contain glandular cells that secrete digestive enzymes such as pepsin, trypsin, amylase, lipase and cellulase. Pepsin breaks down proteins into proteoses and peptones, while trypsin further hydrolyzes these into amino acids. Amylase converts starch into maltose, lipase breaks down fats into glycerol and fatty acids and cellulase digests cellulose into cellobiose.

In the earthworm, digestion is extracellular, similar to higher animals like frogs and rabbits. The intestine is responsible for absorbing the digested nutrients. Once absorbed by the intestinal epithelium absorptive cells, the nutrients are passed into blood capillaries located in the intestinal wall. The presence of the typhlosole in a large portion of the intestine increases the surface area for both digestion and absorption. Undigested food and soil are expelled through the anus in the form of worm castings. In *Pheretima*, these castings appear as distinct, small, rounded pellets or balls, whereas in *Eutyphaeus*, they form a large, tower-like heap with an open passage in the centre.

Circulatory System

The circulatory or blood vascular system in earthworms is a closed system, comprising blood vessels and capillaries that extend to all parts of the body. The blood consists of fluid plasma and colourless corpuscles, which are functionally similar to the leucocytes of vertebrates. The respiratory pigment haemoglobin (or erythrocruorin) is dissolved in the plasma, giving the blood its red colour and facilitating the transport of oxygen for respiration.

Blood Vessels

In *Pheretima posthuma*, the blood vessels are classified into three types: (1) longitudinal, (2) lateral and (3) intestinal plexuses.

Longitudinal Blood Vessels

There are five longitudinal blood vessels that run along the length of the body:

1. **Dorsal Vessel:** The dorsal vessel is the largest blood vessel, running mid-dorsally above the alimentary canal from one end of the body to the other. It has a thick, muscular and rhythmically contractile wall and each segment contains a pair of valves located in front of the septum. Blood flows through the dorsal vessel from the back of the body towards the front. Behind the 13th segment, the dorsal vessel acts as a collecting vessel, receiving blood from the intestine via two pairs of dorso-intestinal vessels and from the sub-neural vessel through a pair of commissural vessels in each segment. In front of the 13th segment, it distributes blood to the anterior regions of the alimentary canal and supplies blood to the ventral vessel through structures referred to as "hearts." Extending to the cerebral ganglia, the dorsal vessel branches into three parts, which are distributed over the pharyngeal bulb and the roof of the buccal chamber. In the 3rd, 4th, 5th, 6th and 8th segments, it also sends branches to the gizzard.
2. **Ventral Vessel:** The ventral vessel is a large blood vessel running mid-ventrally beneath the alimentary canal and above the nerve cord, extending from one end of the body to the other. Its walls are thin and non-contractile and it lacks valves. Blood flows through it in a posterior direction. The ventral vessel primarily functions as a distributing vessel. In each segment, it supplies blood through a pair of ventro-tegumentary vessels to the integumentary nephridia, body wall, septa and reproductive organs. Behind the 13th segment, each ventro-tegumentary vessel gives off a small branch called the septo-nephridial branch, which supplies blood to the septal nephridia. Additionally, in each segment behind the 13th, the ventral vessel sends out a median ventro-intestinal vessel to the intestine.
3. **Lateral Oesophageal Vessels:** The lateral oesophageal vessels are two vessels located on either ventro-lateral side of the gut, extending from the anterior end of the body to the 13th segment. In each segment, these vessels receive blood from a pair of ventro-tegumentary vessels, which collect blood from the body wall, septa, nephridia and reproductive organs. Blood flows posteriorly in these vessels, with some of it passing to the supra-oesophageal vessel through a pair of anterior loops in the 10th and 11th segments, as well as through

several ring vessels running through the wall of the stomach. The remaining blood flows backward into the sub-neural vessel.

4. **Sub-neural Vessel:** The sub-neural vessel is a slender vessel running directly beneath the nerve cord in the mid-ventral position, extending from the 14^{th} segment to the posterior end of the body. It is formed by the union of two lateral oesophageal vessels. Blood flows from the front towards the back. The sub-neural vessel serves as a collecting vessel, receiving blood from the ventral nerve cord and ventral body wall through a pair of small branches in each segment. It transfers this blood to the dorsal vessel via a pair of commissural vessels in each segment.

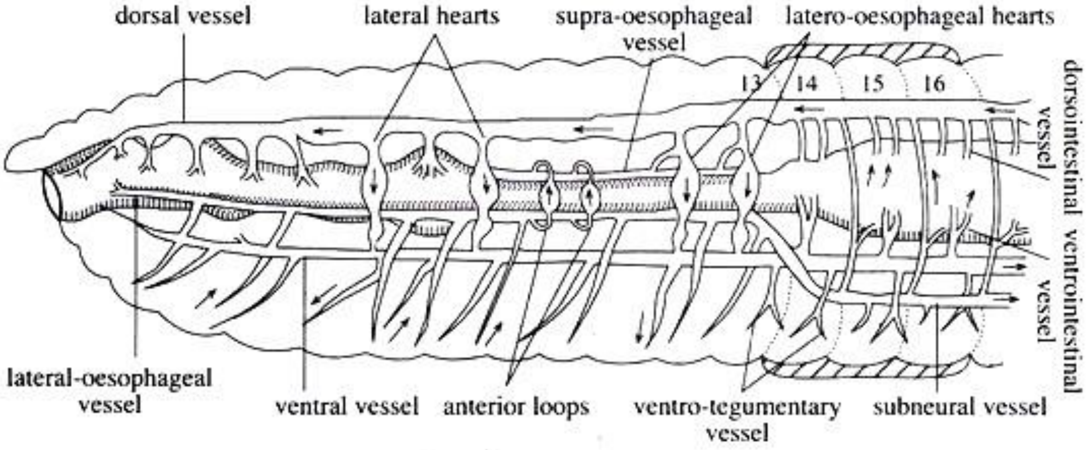

Fig. 2.12: *Pheretima.* Blood-vascular system in first 13 segment.

5. **Supra-oesophageal Blood Vessel:** The supra-oesophageal vessel is a short, thin-walled collecting vessel located dorsally above the stomach, confined to segments 9 through 13. It is connected to the lateral oesophageal vessels through two pairs of anterior loops and to the ventral vessel via two pairs of latero-oesophageal hearts. At certain points, the supra-oesophageal vessel divides into separate vessels, which later rejoin to form a single vessel. It collects blood from the stomach, gizzard and lateral oesophageal vessels (via the anterior loops) and pumps it into the ventral vessel through the lateral oesophageal hearts.

Lateral or Transverse Blood Vessels

All the longitudinal blood vessels in the earthworm are interconnected, either directly or indirectly, through numerous segmentally arranged transverse or lateral blood vessels. The lateral blood vessels in the anterior region (first 13 segments) and those in the posterior or intestinal region (beyond the 13^{th} segment) are described separately:

A. Lateral Blood Vessels of Anterior Region (First 13 Segments)

1. **Hearts:** In each of the 7^{th}, 9^{th}, 12^{th} and 13^{th} segments, there is a pair of large, thick, muscular and rhythmically contractile vertical vessels known as hearts. These hearts pump blood from the dorsal vessel to the ventral vessel, while the reverse flow is prevented by

internal valves. The hearts in the 7th and 9th segments connect only the dorsal and ventral vessels and are referred to as lateral hearts. The hearts in the 12th and 13th segments connect the dorsal and supra-oesophageal vessels with the ventral vessel and are known as latero-oesophageal hearts.

1. **Anterior Loops:** In the 10th and 11th segments, there is a pair of thin-walled, non-pulsatile, non-muscular and loop-like broad vessels, without valves, known as anterior loops. These vessels carry blood from the lateral oesophageal vessels to the supra-oesophageal vessel.
2. **Ring Vessels:** These are circular vessels located within the muscular coat of the stomach, with about 12 vessels per segment. The ring vessels allow blood from the lateral oesophageal vessels to reach the supra-oesophageal vessel.
3. **Ventro-tegumentary Vessels:** In each segment, the ventral vessel gives off a pair of ventro-tegumentary vessels that supply blood to the body wall, septa, nephridia and reproductive organs of the same segment.

B. Lateral Vessels of the Intestinal Region (Behind 13th Segment)

1. **Ventro-tegumentary Vessels:** In the posterior region, the ventral vessel gives off a pair of ventro-tegumentary vessels in each segment. These vessels send a delicate septo-nephridial branch to the septal nephridia, which runs upward along the anterior face of the septum. The septo-nephridial branch then pierces the septum to enter the segment behind, supplying blood to the body wall and integumentary nephridia.
2. **Commissural Vessels:** Starting from the 14th segment, each segment contains a pair of commissural vessels. These vessels run upward along the posterior face of the septum, one on either side, carrying blood from the sub-neural vessel to the dorsal vessel. Each commissural vessel gives off a small septo-intestinal branch to the intestinal plexus and also receives branches from the septal nephridia and body wall.
3. **Dorso-intestinals:**
   In the intestinal region, there are two pairs of dorso-intestinal vessels in each segment. These vessels transport blood from the intestinal wall to the dorsal vessel.
4. **Ventro-intestinals:**
   Similarly, a single median ventro-intestinal vessel is found in each segment of the intestinal region. This vessel carries blood from the ventral vessel to the intestinal wall. (fig: 2.12)

[II] Intestinal Plexuses

The wall of the intestine contains numerous blood capillaries arranged in two networks, or plexuses:

- **External Plexus:** This network is located on the surface of the gut. It receives blood from the ventral vessel through the ventro-intestinals and septo-intestinals and passes it to the internal plexus.

- **Internal Plexus:** Located between the circular muscles and enteric epithelium, this network passes blood, along with absorbed nutrients, to the dorsal vessel via the dorso-intestinals.

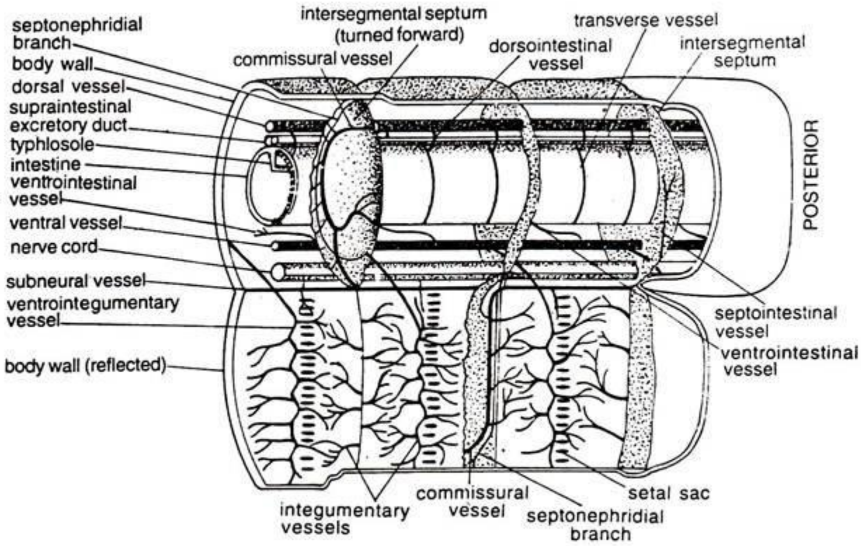

Fig. 2.13: *Pheretima.* Blood vascular system in a segment of intestinal region

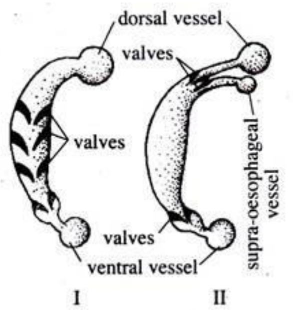

Fig. 2.14: *Pheretima.* Diagrammatic representation of hearts in section. A-Lateral-heart. B-Lateral-oesophageal heart

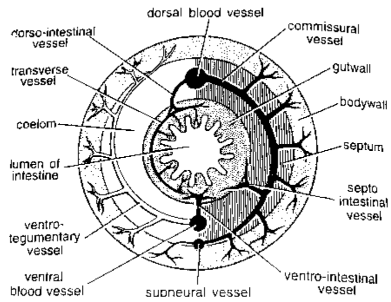

Fig. 2.15: *Pheretima.* T.S. body through intestinal region showing arrangement of blood vessels. Section of the right half passes through a septum

Circulation of Blood

In the earthworm, blood flows from the posterior to the anterior direction the dorsal, latero-oesophageal, supra-oesophageal and sub-neural vessels, while it flows from the anterior to the posterior direction in the ventral and sub-neural vessels. The **ventral vessel** is the primary distributing vessel, delivering blood to all parts of the body.

- In the first 13 segments, the ventral vessel supplies blood to the body wall, septa, nephridia and reproductive organs through the ventro-tegumentary vessels.

- Behind the 13th segment, it supplies blood to the body wall via the ventro-tegumentary vessels and to the gut wall via the ventro-intestinal vessels. The sub-neural, lateral oesophageals and supra-oesophageals are the main collecting vessels:
- The lateral oesophageals collect blood from the alimentary canal, body wall, nephridia, septa and reproductive organs in the first 13 segments. They discharge the collected blood into the supra-oesophageal vessel through anterior loops and ring vessels.
- The supra-oesophageal vessel also collects blood from the gizzard and stomach and transfers it to the ventral vessel via the latero-oesophageal hearts.
- The sub-neural vessel collects blood from the ventral body wall and nerve cord in the intestinal region, sending it to the dorsal vessel through the commissural vessels. The commissural vessels also receive blood from the body wall, septa and nephridia and distribute some of this blood to the gut wall through the septo-intestinal vessels. The dorsal vessel serves both as a collecting and a distributing vessel:
- In the intestinal region, it collects blood from the gut wall via the dorso-intestinal vessels and from the sub-neural vessel, septa and nephridia via the commissural vessels.
- In the first 13 segments, it distributes some blood to the alimentary canal and directs the remaining blood into the ventral vessel through the hearts.

The circulatory system distributes digested food absorbed through the intestinal wall to various parts of the body, while carbon dioxide and nitrogenous wastes are transported to the nephridia, skin and coelomic fluid for elimination.

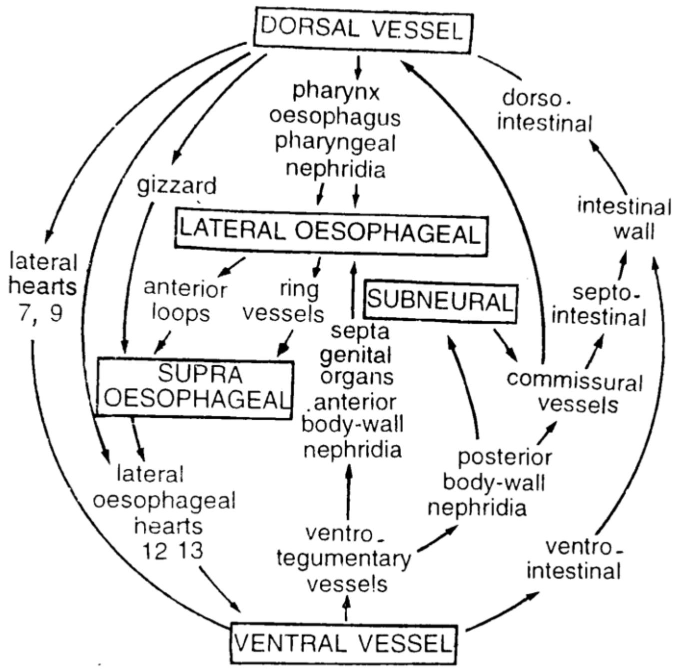

Fig. 2.16: *Pheretima.* Course of circulation of blood

Blood Glands

In segments 4, 5 and 6, located above the pharyngeal mass and connected to the pharyngeal or salivary glands, are small, red, follicular structures known as blood glands. Each gland is composed of a mass of loose cells enclosed by a capsule with a syncytial wall. These blood glands are responsible for producing blood corpuscles and haemoglobin and some researchers also consider them to have an excretory function.

Excretory or Nephridial System

In *Pheretima*, excretion is carried out by segmentally arranged, microscopic, coiled tubes called nephridia. These nephridia are generally unbranched and their inner ends open into the coelom through a ciliated funnel called a nephrostome. Nephridia that open via a ciliated funnel are known as metanephridia. However, in some instances, the nephrostome is secondarily lost, causing the nephridium to become branched. In *Pheretima*, the nephridia are small (micronephridia), unlike the larger meganephridia found in *Nereis* and leeches. Nephridia are present in all body segments except the first three and they are categorized into three types based on their location in the body: (i) pharyngeal, (ii) integumentary and (iii) septal.

[I] Pharyngeal nephridia

The pharyngeal nephridia are located as paired tufts on either side of the pharynx and oesophagus in segments 4, 5 and 6. Each tuft is made up of hundreds of coiled, branched tubules without nephrostomes. The terminal ducts from all tubules in each tuft merge to form a single thick-walled common duct. As a result, there are three pairs of common *pharyngeal nephridial ducts* that run anteriorly, parallel to the ventral nerve cord. The ducts from segments 4 and 5 open into the pharynx, while the ducts from the 6th segment open into the buccal chamber. Therefore, pharyngeal nephridia are classified as *enteronephric*, meaning they open into the alimentary canal.

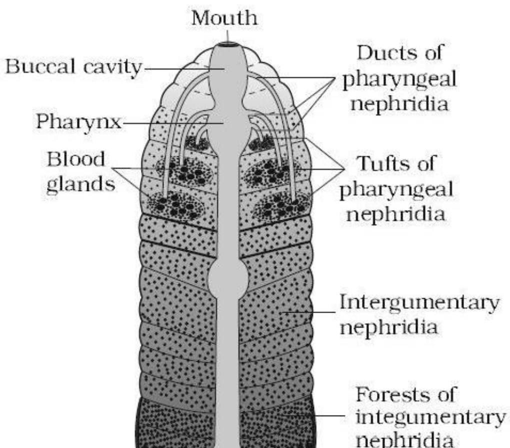

Fig. 2.17: *Pheretima.* Location of the three types of nephridia

[II] Integumentary Nephridia

Integumentary nephridia are scattered across the inner or parietal surface of the body wall in each segment, except for the first two segments. In each segment, there are typically 200-250 nephridia, but in the clitellum segments (14 to 16), their number increases to over 2000, forming what is called the "forests of nephridia." These nephridia are microscopic and V-shaped, lacking nephrostomes. Their terminal ducts open independently on the body surface through tiny openings known as nephridiopores. Because they release waste directly to the exterior, integumentary nephridia are considered exonephric.

[III] Septal nephridia

Septal nephridia are the largest nephridia found in *Pheretima* and are attached to both sides of each intersegmental septum, starting from behind the 15^{th} segment. (fig: 2.17)

1. **Structure**

A typical septal nephridium is composed of three main parts:

(a) Nephrostome: This is a ciliated funnel that communicates with the coelom. It consists of an elliptical pore surrounded by an upper and a lower lip. The upper lip is made up of a large central cell and 8 or 9 marginal cells, while the lower lip is composed of 4 or 5 compact cells. All these cells are ciliated.

(b) Body of Nephridium: The nephrostome connects to the main body of the nephridium via a short, narrow, ciliated neck. The body has two parts: a short straight lobe and a long twisted lobe with a narrow apical section. The straight lobe is about half the length of the twisted lobe, which consists of a proximal limb and a distal limb that are spirally twisted around each other. The proximal limb is connected to the neck.

(c) Terminal Duct

The distal limb of the nephridial body ends in a short and narrow tube called the terminal duct. Nephridial Tubule. The nephridium is composed of a syncytial glandular mass, traversed by a coiled tubule that features four ciliated tracts along its course: one in the neck, two in the body and one in the terminal duct. There are four parallel tubules in the straight lobe, three in the basal part and two in the apical part of each limb of the twisted loop. Additionally, a single tubule runs through both the neck and terminal duct.

2. **Arrangement**

Each septum behind the 15^{th} segment contains four rows of septal nephridia: two on its anterior face and two on the posterior face. Each row contains about 20 to 25 nephridia, resulting in a total of 80 to 100 nephridia on each septum within a coelomic compartment. These nephridia are suspended freely in the coelom of each segment and their terminal ducts connect to the septal excretory canals. These canals run inward along the posterior face of the septum, with one on each side of the commissural vessel. They discharge their contents dorsally into a pair of supraintestinal excretory ducts, which are located mid-dorsally, just above the intestine and beneath the dorsal blood vessel. These ducts extend from the 15^{th} segment to the last body segment and open into the intestine of each segment via narrow ductules with sphinctered openings. Therefore, septal nephridia are classified as enteronephric (Fig. 2.18, 2.19).

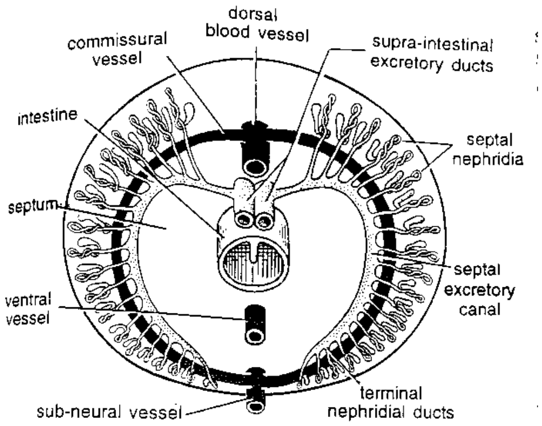

Fig. 2.18: *Pheretima.* A diagrammatic representation of arrangement of septal nephridia on the septum.

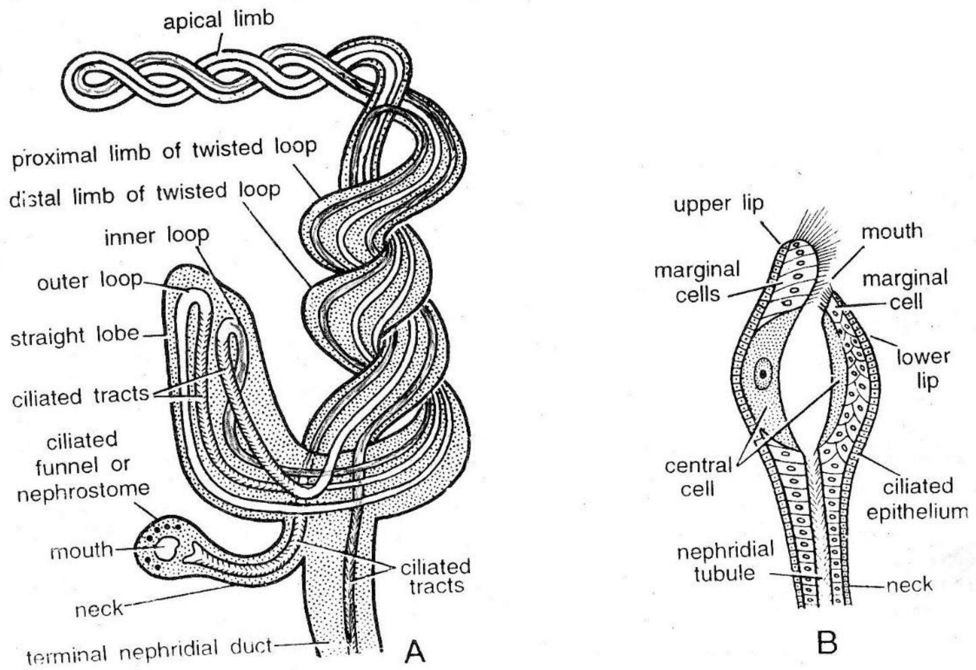

Fig. 2.19: *Pheretima.* A septal nephridium. A-Entire nephridium. B-Nephrostome in L.S.

Physiology of Excretion

The nephridia are richly supplied with blood vessels. The gland cells of the nephridia extract excess water and nitrogenous wastes from the blood. In addition to filtering blood, septal nephridia also remove excretory materials from the coelomic fluid. Integumentary nephridia, being exonephric, release their waste materials directly to the external body surface through nephridiopores. Pharyngeal and septal nephridia, being enteronephric, discharge their waste into the gut lumen. Aquatic oligochaetes primarily excrete ammonia, while terrestrial species, like earthworms, excrete urea. However, earthworms are less ureotelic than other terrestrial animals. Their excretory fluid contains approximately 40% urea, 20% ammonia and 40% amino acids and other nitrogenous compounds, but no uric acid or urates.

Respiration

Respiration occurs through the diffusion of gases across the general body surface. The exchange of gases, i.e., the uptake of O_2 and the release of CO_2, happens between the blood capillaries in the outer epidermis and a surface layer of moisture, which is contributed by secreted mucus, excreted waste and coelomic fluid. Heamoglobin dissolved in the plasma of the blood serves as a respiratory pigment, carrying oxygen to body tissues. These are then expelled along with the faeces.

Nervous System

The nervous system is well-developed and concentrated. It consists of three main parts: the central, peripheral and sympathetic nervous systems.

1. **Central Nervous System:** This is made up of an anterior nerve ring and a posterior ventral nerve cord.

(a) **Nerve Ring:** The nerve ring consists of paired cerebral ganglia and circumpharyngeal connectives. A pair of closely connected, white, pear-shaped cerebral or supra-pharyngeal ganglia, often referred to as the "brain," are located dorsally in a depression between the buccal cavity and pharynx in the third segment. From these ganglia, thick, lateral circumpharyngeal connectives emerge, encircling the pharynx and connecting ventrally at a pair of fused sub-pharyngeal ganglia found beneath the pharynx in the fourth segment. This structure forms a complete nerve ring around the pharynx. (fig: 2.20)

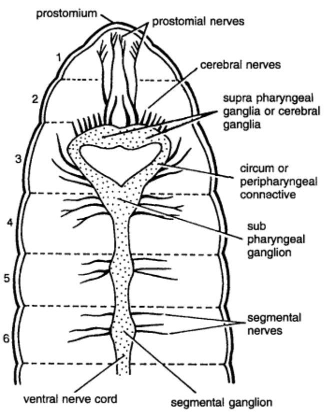

Fig. 2.20: ***Pheretima.*** **Nervous system in the anterior end of body in dorsal view**

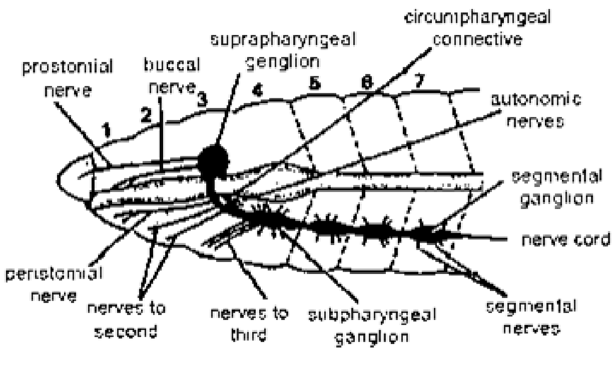

Fig. 2.21: ***Pheretima.*** **Nerve ring and ventral nerve cord in the anterior end of body in lateral view**

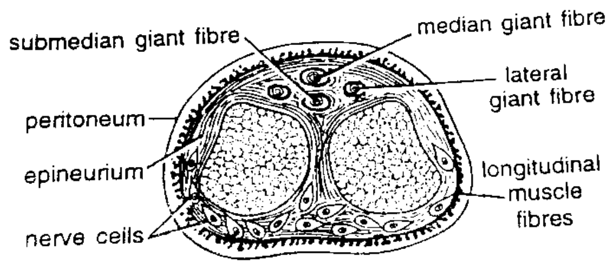

Fig. 2.22: ***Pheretima.*** **T.S. Ventral nerve cord**

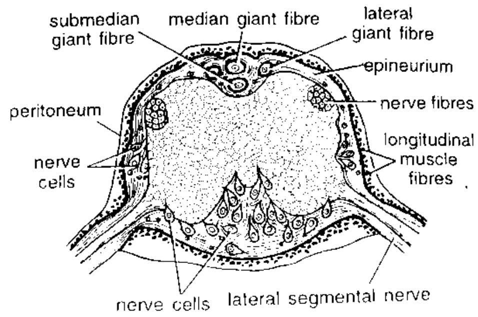

Fig. 2.23: ***Pheretima.*** **A segmental nerve ganglion in T.S.**

(b) Ventral Nerve Cord. The ventral nerve cord originates from the sub-pharyngeal ganglia and extends backward along the mid-ventral line, reaching the posterior end of the body. In each segment, it shows a slight enlargement, or ganglion. Though the ventral nerve cord appears singular, it is actually double, consisting of two closely united cords—right and left—visible in a transverse section. Each segmental ganglion is formed by the fusion of a pair of ganglia, with one from each cord of the double ventral nerve cord. Histologically, the ventral nerve cord is composed of nerve fibres and nerve cells. Externally, it is covered by a layer of visceral peritoneum, beneath which lies a thin layer of longitudinal muscle fibres surrounding a fibrous capsule called the epineurium. The core of the cord is made up of nerve fibres and two distinct cores can be seen in a cross-section, reflecting the double structure of the cord. In the regions containing segmental ganglia, these two nerve cores are fully fused along the middle line. Surrounding the nerve fibres on the sides and below are nerve cells. These nerve cells, which are embedded in connective tissue known as neuroglia, are of two types: motor neurons and associating neurons. The nerve cells and fibres are housed in this neuroglial tissue. Dorsally, four giant fibres run along the length of the entire nerve cord through the mass of connective tissue: one median fibre, two submedian fibres and two lateral fibres. These fibres, similar to those found in Nereis, are responsible for triggering sudden, forceful contractions of the body in response to alarms. They contain a homogeneous, plasma-like fluid that aids in these rapid contractions. (fig: 2.22)

2. **Peripheral Nervous System.** Each cerebral ganglion emits 8 to 10 lateral nerves, which innervate the prostomium and buccal chamber. Nerves originating from the peripharyngeal connectives supply the peristomium and buccal chamber, while the sub-pharyngeal ganglia innervate structures in the 2^{nd}, 3^{rd} and 4^{th} segments. Each segmental ganglion of the ventral nerve cord sends out 3 pairs of lateral nerves: one pair in front of the setae and two pairs behind. These nerves supply the gut wall, body wall and other internal organs within their

respective segments. The nerves are mixed, consisting of both afferent (sensory) fibres and efferent (motor) fibres.

3. **Sympathetic Nervous System.** The sympathetic nervous system in the earthworm consists of an extensive network of nerve plexuses spread throughout the epidermis, beneath the body wall muscles and on the alimentary canal. These plexuses are connected to the peri-pharyngeal connectives. All the activities of the earthworm are controlled by the nervous system, although not always directly by the brain. The nerves contain both afferent (sensory) and efferent (motor) fibres. Afferent fibres begin from sensory cells or receptor organs in the epidermis and terminate in the ventral nerve cord as fine branches. Near these branches, efferent fibres form synapses and extend outward to terminate in the muscles. Sensory stimuli are carried from the receptors by the afferent fibres to the ventral nerve cord, where they are reflected back as motor impulses along efferent fibres, causing the muscles to contract. In some cases, an adjustor neuron may be present between the sensory and motor neurons. This allows the impulse to be transmitted to the opposite side of the same segment or to several other segments, coordinating the activities of different parts of the body. The giant fibres in the nerve cord transmit impulses more rapidly than other nerve fibres, triggering sudden, whole-body movements when a specific point on the body is intensely stimulated.

Reproductive System

Earthworms do not reproduce asexually and their reproductive organs are somewhat complex. Although earthworms are monoecious (hermaphroditic), they cannot fertilize their own eggs because they are protandrous, meaning sperm is produced before eggs mature. As a result, cross-fertilization typically occurs, usually following copulation and cocoon formation.

[I] Male Reproductive Organs

The male reproductive system includes the testes, testis sacs, seminal vesicles, vasa deferentia, prostate glands and accessory glands.

1. **Testes:**

   There are two pairs of small, white, lobed testes—one pair located in the 10^{th} segment and another in the 11^{th} segment. These testes are situated ventro-laterally to the alimentary canal, near the mid-ventral line on either side of the nerve cord and are attached to the anterior wall of their respective testis sacs. Each testis has a narrow base from which four small, finger-like processes arise, containing rounded cells called spermatogonia. Testes are well-developed in young worms but degenerate in adults.

2. **Testis Sacs:** Each pair of testes is enclosed in a wide, thin-walled testis sac, which is a coelomic compartment separated from the general body cavity. There are two testis sacs located in the 10^{th} and 11^{th} segments, one behind the other, beneath the alimentary canal.

Each testis sac contains a pair of testes, ciliated spermiducal funnels and communicates with two seminal vesicles in the following segment through tubular connections. The testis sac in the 11th segment is large enough to also enclose the seminal vesicles of that segment.

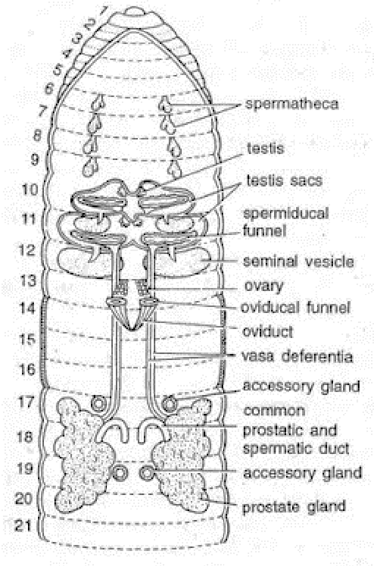

Fig. 2.24: *Pheretima.* Reproductive system

3. **Seminal Vesicles:** There are two pairs of large, white seminal vesicles located in the 11th and 12th segments. These vesicles, also known as septal pouches, develop as outgrowths from the septa. The testis sac in the 10th segment connects to the seminal vesicles in the 11th segment, while the testis sac in the 11th segment connects to the seminal vesicles in the 12th segment. The seminal vesicles in the 11th segment are enclosed within the testis sac of that segment, whereas those in the 12th segment lie free in the body cavity.
4. **Spermiducal Funnels:** Each testis sac contains two pairs of ciliated spermiducal funnels (also known as spermrosettes), with one funnel located behind each testis in the same segment. These funnels are responsible for collecting sperm and are enclosed within the same testis sac as the testes.
5. **Vasa Deferentia:** Each spermiducal funnel leads into a slender, ciliated, thread-like sperm duct called the vas deferens. The two vasa deferentia on each side of the body run posteriorly along the ventral body wall, from the testes to the 18th segment, where they join the prostatic duct.
6. **Prostate Glands:** The prostate glands are a pair of dirty-white, flat, solid, lobulated masses located on either side of the gut. These glands are free in the body cavity and extend from the 16th or 17th segment to the 20th or 21st segment. Each prostate gland consists of a large, glandular portion and a smaller, non-glandular part. The glandular portion is a racemose gland made up of closely packed lobes, while the non-glandular portion consists of several small ducts that converge to form a short, thick, muscular and curved prostatic duct in the

18th segment. As the prostatic duct emerges from the gland, it becomes enclosed in a common muscular sheath along with the two vasa deferentia on its side, forming a common spermatic and prostatic duct. Although housed within the same sheath, the three tubes remain separate. These common ducts curve inward and open independently at the male genital pores on the ventral surface of the 18th segment. The prostate glands secrete a prostatic fluid, though its exact function is still unknown.

7. **Accessory Glands** In each of the 17th and 19th segments, there is a pair of round, white, fluffy masses called accessory glands, located on the ventro-lateral body wall, one on either side of the nerve cord. These glands open to the exterior through several ducts that lead to two pairs of genital papillae, found externally on the 17th and 19th segments, one on each side of the mid-ventral line. The secretion from these glands likely helps to unite the two worms during copulation. From the testes, spermatogonia (sperm-mother cells) are released into the testis sacs. They then move to the seminal vesicles, where they mature into spermatozoa. Once mature, the sperm return to the testis sacs, pass into the spermiducal funnels, travel along the vasa deferentia and are eventually released through the male genital pores during copulation. (fig: 2.24)

[I] Female Reproductive Organs

The female reproductive system includes the ovaries, oviducal funnels, oviducts and spermathecae.

1. **Ovaries:**

   A pair of small, white, digitate ovaries is located in the 13th segment, attached to the posterior face of septum 12/13, one on each side of the ventral nerve cord. Each ovary consists of a compact white mass with finger-like processes, in which ova (egg cells) are arranged in a linear series at various stages of development.

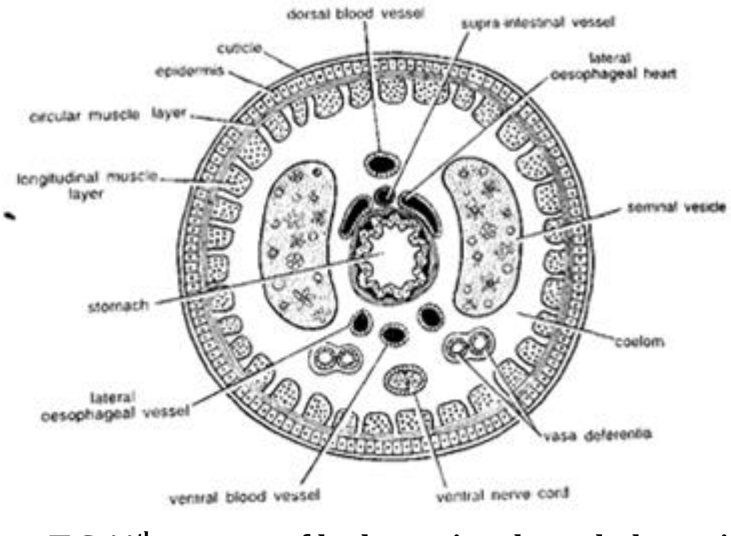

Fig. 2.25: *pheretima.* T.S.11th segment of body passing through the testies sacs, testes and seminal vesicles

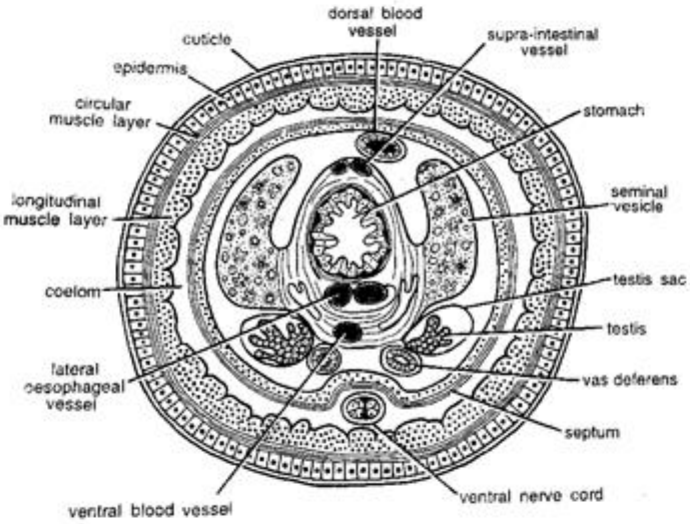

Fig. 2.26: *Pheretima.*T.S.12th segment of body, passing through seminal vesicles and vasa deferentia

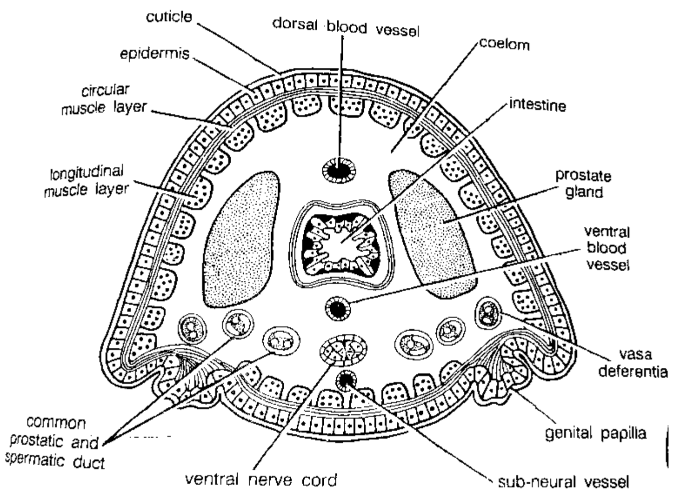

Fig. 2.27: *Pheretima.* T.S.17th segment of body passing through prostate glands and genital papillae.

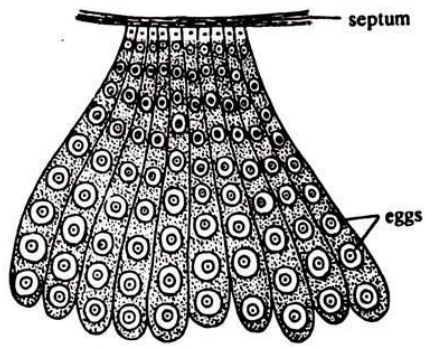

Fig. 2.28: *Pheretima.* Ovary

2. **Oviducial funnels**. The 13th segment has a huge saucer-shaped oviducal funnel with heavily folded and ciliated borders, located immediately below each ovary.
3. **Oviducts.** Each oviducal funnel leads to a short conical ciliated tube known as the oviduct. The two oviducts run backwards, perforating septum 13/14 before converging in the ventral body wall behind the nerve cord to produce a very short common oviduct. The female genital opening, located mid-ventrally on the 14th segment, provides access to the outside world.
4. **Spermathecae.** Earthworms have four pairs of small, flask-shaped structures called spermathecae or *Receptacula seminales*. These are located ventro-laterally, with one pair in

(ISBN: 978-93-48620-26-2)

each of segments 6, 7, 8 and 9. Each spermatheca consists of a broad, pear-shaped body called the ampulla and a short, narrow neck. From this neck extends a long, narrow, blind sac known as a caecum or diverticulum, before opening to the exterior. The four pairs of spermathecae each open to the outside through separate spermathecal pores, located ventro-laterally in the grooves between segments 5/6, 6/7, 7/8 and 8/9. During copulation, spermathecae receive sperm from another earthworm, which is stored in the diverticula in *Pheretima* and in the ampullae in other species of earthworms. When mature ova are released from the ovaries, they are captured by oviducal funnels, travel through the oviducts and exit via the female genital aperture to be deposited inside the cocoon.

Copulation and Fertilization

Earthworms are hermaphroditic (bisexual), but self-fertilization does not occur because they are protandrous, meaning the male reproductive organs mature before the female ones. Instead, cross-fertilization takes place between two worms, where sperm from one worm is transferred to another in a process called copulation. While copulation in the Indian earthworm *Pheretima posthuma* likely happens underground and has not been studied in detail, it has been observed in *Pheretima communissima*. This usually occurs at night during the rainy season and lasts about an hour. Earthworms lack specialized organs like a penis or vagina for sperm transfer. During copulation, two worms align ventrally with their head ends pointing in opposite directions, positioning their male genital pores against the spermathecal pores of the other. The areas around the male genital pores are raised into papillae, which are successively inserted into the spermathecal pores of the other worm. These papillae discharge a spermatic and prostatic fluid containing spermatozoa, which are stored in the spermathecae of the other worm. After the mutual exchange of sperm, the two worms separate. Later, each worm lays eggs in cocoons, where external fertilization takes place within the cocoon.

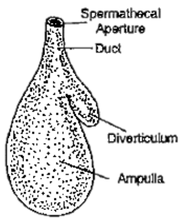

Fig. 2.29: ***Pheretima*. A spermatheca**

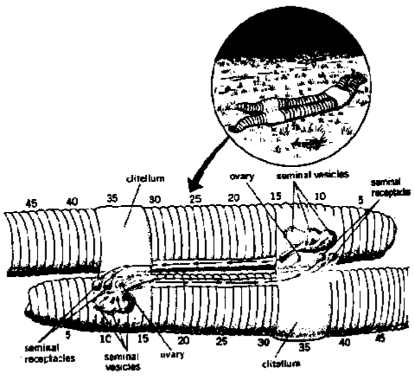

Fig. 2.31: ***Pheretima*. Two worms in copulation**

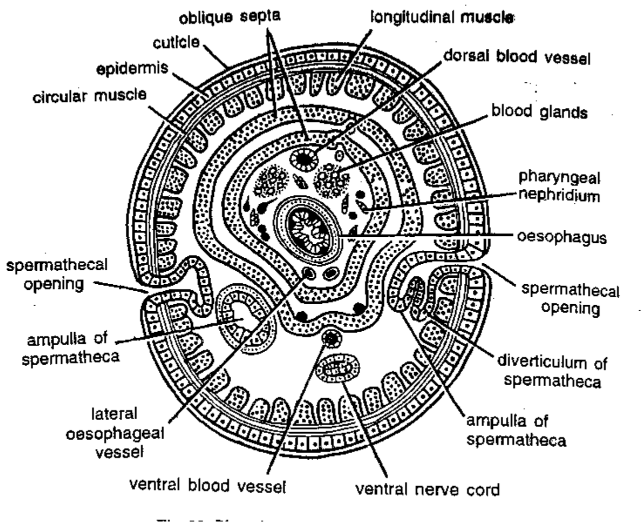

Fig.2.30: *Pheretima*. T.S. body through spermathecae

In *Eutyphaeus waltoni*, the area surrounding each spermathecal pore is raised to form a papilla, which closely fits into the male genital cup temporarily formed around each male genital aperture of the other worm. During copulation, the end of each worm's common spermatic and prostatic duct everts to form a penis, which bears a pair of penial setae. These setae are inserted into the spermathecal pore of the other worm, allowing the transfer of spermatozoa into its spermatheca.

Cocoon Formation

Cocoon formation in *Pheretima* has not been studied in detail. However, in other earthworms like *Eisenia* and *Rhynchelmis*, the cocoon is secreted as a sticky, gelatinous substance by the clitellar glands, forming a broad membranous band or girdle around the clitellum. This substance gradually hardens upon exposure to air, forming a tough yet elastic tube, which becomes the cocoon or egg capsule. Additionally, epidermal mucous cells of the clitellum secrete a slime tube over the cocoon.

As the worm wriggles backward, the slime tube and cocoon are pushed forward over the head. Along this path, the cocoon receives ova from the female genital aperture and sperm from the spermatheca of the other worm, ensuring cross-fertilization and the formation of zygotes. An albuminous fluid, secreted by glands from specific body segments, is also deposited inside the cocoon. Once the cocoon is slipped off the head, its elastic ends close, forming a yellowish, rounded cocoon. Fertilization occurs inside the cocoon after it has been deposited in a moist location. In *Pheretima*, the cocoon is a small, spherical body, light yellow in color. Cocoon formation typically occurs during the summer, particularly during and after the monsoon season. Multiple cocoons may be produced in succession after each mating, ensuring that not all sperm stored in the spermathecae are used at once. (fig: 2.32)

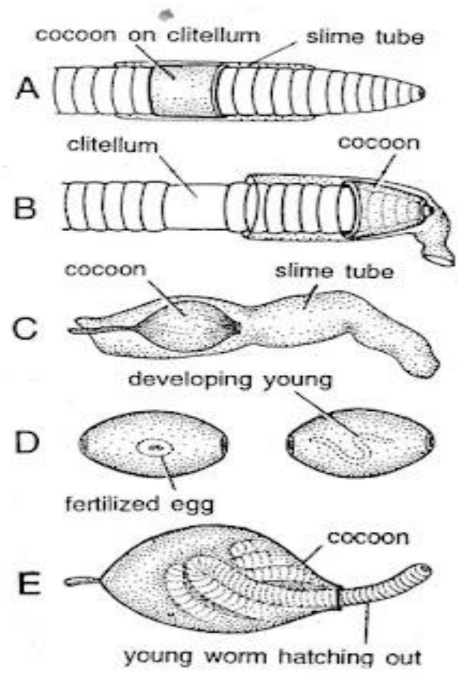

Fig. 2.32: *Eisenia foetida*. Stages of cocoon formation. A-Slime tube and cocoon formed. B-Earthworm withdrawing posteriorly. C-Cocoon left in its slime tube. D-Cocoon with fertilized egg and developing Young. E-Young worm hatching out of the cocoon

Development

A cocoon may contain many fertilized eggs, but only one embryo develops, at the expense of other eggs used as nurse cells and albumen stored in the cocoon. Cleavage is holoblastic and uneven and development occurs directly without a free larval stage. Invagination causes a hollow blastula to form, followed by a gastrula. Mesoderm arises from two enormous blastula cells known as mesoblasts. They divide into two mesoblastic bands, which eventually give rise to the coelomic epithelial lining. When a young worm is completely grown, it crawls out of its cocoon in two or three weeks. A newly hatched baby worm receives no parental care and resembles an adult except for size and the absence of clitellum.

Regeneration and Grafting

Earthworms do not reproduce asexually, but they have a high ability for regeneration. If the ends of the body are accidentally cut or removed, a head or tail is regenerated to replace the missing component. Earthworms can also do this. Some atypical varieties, such as Planaria, have been made experimentally as worms with two tails, short worms by grating together two terminal portions, or unusually long worms by connecting together end-to-end segments of many worms. However, such freaks do not survive since they cannot eat.

Adaptations of Earthworm

Earthworms are highly adapted to their subterranean or burrowing lifestyle.

1. Their elongated, slender, cylindrical and streamlined body shape is ideal for burrowing through soil.
2. Setae (bristle-like structures) and well-developed musculature aid in both movement and anchoring the body firmly within their burrows.
3. They secrete mucus to line the internal walls of their burrows.
4. Coelomic fluid, which seeps out through dorsal pores, keeps the skin moist, allowing for gaseous exchange in the absence of respiratory organs.
5. Amoebocytes in the coelomic fluid help destroy harmful bacteria and parasites, providing protection to the body.
6. Their nocturnal and burrowing habits offer protection from predators.
7. Due to their burrowing lifestyle, they lack specialized sensory organs such as eyes and ears.
8. Hermaphroditism and their ability to regenerate help ensure the survival of the species despite life's many challenges.
9. Reproduction on dry land is facilitated by copulation, followed by the formation of cocoons for fertilization and development.

Economic Importance

Earthworms, though simple and common creatures, hold significant economic importance for humans. They may be small, but they provide direct and indirect benefits to us. Without them, our planet would be quite different.

1. **As Bait and Food**. Earthworms are widely used as bait for fishing all over the world. Various methods are employed to extract them from their burrows for large-scale collection. Some of these methods include jarring the soil by striking a stick inserted into the ground, pouring toxic chemical solutions like mercuric chloride, or even applying electric currents. Earthworms also serve as excellent food for fish in aquariums. A small white earthworm species (*Enchytraeus albidus*) is often cultivated in soil to feed aquarium fish and small laboratory animals. In some parts of the world, earthworms are used as food by indigenous peoples. Additionally, many birds, particularly robins and chickens, eagerly hunt them for food. Frogs, moles, lizards, small snakes, centipedes and other predatory invertebrates also consume large numbers of earthworms.
2. **In agriculture**, earthworms are generally beneficial. Although they may occasionally harm young and delicate plants, they are valuable allies to gardeners and farmers, as they continuously till and fertilize the soil. Their burrowing and ingestion of earth contribute to soil fertility in various ways. Their tunnels allow air and moisture to penetrate porous soil, improve drainage and facilitate deeper root growth. The grinding of soil in their gizzard serves as an efficient form of soil "cultivation." Earthworms also drag dead leaves into their

(ISBN: 978-93-48620-26-2)

burrows, using them both to make their underground habitat more comfortable and as food. These leaves are only partially digested and the remains are thoroughly mixed with their castings, adding humus to the soil. Over time, earthworms have contributed to the formation of much of the world's vegetable mould. However, the claim that adding earthworms to unproductive land will significantly boost fertility is inaccurate. The excretory wastes and other secretions of worms further enrich the soil by adding nitrogenous substances, which are essential nutrients for plants. Earthworms have a significant impact on soil turnover. One acre of land may contain around 50,000 earthworms and the amount of soil they bring to the surface as castings has been estimated by Darwin to be about 18 tons per acre per year. In recent years, there has been increased emphasis on earthworm farming to enhance soil fertility.

1. **In medicine**, earthworms were historically used in various treatments. Hamdullah Mustaufi of Qazwin, in his work *Naizat-ul-Qutub* written in 1340 A.D. and Damari in *Hayat-ul-Haiwan* (The Life of Animals), written in 1371 A.D., describe medicines made from earthworms to treat bladder stones, jaundice, pyorrhea, piles, rheumatism or gout, diarrhea, post-pregnancy weakness and sexual impotence. Even today, earthworms are reportedly used in traditional medicines in China, Japan and India.
4. **In laboratories**, earthworms are easily accessible and are a convenient size for dissections. For this reason, they are commonly used in educational settings and in general and comparative physiology research.
5. **Harmful worms:** In certain situations, earthworms can become harmful. Their burrows may lead to water loss by seepage from ditches in irrigated lands and their castings on sloped terrain can be washed away by rain, contributing to soil erosion, though to a lesser degree. Some species act as external parasites on frogs and humans. Occasionally, they invade buried animal carcasses, potentially bringing disease-causing germs to the surface, which could then infect other animals. Earthworms are also known to act as intermediate hosts in the transmission of parasites like the tapeworm (*Amoebotaenia sphenoides*), the gapeworm (*Syngamus*) in chickens and the lung nematode (*Metastrongylus elongatus*) in pigs. The latter parasite carries a virus, which, along with a bacterium, contributes to swine influenza. Additionally, some species are considered plant pests. *Pheretima elongata* is suspected of damaging the roots of betel vines (*Piper betel*) in Coimbatore, while *Malabaria podudicola* and *Aphanascus oryzivorus* are reported to harm paddy roots in Malabar. A species of *Perionyx* also damages cardamom stems in the Anamalai Hills.

Chapter 3
EARTHWORMS FOR VERMICOMPOSTING

An invertebrate with segments is the earthworm. Because of the liquid known as coelomic fluid, which is situated between the alimentary canal and the body wall, the organism's body retains its tube-like structure. The body of an earthworm is long and cylindrical and its head is pointed. Certain species have a somewhat flattened rear end, while other species have a completely cylindrical shape. The earthworm can twist and turn because of the rings that round its soft, fluid body especially because it lacks a backbone. The earthworm can crawl because it lacks true legs and can move its bristles, or setae, back and forth on its body. The surface of the earthworm is used for breathing. Food is swallowed and enters a structure called a crop, which resembles a bag. Certain animals lack a noticeable crop. 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: 3.1)

Fig. 3.1: Earthworms

Distribution

Earthworms can be found practically anywhere in the world, with the exception of regions that are always covered in snow or ice, mountain ranges, deserts and regions with little to no soil or flora. Peregrine species are those that are widely distributed, whereas endemic species are those that are unable to successfully expand to new locations.

Factors affecting distribution

The physical and chemical properties of the soil, including temperature, pH, moisture, organic matter content and soil texture, have an impact on the distribution of earthworms in the soil.

Temperature

The effects of temperature on earthworm activity, metabolism, growth, respiration and reproduction are substantial.

pH

pH plays a critical role in determining earthworm dispersal as they are sensitive to hydrogen ion concentration. The distribution and number of earthworms in soil are influenced by pH and pH-related variables. The majority of earthworm species, according to a number of researchers, favour neutral pH of soil. There is a strong positive relationship between pH and juvenile and young adult seasonal abundance.

Moisture

Since that 75–90% of an earthworm's body weight is made up of water, preventing water loss is essential to their existence. They can, however, withstand extremely dry conditions by either evacuating or migrating to an area with higher moisture content. Because different earthworm species have varying moisture requirements in different parts of the world, earthworm activity is determined by the availability of moisture in the soil. The quantity and biomass of earthworms are also influenced by soil moisture.

Organic matter

The distribution of organic matter has a significant impact on the dispersion of earthworms. Earthworm populations in low-organic matter soils are typically not very high. Numerous researchers have found a significant positive relationship between the amount of organic matter in the soil and the number and biomass of earthworms. (Ismail,1997).

Soil texture

Because soil texture affects other qualities, like cation exchange capability, nutritional status and soil moisture connections, all of these factors have a significant impact on earthworm populations.

Table 3.1: A list of common earthworm species suitable for vermicomposting

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

Some of these species identified as most suitable for breaking down solid wastes are: *Eisenia foetida* (and the closely-related *E. andrei*), *Eudrilus eugeniae* and *Perionyx excavatus*. 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 are the common species.

FAMILY: LUMBRICIDAE

1. Bimastos parvus (= Allolobophora (Bimastos) parvus Eisen)

Belongs to the lumbricidae family and has a wide distribution. India: Kashmir (Gorai and Srinagar); Himachal Pradesh (Kasauli, Barog, Simla and Kotkhai); Punjab (Ferozepur and other places); Rajasthan (Pratapgarh); and Uttar Pradesh (Nainital).

Initial Differentiating Characteristics: Brownish red body with saddle-shaped clitellum, dorsally converging six or more segments, from XXV or XXV to XXX; length 25-40 mm; diameter 1-2 mm; total segments 85-111, usually 90 Other characteristics are morphological and can only be differentiated by an expert for confirmation.

Note

i. Parthenogenetic, with 1–6 individuals in a cocoon. Breeding biology merits investigation.
ii. In temperate areas, allied species such as *Allolobophora chloritica*, *Dendrobaena rubida*, *Eisenia hortensis* and *Lumbricus rubellus* are utilized in vermitechnology. With the exception of *E. hortensis*, all of these species are well-established in temperate India.

Obviously, in such areas, vermitechnology with these species warrants consideration, as live individuals would be more easily available in nature and more suited to local conditions. Only one search is required to learn about the local distribution or incidence in various places. As a result, for the convenience of users, a distribution range is provided.

The distribution of temperate species. (1) *Allolobophora subrubricunda* Western Himalayas, viz., Simla (H.P.), Sandakphu and Pallut, Darjeeling species may be predicted to be well established in most mountainous locations where Britishers had settled and imported plants for cultivation. 2) *Allolobophora chloritica*, can also be predicted in locations where British people settled. Current status should be determined through faunistic surveys. (3) J. Sephenson renamed *Dendrobaena rubida* to *Allolobophora rubida f. typica* Michaelsen and reported its distribution in Simla, but Indian taxonomists have yet to clarify the taxonomic status and current distributional status of species reported to occur in India.

The form appears to have been introduced by early British settlers. (4) Lumbricus rubellus Hoffmstr. was first identified from the Nicobar Islands in 1930 and its current distribution deserves more investigation because the species is widely utilized in vermiculture technologies around the world.

2. Eisenia foetida (Sav.)

Distribution: sewage dumps, sludge tanks are found practically everywhere in India. Most usually found naturally on sewage filter mesh grills. The only requirement is to locate in different regions, as the species is rather prevalent near most cities. Furthermore, with increased awareness, it has been frequently used in vermitechnology. In reality, many vermiculturists have been selling this worm under several names such as Red Worm, Pink Worm, Purple Worm, Tiger Worm, Brandling Worm and even vermiculture or vermicomposting worm.

In many technical works, the scientific name is incorrectly given as *Eisenia fetida*. Such inaccurate citations are technically incorrect. Except in very distant regions, most of us can collect and cultivate skills for mass multiplication.

Preliminary differentiating characters: Worms seem colored when they are alive (red, brown, purple, or even deeper). With careful attention, one may see bands, which are often two per segment. The ventral part of the body is whitish. Clitellum matures in 7-9 segment lengths across XXIV, XXVXXV, or XXVI to XXXII body segments. Ridges form on these as they mature.

Eisenia foetida is likely the most often utilized earthworm in vermicomposting. The species has also been widely used in many experiments, such as test earthworms. Some essential life aspects or qualities of the species, therefore, warrant examination.

Life worms are quite resilient and can with stand a wide range of temperatures and humidity. As a result, the method of species cultivation is rather simple. Feeding adaptability or adjustment to organic matter is quite good on a wide range of biodegradable/decomposable organic waste. On average, conversion efficiency ranges up to 7 mg/ worm/ day. So the growth rate is extremely rapid. Mature adults reach a body weight of up to 1.5 gm and can reproduce within 50-55 days of hatching from the cocoon.

On average, each mature worm produces one cocoon every third day and each cocoon hatches (within 23 days), producing one to three individuals. However, it is unlikely that all emerging individuals will survive. On average, numbers can multiply or rise by up to 30 times. Life lasts 70 days.

In general, live individuals do not travel outside the feed substrate (decomposing organic waste). When there is enough dampness in the substrate, live individuals swiftly go into it after being released at the surface. Many experts propose a humidity level or moisture content of 40% in the substrate, which can be generally estimated by inserting a circular bamboo stick. When inserted into the substrate, this should retain some or all of its sticking mass. In actual applications, trickling has shown good climatic temperature tolerance; however, in the tropics or India, a thatched roof protection over substrate medium is appropriate.

FAMILY: MEGASCOLECIDAE

Only six species of this family have been used in vermitechnology around the world. The species are Amythas diffrigens, Lampito mauriti, Metaphire anomala, Metaphire brmanica, Perionyx excavatus and Perionyx sansbaricus. Perionyx excavatus, which is endemic to India, is the most often utilized species. Its spread to other countries appears to have begun with an introduction in India. Given the benefits of indigenous species, such as their suitability to our conditions and distributional availability within our regions, it is vital to understand the distribution of various species in India.

For all taxonomic characteristics, discussions with specialists are required. Many people are unaware of the current taxonomic and distributional status of earthworm fauna, owing to a lack of up-to-date documentation on the subject. This type of evidence necessitates extensive research. As a result, the current descriptions are confined to a select few species.

1. Lamptio mauritii (Kinb.)

The species was previously known as Megascoles mauritii (Kinb.). Distribution. Throughout India, except in Uttar Pradesh, where the current distribution is unknown. Other regions in India where this has been documented include Kapurthala, Punjab, several districts of Bengal, Gujarat and Maharashtra. Gujarat, Madhya Pradesh, Southern Rajasthan andhra Pradesh, Tamil Nadu, Goa, Kerala, the Andaman Islands and Lakshdweep Island. According to reports, the species is common in South and Southeast Asia.

Preliminary differentiation characters: The body is dark yellow except for the anterior end, which has a purplish hue. Total body length ranges from 80 to 210 mm, with a diameter of 3% to 5 mnm and 166 to 190 body segments. Clitellumn has four body segments ranging from XIV to XVII and is ring-shaped. Male pores on papillae, female pores close each other in pairs on the XIV segment and spermathecal pores in three groups.

2. Metaphire anomala Mich. (= Pheretima anomala)

Distribution: Reported from Sibpur, Calcutta. The current distributional status requires further investigation (in light of the benefits of vermiculture) and is excluded from Orrisa, Bihar, South-East Madhya Pradesh andhra Pradesh, Tamil Nadu, Karnataka and Kerala, as well as a portion of Maharashtra.

Preliminary differentiation characters: Body colorations have not yet been studied. The overall body length is 80-90 mm, the diameter is 5 to 5.5 mm and there are 130 body segments. Clitelum, ring-shaped encompassing three body segments, L.e. XIII-XVI, XIV ventrally with setae. Spermathecae pores are lacking, but copulatory papillae exist in pairs.

Details about species' performance in vermiculture activities and what they seek. Similarly, further information is needed on Metaphire birmanica (Rosa), which has been reported from Bhamo, Burma but produces huge castings in masses of up to 1.2 kg. This indicates prospective use in compost heaps.

3. Metaphire posthuma (or Pheretima posthuma)

This is likely the most widespread species in India and the late Prof. K.N. Bhal has provided the most thorough morphology and anatomical memory since 1930. Unfortunately, no more specifics on vermitechnological applications have been examined as of yet.

4. Perionyx excavatus, E. Perr.

Within India, Genus is thought to have spread from the eastern or western Himalayas downward in areas of abundant rainfall. Now, species may be extensively distributed and two foreign species, Perionyx excavatus and Perionyx sansbricus, are thought to have been brought from Australia or New Zealand, but are now established in India as peregrinus species. Only P. excavator is thought to be used for vermitechnology in various parts of the world. Evaluation of additional Perionyx species in vermitechnology is basically lacking.

Distribution: In India, the species is allegedly one of the most abundant worms in the Eastern Himalayas (Dibrugarh, Sadiya and Darjeeling), Western Himalayas (Kumaon District, Sahastradhara, Dehradun, Simla), Pilibhit, Bengal (Calcutta, Rajasthan, Sibpur), Maharashtra (Bombay) and the Little Andman Islands. Outside of India, Ceylon, Malay Archipelago, Siam, Cochin China and the Philippines. Many areas of Europe and America have invasive species.

Preliminary differentiation characters: Dorsal surface (top section) rich purple to reddish brown, lower side light. Total length 23 to 120 mm; diameter 2.5; clitellum ring-shaped, with five or fewer segments on XII or portion of XIII to XVII. Male pores in a depression (line or location). Spermathecal pores in 7/8 and 8/9 are almost the same distance as male pores.

Note: This species is one of the most abundant in many parts of India and it is quickly expanding due to vermiculture. The species is highly versatile and can survive varied levels of moisture and organic materials. So far, species have been recorded from dead wood, plant stems, leaves and moving rivers. Perionyx sansbaricus, an allied species, may also be found naturally in sewage or filter overflow drains. Indeed, both species' current habitats and habits require reassessment. Prof. R.D. Kale was dominant.

Several researchers have conducted studies on the breeding biology of P. excavatus in various parts of the world, especially with the goal of using the species in vermitechnology. Prof. K. Gunathilagaraj of Tamil Nadu April University has reported the following essential features:

The life cycle lasts +/- 46 days, with a daily growth rate of 3.5 mg and a maximum body weight of 600 mg. The reproduction rate is quick. Maturity occurs within 21-22 days and reproduction (cocoon laying) begins by the 24th day. The average cocoon formation rate is 1.1 per worm/day. This is about twice the reproduction rate of the most widely used worm vermiculture, Eisenia foetida. The number of hatchings from each cocoon varies; on average, it ranges between one and three. Prof. R. D. Kale, K. Bahu and R. V. Krishnamoorthy conducted experiments to demonstrate that the quantity of cocoons produced varied depending on the organic mass, with sheep dung medium producing the most and cow dung media producing the least.

The reproductive phase was, however, shorter in sheep dung media and had a lower longview than in cow dung media. Such points have a wide range of applications in cultural development and can be easily confirmed by regular observations of different species. The incubation time is stated to be 8.7 days, with an average of 1 to 3 hatchings per cocoon. Many believe that species is among the finest suited for vermicomposting in tropical areas.

5. Perionyx sansbaricus

Distribution: Widely diffused in India. However, records are incomplete due to a lack of survey reports. The species has been reported in natural environments in Gujarat (Baroda), Maharashtra (Igatpuri, Manmad, Wathur near Mahabaleshwar and Londa near Castle Rock), Madhya Pradesh (Khandwa and Kala Khund near Indore), South India (Coonoor and Kotagiri in the Nilgiris, Kodaikanal) and North India (Delhi and surrounding areas). Species are likely to be found in a variety of additional locations, however surveys are lacking.

Preliminary distinguishing characteristics of earthworms. The dorsal body coloration is purple, which is darker in the anterior half. On the bottom side (ventrally), the body is pale. Body length ranges from 32 to 63 mm, with a diameter of 2% to 3%. Total body segments range from 84 to 108. Clitellum is ring-shaped, with five segments extending over XII-XVII body segments. Male pores have varying area (XVIII). Spermathecal pores at the middle line: -6/7, 7/8 and 8/9. Other characteristics are morphological in nature and can be determined by comprehensive investigations or diagnostic descriptions.

FAMILY: OCTOCHAETIDAE

Species of this family are supposedly found across India, although are more often in tropical regions (such as the Indian Peninsula) and less frequently in temperate climes (such as northern India). This family's species are thought to be found in New Zealand and South Madagascar, in addition to India. Six species in the family appear to be potential for vermitechnology: *Dichogaster bolanui, Dichogaster curgensis, Disogaster saliens, Dichogaster affinis, Ramiella bishambari, Hoplochatella khandalensis, Hoplochatella suctoria and Octochaetona surnensis.*

These were suggested by Dr. J.M. Jhulka in 1993. However, according to Kubra Bano's book, only *Dichogaster curgensis* and *Octochateus* (Octochaetoides) *surnesis* (*Octochaelona surnensis*) are used in India for vermicultural purposes. As a result, relevant descriptions are currently limited to only these two sorts of species. Others receive merely introductory words.

1. *Octochaetus (Octochaetoides) surnensis*

Kubra Bano mentioned the species *Octochaetona surnensis* in 1991, which is most likely Octochaetus (Octochaetodies) surnensis Mich. As a result, the issue of description is addressed. Distribution: B Barkul and Sur Lake, Orrisa. Probably has a greater distribution span along the Indian Peninsular.

Preliminary distinguishing characteristics. The body grey is apparently tinted with a black hue dorsally on the front section. Body segment 113 (variation conceivable and verification required). Total length 75 mm, diameter 2 to 2.5 mm. Clietllum is divided into five sections, numbered XIII through XVII. It is formed like a ring. Male pores located in a square-shaped location on body segment XVII. Female pores are associated with spermathecal pores on segments VIII and IX, however they are inconspicuous.

2. Ramiella Bishambari (Steph.)

Distribution. Reported from Saharanpur, Uttar Pradesh, but more likely widespread throughout Northern India.

Preliminary differentiation characters: Body form is slender and drab in hue. The body is 35 mm in length, 1 mm in diameter and has 85 total body segments. Clitellum on the thin body section, divided into three segments (XIV to XVI). Other characteristics are difficult to distinguish for non-biologists.

SUB-FAMILY: DIPLOCARDINAE.

Stephenson classified this subfamily as Megascolecidae and combined two families based on taxonomic similarities. To avoid technicalities for the ease of non-biologists. This section focuses on species from the *Dichogaster* genus. *Dichogaster* species have a scattered distribution along the West Coast, in Rajasthan, the Gangetic Delta and the Darjeeling District. Obviously, species in the genus must have a more or less continuous range and warrant confirmation. So far, only two species, *Dichoqaster curgensis* and *D. travancorensis*, are deemed endemic to India; nevertheless, several species have been identified in Tropical Africa, the West Indies, Central America, the Malay Archipelago and Polynesia. The current descriptions are limited to those indicated for Indian conditions for vermiculture work.

1. Dichogaster bolaui (Mich.):

Distribution: Reported from South India (Ernakulum, Trivandrum and maybe the entire country), West Bengal (Rangamati, Sibpur, Calcutta and many other places), Gujarat (Kathiawar and Baroda), Maharashtra (Bombay) and Rajasthan (Bayana). Species are thought to be naturally distributed in several locations of India and require confirmation. Outside of India, species have been documented from Tropical Africa, America (except the east and west) and the West Indies

Preliminary differentiation characters: Body color is unpigmented; thus, it is most likely flesh-colored, which is pinkish brown. This, however, must be defined in technical terms. Body length is 20-40 mm, with a diameter of up to 1½ mm. Total body segments: 78-97. Clitellum is divided into 5 to 8 segments, which range from XIII or XIV to XVIII, XIX, or XX. There are two pairs of spermathecal pores and one female pore on each papillae. Prostatic pores on segments XVII and XIX.

2. Dichogaster affinis (Mich.):

Distribution. Reported in Gujarat (Baroda), Maharashtra (Bombay) and South India (Shasthancotah, Trivandrum and Travancore). Species can be expected in numerous locations that require confirmation. Outside India, species have been reported from Ceylon (Peradeniya and Anuradhapura), East Africa, Mozambique, Madagascar, the Comora Islands, Siam, the Cape Verde Islands and Colombia.

Preliminary differentiation characters: . Body coloration is not specified and is claimed to be colorless; it is most likely "hesh coloured" or pinkish brown. This must be specified by taxonomists. Total body length is 30-32 mm, with a diameter ranging from 1.2 to 1.5 mm. Total body segments: 140. Clitellum sadale-shaped, covering 8-10 body segments, from XIII or XIV to X or XXI1. Prostatic pores in two pairs on XVII. Spermathecal pores are two pairs on 1-3 midventral papillae on 7/9-9/10 or 8/9 and 9/10.

3. Dichogaster curgensis (Michael).

Distribution: South India is expected to be distributed in other areas of vermiculture (Coorg). Species Southern India. India (Moowad and Bhagmanola, preliminary distinguishing characters). Body Coloration 'even gray'. Total length: 65-75 mm; maximum of 90-110 total body segments. Clitellum) dorsally but less ventrally; diameter, Ca: 2 mm; prominent ring form that appears saddle shaped when incompletely developed. Clitellum covers eight segments ranging from XIII to XX segments. Male reproductive area appears depressed. Female pores on Segment XIV. Spermathecal pores are not clearly defined, with two pairs in 7/8 and 8/9. 4. Dichogaster saliens (Bedd.)

Preliminary differentiation characters: Body coloration is supposedly unpigmented, meaning it is slightly fleshy or pinkish. This must be specified by taxonomists. The entire length is 25-40 mm, the diameter is 1.5 mm and there are 96-120 body segments. Clitellum saddle shaped, covering seven segments from XII to XIX. Prostatic pores, one pair on a half-moon-shaped papilla in segment XVII. Spermathecal pores appear in two pairs on 7/8 and 8/9.

5. Ramiella Bishambari (Steph.)

Distribution. It was reported from Saharanpur, Uttar Pradesh.This endemic species is expected in a variety of additional places and its current distribution deserves confirmation given its importance in vermitechnology.

Preliminary differentiation characters: Body colouration is an indeterminate grey colour. This must be specified by taxonomists. The overall body length is 35 mm, the diameter is 1 mm and there are 85 body segments. The body appears thin. Clitellum consists of three segments numbered XIV-XVI and the body appears thin near the posterior end of the clitellum. Prostatic pores on segments XVII and XIX.

Preliminary distinguishing characteristics must be further defined for easy identification. A few people have recommended using *Hoplochaetella khandalensis* and *Haplochaetella suctoria* in vermitechnology. However, the current taxonomic position of these two species must be determined before vermiculturits can conduct additional research. On *Haplochaetella suctoria*, some information is known from the publication of J. Stephenson, who synomised the species as *Erythraeodrilus suctorius* (Steph.), hence the species is being addressed with.

6. Erythodraeodrilus sutorius (Steph.)

Distribution."Sawvordem, Portuguese, India". The current distributional status must be characterized using faunistic surveys inorder to understand the variety affinities reported from Marmugao, Goa and its potential applications in vermitechnology.

Preliminary differentiation characters: Body coloration: dorsally light brown, ventrally pale with a darker median stripe. The entire length is 140 mm, the diameter is 6 mm and there are 145 body segments. Male field or section differentiable in segment numbers XVII to XIX, having two pairs of prostatic pores in a depression containing three sucker-like structures within an oval shape. Spermathecal holes are found in two pairs on body segment VIII. E. suctorius variation affinities (Steph.) is said to differ from male-specific characteristics. The male area in the variation is inside body segment numbers XVII, XVIII and XIX, but the outer margin is oval-shaped and expands to XVI (on the anterior side) and XX (on the posterior side) and the prostatic pores are two pairs, XVII and XIX, with two sucker-like features at the anterior and posterior ends.

Taxonomic investigations on these two types would be fascinating from a variety of perspectives, including distributional area (more or less the same niche), but also displaying significant morphological differences. These papers suggest promising future study directions for biologists.

6. Ocnerodrilus occidentails (Eisen)

Distribution. India includes Rajasthan (Kota), Maharashtra (Bombay), Karnataka (Nedumangad and Travancore) and the Andaman Islands. Obviously, the species is likely to be present in many other regions as well, therefore the distributional status of Vermiculture distribution needs to be redefined. Outside of India, species have been reported from Panadhure, Ceylon, North America, Africa, Cape Verde and Comoro, which are known as "widely peregrine islands." Stephenson states, "The species has been species." Clearly, the species appears tolerant and adaptable to niche fluctuations.

Preliminary differentiation characters: Body color is not a factor in nominations. Taxonomists define and describe total body length (15). 30 mm in size, with a maximum extension of 38 mm when alive. Body diameter is 1 mm and there are 70 clitellum rings covering 6-8 segments from numbers XIII or XIV to XIX or XX. Male pores on a papillae on segment XVII.

FAMILY: EUDRILIDAE

Eudrilus eugeniae (Kinb)

Distribution. Originally disseminated over Equatorial West Africa. Presently found scattered (and maybe naturally occurring) in most parts of the world, having been introduced for a variety of applications in vermitechnology. It is common in portions of both America and Europe. In some parts of America, this species is commonly known as the Night Crawler. Recommended vermiculture species are widely used in many vermiculture enterprises in India, notably in Southern India. Since the 1930s, the species has apparently been found in Travancore, Pune and the North Konkan.

Preliminary differentiation characters: Worms seem "brown and red dark violet" when alive and their coloration is similar to animal flesh in general. The body length ranges from 32 to 140 mm, the diameter is 5-8 mm and the total number of body segments is 145–196. In mature adults, clitellum is divided into 5-6 segments, numbered XIII or XIV to XVII. Spermathecal and female pores join after 13/14 body segments. Male pores appear before 17/18 body segments.

Note: This species is arguably the fastest growing and second most commonly utilized earthworm in vermitechnology for composting and as vermi-protein. Growth is rapid (assimilation and conversion to biomass), outperforming other species by up to 12 mg per day. The maximum body weight obtained is 4.3 mg per individual. Maturity occurs within 40 days and a week later, individuals begin laying cocoons at a rate of about one cocoon per day or up to four cocoons per three days for 46 days, depending on the environment.

The total life span in the laboratory is predicted to be between one and three years. The cocoon incubation cycle lasts 16-17 days, with 2-3 individuals per cocoon. According to others, the number of people per cocoon might range from one to five. Low temperature tolerance is lower than Eisenia foetida, but high temperature tolerance exceeds 48°F in room circumstances, i.e., with indirect sun exposure. Under enclosed conditions, survival without significant disturbance to conversion capacity or limits is thought to range from 5°F to 48°F, given proper culture conditions.

Many assume that harvesting the species from culture heaps is difficult. However, an easy approach is to turn the heap and leave it for l-3 hours until all of the worms have moved to the lower layer. Compost can be collected from the top layers and worms can be replenished in culture media or harvested for further use.

Harvesting worms becomes necessary as reproductive activity declines and, as a result, composting activity reduces after the second or third year. In such cases, worms should be used for animal feed or buried in fields (a nitrogenous waste).

Prof. Kubra Bano, R.D. Kale and G.N. Gajanan investigated the nutritional value of casts of *Eudrilus eugeniae* prepared on six different diets and presented their findings. Nutritive characteristics ranged from pH 6.65 to 7.20, EC (m.mhos/ cm) 0.950 to 1.800, percent OC 3.84 to 5.04, percent N 0.455 to 0.560, percent P,O: 0.716 to 1.215 and percent K2O 0.075 to 0.115. When compared to other organic manures such as decomposed FYM, organic matter, cow dung and pig manure, these values indicated greater percentages of N (0.52), P2O5. (0.94) and K2O (0.999), with the exception of N in pig manure, which was just 0.03%. Karnataka has since published the Eudrilus cast.

FAMILY: MONILIGASTRIDAE

1. *Moniligaster perrieri (Mich.).*

South Indian at Kodaikanal and Tiger Shola in Palini Hills, Ponmudi and Bonnaccord, Karnataka. It is expected to be found throughout South India. The current distribution range requires further investigation.

Preliminary differentiation characters: Body coloration is blackish grey, which is darker above than on the ventral side. Total body length is 210 mm, with a diameter of up to 5 mm. Total number of body segments: 175. Clitellum ring-shaped, less noticeable at the anterior and posterior ends, with somewhat more than 5 segments from IX to XIV. Male pores on 10/11, 11712, or 12/13 are relatively laterally positioned in a hexagonal depression. Female pores are one pair, in 11/12 or on XIl or XIV. Spermathecal pores in 7/8 or 8/9 Cd. By habit, this species is semi-aquatic and can be found in water. This suggests that it is tolerant to high moisture levels.

2. *Drawida Willisi (Mich.)*

Distribution. Madhya Pradesh (Bilapur) and Andhra Pradesh. The present merits more investigation in light of the current distributional range of utilities in vermiculture.

Preliminary differentiation characters: Nearly 48 species have been recorded to occur in India. So, for non-biologists, it is impossible to distinguish. Differentiating species without a taxonomic key is difficult. The characters listed below are from Drawida willsi and are intended to enable and Vermicompost (Earthworm). Others can also differentiate up to the general level. Body coloration is commonly bluish grey or reddish grey, however the tints vary. The overall body length is 55-60 mm, with a diameter of up to 2.5 mm and 155-160 segments. Clitellum ring shaped, covering four segments of X-XIII.

There is a need to adjust and adapt our study curriculum and research programmes so that the necessary information can be developed progressively from across the country. After selecting acceptable species for vermiculture, it is important to begin the establishment of a mass culture for composting. This entails two steps: (1) maintaining the base or seed culture or mother culture and (2) multiplying for introduction in composting heaps or tanks.

Maintaining the base culture

Base, morther, or seed culture is a substance that is progressively multiplied for large-scale culture and use in various forms of vermitechnology. This must be carefully maintained and examined for the health of live individuals, as well as the conditions of the feed, which should not contain any chemicals that are fatal to worms. This means procurement point. Check organic waste for seepage and contamination of feed. For initial multiplication, the best feed substrate is cow dung manure that is more or less in the advanced stages of decomposition. Spread it on the ground to see if any parasites are present. The materials are then presented pre-treatment.

(ISBN: 978-93-48620-26-2)

Chapter 4
VERMICULTURE

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

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 Taxonomic classification of one of the species' of this family, *E. fetida* which is known as red worm, brandling worm and red wiggler worm is as follows:

Phylum:	Annelida
Class:	Oligochaeta
Subclass:	Clitelata
Order:	Haplotaxia
Suborder:	Lumbricina
Superfamily:	Lumbricoidea
Family :	Lumbricidae
Subfamily:	Lumbricinae
Genus:	*Eisenia*
Species:	*foetida*

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)**

Many species with deep pigmentation, including reddish-colored ones, inhabit the decomposing litter or organic matter that covers the soil's surface. Compared to actual soil-dwelling earthworms, they multiply and grow extremely quickly.

Some of the species commonly used in vermicomposting are *Dendrobaena veneta* (blue nosed worm), *Eisenia foetida* (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 dig persistent, vertical burrows down to a depth of two meters in the soil profile. By pulling dead organic material from the soil's surface into their burrows, ingesting it along with dirt and then egesting the mixture back onto the surface as nutrient-rich earthworm castings, they contribute to the creation of topsoil. These species are extremely valuable and have been successfully bred for land restoration initiatives. The Anecic species bury deeply in the ground, but they emerge at night to feed on recently decomposing leftovers. One beneficial species is *Lumbricus terrestris* (the lob worm). (Fig: 4.1)

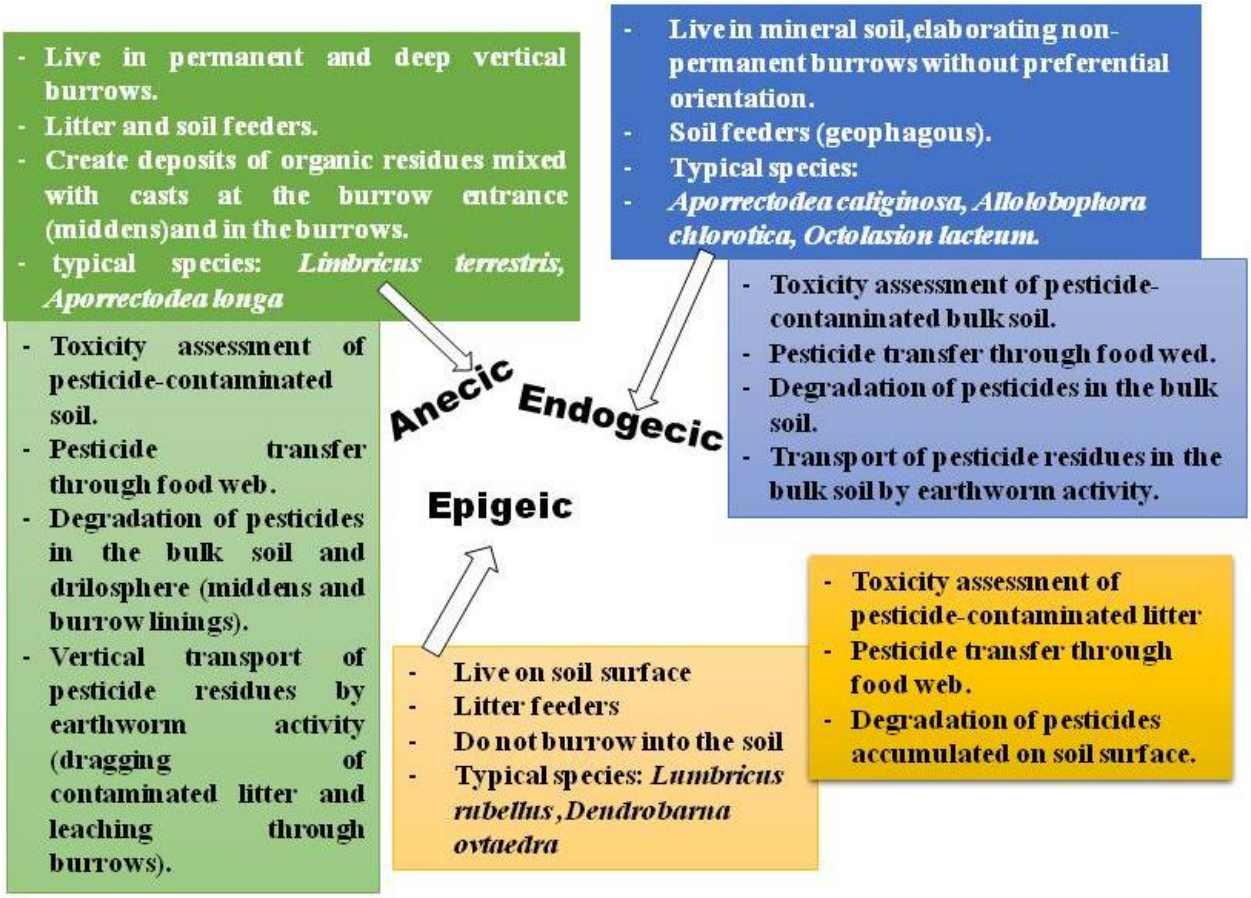

Fig. 4.1: Groups of Earthworm

Basic Requirements

Earthworms need these basic things for vermicomposting:

1. Bedding:

Any substance that gives the worms a reasonably stable home is considered bedding. The following qualities must be present in this habitat:

- High absorbency: Because worms breathe through skin, so these organisms require a damp environment to survive. A worm dies if its skin dries off. For the worms to flourish, the bedding needs to have a reasonable capacity to both absorb and hold water.
- Capacity of container: The flow of air is decreased or eliminated if the material is initially too dense or packs too firmly. Just as humans need oxygen to survive, so do worms. Numerous elements, such as the texture, strength and rigidity of the bedding's structure and the range of particle sizes and shapes, influence the bedding's overall porosity.
- Low protein and/or nitrogen content (high C: N ratio): It is crucial that the worms eat their bedding gradually, even though they do so as it decomposes. Elevated quantities of protein and nitrogen can cause fast deterioration and the warmth that follows, resulting in unfavourable and frequently deadly circumstances. In a vermiculture or vermicomposting system, heating is safe in the food layers but not in the bedding.

2. Housing:

It is advised to cultivate worms in a covered area to shield them from harsh sunshine and precipitation. Cheap units can be set up in backyards, basements and abandoned cowsheds or poultry buildings.

3. Containers:

A separation wall is to be built between each batch of bricks or cement tanks.

4. Environmental conditions:

The breeding, cocoon formation and hatching of juvenile earthworms are all impacted by the environmental factors, which are crucial.

a. Temperature

Temperatures for vermicomposting are typically kept below 35°C. The majority of worm species used in vermicomposting need temperatures between 10^0 C and 35^0C. Temperature requirements are largely similar across species, however tolerances and preferences differ. Earthworms can generally withstand colder, wetter weather significantly better than they can withstand hotter, drier weather.

b. Moisture

A lot of moisture is necessary for earthworm growth and survival. They require between 60 to 75 percent wetness. In order to prevent an anaerobic environment and push earthworms out of the bed, the soil shouldn't be very damp (Ronald and Donald, 1977). In order to ensure that the overall moisture level is properly balanced, it is crucial to moisten the dry bedding materials before placing them in the bin.

c. pH

Because they are pH sensitive, the majority of earthworms typically thrive in pH ranges of 4.5 to 9. The fragmentation of the organic materials as a result of several chemical reactions is what causes the pH to change in the worm bed. One of the main factors affecting earthworm distribution and abundance is the pH of the soil.

Nutrition

- The food source for earthworms is microbes, particularly fungus and nematodes.
- As organic wastes move through earthworm stomach the grinding action of their gizzards increases the surface area of the organic matter and encourages microbial activity.
- Aerobic bacteria are preferred over anaerobic ones when earthworms are fed.
- Vermicomposts have a wide range of microbial communities and are significantly more microbially active than their parent organic wastes.

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. It should be possible for worms to live on a variety of organic materials.
2. It should have a quick incubation period and a high fecundity rate.
3. There should be very little time between hatching and maturity.
4. It ought to experience less vermistabilization, or the dormant stage following an initial exposure to organic wastes.
5. Wide tolerance (adaptability) to environmental influences (ability to survive in fluctuating moisture and temperature);
6. Rapid development, brief incubation, abundant reproduction and rapid manufacture of cocoons
7. Rapid absorption, digestion and consumption rates for the breakdown of organic matter;
8. Simple to adapt to new cultures.

There is heterogeneity in the nutrient makeup of the vermicompost made with various earthworm species. Therefore, choosing the right species for a given vermicomposting application is crucial. The widespread usage of epigeic earthworm species for the vermicomposting of various organic wastes is well known. (Ismail,2005).

Microbiology

In the earthworm's alimentary canal, microorganisms coexist in a complex web of mutually beneficial relationships. *Eudrilus eugeniae*'s gut contains some of these microorganisms, which have recently been isolated and identified. (Ansari, A. A and Ismail, S. A., 2012; Prabha, M.L., et al 2014). *Proteus mirabilis, Staphylococcus aureus, E. coli* and *Klebsiella* sp. were among the many types of bacteria that were isolated and identified; *Aspergillus flavus, A. niger, A. ternus, Alternaria* sp. and *Pencillium* sp. were the fungi that were identified. The microbial population in earthworm casts is found to be significantly higher than that of the surrounding soil, despite the fact that these microorganisms are the same as those in the soils. In comparison to the nearby soil, earthworm casts typically contain larger levels of bacteria, fungus and actinomycetes as well as higher levels of enzyme activity. By making the worm-cast soil more stable than the surrounding soil, microbial activity in earthworm casts may have a significant impact on the structure of the soil crumb. When it comes to introducing microorganisms into soil, earthworms are crucial. Many soil microorganisms are in a state of dormancy, with little metabolic activity, until they find the right environment, such as the mucus or the gut of an earthworm, to become active. It has been demonstrated that earthworms boost soil microbial respiration overall, which promotes organic matter microbial breakdown.

Microbial action

Vermicompost is created by earthworms digesting waste. Alongside them are other creatures that contribute to the intricate process of dissolving the substance. The following outlines the general mechanism underlying this:

1. The earthworm's digestive tract processes the bacteria, nematodes, fungi, algae and organic substances that it has consumed. Most of the organic debris and bacteria pass through undigested as "casting," along with waste products from metabolites such proteins, urea and ammonium.
2. The worm also secretes mucus during this time, which contains proteins, polysaccharides and other nitrogenous substances. Worms produce numerous "burrows" in the material through eating and excreting, which aids in aeration.
3. While some bacteria prefer to exist without oxygen (anaerobic), others need it (aerobic). The sulphurous smell emanating from landfills and stagnant sewers is caused by anaerobic bacteria. Aerobic microbial growth is enhanced by the vermicompost's aerobic environment. The decomposition of organic nitrogen molecules into ammonia and ammonium occurs in tandem with this microbial growth. The unpleasant odour of anaerobes is overpowered by the pleasant-smelling aerobic process. This explains the pleasant scent of well-maintained worm compost piles.
4. The entire process breaks down organic debris and ruffles the surface of the burrow walls,

creating an environment that is advantageous for obligate aerobes (like *Pseudomonas sp*, *Zoogloea sp*, *Micrococcus sp* etc.). The rate at which the substance decomposes is increasing due to the ongoing rise of the microbiological population.

5. The material's ability to breathe reduces the production of ammonia and sulphide gases, which are odorous substances that are normally present in anaerobic environments. Because of the vermicast-associated bacteria, offensive odours quickly go away.

Reproduction

The clitellum is a noticeable band that surrounds the body of mature worms. This often manifests between the ages of 8 and 12 weeks. The worms will mate at the clitellum, sometimes staying together for a considerable amount of time. There is a trade of reproductive materials. A ring of mucus substance forms at each worm's clitellum when the worms divide. We call this procedure copulation. (Fig: 4.2)

Fig. 4.2: Copulation

The other worm's sperm are kept in sacs. The sperm and eggs inside the worm are covered in mucus as it travels over it. Both ends seal after escaping the worm, creating a lemon-shaped cocoon that is about 3.2 mm long. In around three weeks, one end of the cocoon will hatch into two or more baby worms. 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: 4.3)

Fig. 4.3: cocoon

Calculating Rates: If the following conditions are met, epigeic worm populations reproduce extremely quickly, doubling every 60 to 90 days.

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/m2 but not more than 5 kg/m2

The weight (beginning) of worm biomass per unit area of bedding is referred to as "stocking density." For example, the first stocking density would be 2.5 kg/m2 if we began with 5 kg of worms in a bin with a surface area of 2 m2. At very low concentrations, fast reproduction will not start right away and may even halt altogether. It is evident that worms require a specific density to increase their likelihood of seeing one another and procreating regularly. They simply don't discover each other as frequently as a conventional worm grower would like at lower concentrations.

Nonetheless, as competition for food and space increases, densities greater than 5 kg/m2 cause them to start slowing down their productive desire. Worm densities for vermicomposting are typically between 5 and 10 kg/m2, while they can go as high as 20 kg/m2.Worm growers typically stock at a density of 5 kg/m2, "splitting the beds" when the density has doubled, presumably because by then the optimal densities for reproduction have been exceeded. When following the aforementioned criteria, worm biomass should double every sixty days or so for growers. This implies that a starting stock of 10 kg of worms may theoretically grow to 640 kg after a year and around 40 tones after two years.

The following are the primary obstacles to reaching ideal rates of reproduction: Absence of expertise and experience It takes both science and a "green thumb" to grow worms. In addition to having the necessary knowledge, you must practice in order to gain proficiency. Insufficiently focused resources monitoring the situation and taking appropriate action are necessary to increase worm populations.

It requires work and time to accomplish this. The worms will probably survive if the windrows or beds are ignored, but their number will not grow as quickly.

Life cycle and population

Due to their hermaphrodite nature, earthworms can be either male or female (Diaz Cosin, D.J., *et al.*, 2011). All worms still need to mate with other members of their species in order to procreate, though. Any two adult worms can team up to fertilise each other's eggs during mating. The fertilised egg is enclosed in an egg-case or cocoon that descends from its mouth into the earth by a mucous tube released by the clitellum, covering its head. The size of a matchstick head, these cocoons change colour as the young worms grow. They begin as a pale yellow colour and turn reddish-brown when the hatchlings are ready to emerge.

Each species has a different number of cocoons and a different hatchling period depending on the environmental factors. Although the earthworm's natural lifespan is unknown, scientists believe it to be roughly three years. The amount of food, accessible space and environmental factors all act as self-limiting factors on the earthworm population.

Multiplication

Earthworms can be multiplied in a cement tank, wooden box, or plastic bucket with adequate drainage facilities using a 1:1 mixture of decomposing leaves and cow manure. The worm nucleus culture must be added to the mixture above at a rate of 50 worms per 10 kg of organic waste that has been adequately mulched with straw or dried grass in a moist gunny bag. The device needs to be kept in the shade. An occasional misting of water will help to maintain a sufficient moisture level. The worms grow 300 times in 1-2 months, which is useful for large-scale vermicomposting.

It was determined whether municipal biosolids and cattle manure were suitable substrates for vermicomposting and it was found that the substrate including dry olive cake produced greater weights of freshly hatched earthworms. In a different study, maize straw was discovered to be the best feed material for the tropical epigeic earthworm, *Perionyx excavatus*, when compared to soybean (*Glycine max*), wheat, chickpea (*Cicer arietinum*) and city garbage.

(ISBN: 978-93-48620-26-2)

Chapter 5

VERMITECHNOLOGY IN WASTE MANAGEMENT

Open dumping is the most common method of solid waste disposal in many developing countries. However, this approach has become increasingly costly and harmful to the natural environment. As a result, there is a pressing need to explore the potential of earthworms in waste management. For thousands of years, earthworms have been enriching soil, making it suitable for plant colonization and growth and they have significantly contributed to agriculture. Their importance in waste disposal and management systems is becoming more evident. In large-scale, dense populations, earthworms are capable of processing nearly all types of biological waste.

Vermitechnology, which leverages the natural ability of earthworms, has the potential to manage large amounts of organic waste and is considered a viable industrial process capable of continuous commercial operation (Sharma *et al.,* 2005). The central component of the system is the process bed, where millions of earthworms are consistently fed organic waste and the stabilized organic matter produced by the worms, known as vermicompost, is harvested.

Feeds for Vermitech systems

Vermitech systems rely on various organic materials as feed for earthworms. These systems can utilize a wide range of organic waste, including animal manure, agricultural residues, kitchen waste and other biodegradable materials. The choice of feed impacts the efficiency of vermicomposting and the quality of the vermicompost produced. Organic materials rich in nutrients, such as cattle manure, are often preferred, as they promote optimal growth and reproduction of earthworms. Pretreatment of certain wastes, like poultry manure, may be required to reduce harmful elements before they can be effectively used in the system.

Animal manures

The use of animal manure as a primary feed for earthworms is widespread in vermitech systems. Among all animal wastes, cattle manure is the most ideal for increasing earthworm biomass, as it typically lacks substances that inhibit earthworm growth. Cow dung slurry serves as a suitable substrate for vermicomposting, whether mixed with solid materials or applied to bedding materials containing earthworms. Horse manure is also beneficial for earthworm growth. According to Manaf *et al.* (2009), horse manure contains 0.7% nitrogen, 4.38% protein, 60% organic matter, along with trace amounts of phosphoric acid and potassium oxide (Ronald and Donald, 1977), making it suitable for direct use as feed. Pig waste is likely considered the most productive for growing earthworms. Poultry manure has the highest content of protein, nitrogen and phosphoric acid compared to other animal manures. However, fresh poultry waste contains significant amounts of inorganic salts, which, if used directly, could jeopardize the worms' survival (Edwards, 1988). These wastes need to be pretreated through composting, washing, or aging to reduce inorganic salt levels and lower the heating potential.

Kitchen Waste and Urban Waste

Residential and commercial sectors account for approximately 50 to 70 percent of the total municipal solid waste (MSW) produced in a community. This solid waste can be categorized into two types:

A. Biodegradable or Organic – includes kitchen waste, straw, hay, paper and animal excreta.

B. Non-biodegradable – consists of materials such as ash, stone, cinders, plastics, rubber and metals.

Food waste from households, restaurants and yard waste is highly beneficial for earthworm growth (Gandhi *et al.*, 1997; Bharadwaj, 2010). Kitchen vegetable scraps and yard waste create an ideal feed bed for cultivating earthworms. Earthworms can process municipal biosolids along with green mulch, converting about two-thirds of the material into vermicompost (Giraddi *et al.*, 2008; Singha, 2011).

Paper Pulp and Cardboard Solids

Paper and cardboard are ideal materials for both feeding and bedding earthworms due to their high cellulose content. Earthworms break down cellulose more rapidly than proteins and other carbohydrates, converting it into usable nutrients. These wastes do not require special pretreatment and can be directly applied as feed. In a recent study, Basheer and Agrawal (2013) successfully used the epigeic earthworm *Eudrilus eugeniae* to convert paper waste into vermicompost.

Compost and Waste Products

Spent mushroom compost serves as an effective medium for growing earthworms, despite its low plant nutrient content. Brewery waste, on the other hand, requires no adjustments in moisture levels and can be processed rapidly by earthworms.

Industrial Wastes

Wastes from canning plants and potato or corn chip manufacturing units are excellent food sources for earthworms. Similarly, waste from vegetable oil factories is also suitable as feed (Kale, 1998). Substrates like logging and carpentry waste, as well as byproducts from sugar factories, can be used to feed earthworms. When earthworms are reared in a 1:1 mixture of sawdust and press mud, the resulting castings show 1.2 times more Colony Forming Units (CFU) than sawdust alone and 1.6 times more than press mud alone (Parthasarathi *et al.*, 1999). Earthworms also have the ability to partially detoxify wastes. Fly ash, a waste product from thermal power plants, poses significant disposal challenges due to its heavy metal content, although it is rich in microbial biomass. Studies have shown that a mixture of organic waste—

such as sisal green pulp, Parthenium and green grass clippings—combined with 25% fly ash, can be a valuable feedstock for *Eisenia fetida* biomass production.

The vermicompost produced contains a higher NPK (nitrogen, phosphorus, potassium) content than other commercially available manures. In some instances, earthworms are also employed to manage distillery waste, which includes malt waste, spent grain wash, yeast and molasses settled at the bottom of lagoons. Seenappa *et al.* (1995) noted that the ratio of cow dung and leaf litter to distillery waste and press mud should be balanced to positively influence earthworm biomass growth and production. Lakshmi and Vijayalakshmi (2000) reported that filter press mud from sugar factories could serve as feed in vermicomposting units, with worms converting it into nutrient-rich manure while improving its physico-chemical properties. Murali *et al.* (2011) demonstrated that coir waste could be transformed into vermicompost using *Eudrilus eugeniae*. Additionally, studies by Sreenivasan (2013) showed that chip wash residue, a type of wood waste from wet-process hardboard factories, could also be converted into vermicompost with the help of *E. eugeniae*.

Other Applications

1. In Aquaculture

In aquaculture, land spreading is the most common method of solid waste disposal, but it leads to pollution of soil, surface and groundwater, which can result in the premature death of aquatic organisms. Vermicomposting of such waste helps to control water and soil pollution, thus promoting the survival and growth of fish, prawns and other aquatic species in their natural habitats. Applying vermicast, a high-quality organic fertilizer, to aquaculture ponds reduces input costs and enhances profitability. It also mitigates the harmful effects of any residual chemical fertilizers in the water.

Large-scale vermiculture offers the potential to produce earthworm meal as a replacement for fishmeal (Pucher *et al.*, 2014). Earthworm meal provides all the essential amino acids required in fish feed, with higher levels of methionine and lysine compared to standard fishmeal. Additionally, the demand for protein-rich raw materials is growing in other animal feed industries.

2. Vermifilter

Groundwater Recharge

Earthworms enhance hydraulic conductivity and natural soil aeration by granulating clay particles. They also break down silt and sand particles, increasing the overall specific surface area, which improves the adsorption of organic and inorganic substances from wastewater. This makes vermifilters particularly effective for treating dilute wastewater, such as sewage. The figure illustrates a vermifilter that can be used for groundwater recharge, with a wastewater loading rate calculated at $2m^2$ per m^3 of sewage. Earthworms ensure bio-sanitation and prevent "sewage sickness" by regenerating the adsorption capacity through bacterial farming and by grazing on excess bacterial biomass (Bhawalkar, 1995).

Water Recovery

Vermifilters can be designed with either single or multiple stages, depending on the wastewater's strength and the desired quality of the treated water. A single unit, in principle, can achieve any level of water purity by increasing the recycling ratio, which reduces the organic load. The first stage performs rough filtration, while the second stage provides fine polishing (Bhawalkar, 1995).

Table 5.1: Different feeds for earthworms and their properties

Type of Feed	Advantages	Disadvantages	Remarks
Cow dung	Proper nutrition comes from natural food, requiring minimal care.	The presence of weed seeds makes pre-composting essential.	All manures should be partially decomposed before being consumed by worms.
Poultry droppings	A high nitrogen (N) content leads to excellent nutrition and a nitrogen-rich product.	High protein levels can be harmful to worms, so they should be mixed with other organic residues or pre-composted.	Poultry manure is generally considered unsuitable for worms due to its high temperature. However, research suggests that worms can adapt well if the initial poultry manure-to-bedding ratio is 10% or less by volume.
Sheep/ Goat excreta	Good nutrition	Pre-composting is necessary to eliminate weed seeds and the small particle size can cause compact packing, requiring additional bulking material.	With the appropriate additives to enhance the C:N ratio, these manures can also serve as effective beddings.
Pig waste	Proper nutrition results in high-quality vermicompost.	Typically found in liquid form, it must either be dewatered or combined with a large amount of highly absorbent bedding.	Vermicompost produced from pig manure surpassed all other vermicomposts and even commercial fertilizers.

Agricultural waste	Higher nitrogen content make these good feed as well as reason able bedding	Moisture levels not as high as other feeds; requires more input and monitoring	For improved results, combine this feed with animal manures.
Horse excreta	It has the potential to be an excellent material for vermiculture.	Its nitrogen content is lower than that of cow dung, while its C:N ratio is significantly higher.	For improved results, combine this feed with animal manures.
Aquatic weeds	Proper nutrition leads to a superior product that is rich in micronutrients and beneficial microbes.	Salt must be rinsed off because it harms worms and its availability differs by region	Certified organic vermicompost is made from cattle manure and seaweed, while water hyacinth has been evaluated as a feedstock for earthworms.
Pre consumed vegetable waste	A higher nitrogen content produces an excellent product and worms favor this material.	The moisture level is high and requires careful monitoring.	Pre-consumed vegetable waste can be vermicomposted within 8-10 days.
Paper waste	This material provides excellent nutrition, which is highly favored by worms.	The material must be shredded and/or soaked (if non-waxed) before feeding.	Some worm farmers suggest that corrugated cardboard enhances worm reproduction
Municipal Solid Waste (MSW)	Proper nutrition leads to an outstanding product that is rich in micronutrients.	Precautions must be taken to control harmful microorganisms when using sewage sludge.	The Institute of Natural Organic Agriculture (INORA) has developed methods for vermicomposting municipal solid waste (MSW).

Source: CCS HAU, Hisar

Chapter 6
VERMICOMPOSTING: BASIC PROCESS

Vermicompost is made in five steps. The process occurs in the mesophilic temperature range of 30 to 35°C. The following are the several stages of the process:

Initial pre-composting phase: Before being fed to earthworms, the organic waste is pre-composted for approximately 15 days. This stage involves the breakdown of easily broken down chemicals and the removal of potentially volatile substances that could be harmful to earthworms. In order to prevent heating within the worm system, pre-composting the feedstock lowers the amount of energy contained in the material. Feedstock that has been pre-composted for ten to fourteen days keeps the worms sufficiently nourished, but not so much that they can produce heat (Nair, *et al.,* 2006).

Mesophilic phase: The predigested waste should be combined with 30% animal manure, either by weight or volume. Fill the tub or container to the brim with mixed garbage. The moisture level should be kept at 60%. If necessary, sprinkle water over the bed instead of pouring it. The selected earthworm is uniformly distributed over this substance. For a one-meter length, one-meter breadth and 0.5-meter height, 1 kg of worm (1000 pieces) is needed. During this phase, earthworms combine organic matter with soil particles, promote microbial activity and condition organic waste products to generate organic manures.

Maturing and stabilization phase: Earthworms play a dual role in the vermicomposting process, acting both physically and chemically. Fragmentation occurs when the organic materials are physically broken down, which increases the surface area available for additional microbial colonisation. Enzymatic digestion, enrichment by nitrogen excretion and the movement of both organic and inorganic material are the biochemical processes involved in the breakdown of organic matter.

The substance quickly transforms the locked-up forms of calcium, phosphorus, potassium, nitrogen and other minerals into forms that are far more soluble and accessible to plants than the parent material as it passes through the earthworm intestine. This is made feasible by a variety of digestive enzymes found in their stomachs as well as specific types of ingested microbes, enzymes such as proteases, lipases, amylases, cellulases, chitinases, etc., which break down the proteinaceous and cellulose elements found in organic waste. The earthworms and the microbes they eat for the purpose of breaking down the organic stuff in their food appear to have evolved a mutualistic connection. Thus, the combined activities of the microorganisms and earthworms result in the final quality of the vermicompost.

(ISBN: 978-93-48620-26-2)

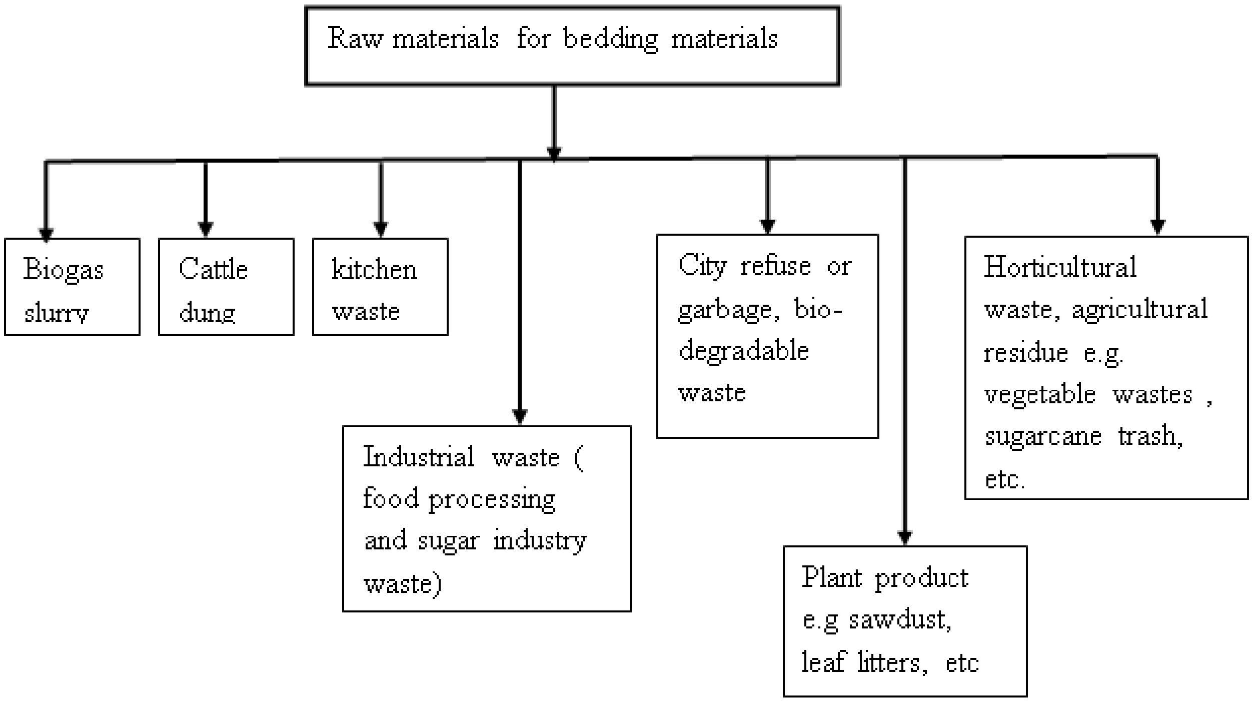

Fig. 6.1: Raw Materials for Bedding

The steps involved in the process of vermicomposting

Step 1: Waste collection, shredding, mechanical separation of metal, glass and ceramics and storage of organic waste.

Step 2: Pre-digest organic wastes by mixing them with cattle dung slurry. This procedure partially digests the material, preparing it for earthworm eating. Wet cattle dung is suitable for vermicompost formation but it should not be fresh, we can use after one month.

Step 3: Prepare the vermibed. A concrete base is required to place trash for vermicompost preparation. Loose soil encourages earthworm access into the soil and allows water and all soluble nutrients to seep in.

Step 4: After harvesting vermicompost, collect earthworms. Separating the totally composted material by sieve it. The partially composted material will be added to the vermicompost bed again.

Step 5: Properly store the vermicompost to retain moisture and promote the growth of beneficial bacteria**.**

Mechanism of Earthworm action

Earthworms serve as an aerator, grinder, crusher, chemical degrader and biological stimulant in addition to encouraging the growth of "beneficial decomposer aerobic bacteria" in waste biomass. Millions of decomposers (biodegrader) bacteria live in the guts of earthworms. According to Edwards (1988), when food moved through the digestive tract, the quantity of bacteria and "actinomycetes" it contained multiplied up to a thousand times. In a short amount of time, a worm population of roughly 15,000 will support a microbial population of billions.

Earthworms and microorganisms work in harmony and symbiosis to promote and quicken the breakdown of the organic materials in trash under the right circumstances.

The cellulose found in food waste, grass clippings and garden waste leaves is broken down by microbes. The waste feed components are swallowed and then sent to the gut for enzymatic processes after being finely crushed into small particles (2-4 microns) with the help of stones in their muscular gizzard. The worm's gizzard and gut function as a "bioreactor," secreting enzymes such as lipases, proteases, amylases, cellulases and chitinases that speed up the biochemical conversion of the waste organics proteinaceous and cellulose components. The last step in the vermiprocessing and organic matter degrading process is called "humification," which turns the big organic particles into a complex, amorphous colloid that contains "phenolic" components.

Fig. 6.2: Leaf and Vegetable Waste Shredder Machine

Chapter 7
VERMICOMPOSTING: SYSTEMS

Worldwide, vermicomposting technologies for volume reduction, organic load extraction, cost and energy reduction and quick processing are generally employed. Depending on the amount of trash to be processed, the kind of waste or bedding material, the area available and other factors, any of these methods can be used for vermicomposting.

A. Windrow system

This approach deals with the creation of windrows under shade to avoid direct sunlight. This procedure begins by spreading a layer of worms and bedding on the floor or ground (Fig. 6).The first layer of a new windrow should be 10 to 15 cm tall. Earthworms can be raised in a production nursery or in rectangular boxes before being inoculated in the windrows. The worms feed from bottom to top of the bed. The windrow must be examined regularly and if signs of surface feeding are detected, an additional 7 to 10 cm layer of feedstock can be added.

Thick layers of feedstock are avoided because they reduce oxygen penetration into the windrow. This can induce the worms to migrate to the upper surface before the lower layers have been fully digested, resulting in anaerobic fermentation. The windrows are irrigated with center post sprinkler up to twice daily to maintain optimum moisture content of 80% throughout the windrow. The top material is now removed to make way for a new row, while the bottom material is vermicompost. The new row can begin in a new location. Alternatively, it can be moved longitudinally by about 20 feet by depositing the worm-inhabited material beyond the end of the row, digging out some vermicompost and then shuffling some more worms across.

This method's drawback is that it necessitates some manual digging. In order to get some material off the top, it could be feasible to use a loader to drive into the side of the windrow if it is sufficiently wide. The loader will just push it over and off the other side of the row, so the remaining portion will need to be split off by hand. When excavating off the top, material will roll down the sides no matter how careful you are and you have to be careful to make sure the material doesn't end up mixed in with the finished product.

Where temperatures are consistently at just the correct level, windrows thrive. If the windrows are outside, they should preferably be on a concrete platform that is slightly raised and covered by a shade structure. Compost coverings must be prepared for usage in the event of persistent or heavy rain if there is neither a shade structure nor one that sheds rain. Because compost covers are bulky and heavy, handling them typically takes two or more people. Even in the absence of concrete, there must be some kind of impermeable surface, such certain kinds of clay or asphalt. (Fig: 7.1)

Fig. 7.1: Windrow system

B. Wedge System

This is a modified windrow technique that eliminates the need to separate vermicompost from worms, optimizing space and streamlining harvesting. Layers of organic wastes are applied at a 45-degree angle to a completed windrow. To stop nutrients from leaking out, the piles can be built within a building or outside with a compost or tarpaulin cover. A windrow that is 1.2 to 3 m wide and any suitable length is created using a front-end loader. The windrow is started by spreading an organic material layer that is 30 to 45 cm long and the length of one end of the available space. The amount of worms added per square metre of windrow surface area can reach up to 0.45 kg. Subsequent layers of 5 to 7.5 cm of organics are added weekly and preferably more addition in colder seasons.

Worms in the initial windrow will gradually move towards the fresh feed after the windrow is two to three feet deep. The worms will keep going through the windrows in a lateral manner. The first windrow and each subsequent pile can be harvested after one to two months (depend on quantity of earthworm). A migratory windrow is used in a variant of this technique. In this case, a row may begin as a layer and develop into a windrow, or it may begin as a windrow.

One side of the row is fed by a loader, which widens it while maintaining the same height and length. Vermicompost is eventually taken out of the side that isn't being fed using a loader. The completed compost is thereafter taken out from the same side once more. As it is picked along one side and fed along another, the row moves laterally. The direction of migration can be altered at any moment by switching the feeding and harvesting sides.

Fig. 7.2: Vermicomposting on open land

C. Container System

a. Pits, Tanks and Cement rings

Vermicomposting pits are 1.5 m wide and 1 m deep. The length adjusts according to need. Tanks composed of various materials, including regular bricks, hollow bricks, asbestos sheets and locally accessible pebbles, were assessed for their potential to prepare vermicompost. It is possible to build tanks with the right proportions for their intended use. Tanks measuring 1.5 meters (5 feet) in width, 4.5 meters (15 feet) in length and 0.9 meters (3 feet) in height have been examined by scientists at ICRISAT. The partition wall of the commercial biodigester has tiny holes in it to make it easier for earthworms to travel from one tank to the next. Cement rings can also be used to prepare vermicompost above ground. The cement ring should have dimensions of 30 cm in height and 90 cm in diameter. (Nagavallemma, *et al.,* 2004) (Fig.7)

a. Commercial model

The four chambers in the commercial vermicomposting model are separated by a wall and measure 1.5 meters in width, 4.5 meters in length and 0.9 meters in height. The walls are constructed from a variety of materials, including locally accessible rocks, asbestos sheets and regular and hollow bricks. The partition walls of this model include tiny openings in them to make it easier for earthworms to travel from one chamber to another. It is easier to collect extra water when each chamber has an outlet at one corner with a slight slope. This water can then be recycled or applied to crops as earthworm leachate.

Plant remnants are added to each of the four tank components one at a time. After layer by layer filling the first chamber with cow manure, earthworms are unleashed. Next, layer by layer, the second chamber is filled. The earthworms proceed to chamber 2, which is already filled and prepared for earthworms, once the contents of the first chamber have been processed. This saves labour for harvesting and introducing earthworms and makes it easier to harvest degraded material from the first chamber. This system saves time, money and water in addition to lowering worker costs. (Fig: 7.3, 7.4)

Fig.7.3: Vermicomposting in a semi-commercial unit (brick tanks)

Fig.7.4: Cement rings used as Vermicomposting tanks

b. Beds or Bins

1. Top-fed type

A top-fed bed is often located within a structure and operates within four walls and a floor. Perhaps an insulating "pillow" or layer on top will suffice if the bins are quite large, wind-sheltered and the feedstock has a reasonable amount of nitrogen. These can be as basic as straw bales or bags. It should be noted by the reader that vermiculture, not vermicomposting, is the intended use for these beds. The most straightforward way to harvest vermicompost is to use horizontal migration. To harvest, the operator just needs to stop providing food to one of the beds for a few weeks, giving the worms enough time to consume the material before moving on to the other beds in quest of new nourishment.

Feeding is then resumed after the "cured" bed has been emptied and replenished with bedding. This is done repeatedly in a rotating manner. If the beds are big enough, a tractor can be used to empty them rather than people.

2. Stacked type

The bed or bin system's primary drawback is the quantity of surface area needed. The windrow and wedge systems likewise operate in similar manner, but they are outside, where space is less expensive than it is indoors. If this problem is not resolved, raising worms indoors or even in an unheated shelter will prove to be a costly endeavour. Stacked bins give vermicomposting a vertical dimension, which helps with the space issue.

When filled with moist material, the bins need to be small enough to be lifted with a forklift or by hand. They can be fed continuously, although doing so requires routine care. Using a batch procedure, which involves pre-mixing the material and placing it in the bin, adding worms, stacking the bin for a predetermined amount of time and then emptying it, is the more cost-effective option. Many experienced producers of vermicompost employ this technique

Setting up a stacked-bin system is expensive initially. A forklift or other appropriate equipment is needed to stack the bins, along with a shelter, bins and a means to combine the feed and bedding. Naturally, all of this might be accomplished by hand on a smaller scale. When it comes time to harvest, there is still another drawback. The worms must be removed from the product, just like in batch windrow systems. In order for the worms to move into fresh material, there needs to be a harvester or another stage in the process where the material is heaped.

D. Continuous Flow Systems

Many mid-scale operations have embraced this approach, which was first created by Dr. Clive Edwards of the Rothamstead Agricultural Research Station. It is becoming more and more well-liked. The more material processed, the more efficiency savings their continuous flow architecture provides.

These days, commercial mid- to large-scale vermicomposting systems nearly always use this system design. In all three systems, the composting mass is positioned on an elevated wire mesh floor within a relatively deep top-fed container. Food waste is gradually introduced to the system along with worms and bedding material piled on top. Up until the bin is almost full, the system is fed continuously. Vermicompost is gathered from below by scraping or chopping a thin layer of completed material from immediately above the grill with a rake or a manually or hydraulically-operated blade. The worms often migrate upward through the feedstock/bedding layers.

Systems with continuous flow provide medium-to large-scale composting processes with a number of benefits. Their construction and operation are quite simple. When it comes to operation and harvesting final material, they are labor-efficient. They eliminate the requirement for costly machinery related to sophisticated "in-vessel" systems as well as the necessity to spin and screen material that has been twisted. It should be emphasised that windrows remain the most widely used large-scale vermicomposting method, even with the recent and growing interest in this design.

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Maintaining Continuous Flow

Cconstant flow Vermicomposting systems can be simply removed from the system without disturbing the worm activity or needing laborious or complicated harvesting techniques. They also provide a continuous flow of vermicompost. For large-scale applications, these system designs are almost as popular as windrows because to their operating efficiency. The continuous flow approach, like all vermicomposting systems, is not without its difficulties, though.

The phrase "surface feeder" is typically used to describe to the worms that are most frequently utilised in vermicomposting, in an effort to simplify some of the technical language. Generally speaking, it is assumed that they are only active at or near the surface. This isn't always the case, though. Earthworms are moisture-loving, oxygen-breathing creatures that need organic matter to be bacterially active before they can consume it.

This is often the top few inches of soil or surface organic litter, such leaves, in their native habitat. If the system is not adequately controlled, earthworms may spread throughout the material in any system that has an ample supply of decomposing organic material, a free flow of oxygen and a monitored moisture level. Because of this, earthworms can be found anywhere in continuous flow systems that suit their needs.

The simplicity with which a constant supply of vermicompost may be extracted from the system is one benefit of the continuous flow design. But the finished material shouldn't be harvested until the system is almost completely full. A minimum depth of material in the system of between 12" and 18" has been determined by many operators to assist ensure that few, if any, worms would be low in the bed and drop through, or fall out with the harvested vermicompost. This is in addition to suitable loading rates. Vermicompost must be removed from the system at a rate that keeps the amount of material in it generally constant once it has fully charged.

Feeding Rates

The exact loading rate—the pace at which unprocessed feedstock can be supplied to a worm bed in order to promote worm concentration at or near the surface—varies based on the feedstock type, temperature, moisture content and worm population density. It is necessary to wait to add new feedstock until most of the previously introduced feedstock has broken down in order to maintain proper loading rates. If fresh feedstock is added too soon, unprocessed material may accumulate in lower layers.

As a result, rather than being concentrated just below the surface, there will be enough food accessible deeper within the container. After then, the worms will disperse over every region that has food. Vermicompost frequently falls through the mesh floor of a flow-through system before it has had enough time to breakdown due to worm movement in the lower levels of the system. Additionally, worms that are still low in the material may fall through with the vermicompost when the system is harvested, meaning they will either need to be lost to the system or require labour-intensive screening techniques to remove them.

The majority of continuous flow system operators discover that the best results are obtained from regular additions of thin feedstock layers that are 1-2" deep and distributed over the surface. Occasionally, feedstock is combined with bulking agents such as straw, cardboard, paper, shredded leaves, or compost, or it is coated with a thin layer of these materials. Earthworms favour paper products as a feedstock because they are a readily available and easily digested source of carbon.

Excessive Heating

The possibility of heat buildup in the feedstock is another difficulty facing any vermicomposting system, regardless of size. In an oxygen-rich environment, microbial activity produces heat, carbon dioxide, water and other gases. Bacteria are the principal decomposers of raw organic matter. The mass of the system can sustain the activity of billions of bacteria when raw materials are introduced, especially in large quantities. Heat produced by bacterial activity can be quite high and could get trapped in the system.

If there is enough energy in the raw material to sustain high levels of bacterial activity, even a tiny volume can cause heating. The assessment system loading rates are complicated by this heating potential. It should be noted that thousands of different kinds of microorganisms and invertebrates can be found in a worm bed and that all of these species are essential to the environment of vermiculture. As a result, the loading rate in that system cannot be determined exclusively by the requirements or capabilities of a single organism. Since that bacteria will have access to the feedstock before worms do, bacterial activity might have an equal or greater impact.

Overfeeding may produce enough heat to detect worm activity, depending on the design capacity, feedstock type and/or system activity level. The loading rate must be lowered to a point where heating is not an issue, even if it means feeding less material than the worms can process, unless design changes can be made, such as adding fans to remove excess heat.

Chapter 8

PROCESSING: TIME AND ACCELERATION

1. Vermicompost can be obtained in 4–5 weeks under large worm populations and frequent management; in 2–3 months (60–90 days) under favourable conditions; however, 4–6 months is a better estimate with little worm bed management.
2. It has been noted that in high volume flow through systems, a marker, such a coin, put on the bed's surface will usually fall out of the bed's bottom after around 60 days.
3. Animal dung or kitchen wastes will breakdown in two to four weeks if there is a high worm population. The material must worm compost for two months (8 to 10 weeks) in a batch system if it is to be used in certified organic agriculture systems.
4. After two months without additional feed, worm populations will obviously decrease. Over the course of a month, worms are extracted. It takes up to a month to leave a low population of worms before screening the completed compost. This gives more worms time to hatch from their cocoons.

Maturity and Stability

The grade of compost and vermicompost is evaluated based on their age and stability. A high-quality compost should have a uniform, slight moisture, loose granular texture that is visually pleasing. During aerobic or worm composting, a great deal of physical, chemical and biological transformations took place.

The C/N ratios, water soluble carbon, cation ion exchange capacity, CO_2 evaluation, NH_4-N/NO_3-N ratio, organic carbon content and humus content are among the various parameters that have been suggested to evaluate the compost's maturity. Nonetheless, the germination index (GI), which gauges phototoxicity, is regarded as a trustworthy indicator of compost maturity. Pathogen reduction is indicated by a positive coliform test result.

Composting and Vermicomposting - A comparison

Vermiculture, as opposed to composting, offers a number of unique applications and, depending on volume or time limits, the ability to create varying grades of end product:

1. Worm casts, the highest-grade final product produced by this method of fully digesting organic wastes, are the result. The concentrations of essential elements in these are usually far higher than in regular composted material. In the horticulture industry, worm casts are typically utilized as a premium (and expensive) soil conditioner as opposed to bulk compost or plant bedding material.
2. Partial processing of organic material to produce a higher-quality product than regular compost or to quicken the composting process.

3. The removal of offensive smells caused by the decomposition of organic materials, as in open-air composting methods that don't use sealed "in-vessel" equipment.
4. Compared to current waste disposal methods, vermicomposting has very low energy requirements and very low processing costs.
5. The worms' reproduction. While it may not be the main worry for a municipal composting installation, a facility of this kind would need a very high worm population to function well. Thus, as the facility grows, worm populations must be maintained and increased in order to grow from the beginning.

Process acceleration

1. **Employing additional additives and organic nutrients.**

A review of the literature in this field of study revealed that there were surprisingly few studies on the effective use of additional additives or organic nutrients to speed up the vermicomposting process. In order to achieve both quality and quantitative improvements in vermicomposting, a recent paper by Parray *et al.* (2014) described the usage of *Spirulina* and *Trichoderma* as probiotic and microbial inoculants during the pre-decomposition period. According to studies conducted in 2011, Jeevamirtham, an organic nutrient made from cow dung, urine, jaggery and black gramme flour, is advised for use in vermicomposting in order to improve earthworm function and raise the vermicompost's fertilizer value.

2. **Using Effective Microorganisms (EM)**

EM is a multi-culture of co-existing anaerobic and aerobic beneficial microorganisms. (Higa, 1991). 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.*
- Actinomycetes - *Streptomyces albur, S. griseus.*
- Fermenting fungi - *Aspergillus oryzae, Mucor hiemalis.*

Because they can grow and reproduce in solid wastes and other leftovers under the right conditions and can turn wastes into high quality compost, they are directly used in waste management programs. According to research conducted by the author in 2013, EM can be utilised to transform various lignocellulosic leftovers from a sizable wood industrial complex into a form that can be reused (E. Sreenivasan, 2013b).

The author's initial trials were successful in their attempts to reinforce the vermibed employing an effective microbial suspension in order to increase the efficiency of the earthworms participating in the vermicomposting of wood waste. To determine and suggest the use of Effective Microorganisms for improved earthworm functioning, more research is needed for this project.

Chapter 9
TROUBLESHOOTING

We may arise some obstacles while doing vermicomposting. Let us discuss some abiotic and biotic factors in front of system and solutions with the issues:

1. Temperature

Both heat and cold pose significant challenges to vermicomposting. A red wiggler becomes inactive when the temperature of the bedding exceeds 29oC. This might be avoided by keeping the bin under shade at all times, especially if it is placed outside during the hotter months. Evaporative cooling of the moist bedding keeps the bin cooler than the surrounding air, but additional water may be required during the summer. The larger risk of overheating the worms is from heat generated within the bin, which can be significantly minimised by giving small amounts of food frequently rather than a large amount at once. Worms generally prefer chilly conditions. They reach their peak activity and reproductive levels as the weather cools in the autumn 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 materials releases organic acids, which reduce the pH of the bedding soil. The simplest technique to deal with this is to add several cups of ground limestone to the bedding and apply Zeolite in the right amount. Limestone will serve a dual purpose, regulating acidity and providing calcium to the worms. Other goods that can be used include powdered limestone and dolomite limestone. Baking soda should be avoided due to its high salt concentration.

4. Pests and Diseases

Vermicompost worms are not susceptible to microorganism-borne diseases, but they are vulnerable to predation by some animals and insects (red mites being the worst), as well as a disease known as "sour crop" induced by environmental factors. A brief summary of the most prevalent pests (see Fig. 11) and illnesses is provided below:

Ants: These little insects are a big nuisance because they are known to attack young worms and cause serious injury in addition to consuming the worm feed. Because sugar attracts ants more than other substances, reducing sweet feeds in the worm beds minimises this issue. Alternately, creating a water path around the bottom of the vermi-tank will end the ant problem for good.

The centipede: Compost worms and their cocoons are consumed by these insects. Luckily, harm is typically little because they don't seem to spread widely within worm beds or windrows. If worms do become an issue, heavily wetting (without flooding) the worm beds is one suggested way to reduce their population. Centipedes and other insect pests are driven to the surface by the water (not the worms), where they can be eliminated with a hand-held propane torch or similar tool **(**Fig.9.1)

Fig. 9.1: Predators of earthworms in vermibeds (a) Ants (b) Millipedes

Birds: Although they normally don't cause much trouble, if they find your vermibeds, they will return frequently in search of the worms. This issue can be resolved by covering the material in open-air systems or by placing a lid on the tank. In addition to keeping moisture in, these covers help stop excessive leaching after rainstorms. An old carpet works really well for this kind of application.

Rodents:

Fig. 9.2: Predators of earthworms in vermibeds (c)Birds(d) Rodents

Rats and mice can easily chew through plastic or wood and don't require much space to move through a surface, so if a rat gains access to your worm bed, you can quickly lose a lot of worms. This is usually only a problem when using open-air systems in fields, but it can be avoided by using a barrier, such as wire mesh for the lids. **(**Fig.9.2)

Bad harvest: According to reports, this is the outcome of protein poisoning brought on by excessive bedding. Only when the worms are overfed does this occur. As protein decomposes, it releases gases and acids into the bedding. Farmers should avoid overfeeding and regularly monitor and adjust pH levels in order to prevent sour crops. Avoiding the need for these steps is possible if the pH is kept at neutral or above.

Mite Pests: Wormbeds draw insects because of their organic and damp atmosphere. Since mites are drawn to moist, acidic environments, improper maintenance of the bedding may cause acidity to build up in the bedding soil. While tiny populations of mites are beneficial in all worm beds, an overabundance of them could pose a threat. Worms that have high levels of mite populations also dig deep holes and stop feeding.

White or Brown Mites

Since they are not predators, brown or white mites often exclusively eat damaged or decomposing worms. Nevertheless, these mites have the ability to consume a large portion of the food in earthworm beds during infections, depriving the worms of their nutrients.

Red Mites

When these mites are magnified, little white or grey clusters that resemble mould are seen. These are juvenile red mites at different stages of growth. The mature red mite has an egg-shaped body with four pairs of legs and it is smaller than the white or brown mites. Its colour is vivid red. It is well known that red mites parasitise earthworms. Seizing hold of the worm, it savours its coelomic fluid. They can also swallow the egg capsules' cytoplasmic fluids.

Mite Prevalence and Prevention

Worm bed maintenance can help avoid harmful mite accumulation. The following circumstances are typically linked to a high mite population:

a. **Excess water:** Overly damp beds foster an environment that is better suited for mites than worms. By enhancing drainage, rotating bedding often and modifying watering schedules, excessive bed wetting can be prevented.

b. **Over feeding:** Overfeeding can cause fermented feed to build up in worm beds and reduce the pH of the beds. Seasonal fluctuations may require adjustments and modifications to the feeding regimens. Beds should be kept at pH 7, which is neutral, with calcium carbonate acting as a buffer.

c. **High moisture content feed or fleshy feed:** In worm beds, vegetables with a high moisture content may draw large populations of mites. Such feed should only be used sparingly; if high mite numbers continue, it should be stopped used until the mite population is under control.

Mite Removal

There are several approaches that have been proposed to get rid of mites from earthworm beds. However, unless worm-bed management is changed to create an environment that is less conducive to mites, any kind of mite removal, chemical or physical will only be temporary. The methods that follow range in intensity from low to high.

Sunlight should be allowed to reach the worm beds for a few hours, but care must be taken to prevent direct sunlight exposure for the earthworms. Cut back on the amount of feed and water. The mites will be much more motivated to abandon the bedding as a result.

- You can put moistened newspapers or jute (jute) bags on top of the beds and you can take them off when mites start to build up. You can keep doing this until the number of mites is significantly decreased.
- You can put potato slices or watermelon pieces on top of the worm beds. The mites might then be used to remove the peels.
- Excessive watering of the bed won't cause floods. The mites will be forced to rise to the surface as a result. Next, burn the mites with a portable propane torch. If necessary, this process can be performed multiple times, every three days.
- Dusting with little sulphur will eliminate the mites. Alternatively, the bed might be moistened (as previously mentioned) and the sulphur added straight to the mites. The recommended amount of sulphur application is 2 g per 0.93 square metre of bed. Although sulphur won't hurt the worms, it could eventually make the bed more acidic. In the past, worm beds have been treated with a few chemical insecticides. However, using these chemical compounds is not recommended due to their biomagnification. Safer miticides are available, but they are not designed with the vermibed in mind.

5. Odour Problems

Unpleasant smells are a result of too much food waste in the compost, which depletes the oxygen concentration, as well as moisture buildup in the bin contents. The fix is to cease adding food waste and give the entire contents a little shake to encourage aeration after the worms and bacteria have finished breaking down the initial feed. One could examine the drainage holes for obstructions. You can drill more holes if the drainage is inadequate.

If the environment is not conducive to their growth, worms have been known to crawl out of the bedding. The bedding may be acidic if the soil's moisture content does not cause this migration. Citrus peels and other acidic foods should not be added to the bedding as this could lower the pH of the bedding soil. By reducing acidic wastes and adding a small amount of garden lime, one can overcome this acidic medium.

Chapter 10

HARVESTING TECHNIQUES

Once vermicomposted, the material's volume will be significantly decreased, may be to 10% of its original size. The finished material will be blackish brown and earthy, with the original bedding no longer recognizable. The vermicompost may require post-screening, especially if coarse green waste was used in the bedding, which takes longer to break down. This can be done manually on a small scale, but it is the same as screening and separating with a professional rotating screener.

The worms are successfully extracted from the completed vermicompost, but cocoons and hatchlings are lost. If only worm casts are required as fertilizer, any of the following methods are suitable. To separate and retain worms and castings, use the light separation method or a wire mesh screen. The approaches discussed here are best suited for smaller-scale containerized systems or pilot operations that aim to breed early worm populations. A commercial-scale mesh screener will be required as the system expands.

Fig. 10.1: General Equipments for Harvesting

Light Separation

Earthworms are extremely sensitive to light and this separation method takes use of this, as well as their desire to dig beneath the surface in order to avoid light sources. The final substance can be removed and dispersed on a surface, or it can be kept in place but exposed to light. The worms will burrow fast below, removing the surface material. After repeating the process, a thin layer of material remains, containing all of the worms. This should be mixed with the new bedding and a fresh supply of feed. This yields a harvest of worm castings and unhatched capsules. These capsules will be lost because the hatchlings will not survive in garden soil, but the surviving worms will rapidly replenish them. Before using the castings as fertilizer, keep them for a week or two.

Sideways Separation

The finished material remains set to one side and fresh bedding mixed with organic waste is placed alongside it. In the next 7 to 14 days, the worms will migrate from the final vermicompost to the fresh bedding. This strategy has the advantage of allowing the capsules to hatch in the meanwhile and the majority of them will move across.

Vertical Distancing

A nylon mesh screen that is marginally bigger than the container's surface area is placed on top of the vermicompost. The screen enough to be big enough to make the container's top side overlap flat. On top of the screen, the container is refilled with new bedding and supplied with organic waste. As the food source below is exhausted, the worms will migrate up through the screen and into the new bedding.

When the upper portion is ready for harvesting, the screen and completed material containing the worms are removed from the container. The leftover material in the container's bottom will be high in worm castings and low in worms, hatchlings, or capsules. After this, the worm-filled material on top of the screen is removed and placed in the bottom of the container, with fresh bedding on top of it

Gradual Transfer

This simple procedure creates castings but no additional worms. Continue to add kitchen scraps to the container for up to four months. A second container should be established and filled with fresh bedding and worms from the first box. The first container continues until the second is full, at which point the first container will have a large proportion of fine castings but relatively few worms. To ensure that there are enough worms for both containers, prepare the second container approximately a month in advance and add worms to it every time the first container is fed.

Gathering Earthworms (Harvesting Earthworm)

Following the generation of vermicompost, the earthworms in the tub or small bed may be collected using the trapping technique. Prior to harvesting the compost in the vermibed, a little ball of fresh cow dung is formed and placed inside the bed in five or six locations. The lump of cow poo is removed after a day. Every worm will be firmly attached to the ball. This attached worm can be separated by submerging the ball of cow dung in a pail of water. The worms that were gathered will be used in the upcoming composting batch.

Worm harvesting is not typically done to establish new worm beds, but rather to sell the worms. By separating the beds, or removing a section to start a new one and replacing the material with new bedding and feed, the operation can be expanded (additional beds can be added). Worms are typically carried in a relatively sterile medium, like peat moss, after being sorted and weighed before being sold. In order to achieve this, the worms need to be taken out of the bedding and vermicompost. Growers harvest worms using three main sorts of methods: mechanical, migration and manual. In the sections that follow, each of these is covered in further detail.

Manual Method: This is the procedure utilized in units that sell worms and vermicompost on a modest scale to the local market. It includes hand-sorting, or taking the worms out of the compost by hand. This process can be accelerated by exploiting the fact that worms avoid light. If worm-containing material is put in a pile on a flat surface with a light above it, the worms will immediately dive beneath the surface.

The harvester can then remove a layer of compost, pausing when the worms are visible again. This process is done multiple times until all that remains on the table is a huddled mass of worms beneath a thin layer of compost. These worms can then be swiftly scooped into a container, weighed and ready for transport.

Fig. 10.2: Vermicompost sieving machine

Self-Harvesting or Migration Method: This harvesting method takes advantage of worms' natural desire to travel to new areas for food or to avoid adverse conditions. Unlike the manual procedures discussed above, simple devices like as displays are used for the task.

The screen approach is quite popular and simple to utilize. A box is built with a screen bottom. Mesh is typically ¼", but 1/8" can be utilized. There are two distinct approaches. The downward-migration system is similar to the manual system in that the worms are pushed downward by intense light. The screen system differs in that the worms pass through the screen into a pre-weighed container of moist peat moss. The compost in the box is taken out and replaced with a fresh batch of worm-rich compost after all the worms have gone through.

The operation is continued until the box with the peat moss reaches the specified weight. Like the manual technique, this system may be set up in multiple locations at the same time, allowing the worm harvester to travel from one box to the next without having to wait for the worms to relocate.

The upward migration mechanism is identical, with the exception that the mesh-bottomed box is placed directly on the worm bed. It has been filled with a few centimeters of damp peat moss and then dusted with worm-attracting food such as chicken mash, coffee grinds, or fresh animal manure. The box is removed and weighed once visual inspection reveals that enough worms have crawled up into the substance. This approach is widely utilized in Cuba, with the exception that huge onion bags are used rather than boxes. This approach has the advantage of keeping the worm beds undisturbed.

The biggest downside is that the harvested worms are in material containing a significant amount of unprocessed food, making the material dirtier and increasing the chance of heating inside the packaging if the worms are delivered. The latter issue can be addressed by removing any conspicuous food and giving the worms enough time to devour what remains before packaging.

Packing and Storage

Vermicompost should be stored in a dark, cool area. It should have at least 40% moisture. Sunlight should not fall on the compost. It causes moisture and nutrition loss. It is recommended that the gathered compost be stored freely rather than packed in an over sac. Packing can be completed at the time of sale. If it is stored in an open area, sprinkling with water on a regular basis can help to maintain moisture levels and a beneficial microbial population. If it is necessary to store the material, laminated over sacs are employed for packaging (Fig. 10.1). This will reduce moisture evaporation loss. Vermicompost can be kept in storage for a year at a temperature of 40% moisture content without losing any of its quality.

Vermicompost Attributes or Characteristics of vermicompost

Vermicompost is a material that resembles peat and has excellent porosity, aeration, drainage, water-holding capacity and microbial activity. It is the result of the non-thermophilic biodegradation of organic material by earthworms and microorganisms. It has a wide specific surface area that offers several microsites for microbial activity and for the strong retention of nutrients. It also contains all nutrients in plant-available forms, such as phosphates, nitrates, exchangeable calcium, soluble potassium, etc.

Vermicompost has been shown to include plant growth regulators and other plant growth affecting components such as auxins, cytokinins, humic compounds and so on, which are created by microorganisms. Humic compounds isolated from vermicompost have been shown to stimulate auxin-like cell proliferation and nitrate metabolism in carrots (Daucus carota). Humic compounds can be found naturally in mature animal manure, sewage sludge and paper mill sludge, but vermicomposting significantly increases their volume and pace of synthesis.

Table 10.1: Comparison between chemical fertilizer and vermicast

Criteria for comparison	Chemical fertilizers	Vermicast
Macro nutrient contents	Mostly contains only one (N in urea) or at the most two (N &P in DAP) nutrients	Contains all i.e. nitrogen (N), phosphorus (P) & potassium (K) in sufficient quantities
Secondary nutrient contents	Not available	Calcium, magnesium & sulphur is available in required quantities
Micro nutrient contents	Not available	Zinc, boron, manganese, iron, copper, molybdenum and chlorine also present
pH balancing	Disturb soil Ph to create salinity and alkalinity conditions	Helps in the control of soil pH and checks the salinity and alkalinity in soil
Organic carbon	Not available	Very high organic carbon and humus contents improves soil characteristics
Moisture retention capacity	Reduces moisture retention capacity	Increases moistures retention capacity of the soil
Soil texture	Damages soil texture to reduce aeration	Improves soil texture for better aeration
Beneficial bacteria and fungi	Reduces biological activities and thus the fertility is impaired	Very high biological life improves the soil fertility and productivity on sustainable basis.

The nutrient content of vermicompost is determined by the type of organic waste utilized as feeding for earthworms. A heterogeneous waste mix has been shown to have a more balanced level of nutrients than any single trash kind. It adds to the provision of micronutrients required by crops. Aside from that, the stimulatory effect of vermicompost on nutrient uptake, growth and crop productivity is attributed to earthworm secretions and related bacteria mixed with the cast. The nutrient status of vermicompost produced with different organic waste is shown in Table 10.2.

Table 10.2: 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 11
VALUE-ADDED AND BY-PRODUCTS

1. **Vermiwash**.

A drainage and collecting system are installed in the vermicomposting bed, which contains organic waste, bedding materials and earthworms. Vermicomposting produces leachate as a result of moisture addition through the worm column. Draining the water or leachate is critical to preventing vermicomposting unit saturation and pest attraction. The leachate so collected is referred to as vermiwash. It is advantageous in the sense that it can be collected and utilised as a liquid fertilizer because it has a high concentration of plant nutrients. It is a mixture of the earthworms' mucous secretions and excretory products, as well as the micronutrients from the organic molecules. This liquid is rich in nutrients, vitamins, minerals, amino acids, potassium, magnesium, zinc, calcium, iron and copper, as well as some growth hormones like auxins and cytokinins. It is derived in part from the body of an earthworm, since worms have a lot of water in their bodies. It also has a large number of *actinomycetes, Nitrobacter and Nitromonas* bacteria, which fix nitrogen and dissolve phosphate. When properly collected, vermiwash is a clear, translucent fluid with a honey brown colour. It should be mentioned, none the less, that in order to determine whether pathogens and phytotoxic chemicals are present in vermiwash, a plant bioassay test should be conducted before using it as a foliar spray. Vermiwash is best diluted before using it as fertilizer to prevent damage to plants, but this naturally lowers its nutrient concentration, necessitating combination with other mineral fertilizers. To improve the availability of nutrients for plants, certain chemical compounds are added to commercial liquid fertilizer formulations. Examples of these compounds are polyoxyethylene tridecyl alcohol, which serves as a dispersion and polyethylene nonylphenol, which acts as an adherent. **(**Fig.11.1)

Vermiwash possesses excellent growth-promoting and pest-killing qualities (Suthar, S., 2010). According to a 2003 study by R.S. Giraddi, radish output improved by 7.3% with weekly application of vermiwash. According to another study (Thangavel, P *et al.,* 2003), applying vermiwash and vermicast extracts boosted the growth and yield of paddy. Ansari, A.A. and Sukhraj, K. (2010) examined the relationship between okra (*Abelmoschus esculentus*) productivity and soil characteristics for vermiwash and vermicompost on. Rekha G.S., *et al.* recently (2013) investigated the effects of vermiwash and vermicompost on the development and yield of black gramme (*Vigna mungo*). Farmers in Bihar, North India, stated that this liquid had both growth-promoting and pesticidal effects. They employed it on brinjal and tomato and had great results. The plants were healthy and produced larger fruits with a special lustre. Vermiwash spray was efficient in controlling all insect and disease outbreaks.

Fig. 11.1: Vermiwash

The usage of chemical pesticides and insecticides on vegetable crops was greatly reduced and the goods were distinguishable from others with high market value. To assess its efficacy against thrips and mites for the management of 'thrips' (*Scirtothrips dorsalis*) and 'Mites' (*Polyphagotarsonemus latus*) on chilli, vermiwash was mixed with water in three different dilutions, i.e. 1:1, 1:2 and 1:4 and used as a'seedling dip' treatment and a 'foliar spray' (Saumaya, G *et al.*, 2007). Giraddi, R.S. (2003) found considerably lower insect population in chilli administered 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) reported hormone-like compounds in vermiwash. He investigated its effects on seed germination, root and shoot length in *Cyamopsis tertagonoloba* and compared it to a urea solution (0.05%). Germination was 90% on 50% vermiwash, compared to 61.7% in urea solution. On 100% vermiwash, the maximum root and shoot lengths were 8.65 cm and 12.42 cm, respectively, whereas on urea they were 5.87 and 7.73 cm.

Fig. 11.2: Vermiwash collection unit

Steps in preparation

The following procedures are involved in the preparation of vermiwash:

1. Get a plastic container that can hold roughly 50 litres.
2. Drill a hole at the bottom and use a safety gauge to secure a tap.
3. Fill the container with a layer of shattered bricks and stone fragments that are 10 to 15 centimetres deep.
4. Add another layer of sand, about ten to fifteen centimetres thick, on top of this one.
5. Cover it with a layer of 30- to 45-cm-thick partially decomposed cow manure.
6. Add a second layer of earth, preferably two to three thicknesses.
7. Next, add between 100 to 200 earthworms.
8. Next, a layer of paddy straw is applied, which is 6 cm thick.
9. For seven to eight days, mist water on a daily basis.
10. The liquid vermiwash will be created in ten days.
11. Hang a single pot with a hole in the bottom over the container so that water drips in.
12. The hanging pot has to have four to five litres of water(vermiwash) added to it each day.
13. To gather the vermiwash, keep a second pot under the tap. **(**Fig.12.2)

Table 11.1: Composition of vermiwash and its benefit

Sr. No.	Contents of vermiwash	Benefit of vermiwash
1	Decomposer bacterial	Suppress pathogen
2	Hormones (Cytokines, auxin)	Facilitate plant root and shoot growth
3	Amino acid and mucosal secretion	Suppress pathogen and pest
4	Vitamines	Facilitates growth and development of plant
5	Phosphatase	Stabilize physical, chemical and biological properties of soil as well suppress pathogen and solubilize phosphorus
6	Actinomycetes	Suppress pathogen
7	Amylase, cellulase	Stabilize physical, chemical and biological properties of soil as well applied in carbon turnover by degrading organic matter
8	Varieties of micronutrients Ni, Mg, Fe, Ca, K	Facilitate the growth and productivities of plant

Ways to Use Vermiwash

1. **Dipping Method** – Soak seedlings and plant cuttings in vermiwash solution for 15 to 20 minutes before transplanting or planting. This improves survival rates.

2. **Foliar Spray** – Dilute vermiwash with water at a ratio of 10% (100 ml per liter of water) or 20% (200 ml per 2 liters of water) and spray on crops. This enriches the soil with nutrients and helps control plant diseases.
3. **Drenching** – Mix vermiwash with water and apply it to the soil to help prevent soilborne pathogens due to its antimicrobial properties.
4. **Organic Manure** – Applying vermiwash to the soil enhances nutrient absorption by plants, acting as a natural fertilizer.
5. **Growth Promoter** – Vermiwash serves as an excellent growth enhancer. When used as a foliar spray, three to four applications yield optimal results.

Benefits of Vermiwash in Agriculture

1. **Natural Biofertilizer** – Vermiwash is an eco-friendly, organic fertilizer derived from decomposed organic waste. It is completely free of chemicals.
2. **Plant Tonic and Disease Control** – It functions as a plant tonic, helping to reduce various plant diseases.
3. **Biopesticide and Soil Enhancer** – A 10% vermiwash solution (100 ml per liter of water) acts as a biopesticide and liquid manure. It improves soil texture, aeration and water-holding capacity due to its high organic matter content.
4. **Root and Sprout Growth Booster** – Vermiwash stimulates sprouting and enhances root development in plant cuttings.

2)Vermicompost tea or liquid compost.

Vermicompost tea is a sort of compost tea made by soaking vermicompost in water. It contains helpful bacteria that may help to prevent or control illnesses and improve soil health. According to studies, tea can help decrease plant-parasitic nematodes and arthropod pests (Edwards, C.A, *et al.*, 2007). The nutrients in vermicompost tea vary depending on the source materials and brewing processes. Liquid vermicompost can provide three essential plant nutrients: nitrogen ($N03$ and NH_4), phosphorus (P) and potassium. Nitrate (NO_3) at 77 ppm (parts per million), ammonium (NH_4) at 3.7 ppm, phosphorus (18 ppm) and potassium (186 ppm).

Preparation

Aqueous extracts are produced by:

- Passing water through vermicomposts. Standing vermicomposts
- In water (1–7 days) Modifications of these techniques
- Modifications of these methods
  - Aeration
  - Adding materials
  - Including organic substrates

3) Vermimeal

Vermimeal, often known as earthworm meal, is a feed prepared from processed earthworm biomass. It provides a high concentration of animal protein as well as vital amino acids, lipids, vitamins and minerals for animals, birds and fish. Producing 1 kilogram of vermimeal requires around 5.5 kg of fresh earthworm biomass (18% dry matter). It can be wrapped in plastic bags and stored in a cool, dry place away from direct sunlight for up to three months. Proximate analysis of dried and powdered earthworm vermimeal indicated the following composition: 68% crude protein, 9.57% fat, 11.05% nitrogen-free extract and 9.07% ash. Numerous research on various livestock animals, birds and fish have yielded outstanding results when feeding the animals vermimeal or earthworm meal. This is not surprising given that earthworms provide a natural source of sustenance for birds and other animals in the wild.

4) Enriched Vermicompost

Fig. 11.3: Vermicompost packaging

Another key growing trend is the addition of nutrients and/or microbes to vermicompost, which results in increased agricultural plant development and yield. "Enriched vermicompost" is a combination of vermicompost, natural minerals and microbes. It not only contains more nutrients, but it also produces faster than traditional vermicompost. Another advantage of the new compost is the capacity to adjust components and nutrient concentrations based on the individual needs of different plants and soils. Vermicompost from farm manure and legume wastes is mixed with natural minerals like rock phosphate and mica powder to make the fertilizer. Hashemimajd, K. and Jamaati-e-Somarin, S. (2011) published a study on enriching vermicompost with iron and zinc and its effect on the growth and nutritional condition of peach plants. Microorganisms such as *Aspergillus awamori* and *Trichoderma viride* are also present and they are effective in providing and protecting fertilizers, as well as mineralizing components that crops use. Rajasekar, K. *et al.* (2012) reported on the possibilities of enriching vermicompost with microbial inoculants (i.e., biofertilizer organisms), *Azospirillum brasilense* and *Rhizobium* *leguminosarum*, as well as optimizing inoculum level and inoculation period during vermicomposting. **(**Fig.11.3)

5) Pelleted Vermicompost

Vermicompost is a useful material for enhancing the physical and chemical characteristics of soil. However, two things limit the use of this composted manure. The first issue is that vermicompost often has a high moisture content and volume per unit of weight. As a result, it is difficult and expensive to transport. The second issue is that the vermicompost's quality and nutrient content varies. This also limits the effective use of compost. Molding method for producing compost in convenient pellet form is a viable answer to these issues. **(**Fig. 11.4)

Fig. 11.4: Pelleted Vermicompost

A pellet producing machine can be used to turn composted manure into 0.5-1 cm diameter pellets. Nitin K Tyagi of Meerut, Uttar Pradesh, India created the machine in 2007. It is manually controlled and comprises of a hopper, a flat moving belt, a pellet-forming die and a power transmission system. A single person can operate the equipment. The method utilized here is to combine the vermicompost with an appropriate binder (molasses), place the combination in the hopper, transport the compost using a conveyor belt on a flat bed in the shape of a sheet and run it through a pellet-making die to produce a stream of pellets. Though the use of a conveyor and die system to produce traditional compost pellets is well known (Zafari and Kianmehr, 2012), as well as in the chemical and pharmaceutical industries, the application of this concept to produce "vermicompost pellets" is innovative. If pelleting is to be done without adding any other materials, it is critical to control the moisture level of the compost as well as the rate at which the compost is fed into the pelleting machine's die. The dried pellets maintain their shape throughout storage and distribution and have a volume of only 60-90 percent of raw compost. Pellets created require less storage space and can be distributed uniformly over fields. The delivery of nutrients to plants in pellet form is slower and lasts longer.

Chapter 12
THE VALUE OF VERMICOMPOST

Vermicompost offers numerous advantages for agricultural soil, including improved moisture retention, nutrient-holding capacity, soil structure and microbial activity. A review of the literature reveals that vermicompost outperforms traditional organic manures in a variety of ways.

These include the following:

- **High in humic acids and enzymes**: Plant growth responses to vermicompost appear more like 'hormone-induced activity' associated with Vermicompost has high levels of humic acids and humates, which are not augmented by high levels of plant-available nutrients. Vermicompost also contains enzymes such as amylase, lipase, cellulase and chitinase, which degrade organic matter and improve soil nutrients and fertility. (Chaoui, H.I. *et al.*, 2003; Tiwari, S.C. *et al.*, 1989) They also boost some key soil enzymes such as dehydrogenase, acid and alkaline phosphatases and urease. Urease is important in the nitrogen cycle because it hydrolyzes urea and phosphatase converts soil phosphorus into a form that plants can use.
- **Free of pathogens and hazardous chemicals:** Several studies have found that vermicomposting reduces pathogens significantly after three months of storage. However, the samples that were simply treated to thermophilic composting retained greater amounts of pathogens even after three months. According to studies, earthworms effectively bioaccumulate or biodegrade a variety of organic and inorganic substances in their environment, including heavy metals, organochlorine pesticides and polycyclic aromatic hydrocarbons (PAHs) residues.
- **Plant nutrients**: Vermicompost contains nutrients that are plant-available, such as nitrates (N), phosphates (P), soluble potassium (K) and magnesium (Mg), as well as exchangeable phosphorus (P) and calcium (Ca). Vermicomposts contain enormous particle surface areas, allowing for numerous micro-sites for microbial activity and good nutrient retention.
- **Beneficial microbes**: Vermicompost is high in microbial communities, specifically fungus, bacteria and actinomycetes. Suhane (2007) discovered that the total bacterial count was greater than 1010 per gram of vermicompost. It contained *Actinomycetes, Azotobacter, Rhizobium, Nitrobacter and* phosphate solubilizing bacteria (PSB) in concentrations ranging from 102 to 106 per gram of vermicompost. The PSB plays an important function in making the critical nutrient phosphorus (P) accessible for plant growth promotion. The most abundant microbial community was found in vermicompost made with cow dung and

municipal solid waste as substrates. The use of lime in the substrate increased the population of all of the above-mentioned microorganisms, regardless of the substrate used for vermicomposting. Plant growth promoting bacteria (PGPB) boosts growth by fixing nitrogen (N), solubilizing nutrients and producing growth hormones. There is also evidence that microbes such as bacteria, fungi, actinomycetes, yeasts and algae create plant growth regulators (PGRs) in significant quantities, including auxins, gibberellins, cytokinins, ethylene and ascorbic acids.

- **Stimulate plant growth:** Vermicompost has consistently improved seed germination, seedling growth and development and plant productivity well beyond what would be feasible simply by converting minerals into plant-available forms. Earthworms secrete the growth hormone auxins, cytokinins and flowering hormone gibberellins, which are found in vermicompost. Arancon *et al.* (2006) ascribed vermicompost's growth-promoting impact to the humic acids it contains. Vermicomposted organic wastes have a positive impact on plant development regardless of nutritional transformation or availability. Vermicomposts, whether used as soil additives or as components of horticultural soilless media, have consistently improved seed germination, seedling growth and development and plant productivity far beyond what could be achieved simply by converting mineral nutrients into more plant-available forms. Paul and Metzger (2005) investigated the effects of vermicompost on the quality of vegetable transplants.
- **Disease suppression**: The high amounts of helpful bacteria in vermicompost allow it to protect plants from a variety of diseases. These microorganisms defend plants by out-competing diseases for available resources and preventing them from reaching plant roots by occupying all available sites. This research is based on the "soil food web" idea, which is a soil ecology-based technique pioneered by Dr. Elaine Ingham of Corvallis, Oregon. Edwards Arancon (2004) investigated this aspect of vermicompost and found that relatively small applications of commercially produced vermicomposts reduced the incidence of attacks by *Pythium* on cucumbers, *Rhizoctonia* on radishes in the greenhouse, *Verticillium* on strawberries and *Phomopsis* and *Sphaerotheca fulginae* on grapes in the field. The scientists went on to say that when the vermicompost was sterilized, the pathogen suppression stopped, showing that the mechanism was microbial antagonism.
- **Repel pests:** In field studies with peppers, tomatoes, strawberries and grapes, Edwards and Arancon (2004) found that plant-parasitic nematodes were significantly reduced. More research is needed before vermicompost can be used as a non-toxic pest management alternative.

Vermicompost: Amount and Use

Vermicompost can be utilized for all crops, including agricultural, horticultural, ornamental and vegetable crops, at any stage of growth and in any amount, because it is 'totally safe' for soils and crops.

- For common field crops, 2-3 t per ha vermicompost is mixed with seed at the time of sowing or applied in rows when seedlings reach 12-15 cm in height. Normal irrigation procedures are followed.
- For fruit trees, The amount of vermicompost used ranges from 5 to 10 kg per tree, depending on its age. For effective application, a ring (15-18 cm deep) is formed around the plant. A thin layer of dry cow dung and bone meal is spread, followed by 2-5 kg of vermicompost and water is sprayed on the surface once the soil is covered.
- For vegetables, 1 t per ha of vermicompost is put to the nursery bed to raise transplantable seedlings. This produces robust, vigorous seedlings. However, for transplants, 400-500g of vermicompost per plant is treated at planting and again 45 days later (before irrigation).
- For flowers, 750-1000 kg of vermicompost are applied per hectare.
- For vegetable and flower crops, vermicompost is placed around the plant base. It is then covered in soil and watered on a regular basis.

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

Subsidies and Schemes for Vermicomposting

Governments and agricultural organizations in many countries provide subsidies and support schemes to promote sustainable farming practices like vermicomposting. These schemes are aimed at improving soil health, managing waste and reducing reliance on chemical fertilizers. Below are some of the common subsidies and schemes available for vermicomposting:

1. National Mission on Sustainable Agriculture (NMSA) – India

The Indian government has launched the NMSA to promote sustainable agriculture, which includes financial support for organic farming practices such as vermicomposting. The scheme provides subsidies to farmers for setting up vermiculture units, purchasing vermicomposting equipment and training on the method.

Subsidy Details: A percentage of the total cost for establishing vermiculture units or purchasing required equipment is subsidized, often covering up to 50% of the cost.

Eligibility: Small and marginal farmers, groups of farmers and organic farming initiatives are eligible for this subsidy.

2. Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) – India

PMKSY is a scheme that includes support for organic farming, including vermiculture. Farmers can receive financial assistance to set up vermicomposting units, particularly in areas with water scarcity, to ensure better soil health and improved water retention.

Subsidy Details: Financial assistance for setting up vermicomposting facilities, with the subsidy percentage varying based on the type of scheme and location.

3. National Organic Farming Research Institute (NOFRI) – India

NOFRI, under the Ministry of Agriculture and Farmers Welfare, provides grants to farmers for the development of organic farming systems, including vermiculture. Farmers may receive subsidies for the construction of vermicomposting beds, purchase of earthworms and other necessary tools.

Subsidy Details: The scheme offers a one-time financial assistance program to farmers for setting up organic waste recycling units.

4. Agricultural and Processed Food Products Export Development Authority (APEDA) – India

APEDA offers incentives for promoting organic farming, which includes vermiculture. The authority provides subsidies to farmers for certification and establishment of organic practices, including vermicomposting.

Subsidy Details: APEDA provides financial assistance for training, setting up organic composting units and obtaining organic certification.

5. State Government Schemes (Various States in India)

Several state governments in India offer their own subsidies and schemes for organic farming and vermiculture. These include financial assistance for setting up vermiculture units, purchasing composting equipment and even earthworms. Some states also provide training programs and capacity-building workshops for farmers.

Examples:

Maharashtra: Provides assistance for vermiculture units and training under the "Mahatma Gandhi National Rural Employment Guarantee Act" (MGNREGA).

Kerala: Offers support for small-scale organic waste management and vermicomposting through its "Kerala State Organic Farming Project."

6. Subsidies for Green Farming Initiatives – Various Countries

In countries outside India, governments encourage organic farming through subsidies for sustainable practices like vermiculture. These subsidies may be tied to specific goals, such as reducing carbon emissions or increasing soil health.

7. Corporate or NGO-Sponsored Initiatives

In addition to government schemes, various non-governmental organizations (NGOs) and corporate sustainability programs offer support for vermiculture. These organizations may provide grants, technical assistance, or equipment to farmers adopting vermicomposting.

Example: The World Bank and other international organizations may fund vermiculture projects in developing countries, especially as part of climate change mitigation and sustainable agriculture initiatives.

How to Access These Subsidies and Schemes

1. Consulting Local Agriculture Departments: Farmers can visit local agriculture offices or government websites to get information on available subsidies and application processes.
2. Registering for Organic Farming Programs: Participation in government programs, such as those promoting organic farming, may open access to vermicomposting subsidies.
3. Training and Certification: Many schemes require farmers to undergo training programs, which may be offered free or at a subsidized rate, to ensure effective vermiculture practices.
4. Documentation: Farmers may need to provide proof of land ownership or be part of a farmers' cooperative to qualify for subsidies.

Chapter: 13

VERMICOMPOST: CUSTOMER FEEDBACKS AND FIELD EVALUATION

Organic farming with vermicompost in India

Vermicompost is the foundation for effective organic farming. More than 85% of organic crop farming in India is dependent on it. It has various advantages as an organic seedling development medium: it is relatively high in nitrate, which might improve seedling germination and drive seedling growth; it has strong microbial activity, which may defend against some pests; And it has little to no phytotoxicity. There have been various studies suggesting vermicompost can promote great plant growth and agricultural output. Dhanalakshmi. V., *et al.* (2014) investigated the effect of vermicompost addition on the growth of okra, brinjal and chilli and found that fruit yield increased.

According to a recent review paper by Sinha, K., *et al.* (2010), experiments on the cultivation of important vegetable crops such as tomato (*Lycopersicum esculentus*), egg plant (*Solanum melangena*) and okra (*Abelmoschus esculentus*) have shown very good results. According to this analysis, farmers in India, primarily in the states of Karnataka, Tamil Nadu, Gujarat, Maharashtra, Punjab, Haryana, Himachal Pradesh and Bihar are reaping significant profits from vermicompost. According to this research, farmers in a number of villages in Bihar (classified as 'Bio-Village') have totally gone over to organic farming using vermicompost and have given up the use of artificial fertilizers since 2005.

Because of their rapid growth and maturity, as well as the shorter harvest cycle, the farmers were able to harvest three different harvests in a single year, yielding 2-3 times more.

The key revelations made by farmers about the utilisation of vermicompost noted by the afore said research team are as follows:

1) Reduced irrigation water use;
2) Reduced pest attacks by at least 75%, particularly after spraying vermiwash (liquid drained during vermicomposting).
3) Reduced termite attacks in farm soil with a healthy worm population.
4) Reduced weed growth.
5) Accelerated seed germination and seedling growth.
6) Chemical-free crops produce more fruits per plant (vegetables) and seeds per ear (cereals), resulting in higher quantity and quality.
7) Organic fruits and vegetables have better taste and texture and can be stored for up to 6-7 days, while chemically cultivated produce can only be preserved for 2-3 days.

8) boosted fodder growth by approximately 50% at 30-40 quintal/hectare.
9) Commercial floriculture boosted flower yield by 30%-50% at 15-20 quintal/hectare. Flower blossoms were more vivid and larger in size.

Vegetable field cultivation with vermicompost in WIP.

The following are the major observations made by the author during the 2013-2014 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 (Fig.17-19):

1) Reduced pest attacks in the field;
2) decreased weed growth;
3) Accelerated seedling development for lady's finger, green chilli and brinjal.
4) Increased fruit quality and quantity of each plant, particularly in tomatoes and brinjal.
5) Improved flavour and texture of all vegetables;
6) Faster and more lush development of green vegetables such as red amaranth.

Feedback on Vermicompost by Farmers

Farmers who have adopted vermicomposting generally provide positive feedback about its benefits for agriculture and soil health. Below are their key insights and experiences:

Positive Feedback:

1. Improved Soil Fertility:

Farmers highlight that vermicompost enriches the soil with essential nutrients such as nitrogen, phosphorus, potassium and trace minerals.

It also enhances soil texture, microbial activity and water retention capacity, leading to healthier crops.

2. Higher Crop Yields:

Many farmers report significant improvements in crop productivity after using vermicompost as a natural fertilizer.

The organic composition of vermicompost supports robust plant growth and better flowering and fruiting.

3. Reduction in Chemical Fertilizer Use:

Vermicompost helps farmers reduce or eliminate the use of expensive chemical fertilizers.

This leads to cost savings and healthier, pesticide-free crops, which are more appealing to consumers.

4. Enhanced Crop Quality:

Farmers frequently note improvements in the taste, color and size of their produce.

Vermicompost-grown crops are often more appealing in the market and fetch better prices.

5. Efficient Waste Management:

Farmers appreciate that vermicomposting allows them to recycle agricultural and organic waste, turning it into a valuable resource.

It minimizes farm waste while contributing to sustainable farming practices.

6. Eco-Friendly and Sustainable:

Vermicomposting aligns with sustainable agriculture, allowing farmers to protect the environment while maintaining productivity.

Challenges Faced by Farmers:

1. Initial Investment and Effort:

Some farmers find the setup of vermibeds and maintaining the right conditions (moisture, temperature, etc.) labor-intensive.

2. Knowledge Gaps:

Lack of awareness or technical knowledge can lead to challenges in managing pests, moisture levels, or selecting the right species of earthworms.

3. Weather Sensitivity:

In regions with extreme weather conditions, maintaining the vermicomposting process can be difficult without proper infrastructure.

Chapter 14
FUTURE ASPECT

Future Aspects of Vermicomposting

1. Waste Management at Scale

With increasing urbanization and population growth, the need for sustainable waste management is critical. Vermicomposting can play a key role in managing organic waste on a large scale, reducing landfill burden and associated greenhouse gas emissions.

2. Sustainable Agriculture

As chemical fertilizers harm soil health and the environment, vermicompost serves as a natural alternative, improving soil fertility and promoting sustainable farming practices. The growing demand for organic farming further increases the importance of vermicomposting.

3. Carbon Sequestration and Climate Change Mitigation

Vermicomposting contributes to carbon sequestration by converting organic waste into stable humus, reducing methane emissions from decomposing waste in landfills and promoting sustainable waste recycling.

4. Entrepreneurial Opportunities

Vermicomposting has significant potential for small-scale and large-scale entrepreneurial ventures. Vermicompost and earthworm production can become profitable businesses, particularly in rural areas or regions focusing on organic agriculture.

5. Urban and Community Composting

As cities adopt zero-waste initiatives, vermicomposting can be integrated into urban settings, including households, schools and community centers, to manage food and yard waste effectively.

6. Integration with Circular Economy Models

Vermicomposting aligns with circular economy principles by converting waste into valuable resources. Future systems could incorporate advanced vermicomposting techniques into industrial and municipal waste management frameworks.

7. Technological Innovations

Research and development may lead to innovations in vermicomposting processes, such as automated systems, optimized vermibeds and advanced monitoring tools to improve efficiency and scalability.

8. Environmental Education and Awareness

Promoting vermicomposting through educational programs in schools, colleges and communities can encourage more individuals to adopt this eco-friendly practice, contributing to a greener future.

9. Policy Support and Subsidies

With increasing government focus on sustainable practices, policies and subsidies may support vermicomposting as a preferred method for waste management and soil improvement, ensuring its widespread adoption.

10. Global Adoption and Collaboration

Vermicomposting can address global waste challenges and environmental concerns. International collaborations may foster knowledge sharing, technological advancements and large-scale implementations of vermicomposting practices worldwide.

Bioconversion of organic waste using earthworms to produce a valuable product is an environmental friendly waste management technology. The small critters' ability to consume nearly any organic waste and excrete it as premium organic fertilizer is proving beneficial to farmers and entrepreneurs.

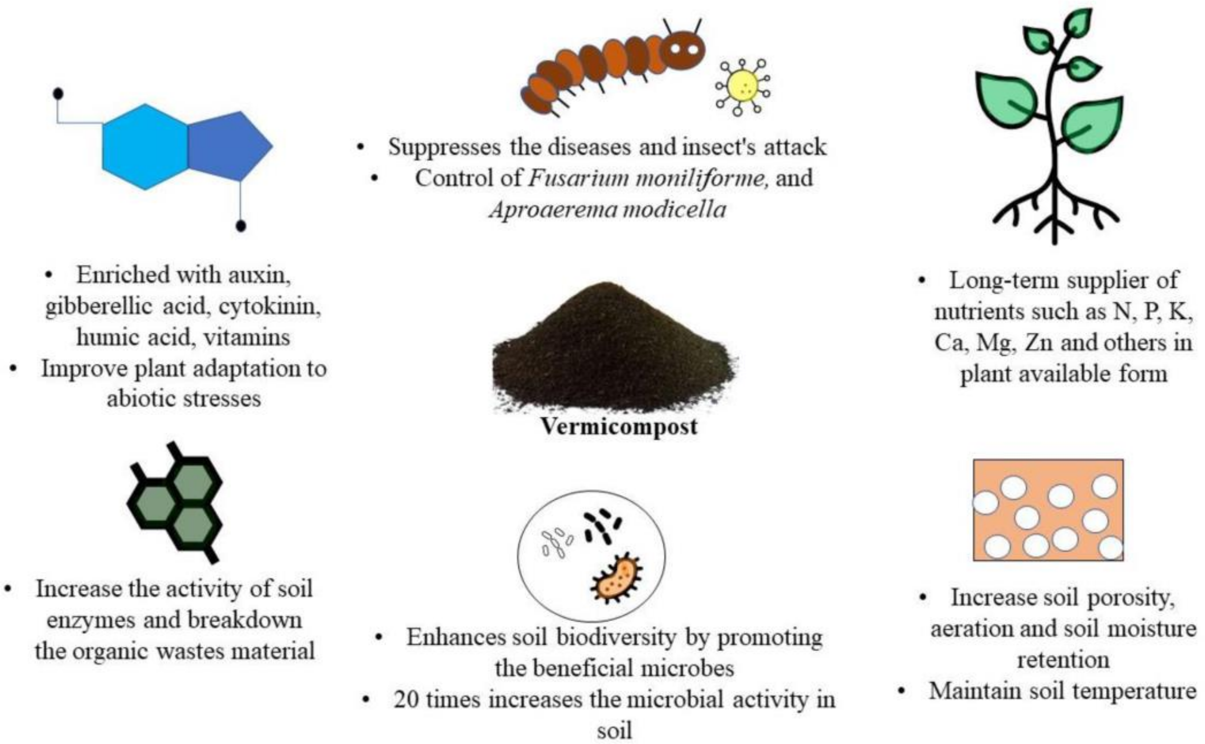

Fig. 14.1: Vermicompost serves as a plant growth regulator and biocontrol agent, enhancing the physical, biochemical and fertility properties of soil while suppressing pest attacks

Keeping environmental and economic considerations in mind, vermicomposting research and development initiatives in under developed countries must be planned, propagated and commercialized. Future research in this topic may involve the following:

1. Improving the vermicomposting procedure to get the most effective process result by adjusting significant variables like, Earthworm variety, Level of moisture content and Bedding layer thickness.

2. Research towards the discovery of more natural species for vermicomposting.
3. Quickening the pre-digestion phase to cut down on the amount of time needed for lignocellulosic wastes and other hard materials to be vermicomposted by doing the following:
    - Using different microbial culture treatments.
    - Employing mechanical and/or physical techniques.
4. Investigate vermicompost teas as an eco-friendly pest control alternative.
5. Attempt to reduce commercial unit operations costs.
6. Conduct on-farm trials to achieve the following objectives:
    - Study the quality, field performance and post-harvest quality of produce from seedlings grown in vermicompost-based media in organic production systems.
    - Vermicompost as an organic seedling medium improves vegetable transplant health and insect resistance.
    - Use vermicompost to improve vegetable yield and plant health on organic farms, increasing efficiency and profitability.

Fig. 14.2: Importance of vermicomposting

Chapter 15

REQUIREMENTS FOR THE COMMERCIAL VERMICOMPOST UNIT

Land: Approximately 0.5–1 acre of land is needed to start a vermiculture production and extension unit. This is enough space for 8–10 180–200 square foot shacks. Watering facilities and a sufficient water supply should be present on the land. Additionally, sub-marginal land could be employed. If someone doesn't own land, they can rent a piece of land for ten or fifteen years.

Fig. 15.1: Land for commercial vermicomposting.

Building and/or Shed: For a business unit, one must invest in an office, warehouses for raw materials and finished goods and infrastructure that include accommodations for the management and employees.

Shed: To keep the vermicompost bed from being saturated by rain or wind, an open shed supported by pillars for the corners or a shed on top with bamboo rafters and wooden tie ups is required. The shed should be provided with ample space for labourers to move around to complete their task.

Vermibeds: The vermibed should have sufficient drainage capabilities to remove extra water and be between 75 and 90 cm thick. To guarantee equal production, the height of the entire bed should be the same. In order to facilitate easy access to the bed's middle, the width of the bed should not exceed 1.5 meters.

Fig. 15.2: Vermibeds and shed

Seed Stock: The main material needed to begin vermicomposting is seeds. Although worms reproduce in six months to a year, the vermicompost bed should begin with roughly 350 worms per m3 to allow the worm population to increase in two to three cycles without negatively impacting productivity.

Roads, Paths and Fencing: The site requires suitable infrastructure, including roads and paths for easy mobility of workers, trolleys and wheelbarrows to deliver raw materials to the bed and transport completed compost. The location should be walled off to keep animals and other undesired factors out. The expenditure should be minimal for this purpose, but these facilities are critical to ensuring uninterrupted output.

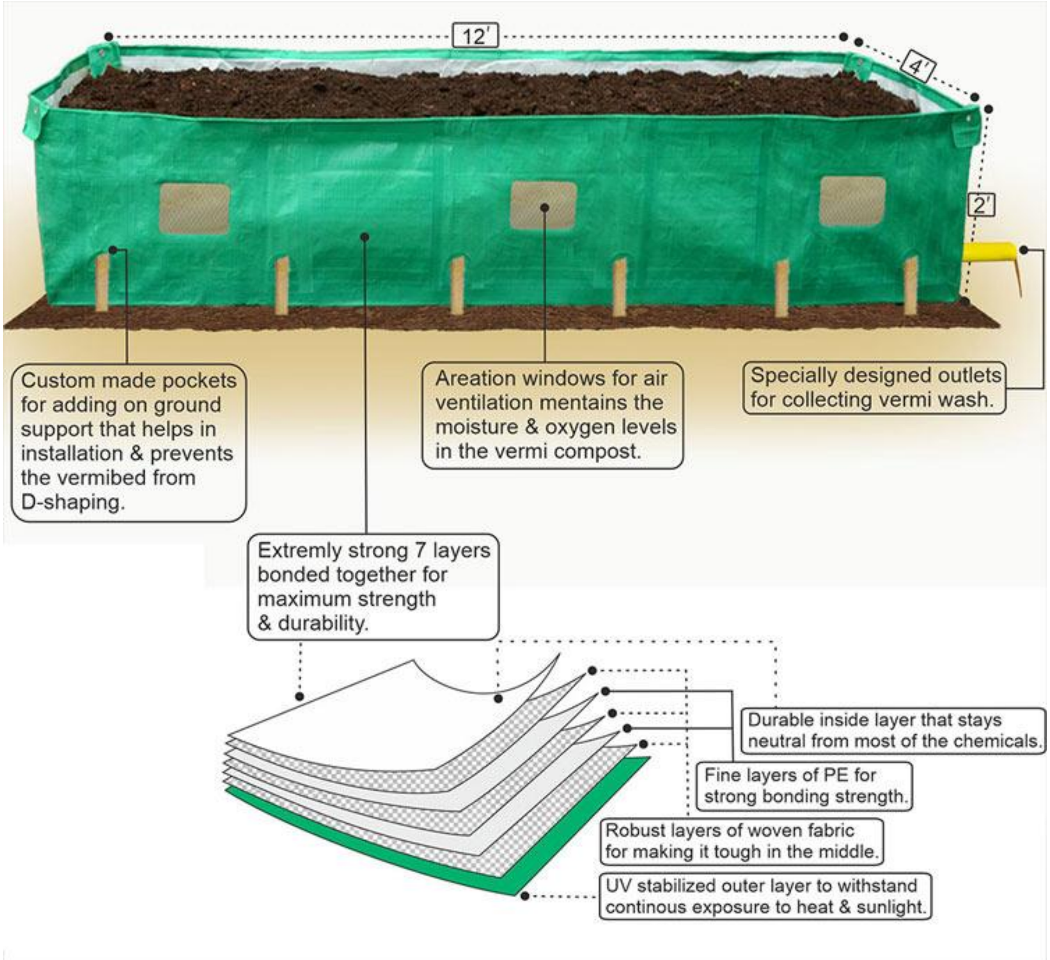

Fig. 15.3: Vermibed and its dimentions

Fig. 15.4: Seed Stock

Water Supply System: The vermicompost beds must be kept moist, with around 50% water content. Adequate water supply with a well-designed water distribution system is required. Drippers with constant water flow would be suitable for continuous water supply while also saving water. This may be an expensive investment, but it lowers the operational expenses of manual watering and is more cost effective in the long run.

Machinery: A shredding machine to shred raw material, wheelbarrows and trolleys for transport to and from the site for compost loading and unloading, aeration, air drying, sifting, stitching and automatic packing.

Transport: If the raw material source is located distant from the unit, transportation is necessary to move the raw materials to the site. Smaller units may utilise smaller vehicles depending on their production, but a truck with a minimum capacity of three tonnes is needed for a unit that produces roughly one thousand tonnes of compost annually. The raw materials need to be transported from the warehouses to the shacks using on-site vehicles, such as trolleys. These costs might be factored into the project estimate.

Furnishings: A reasonable amount could be spent to outfit the office, which could also be used as a storehouse, spending on the basic requirement for an office and storage racks.

Operational Costs: Some of the costs included in the operational cost are ongoing. These expenditures consist of the price of raw materials, gasoline and transportation charges, electricity, insurance, maintenance and repair, worker pay and staff salary. The number of employees and workers hired should be determined by the size of the unit and the number of people required at each stage of production. Every work location should have appropriate management and use of its work force.

Extension Service: By offering cultural material of desired species and offering training to farmers and aspiring entrepreneurs interested in vermicomposting, a vermicomposting facility could benefit the surrounding community. The current units offer competitive prices for culture material and practical help to those who have the notion to start their own commercial vermicomposting units. Extension services unit could help these vermicomposting plants by providing consulting and selling culture material. Additionally, units might build more compact, straight forward models to demonstrate to farmers, gain widespread media coverage and help vermicomposting become more common.

Fig. 15.5: Extension activity

Marketing Channels

A marketing channel refers to the pathway through which a product is transported from its production site to the point of consumption. There is no dedicated or specialized market for vermicompost. The majority of vermicompost is sold directly by producers to local consumers or farmers. Some farmers also produce vermicompost exclusively for their own use, which helps them save money on purchasing inputs from the market. Local consumers typically include farmers, researchers, government organizations and public societies.

The product is distributed through various agencies and channels to reach the end user. Several factors influence the marketing of vermicompost, such as the weight and bulkiness of the product, availability of storage facilities, the strength or efficiency of the marketing agency and the distance between the producer and the consumer. In our country, there are multiple types of marketing channels available for the distribution of vermicompost.

Marketing Channels for Vermicompost

A. **Producer → Consumer (Direct Sale):**

The producer sells vermicompost directly to the consumer without any intermediaries.

B. **Producer → Village Merchant → Consumer (Local Sale):**

Vermicompost is sold by the producer to a village merchant, who then sells it to the consumer.

C. **Producer → Wholesaler-cum-Commission Agent → Retailer → Consumer:**

The producer supplies vermicompost to a wholesaler who also acts as a commission agent. The wholesaler then distributes the product to retailers, who ultimately sell it to consumers.

D. **Producer → Primary Wholesaler → Secondary Wholesaler → Retailer → Consumer:**

In this multi-level channel, the producer sells to a primary wholesaler, who supplies the product to a secondary wholesaler. The secondary wholesaler then distributes it to retailers, who finally sell it to consumers.

These marketing channels significantly impact various marketing costs, including transportation expenses, commission fees and other charges. They also influence the market margins earned by intermediaries such as traders, commission agents, wholesalers and retailers. The choice of marketing channel determines both the price paid by the consumer and the portion of that price that reaches the farmer or producer. A channel is deemed efficient when it delivers the product to consumers at the lowest possible cost while ensuring that the producer receives the maximum share of the revenue.

Goods and Services Tax (GST) and Vermicomposting

You may already be familiar with the concept of GST. The Goods and Services Tax (GST) is a unified and comprehensive tax levied on goods and services consumed within an economy. Similar to many agricultural products, vermicompost is also subject to GST. Vermicompost, being an organic manure, is tax-exempt if sold unbranded. However, if it is sold in branded packaging, it currently attracts a 5% GST rate.

When transporting or couriering vermicompost, it is essential to include a valid bill along with the goods. Additionally, to sell vermicompost online on platforms like Amazon or Flipkart, you are required to obtain a GSTIN (Goods and Services Tax Identification Number). The GSTIN serves as your unique business identifier issued by the Government of India and consists of a 15-digit alphanumeric code based on your PAN.

To conclude, thorough planning is essential to achieve success in your business. Developing a detailed project plan can significantly reduce risks associated with the vermicomposting business. It is recommended to begin on a small scale and gradually expand as you gain expertise in production and marketing.

Cost of Vermicomposting

For those planning to undertake commercial production of vermicompost, it is important to consider not only the production costs but also the significant investment required for procuring capital items such as land, machinery and tools. Setting up a vermiculture hatchery center where earthworms are reared and a vermicomposting unit would typically require an area of around 0.5 to 1.0 acres of land.

The required land will typically accommodate 10-12 sheds, with each shed measuring approximately 300 square feet. This is just an example; smaller or larger units can be considered and the associated costs will vary depending on the production capacity. For larger-scale operations, leasing the land for a duration of 10-15 years is a viable option. Even sub-marginal land (land with limited agricultural potential) may be sufficient for setting up such a unit.

For smaller vermicomposting units, the one-time capital cost is estimated to be around ₹5,500 to ₹6,500 per tonne of vermicompost production. This relatively high capital cost is due to significant expenses involved in setting up vermibeds, constructing sheds to protect these beds and procuring machinery. However, these costs are non-recurring and are incurred only once.

The operational costs, on the other hand, include recurring expenses such as transportation of raw materials, the cost of raw materials and production costs.

If the sources of organic waste and dung are located far from the production facility and if the finished vermicompost needs to be transported over long distances for marketing, the operational costs will increase accordingly to cover these additional transportation expenses. The most effective way to reduce production costs is to secure your own supply of raw materials and capital assets.

To achieve better market access (the ability to sell goods across borders), ensuring the cost-effectiveness (delivering good value relative to its cost) of the finished product is crucial. For larger vermicomposting units, operating them requires recurring expenditures on various items.

These include staff salaries, wages for laborers, costs of procuring raw materials, transportation charges for moving raw materials and finished products, expenses for packing materials, repairs and maintenance, power costs, insurance and other associated expenses.

The number of office personnel and laborers should be determined in advance. This requires breaking down each activity of the unit into smaller sub-activities, estimating the workload for each sub-activity and assessing the capacity of the staff or laborers required to complete the tasks within the desired time frame. It is essential to ensure that the workforce is kept consistently engaged.

Additionally, sufficient personnel should be allocated to key work points such as stores and vermibeds. They should also be provided with an adequate number of tools and implements to avoid unnecessary delays or idle time.

SUMMARY

Nobody and nothing can be compared with earthworms in their positive influence on the whole living Nature. They create soil and everything that lives in it. They are the most numerous animals on Earth and the main creatures converting all organic matter into soil humus providing soil's fertility and biosphere's functions: disinfecting, neutralizing, protective and productive. Aristotle called worms the "intestines of the earth" and Charles Darwin wrote a book on worms and their activities, in which he stated that there may not be any other creature that has played so important a role in the history of life on earth. There can be little doubt that humankind's relationship with worms is vital and needs to be nurtured and expanded. The following sections touch on some of the most important areas in which our natural environment can be preserved and sustained through a partnership with these engines of the soil.

Vermicompost containing higher amount of growth promoting substances, vitamins and enzymes, which in turn increased the microbial population and the addition *Azospirillum* increased the root biomass production, which resulted in higher production of root exudates increasing the beneficial bacteria, fungi and *actinomycetes* population in rhizosphere region and influenced the soil physical, chemical and biological fertility. Vermicompost spread on farm land will not result in pathogen contamination of ground or surface waters. Also pasturelands seeded and re-seeded with *E. foetida* cocoons could help to prevent water contamination by pathogens, since fresh manure dropped by grazing animals will be quickly colonized by compost worms.

Climate change is one of the most serious and pressing environmental problems of our time. One of the principal benefits of vermicomposting occurs through carbon sequestration. This is the process of locking carbon up in organic matter and organisms within the soil. Soils worldwide have been gradually depleted of carbon through the use of non-organic farming systems. The consistent application of compost or vermicompost gradually raises the level of carbon in the soil. Although carbon is constantly leaving the soil as more is being sequestered, the use of composts can increase the equilibrium level, effectively removing large amounts of carbon permanently from the atmosphere.

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

REFERENCES

- Abbasi, S., Hussain, N., Tauseef, S., Abbasi, T. (2018). A novel flippable units vermireactor train system─ FLUVTS─ for rapidly vermicomposting paper waste to an organic fertilizer. J. Clean. Prod. 198:917–930.
- Agarwal SB., Singh A., Dwivedi G. (2003). Effect of vermicompost, farm yard manure and chemical fertilizers on growth and yield of wheat (*Triticum aestivum* L. var HD 2643). Plan Arch 3:9–14
- Ahmed, M., Ahmad, S., Qadir, G., Hayat, R., Shaheen, F.A., Raza, M.A., (2019). Innovative processes and technologies for nutrient recovery from wastes: a comprehensive review. Sustainability 11:4938.
- Alshehrei, F., Ameen, F., (2021). Vermicomposting: a management tool to mitigate solid waste. Saudi J. Biol. Sci. 28: 3284–3293.
- Ananthakrishnasamy S., Sarojini S., Gunasekaran G., Manimegala G. (2009). Flyash—a lignite waste management through vermicomposting by indigenous earthworms Lampito maruitii. Am Eurasian J Agric Environ Sci 5(6):720–724. https://www.idosi.org/aejaes/aejaes.htm
- Ananthavalli, R., Ramadas, V., Paul, J.A.J., Selvi, B.K., Karmegam, N., (2019). Seaweeds as bioresources for vermicompost production using the earthworm, Perionyx excavatus (Perrier). Bioresour. Technol. 275:394–401
- Ansari AA., Hanief A. (2013). Microbial succession during vermicomposting. In: Proceedings of 49th Annual Carribean Food Crops Society Meeting. July 1–5, Port of spain, Trinidad and Tobago, p 441-451
- Ansari AA., Ismail SA. (2008). Relaxation of sodic soils through vermi technology. Pakistan J Agric Res 21:92–97
- Ansari AA., Ismail SA .(2012). Role of Earthworms in vermitechnology. J Agric Technol 8(2):405–415. http://www.ijat-aatsea.com
- Ansari, AA., Sukhraj K. (2010). Effect of vermiwash and vermicompost on soil parameters and productivity of okra (Abelomoschus esculentus) in Guyana. Afr J Agric Res 5:1794-1798. http://www.academicjournals.org/AJAR.
- Arora VK., Singh CB., Sidhu AS., Thind SS. (2011). Irrigation, tillage and mulching effects on Soybean yield and water productivity in relation to soil texture. Agric Water Manag 98(4):563–568. https ://doi.org/10.1016/j.agwat.2010.10.004
- Atiyeh RM., Arancon NQ., Edwards CA., Metzger JD. (2002). The influence of humic acid derived from earthworms processed organic wastes on the plant growth. Bioresour Technol 84(1):7–14

- Badhwar, V.K., Singh, S., Singh, B., (2020). Biotransformation of paper mill sludge and tea waste with cow dung using vermicomposting. Bioresour. Technol. 318:124097.
- Balachandar, R., Biruntha, M., Yuvaraj, A., Thangaraj, R., Subbaiya, R., Govarthanan, M., Kumar, P., Karmegam, N. (2021). Earthworm intervened nutrient recovery and greener production of vermicompost from Ipomoea staphylina–An invasive weed with emerging environmental challenges. Chemosphere 263:128080.
- Bernal MP., Alburquerque JA., Moral R. (2009). Composting of animal manures and chemical criteria for compost maturity assessment. A review. Bioresour Technol 100:5444–5453. doi:10.1016/j. biortech.2008.11.027
- Bernal MP., Paredes SMC., Cegarra J. (1998). Maturity and stability parameters of composts prepared with a wide range of organic wastes. Bioresour Technol 63:91–99. doi:10.1016/S0960-8524(97):00084-9
- Bhat SA., Singh J., Vig AP. (2015). Potential utilization of bagasse as feed material for earthworm *Eisenia fetida* and production of vermicompost. Springer plus 4:11. doi:10.1186/s40064-014-0780-y.
- Biruntha, M., Karmegam, N., Archana, J., Selvi, B.K., Paul, J.A.J., Balamuralikrishnan, B., Chang, S., Ravindran, B. (2020). Vermiconversion of biowastes with low-to-high C/N ratio into value added vermicompost. Bioresour. Technol. 297:122398.
- Bo, Z., Yiyong, C., Zhang, C., Jianlong, L., Hao, T., Jiayu, L., Jun, D., Jinchi, T. (2021). Earthworm biomass and population structure are negatively associated with changes in organic residue nitrogen concentration during vermicomposting. Pedosphere 31:433–439.
- Boruah, T., Barman, A., Kalita, P., Lahkar, J., Deka, H. (2019). Vermicomposting of citronella bagasse and paper mill sludge mixture employing Eisenia fetida. Bioresour. Technol. 294:122147.
- Bridle, T., Pritchard, D. (2004). Energy and nutrient recovery from sewage sludge via pyrolysis. Water Sci. Technol. 50:169–175.
- Budroni, M., Mannazzu, I., Zara, S., Saba, S., Pais, A., Zara, G. (2020). Composition and functional profiling of the microbiota in the casts of *Eisenia fetida* during vermicomposting of brewers' spent grains. Biotechnol. Rep. 25:e00439.
- C. Plaza, R. Nogales, S. Jha, P.K. Ghosh, C.L. Acharya. (2003). Comparative efficacy of three epigeic earthworms under different deciduous forest litters decomposition, Bioresour. Technol. 88:197–206.
- C. Plaza., R. Nogales., N. Senesi, E. Benitez., A. Polo. (2007). Organic matter humification by vermicomposting of cattle manure alone and mixed with two-phase olive pomace, Bioresour. Technol.

- C.A. Edwards. (2004). Earthworm Ecology, CRC Press, Boca Raton, FL,
- Central Pollution Control Board (CPCB). (2004). Management of Municipal Solid Wastes, , New Delhi, India.
- Cestonaro, T., de Mendonça Costa, M.S.S., de Mendonça Costa, L.A., Pereira, D.C., Rozatti, M.A., Martins, M.F.L. (2017). Addition of cattle manure to sheep bedding allows vermicomposting process and improves vermicompost quality. Waste Manag. 61:165–170.
- Chanda GC., Bhunia G., Chakraborty SK. (2011). The effect of vermicompost and other fertilizers on cultivation of Tomato plants. J Hortic For 3:42–45. http://www.academicjournals.org/jhf
- Chaoui HI., Zibilske LM., Ohnot. (2003). Effects of earthworms cast and compost on soil microbial activity and plant nutrient availability. Soil Biol Biochem 35:295–302. www.elsevier.com/locat e/soilb io
- Chauhan A., Joshi PC. (2010). Composting of some dangerous and toxic weeds using Eisenia foetida. J Am Sci 6 (3):1–6. http://www.americanscience.org
- Chefetz B., Hatcher P., Hadar Y., Chen Y. (1996). Chemical and biological characterization of organic matter during composting of municipal solid waste. J Environ Qual 25:776785.doi:10.2134/jeq1996.00472425002500040018x
- Chowdhury, S.D., Hasim Suhaib, K., Bhunia, P., Surampalli, R.Y. (2023). A critical review on the vermicomposting of organic wastes as a strategy in circular bioeconomy: mechanism, performance and future perspectives. Environ. Technol. 1–91.
- Das, M. Srinivasu., M. Bandyopadhyay. (1998). Solid state acidification of vegetable waste, Indian J. Environ. Health 40 (4): 333–342.
- D.Hogg, E.Favoino, M. Centemero, V. Caimi, F. Amlinger, W. Devliegher, W. Brinton, S. Antler. (2002). Comparison of Compost Standards With in the EU, North America and Australia, The Waste and Resources Action Programme (WRAP), Oxon,
- D.W. Nelson., L. E. Sommers. (1982). Total carbon and organic carbon and organic matter, in: A.L. Page, R.H. Miller, D.R. Keeney (Eds.), Method of Soil Analysis, American Society of Agronomy, Madison, pp. 539–579.
- Deepthi, M.P., Kathireswari, P., Rini, J., Saminathan, K., Karmegam, N. (2021). Vermitransformation of monogastric Elephas maximus and ruminant Bos taurus excrements into vermicompost using *Eudrilus eugeniae*. Bioresour. Technol. 320:124302.
- Deepthi, M.P., Nivethitha, S., Saminathan, K., Narendhirakannan, R.T., Karmegam, N., Kathireswari, P. (2021). Effect of vermiwash prepared from livestock biowaste as vermiponics medium on the growth and biochemical indices of Amaranthus viridis L. Environ. Technol. Innov. 21:101-300.

- Deka, H., Deka, S., Baruah, C., Das, J., Hoque, S., Sarma, H., Sarma, N. (2011). Vermicomposting potentiality of Perionyx excavatus for recycling of waste biomass of java citronella-An aromatic oil yielding plant. Bioresour. Technol. 102:11212–11217.
- Delgado-Moreno, L., Bazhari, S., Nogales, R., Romero, E. (2019). Innovative application of biobed bioremediation systems to remove emerging contaminants: adsorption, degradation and bioaccesibility. Sci. Total Environ. 651:990–997.
- Devi, C., Khwairakpam, M. (2020). Management of lignocellulosic green waste Saccharum spontaenum through vermicomposting with cow dung. Waste Manag. 113:88–95.
- E. Smidt., K. Meissl. (2007). The applicability of Fourier-transform infra-red spectroscopy in waste management, Waste Manage. 27:268–276.
- E.Benitez., H. Sainz., R. Nogales., (2005). Hydrolytic enzyme activities of extracted humic substances during the vermicomposting of a lignocellulosic olive waste, Bioresour. Technol. 96:785–790
- Elvira., M. Goicoechea., L. Sampdro., S. Mato., R. Nogales. (1996). Bioconversion of solid paper-pulp mill sludge by earthworms, Bioresour. Technol. 75:173–177.
- E.F. Neuhauser., R. Hartenstein., D.L. Kaplan., (1980). Growth of the earthworm Eisenia foetida in relation to population density and food rationing, OIKOS 35 93–98.
- Edward CA., Burrows I. (1988). The potential of earthworm compost and plant growth media. In: Edward CA, Neuhauser IP (eds) Earthworm in waste Environmental Management. SPB Academic, Hague, pp 211–217
- Edwards CA., Bohlen PJ., (1996). Biology and ecology of earthworms, vol 3. Springer Science & Business Media, pp 426. ISBN:0412561603
- Elumalai D., Kaleena PK., Fathima M., Hemavathi H. (2013). Influence of vermiwash and Plant growth regulators on the exomorphological characters of Abelmoschus esculentus (Linn.) Moench. Afri J Basic Appl Sci 5(2):82–90. https ://doi.org/10.5829/idosi .ajbas .2013.5.2.2332
- Enebe, M.C., Erasmus, M., (2023). Mediators of biomass transformation–a focus on the enzyme composition of the vermicomposting process. Environ. Challenges, 100732.
- Esmaeili, A., Khoram, M.R., Gholami, M., Eslami, H., (2020). Pistachio waste management using combined composting-vermicomposting technique: physico-chemical changes and worm growth analysis. J. Clean. Prod. 242, 118523.
- Fathima M., Balasubramanian A. (2006). Effect of plant growth regulators on the yield and quality of best fibers in Hibiscus sabdariffa L. var. altissima Wester. Int J Bot 2:48–55

- Fialho LL., Silva WTL., Milori DMBP., Simo˜es ML., Martin-Neto L. (2010). Characterization of organic matter from composting of different residues by physicochemical and spectroscopic methods. Bioresour Technol 101:1927–19346. doi:10.1016/j. biortech.2009.10.039
- G.Tripathi., P. Bhardwaj. (2004).Comparative studies on biomass production, life cycles and composting efficiency of Eisenia foetida (Savigny) and Lampito mauritii(Kinberg), Bioresour. Technol. 92:275–278.
- G´omez-Brand´on, M., Lores, M., Domínguez, J. (2013). Changes in chemical and microbiological properties of rabbit manure in a continuous-feeding vermicomposting system. Bioresour. Technol. 128:310–316.
- García-S´ anchez, M., Tauˇ snerov´ a, H., Hanˇ c, A., Tlustoˇ s, P. (2017). Stabilization of different starting materials through vermicomposting in a continuous-feeding system: changes in chemical and biological parameters. Waste Manag. 62:33–42.
- Gemici GA., Kamil Yurekli A. (2000). Effect of some growth regulators and commercial preparation on the chlorophyll content and mineral nutrition of Lycopersicm esculent Mill. Turk J Bot 24:215–219
- Gong, X., Li, S., Carson, M.A., Chang, S.X., Wu, Q., Wang, L., An, Z., Sun, X., 2019. Spent mushroom substrate and cattle manure amendments enhance the transformation of garden waste into vermicomposts using the earthworm Eisenia fetida. J. Environ. Manag. 248:109263.
- Gopal, M., Bhute, S.S., Gupta, A., Prabhu, S., Thomas, G.V., Whitman, W.B., Jangid, K., (2017). Changes in structure and function of bacterial communities during coconut leaf vermicomposting. Antonie Leeuwenhoek 110:1339–1355.
- Goswami, L., Pratihar, S., Dasgupta, S., Bhattacharyya, P., Mudoi, P., Bora, J., Bhattacharya, S.S., Kim, K.H., (2016). Exploring metal detoxification and accumulation potential during vermicomposting of Tea factory coal ash: sequential extraction and fluorescence probe analysis. Sci. Rep. 6:1–13.
- Goswami, L., Sarkar, S., Mukherjee, S., Das, S., Barman, S., Raul, P., Bhattacharyya, P., Mandal, N., Bhattacharya, S., Bhattacharya, S., 2014. Vermicomposting of tea factory coal ash: metal accumulation and metallothionein response in *Eisenia fetida* (Savigny) and Lampito mauritii (Kinberg). Bioresour. Technol. 166:96–102.
- Guerrero RD, (2010). Vermicompost production and its use for crop production in the Philippines; Int J Environ Eng (Special Issue on 'Vermiculture technology'); (Eds.) Rajiv K. Sinha *et al.* (Accepted for publication).
- Gupta PK. (2003). Vermicomposting for sustainable agriculture. Agrobios, India, p 188

- Gusain, R., Suthar, S. (2020) a. Vermicomposting of duckweed (Spirodela polyrhiza) by employing Eisenia fetida: changes in nutrient contents, microbial enzyme activities and earthworm biodynamics. Bioresour. Technol. 311:123585.
- Gusain, R., Suthar, S. (2020) b. Vermicomposting of invasive weed Ageratum conyzoids: assessment of nutrient mineralization, enzymatic activities and microbial properties. Bioresour. Technol. 312:123537.
- H´enault-Ethier, L., Martin, V.J., G´ elinas, Y. (2016). Persistence of Escherichia coli in batch and continuous vermicomposting systems. Waste Manag. 56:88–99.
- Hˇrebeˇ ckov´a, T., Wiesnerov´ a, L., Hanˇ c, A. (2019). Changes of enzymatic activity during a large-scale vermicomposting process with continuous feeding. J. Clean. Prod. 239:118127.
- Hait S., Tare V.(2011). Vermistabilization of primary sewage sludge. Bioresour Technol 102:2812–2820. doi:10.1016/j.biortech.2010.10.031.
- Hanc, A., Castkova, T., Kuzel, S., Cajthaml, T. (2017). Dynamics of a vertical-flow windrow vermicomposting system. Waste Manag. Res. 35:1121–1128.
- Hanc, A., Chadimova, Z. (2014). Nutrient recovery from apple pomace waste by vermicomposting technology. Bioresour. Technol. 168:240–244.
- Hanc, A., Enev, V., Hrebeckova, T., Klucakova, M., Pekar, M. (2019). Characterization of humic acids in a continuous-feeding vermicomposting system with horse manure. Waste Manag. 99:1–11.
- Hanc, A., Hrebeckova, T., Pliva, P., Cajthaml, T. (2020). Vermicomposting of sludge from a malt house. Waste Manag. 118:232–240.
- Haque, M.M., Biswas, J.C. (2021). Emission factors and global warming potential as influenced by fertilizer management for the cultivation of rice under varied growing seasons. Environ. Res. 197:111156.
- Hu, X., Zhang, T., Tian, Hu, X., Zhang, T., Tian, G., Zhang, L., Bian, B. (2021). Pilot-scale vermicomposting of sewage sludge mixed with mature vermicompost using earthworm reactor of frame composite structure. Sci. Total Environ. 767:144217.
- Huang GF., Wong JWC., Wu QT., Nagar BB. (2004). Effect of C/N on composting of pig manure with sawdust. Waste Manag 24:805–813. doi:10.1016/j.wasman.2004.03.011.
- Huang GF., Wong JWC., Wu QT., Nagar BB. (2006). Transformation of organic matter during co-composting of pig manure with sawdust. Bioresour Technol 97:1834–1842. doi:10.1016/j.biorech.2005.08.024.

- Huang, K., Li, F., Li, J., Helard, D., Hirooka, K. (2012). Rapid vermicomposting of fresh fruit and vegetable wastes using earthworm Eisenia foetida. III-113-III-120 J. Jpn. Soc. Civil Eng. Ser. G (Environ. Res.) 68.
- Hirooka, K. (2012). Rapid vermicomposting of fresh fruit and vegetable wastes using earthworm Eisenia foetida. III-113-III-120 J. Jpn. Soc. Civil Eng. Ser. G (Environ. Res.) 68.
- Huang, K., Xia, H., Li, F., Wei, Y., Cui, G., Fu, X., Chen, X. (2016). Optimal growth condition of earthworms and their vermicompost features during recycling of five different fresh fruit and vegetable wastes. Environ. Sci. Pollut. Res. 23:13569–13575.
- Hussain, N., Das, S., Goswami, L., Das, P., Sahariah, B., Bhattacharya, S.S. (2018). Intensification of vermitechnology for kitchen vegetable waste and paddy straw employing earthworm consortium: assessment of maturity time, microbial community structure and economic benefit. J. cleaner Prod. 182:414–426.
- Ismail SA. (2005). The earthworm book. Other India Press, Mapusa, p 101
- Itavo LCV., Santos GT., Jobim CC., Voltolini TV., Faria KP., Ferreira CCB. (2000). Composic¸a˜o e digestibilidade aparente da silage de bagaco de laranja. Revista Brasileira de Zootecnia (In Portuguese) 5:1485–1490. doi:10.1590/S1516-35982000000500029
- J.H. Crawford. (1983). Review of composting, Process Biochem. 18:14–15.
- J.H. Hsu, S.L. Lo. (1999). Chemical and spectroscopic analysis of organic matter transformations during composting of pig manure, Environ. Pollut. 104:189–196.
- J.M. Bremner., R. G. Mulvaney. (1982). Nitrogen total, in: A.L. Page, R.H. Miller, D.R. Keeney(Eds.),Methods of Soil Analysis, Am. Soc. Agronomy, Madison, WI, pp. 575–624.
- Jaikishun S., Hunte N., Ansari AA. Gomathinayagam S. (2014). Effect of vermiwash from different sources (Bagasse, Neem, Paddy Straw in different combinations) in controlling fungal diseases and growth of tomato (Lycopersicon esculentum) Fruits in Guyana. J Biol Sci 14(8):501–507. https ://doi.org/10.3923/jbs.2014.501.507
- Jim´enez, E. I., Garcia, V.P. (1989). Evaluation of city refuse compost maturity: a review. Biol. Waste 27:115–142.
- Jua´rez PDA., Fuente JL., Paulı´n RV. (2011).Vermicomposting as a process to stabilize organic waste and sewage sludge as an application for soil. Trop Sub trop Agro ecosystem 14:949–963. doi:10.1007/s11356-011-0606-1
- K. Lasaridi., Protopapa., M. Kotsou., G. Pilidis., T. Manios., A. Kyriacou. (2006). Quality assessment of composts in the green market: the need for standards and quality assurance, J. Environ. Manage. 80:58–65. Quality assessment of composts in the green market: the need for standards and quality assurance, J. Environ.

- K.E. Lee. (1992). Some trends and opportunities in earthworm research, Soil Biol. Biochem. 24:1765–1771.
- K.R. Butt. (1993). Utilization of solid paper-mill sludge and spent brewery yeast as feed for soil-dwelling earth worms, Bioresour. Technol. 44 (9):105–107.
- Karimi H., Mokhtari M., Salehi F., Sojoudi S., Ebrahimi A. (2017). Changes in microbial pathogen dynamics during vermicomposting mixture of cow manure-organic solid waste and cow manure sewage sludge. Int J Recycle Org Waste Agric 6:57–61. https ://doi.org/10.1007/s40093-016-0152-4
- Karmegam, N., Jayakumar, M., Govarthanan, M., Kumar, P., Ravindran, B., Biruntha, M. (2021). Precomposting and green manure amendment for effective vermitransformation of hazardous coir industrial waste into enriched vermicompost. Bioresour. Technol. 319:124136.
- Karmegam, N., Vijayan, P., Prakash, M., Paul, J.A.J. (2019). Vermicomposting of paper industry sludge with cow dung and green manure plants using Eisenia fetida: a viable option for cleaner and enriched vermicompost production. J. Clean. Prod. 228:718–728.
- Kaviraj., S. Sharma. (2003). Municipal solid waste management through vermicomposting employing exotic and local species of earthworms, Bioresour. Technol. 90:169–173.
- Kizito, S., Luo, H., Lu, J., Bah, H., Dong, R., Wu, S. (2019). Role of nutrient-enriched biochar as a soil amendment during maize growth: exploring practical alternatives to recycle agricultural residuals and to reduce chemical fertilizer demand. Sustainability 11:3211.
- Komakech, A., Zurbrugg, C., Miito, G., Wanyama, J., Vinneras, B. (2016). Environmental impact from vermicomposting of organic waste in Kampala, Uganda. J. Environ. Manag. 181:395–402.
- Kotpal. R.L. (2013). Modern Textbook of Zoology: Invertebrates, Rastogi Publication Sixth reprint (10th edition)
- Kumar, U., Shahid, M., Tripathi, R., Mohanty, S., Kumar, A., Bhattacharyya, P., Lal, B., Gautam, P., Raja, R., Panda, B.B. (2017). Variation of functional diversity of soil microbial community in sub-humid tropical rice-rice cropping system under long- term organic and inorganic fertilization. Ecol. Indicat. 73:536–543. L.F. Diaz, G.M. Savage,
- L.H.Fayolle., D.C.Michaud., J.Stawiecki. (1997). Influence of temperature and food source on the life cycle of the earthworm Dendrobaena veneta (Oligochaeta), Soil Biol. Biochem. 29 (3/4):747–750

- L.F. Diaz., G.M. Savage., L.L. Eggerth., C.G. Golueke. (1996). Solid Waste Management for Economically Developing Countries, International Solid Waste Association, Copenhagen.
- L.P.S.Chan., D.A. Griffiths. (1988). The vermicomposting of pre-treated pig manure, Biol. Wastes 24:57–69.
- Lazcano, C., G´omez- Brand´on, M., Domínguez, J. (2008). Comparison of the effectiveness of composting and vermicomposting for the biological stabilization of cattle manure. Chemosphere 72:1013–1019.
- Li, W., Bhat, S.A., Li, J., Cui, G., Wei, Y., Yamada, T., Li, F. (2020). Effect of excess activated sludge on vermicomposting of fruit and vegetable waste by using novel vermireactor. Bioresour. Technol. 302:122816.
- Liu, N., Liao, P., Zhang, J., Zhou, Y., Luo, L., Huang, H., Zhang, L. (2020). Characteristics of denitrification genes and relevant enzyme activities in heavy-metal polluted soils remediated by biochar and compost. Sci. Total Environ. 739:139987.
- M. Aira., F. Monroy., J. Dom´ ınguez. (2007). Earthworms strongly modify microbial biomass and activity triggering enzymatic activities during vermicomposting independently of the application rates of pig slurry, Sci. Total Environ. 385:252–261.
- M.C.Enebe. and M. Erasmus. (2023). Journal of Environmental Management 345: 118585.
- M.S. Maboeta., L. Van Rensburg. (2003). Vermicomposting of industrially produced Wood chips and sewage sludge using E. foetida, Ecotoxicol. Eniron. Saf. 56256–270.
- Mago, M., Yadav, A., Gupta, R., Garg, V. (2021). Management of banana crop waste biomass using vermicomposting technology. Bioresour. Technol. 326:124742
- Mali´nska, K., Gola´nska, M., Caceres, R., Rorat, A., Weisser, P., Slęzak, E. (2017). Biochar amendment for integrated composting and vermicomposting of sewage sludge–the effect of biochar on the activity of *Eisenia fetida* and the obtained vermicompost. Bioresour. Technol. 225:206–214.
- Manjunath Prasad CT. (2008). Influence of nutrition and growth regulators on fruit, seed Yield and quality of pumpkin CV. Arka Chandan. Karnataka J Agrc Sci 21:115–117
- Michal, P., Hanc, A., Svehla, P. (2019). Inhibiting Effect of Ammonia during Vermicomposting of Sewage Sludge and the Possibilities of its Elimination. Waste, Forum, pp.14: 144–152.
- Morelli JL. (2004). Compostagem de resı´duos produzidos pelas usinas de cana-de-ac¸u´car. In: SIMPO´ SIO SOBRE COMPOSTAGEM: SICOM, 1, 2004, Botucatu. Anais. Botucatu: UNESP, CD-ROM (In Portuguese)

- N. Senesi. (1989). Composted materials as organic fertilizers, Sci. Total Environ. 81/82 :521–524.
- Naeem M., Bhatti I., Hafeez Ahmed R., Yasin Asraf M. (2004). Effect of some growth hormone (GA, IAA and Kinetin) on the morphology and early or delayed initiation of bud of lentil (Lens culinaris Meedik.). Pakistan J Bot 36:801–809
- Ndegwa, P., Thompson, S. (2001). Integrating composting and vermicomposting in the treatment and bioconversion of biosolids. Bioresour. Technol. 76:107–112.
- Nijhawan SD., Kanwar JS. (1951). Physio-chemical properties of earthworm casting and their effect on the productivity of soil. India J Agric Sci 22(4):357–373
- Nwabunwanne, N., Vuyokazi, T., Olagoke, A., Mike, O., Patrick, M., Anthony, O. (2021). Torrefaction characteristics of blended ratio of sewage sludge and sugarcane bagasse for energy production. Appl. Sci. 11:2654.
- Ouzounidou G., Papadopoulou P., Giannakoula A. (2010) Comparative Study on the various plant growth regulators on growth, quality and physiology of Capsicum annum. Pakistan J Bot 42:805–814
- P. Kaushik., V.K. Garg., (2003). Vermicomposting of mixed solid textile mill sludge and cow dung with epigeic earthworm Eisenia foetida, Bioresour. Technol. 90:311–316.
- P. Sangwan., C.P. Kaushik., Garg., (2008). Feasibility of utilization of horse dung spiked filter cake in vermicomposters using exotic earthworm Eisenia foetida, Bioresour. Technol. 99:2442–2448.
- P.M. Ndegwa., S.A. Thompson., K.C. Das., (2000).Effects of stocking density and feeding rate on vermicomposting of biosolids, Bioresour. Technol. 71:5–12.
- Pandit, L., Sethi, D., Pattanayak, S.K., Nayak, Y. (2020). Bioconversion of lignocellulosic organic wastes into nutrient rich vermicompost by *Eudrilus eugeniae*. Biores. Technol. Rep. 12:100580.
- Parthasarthi K., Ranganathan LS. (2002). Supplementation of presumed vermicast with NPK enhances growth and yield in Leguminous crops (Vigna mungo and Arachis hypogaea). J Carr Sci 2:35–41
- Paul, S., Das, S., Raul, P., Bhattacharya, S.S. (2018). Vermi-sanitization of toxic silk industry waste employing *Eisenia fetida* and *Eudrilus eugeniae*: substrate compatibility, nutrient enrichment and metal accumulation dynamics. Bioresour. Technol. 266:267–274.
- Pramanik P., Ghosh GK., Ghosal PK., Banik P. (2007). Changes inorganic: C, N, P and K and enzyme activities in vermicompost of biodegradable organic wastes under liming and microbial inoculants. Bioresour Technol 98:2485–2494. doi:10.1016/j.biortech.2006.09.017

- Provenzano MR., Oliveira SC., Silva MRS, Senesi N. (2001). Assessment of maturity degree of composts from domestic solid wastes by fluorescence and Fourier transform infrared spectroscopies. J Agric Food Chem 49:5874–5879. doi:10.1021/jf0106796
- R. Gupta., V.K. Garg., (2008). Stabilization of primary sludge during vermicomposting, J. Hazard. Mater. 153:1023–1030.
- R.C. Le Bayon., F. Binet. (2006). Earthworm changes the distribution and availability of phosphorus in organic substrates, Soil Biol. Biochem. 38:235–246.
- R.M. Atiyeh., J. Dominguez., S. Subler., C.A. Edwards. (2000). Changes in biochemical properties of cow manure during processing by earthworms (Eisenia andrei Bouche) and the effects on seedling growth, Pedobiologial 44:709–724.
- Raut, M., William, S.P., Bhattacharyya, J., Chakrabarti, T., Devotta, S. (2008). Microbial dynamics and enzyme activities during rapid composting of municipal solid waste–a compost maturity analysis perspective. Bioresour. Technol. 99:6512–6519.
- Rezende MOO., Dores-Silva PR., Silva MD., Zozolotto TCB., Landgraf MD. (2014). Understanding the vermicompost process in sewage sludge: a Humic fraction study. Int J Agric For 4(2):94–99. doi:10.5923/j.ijaf.20140402.08
- Rodella AA., Alcarde JC. (1994). Assessment of organic materials used as fertilizers (in Portuguese). Sci Agric 51(3):556–562.
- Ruggieri, L., Cadena, E., Martínez-Blanco, J., Gasol, C.M., Rieradevall, J., Gabarrell, X., Gea, T., Sort, X., S´ anchez, A., (2009). Recovery of organic wastes in the Spanish wine industry. Technical, economic and environmental analyses of the composting process. J. Clean. Prod. 17:830–838.
- Rupani, P.F., Embrandiri, A., Ibrahim, M.H., Shahadat, M., Hansen, S.B., Ismail, S.A., Ab Kadir, M.O. (2017). Recycling of palm oil industrial wastes using vermicomposting technology: its kinetics study and environmental application. Environ. Sci. Pollut. Res. 24:12982–12990.
- S. Bansal., K.K. Kapoor. (2000). Vermicomposting of crop residues and cattle dung with Eisenia foetida, Bioresour. Technol. 73:95–98.
- S. Gajalakshmi., E.V. Ramasamy. ,S.A. Abbasi. (2002).Vermi-composting of different forms of water hyacinth by the earthworm *Eudrilus eugeniae*, Kinberg, Bioresour. Technol. 82:165–169.
- S. Gajalakshmi., S.A. Abbasi.(2004). Vermiconversion of paper waste by earthworm born and grown in the waste-fed reactors compared to the pioneers raised to adulthood on cow dung feed, Bioresour. Technol. 94:53–56.

- S. Suthar. (2006). Potential utilization of Guar gum industrial waste in vermicompost production, Bioresour. Technol. 97:2474–2477.
- S. Gupta., K. Mohan., R. K. Prasad., S. Gupta., A. Kansal. (1998). Solid waste managementing India: options and opportunities, Resour. Conserv. Recycl. 24:137–154.
- Sangwan P., Kaushik CP., Garg VK. (2008). Feasibility of utilization of horse dung spiked filter cake in vermicomposters using exotic earthworm Eisenia foetida. Bioresour Technol 99(7):2442–2448. doi:10.1016/j.biortech.2007.04.061
- Sangwan P., Kaushik CP., Garg VK. (2010). Growth and yield response of marigold to potting media containing vermicompost produced from different wastes. Environmentalist 30:123–130. doi:10. 1007/s10669-009-9251-3
- Santana, N.A., Jacques, R.J.S., Antoniolli, Z.I., Martínez-Cordeiro, H., Domínguez, J., (2020). Changes in the chemical and biological characteristics of grape marc vermicompost during a two-year production period. Appl. Soil Ecol. 154:103587.
- SAS Institute. (2004). The SAS system for Windows. SAS Inst., Cary
- Sharma, D., Pandey, A.K., Yadav, K.D., Kumar, S. (2021). Response surface methodology and artificial neural network modelling for enhancing maturity parameters during vermicomposting of floral waste. Bioresour. Technol. 324:124672.
- Sharma, K., Garg, V.K. (2019). Recycling of lignocellulosic waste as vermicompost using earthworm Eisenia fetida. Environ. Sci. Pollut. Res. 26:14024–14035.
- Singh BK., Pathak KA., Verma AK., Verma VK., Deka BC. (2011). Effects of vermicompost, fertilizer and mulch plant growth, nodulation and pod yield of French bean (Phaseolus vulgaris). Veg Crop Bulletin 74:153–165. https ://doi.org/10.2478/v1003 2-011-0013-7
- Singh, A., Singh, G.S., (2017). Vermicomposting: a sustainable tool for environmental equilibria. Environ. Qual. Manag. 27:23–40.
- Sinha RK., Herat S., Valani D., Chauhan K., (2009). Vermiculture and sustainable agriculture. Am Eurasian J Agric Environ Sci 5:1–55.
- Soobhany, N., Gunasee, S., Rago, Y.P., Joyram, H., Raghoo, P., Mohee, R., Garg, V.K., (2017). Spectroscopic, thermogravimetric and structural characterization analyses for comparing Municipal Solid Waste composts and vermicomposts stability and maturity. Bioresour. Technol. 236:11–19.
- Srivastava, V., Goel, G., Thakur, V.K., Singh, R.P., de Araujo, A.S.F., Singh, P., (2020). Analysis and advanced characterization of municipal solid waste vermicompost maturity for a green environment. J. Environ. Manag. 255:109914.

- Sudkolai, S.T., Nourbakhsh, F., (2017). Urease activity as an index for assessing the maturity of cow manure and wheat residue vermicomposts. Waste Manag. 64:63–66.
- Suthar S. (2012). Earthworm production in cattle dung vermicomposting system under different stocking density loads. Environ Sci Poll Res Int 19(3):748–755. doi:10.1007/s11356-011-0606-1
- Suthar, S., Sharma, P. (2013). Vermicomposting of toxic weed—lantana camara biomass: chemical and microbial properties changes and assessment of toxicity of end product using seed bioassay. Ecotoxicol. Environ. Saf. 95:179–187.
- U. Reeh. (1992). Influence of population densities on growth and reproduction of the earthworm Eisenia and rei on pig manure, Soil Biol. Biochem. 24:1327–1331.
- V. K. Garg. P. ,Kaushik. (2005). Vermi stabilization of textile mill sludge spiked with poultry droppings by an epigeic earthworm *Eisenia foetida*, Bioresour. Technol. 96 :1189–1193.
- V.K. Garg., P. Kaushik., N. Dilbaghi. (2005). Vermiconversion of wastewater sludge from textile mill spiked with anaerobically digested biogas plant slurry employing *Eisenia foetida*, Ecotoxicol. Environ. Saf. 65 (3):412–419.
- V.K. Garg., Y.K. Yadav., A. Sheoran., S. Chand., P. Kaushik., (2006). Livestock excreta management through vermicomposting using anepigeic earthworm *Eisenia foetida*, Environmentalist 26:269–276.
- Varghese SM., Prabha ML. (2014). Biochemical characterization of vermiwash and its effect on growth of Capsicum frutescens. Malaya J Biosci 1(2):86–91
- Varma, V.S., Kalamdhad, A.S., Khwairkpam, M., (2016). Feasibility of *Eudrilus eugeniae* and Perionyx excavatus in vermicomposting of water hyacinth. Ecol. Eng. 94, 127–135. vermitechnology in waste management: a review on mechanism and performance. J. Environ. Chem. Eng. 7:103392.
- Wang, C., Liu, J., Shen, J., Chen, D., Li, Y., Jiang, B., Wu, J., (2018). Effects of biochar amendment on net greenhouse gas emissions and soil fertility in a double rice cropping system: a 4-year field experiment. Agric. Ecosyst. Environ. 262:83–96.
- Wu, M., Hu, J., Shen, F., Huang, M., Zhao, L., Tian, D., Zhang, Y., Liu, Y., Zeng, Y., Deng, S., (2021). Conceptually integrating a multi-product strategy for the valorization of kitchen waste towards a more sustainable management. J. Clean. Prod. 306:127292.
- Y. Wang., F. Schuchardt., F. Sheng., R. Zhang., Z. Cao. (2004) (2009). Assessment of maturity of vineyard pruning compost by Fourier transform infrared spectroscopy, biological and chemical analysis, Landbauforschung Volkenrode 54:163–169.Author's personal copy 439 R. Gupta, V.K. Garg / Journal of Hazardous Materials 162:430–439

- Yadav, A., Garg, V. (2016). Vermiconversion of biogas plant slurry and parthenium weed mixture to manure. Int. J. Recycl. Org. Waste Agric. 5:301–309.
- Yadav, A., Garg, V. (2019). Biotransformation of bakery industry sludge into valuable product using vermicomposting. Bioresour. Technol. 274:512–517.
- Yuvaraj, A., Thangaraj, R., Ravindran, B., Chang, S.W., Karmegam, N. (2021). Centrality of cattle solid wastes in vermicomposting technology–A cleaner resource recovery and biowaste recycling option for agricultural and environmental sustainability. Environ. Pollut. 268:115688.
- Zhi-Wei, S., Tao, S., Wen-Jing, D., Jing, W. (2019). Investigation of rice straw and kitchen waste degradation through vermicomposting. J. Environ. Manag. 243:269–272.
- Zhong, H., Yang, S., Zhu, L., Liu, C., Zhang, Y., Zhang, Y. (2021). Effect of microplastics in sludge impacts on the vermicomposting. Bioresour. Technol. 326:124777.
- Zziwa, A., Jjagwe, J., Kizito, S., Kabenge, I., Komakech, A.J., Kayondo, H. (2021). Nutrient recovery from pineapple waste through controlled batch and continuous vermicomposting systems. J. Environ. Manag. 279:111784.


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Textbook of Vermiculture and Vermicomposting

ISBN:978-93-48620-26-2

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ISBN 978-93-48620-26-2
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