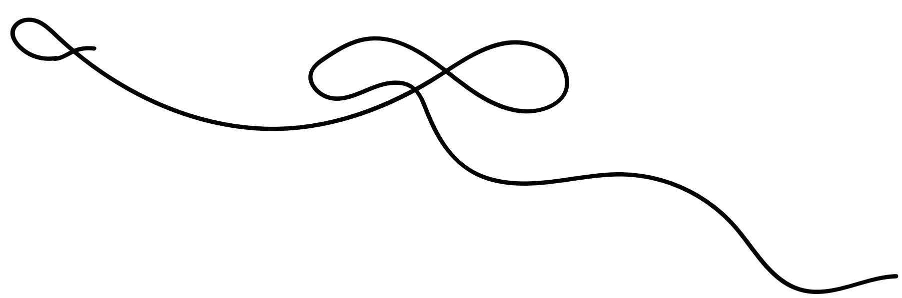
worms



Experiments with worm composting
in Northern and Southern India
2017 – 2021

"It may be doubted if there are any other animals which have played such an important part in the history of the world as these lowly organized creatures."

- Charles Darwin

The Formation of Vegetable Mould Through the Action of Worms (1881)

As a child, I remember being fascinated by these small and slimy creatures appearing suddenly in large numbers during the monsoon. They would be everywhere in the garden, on the porch, even in my room. Somehow, I figured that if I cut them in two, both parts remained alive and started moving away from each other. This was no short of a miracle for a three-year-old.

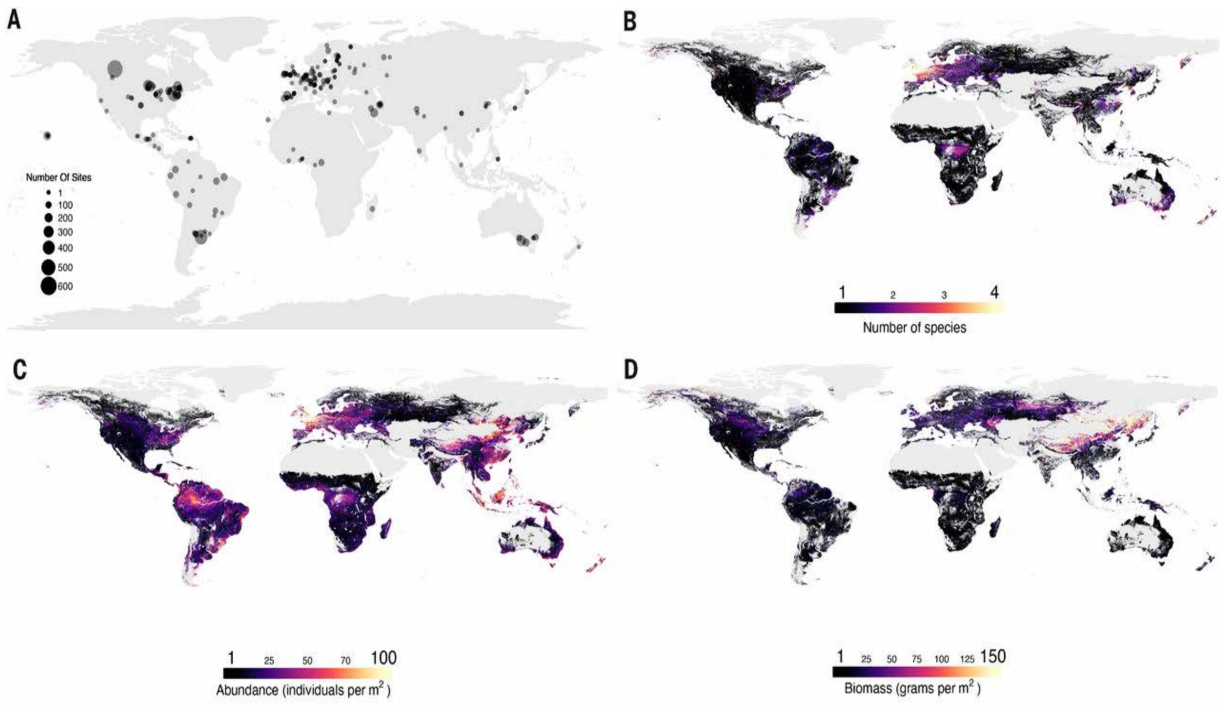
I re-encountered the worms when I was twenty-three, as Angelica and I were beginning to learn about soil and food. The size of these creatures is not at all representative of their importance and function. Popularly called **farmers' best friends**, earthworms play a crucial role in maintaining healthy soils. Besides decomposing organic matter, their burrowing action helps turn the soil, improves soil structure and aeration, for which some people also call them **nature's plough**.

They are known to have originated in the Precambrian era, the first part of the Earth's history from +4 billion years ago to 500 million years ago and since then the humble worm has been moving through earth, like the **pulse of the ground beneath our feet.**

Earthworms are terrestrial organisms with over 7,000 identified species worldwide. For a large number of these, only the name and morphology are known and nothing more about their ecology and biology. Earthworms are **invertebrates** (97% of all animals are invertebrates, i.e., they don't have a bony skeleton that vertebrates like humans have) and classified biologically in the **Annelida** phylum (with over 20,000 species of different kinds of worms) of the Animal kingdom.

Life (Kingdoms):	Eukaryotes – Prokaryotes – Fungi – **Animals** – Plants
Animals (Phylum):	Porifera – Coelenterata – Platyhelminthes – Nematoda – **Annelida** – Arthropoda – Mollusca – Echinodermata – Protochordata – Vertebrata

Earthworms are found all over the world and in all climatic zones, but their populations and species diversity are found to be more in the temperate regions of the world, naturally so because they thrive in moist and cool environments. In temperate ecosystems, the earthworms constitute the largest animal biomass and in tropics they are amongst the most important soil macrofauna along with termites and some ants. They strongly influence the physical, chemical and biological properties of the soil, playing a key role in modifying soil structure, accelerating the decomposition of organic matter, nutrient cycling and ultimately shaping the structure and composition of the above-ground plant community. Yet, we are only starting to appreciate fully the diversity and importance of these seemingly insignificant animals.



From a recent study on global distribution of earthworm diversity (see References)

- **A.** Black dots represent the centers of the study. The size of the dot corresponds to the number of sites within the study.
- **B.** The globally predicted values of species richness
- **C.** The globally predicted values of total abundance
- **D.** The globally predicted values of total biomass

Yellow indicates high diversity;
dark purple, low diversity.

WHY IS IT IMPORTANT TO LEARN ABOUT WORMS?

Integrity of soil ecosystems

Worms form an integral part of a healthy soil food web and have a specific role in decomposition of organic matter and nutrient cycling in the soil. Any study on the quality of the soil of a particular place must include the study of worms present in the soil and their habitat and behaviors which reveal important information about soil structure and biology.

Natural farming

Natural farming or closely associated methodologies that emphasise on enhancing natural processes and minimizing intervention require a deep understanding of how nature works by itself.
By understanding how the worms move and work can help us encourage their growth for soil health and reduce dependence on labour and resource intensive methods of cultivation that destroy soil life.

Accelerating decomposition

Composting with worms can help decompose waste from households, farms and industries. These nutrient dense materials which would otherwise end up as 'garbage' or pollute water sources, can be turned into rich compost to feed gardens in the home or agricultural fields.
Not only as a way of decomposing *unwanted* biomass, composting with worms also helps in enriching the quality of the biomass as a fertilizer for growing food.

HOW WORMS TRANSFORM THE SOIL

Earthworms influence the soil ecosystem in the following ways:

1. Decomposition
   Earthworms are decomposers. They are part of a complex soil food web that is responsible for cycling nutrients in ecosystems, digesting dead biomass and make this energy available for new growth through microbes and plants. Besides digesting the organic matter, themselves, they break the organic matter into smaller pieces, thereby increasing microbial activity and facilitating faster decomposition. Rightly so, they were called the *intestines of the Earth* by Aristotle.

2. Soil biology
   The gut of an earthworm is full of diverse bacteria that help digest a variety of organic matter. The castings (worm excreta) produced by the worms are rich in soluble nutrients and these bacteria. Studies have shown that worm castings enhance bacterial populations in the surrounding soils by 2-12 times. The castings also serve as *culture plates* for development and multiplication of several strains of bacteria in the soil, that are only naturally found in the earthworm gut.
   Thus, the worms not only maintain the soil food web but also enrich it in diversity and population.

Earthworms being higher in the soil food chain and web, indicate healthy populations of bacteria, fungi, protozoa, nematodes and other soil microbial life, which is important to maintain a healthy soil ecosystem. The health of earthworms in the soil is therefore an indicator of the soil health and fertility.

3. Soil structure
   Earthworms have been called ***ecosystem engineers*** because of their ability to alter soil structures by creating deep horizontal and vertical burrows. These burrows increase the porosity of the soil and therefore increase its *aeration* and *water infiltration and holding capacity*.
   Moreover, as worms eat soil mixed with organic matter, they are constantly macerating soil particles and aggregating them with their intestinal mucus and along with organic matter, bacteria and other microbes which also creates structure in the soil. The worm casting themselves, like humus, have a high surface area which too contributes to a healthy soil structure.

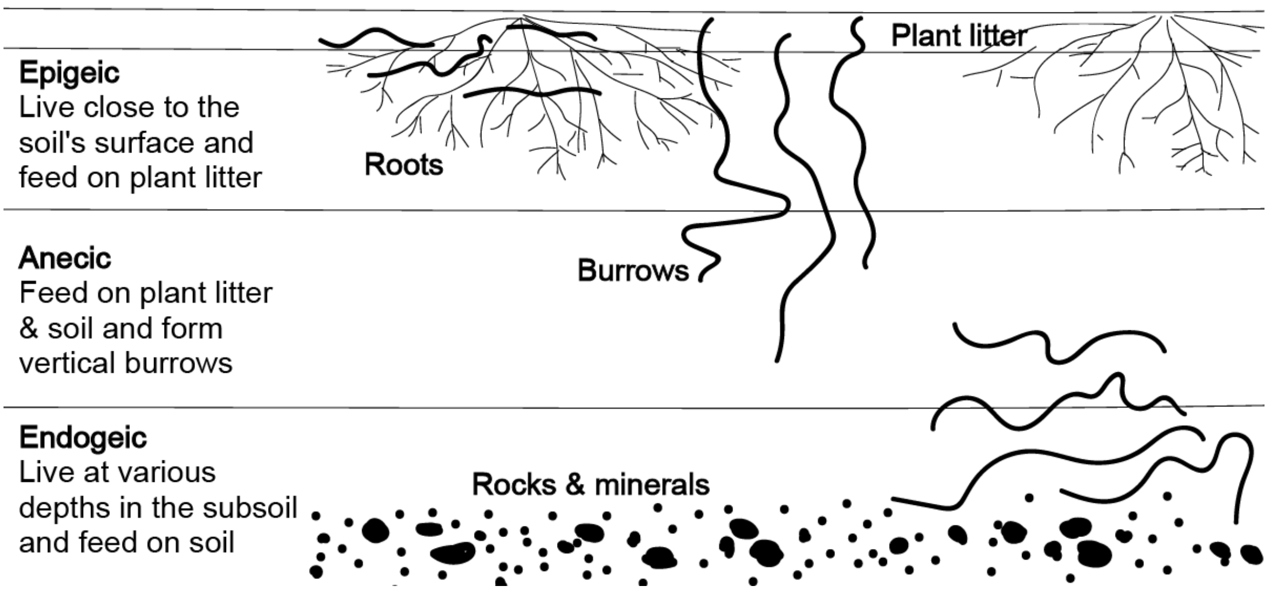
4. Bioturbation
   From the Latin '*turbation'* meaning disturbance, bioturbation refers to movement of soil particles due to living beings. The living beings predominantly responsible for bioturbation are the soil macrofauna like earthworms, termites and ants.
   Earthworms form a link between the top and the deeper layers of the soil. As the worms move, they mix different layers of the soil with each other and with organic matter influencing the structural, chemical and biological properties of the soil. This volume of the entire soil and organic matter, including their burrows, that the worms influence through their association with a diversity of soil microbes, is called *drilosphere*.

5. Soil formation
   Because of their movement through the soil, earthworms serve as a link between the various layers at different depths in the soil bringing more minerals to the top and building organic matter in the deeper layers. They play a significant role in top soil formation through their direct action as decomposers and, in *physical weathering* of mineral particles in their guts and *biochemical weathering (chelation)* by enhancing the biology of the soil.

6. Soil chemistry
   Through their interaction with the organic matter and soil microbiology, the earthworms also affect the chemical nature of the soil. They transform the nutrients stored in minerals and organic matter and make them bio-available to the plants and the microbes, thereby influencing the nutrient concentrations in the soil. While worm castings are generally of a neutral pH, earthworm environments tend to be on the acidic side due to the presence of organic acids released by the microbes to digest the organic matter.

TYPES OF WORMS AND THEIR HABITAT

Earthworms can be classified based on the niche they occupy – the depth of the soil where they live and the kind of food they eat. Although all earthworms have some common characteristics, features like size, pigmentation (skin colour) and quickness of movement reflect which niche different species occupy.



Three main ecological categories of earthworm. However, not all earthworms fit in these categories neatly as some earthworms vary their burrowing and feeding habits based on their stage of growth and soil conditions.

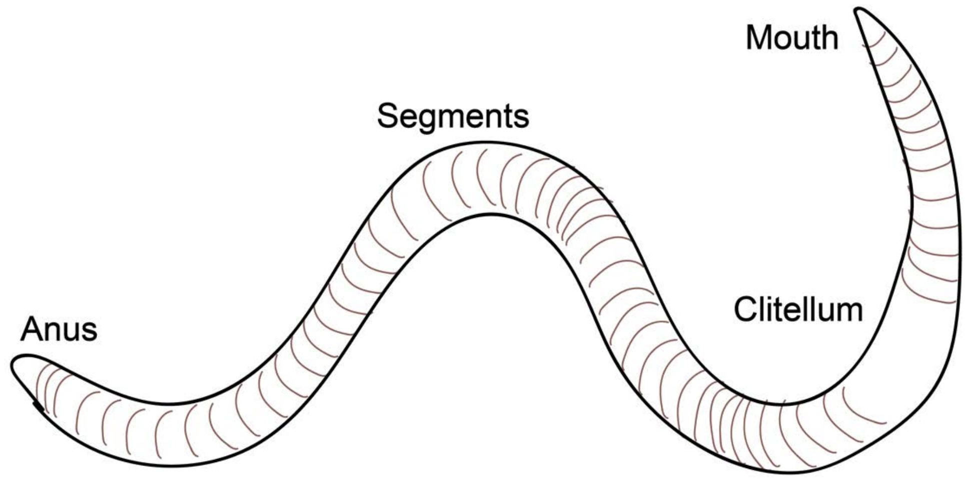
	Epigeic	Anecic	Endogeic
Niche	Surface	Top soil	Sub soil
Food	Phytophagous	Geophytophagous	Geophagous
Proportion of humus in food	Polyhumic	Oligohumic	Mesohumic
Burrows	No	Deep vertical	Branched horizontal
Pigmentation	Dark	Medium	Light
Muscles	Thick	Week	Medium
Movement	Quick	Sluggish	Moderate
Metabolic rate	High	Medium	Low
Reproductive rate	High	Medium	Low
Life cycle	Short	Medium	Long
Length (cm)	Small (1-18)	Long (3 – 140)	Medium (2.5 – 30)
Examples	*Perionyx excavatus, Eisenia foetida, Eudrilus eugeniae, Lumbricus terrestris*	*Lampito mauritii*	*Octochaetona thurstoni*

The epigeic earthworms form the major component of earthworm fauna in temperate regions and the endogeic earthworms are predominant in tropical forests. Thus, tropical earthworms depend more on soil mixed with different levels of humic substances rather than surface litter.
The litter feeders, which are not burrowers, constitute a very small number in tropical situations.

According to the recent report by Julka et al, there are 590 species of earthworms in India with different ecological preferences, but data on the functional role of the majority of the species and their influence on the habitat is lacking. *L. mauritii* is the dominant species found almost all over India along with other earthworm species and is found in abundance in cultivated, agricultural, orchard, semi-forested lands while in old growth forests, it is common to find its close cousin *Lampito kumiliensis*.

Epigeic earthworms are most likely to be used for worm composting as they feed on and live within organic matter. They are also vigorous in their feeding habit and growth and hence can decompose organic matter rapidly. The most popular composting worms in India are the Red wrigglers (*Eisenia foetida*) and the African night crawlers (*Eudrilus eugeniae*). However, both of them are exotic to India. *Perionyx excavatus* is an endemic specie which has also been recognized as an effective composting worm and is now receiving more and more attention in India.

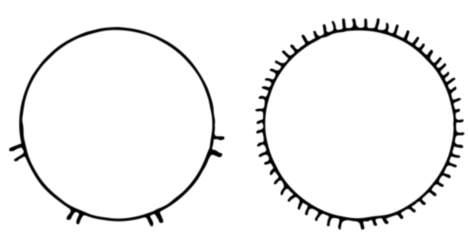
BIOLOGY OF A WORM



All earthworms have long cylindrical bodies with **segments** and a permeable skin through which they respire.

The first segment of the earthworm into which the mouth opens is called the **peristomium** with a lobe like structure on it called the **prostomium**. The prostomium is the head portion of the body of annelids and contains mouth and sensory organs like eyespots. The peristomium is the first and the oldest segment of the annelid's body and surrounds the mouth. The last segment of the worm is called the anal segment and has a hole for the **anus** at the end. As the worms mature, few segments in the anterior portion of their body fuse together to form a thickening of the skin. This is called the **clitellum**. Its function is to secrete a viscous fluid to form the cocoon for the eggs.

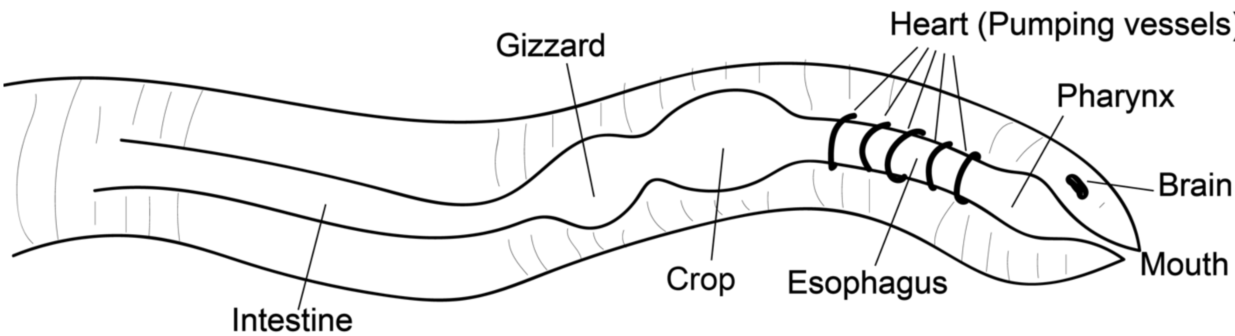
The worms move with the help of hair like structures, **setae** which are chitinous bristles located on the skin. They move with the help of the thick muscular wall beneath the skin of the worms, by a rhythmic contraction and expansion of the muscles. The setae help to grip onto the surface.



A cross section of worm showing different setae arrangements.
The number and arrangement of setae varies with species

Inside the body of the worm is the digestive tube, the mouth leading to the **pharynx** followed by **esophagus**, **crop** and **gizzard** opening into the **intestine** finally ending at the **anus** in the last segment.

Soil and organic matter are drawn into the mouth by the sucking action of the pharynx muscles. In the pharynx secretes juices which moistens the food and makes it easier for it to move through. The crop stores the food and finally moves it to the gizzard which breaks the food into fine particles and moves it to the intestine. In the intestine, digestive juices and enzymes from bacteria help digest the food and release the required nutrients for the worm. Undigested soil and organic matter are expelled through the anus as **castings** which are also called **worm castings** or **vermicastings**.

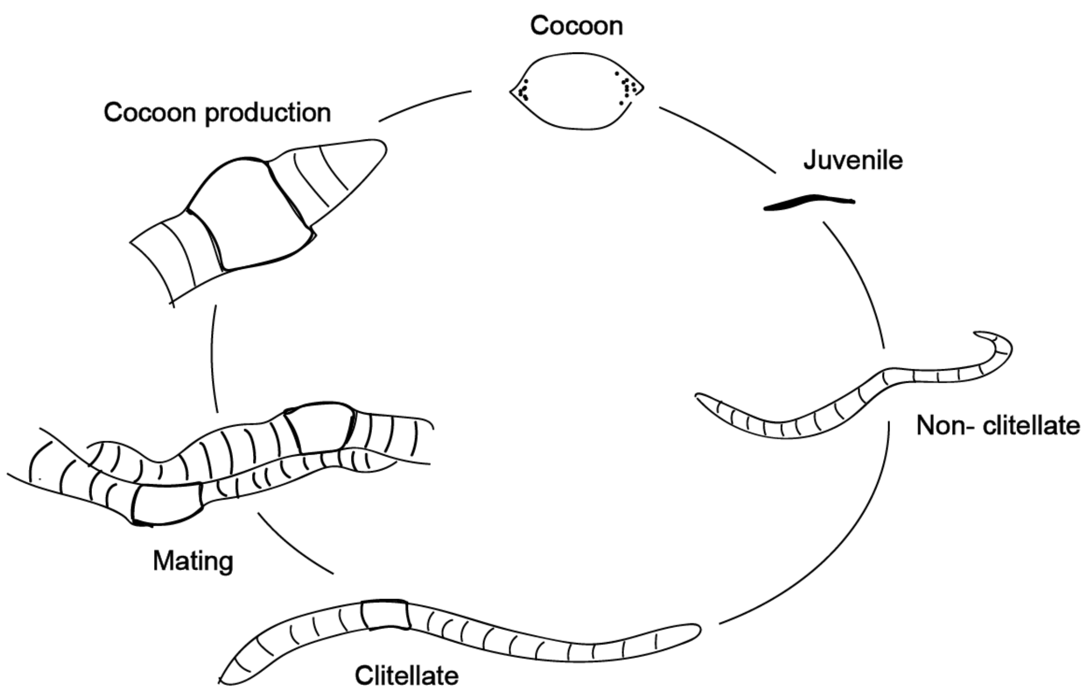


Worm biology

The colour of the worms varies generally from pale to dark brown and purple. The colour of the skin is an adaptation to protect the worms from sunlight. Hence, epigeic worms are darker in colour than the endogeic worms.

Earthworms are hermaphrodite creatures, which means that they have both male and female reproductive organs in the same body. However, they don’t generally self-fertilize. Two worms copulate by joining to each other’s body through the reproductive pores (male and female) close to the clitellum. The sperm from the male pore of one worm is then transferred to the female pore of the other.

LIFE CYCLE OF A WORM



The earthworm life cycle, like many others, starts with an egg. **Cocoons** are *lemon shaped* casings containing a few or many eggs. The shape, size and number of eggs as well as the incubation time for the eggs varies in different species. Once the cocoon hatches, **juveniles**, are released which grow bigger but still without a clitellum and are therefore called **non-clitellates**. Once mature, they develop the clitellum and are called **clitellates**. This marks the beginning of the reproductive period of a worm's life. During this time, the worms copulate either by mating or self-fertilization (*parthenogenesis*) which is followed by cocoon formation around the eggs. Gradually, the cocoons are shed in the soil and this completes the life cycle.

The life span of worms varies according to species. *Lampito mauritii* can live up to a year after it is hatched while Eisenia foetida can live up to five years.

The life cycle of *L. mauritii* is about 60 days and that of *E. foetida* is 60-80 days.

Besides this, earthworms have the ability to regenerate their lost segments. However, it is easier for a worm to regenerate the tail than the head. So, while we believe that cutting the worms into two will multiply them, it is not always true.

WORMS IN AUROVILLE

The worms that are commonly observed in and around Auroville are:

Common name	Common Indian earthworm / Mauritian worm	Red wrigglers / Tiger worm	African night crawler
Scientific name	*Lampito mauritii*	*Eisenia foetida*	*Eudrilus eugenia*
Origin	Endemic	Europe	Africa
Climate suitability	Tropical	Tropical and temperate	Tropical
Special characteristics	Bioluminescence*	Adaptability to moisture and temperature	Voracious feeding and reproduction
Habit	Anecic	Epigeic	Epigeic
Vertical distribution (from surface)	10-30 cm	Only in compost	Only in compost
Food	Soil+ Organic matter	Organic matter	Organic matter
Optimum temp.	25-27 c	25 c	25 – 30 c
Moisture	55%-65%	65%-75%	65%-75%
pH	7.5	6.5	28-34 c
Soil preference	Red sandy / Laterite	-	-
Life cycle** (days)	~ 60	~ 60-80	~ 45-50

* *Only a few species of the earthworms are known to exhibit bioluminescence. Lampito mauritii in one of these rare miracles. Though researchers are still not convinced about the role of this adaptation in the worms, it is suggested that it is probably associated with defense against nocturnal predators or for attracting members of the same species in general or for mating.*

** *Cocoon to sexual maturity*

Deepika & Bernard from Pebble Garden have also seen *Perionyx excavatus* (also endemic) in the soil until a few years ago. They say the worms one day suddenly disappeared.

A note on common Worm Snake (*Ramphotyphlops braminus*)

While looking for earthworms at AuroOrchard, I came across something of the shape and size of a worm but appearing and moving like a snake. This was the Brahminy blind snake, or common worm snake. They are one of the world's smallest snakes, generally 10-20 cm long. As the name suggests, they are blind but can distinguish between light and dark. They feed on small invertebrates in the soil (especially Ant and termite eggs) and on decomposing material. The species ranges throughout Southeast Asia, and has been documented in other parts of the world like the Middle East, Africa and the U.S.

VERMICOMPOST

Vermicompost is the excreta of earthworms (also called worm castings or vermicast). Being rich in both biology and nutrient concentration, it is an excellent soil fertilizer and conditioner. Besides having all the qualities and benefits of a compost, vermicompost is particularly rich in plant available nutrients and beneficial microbes.
Vermicompost is also great way of decomposing organic matter and returning it to the soil at a domestic, agricultural or industrial scale.

Culturing worms to produce vermicompost is a simple process but requires care and attention.

These are the essential conditions required by the worms to grow:

1. A hospitable habitat (vermibed)
2. Availability of food (either added all at once or layer by layer at regular intervals)
3. Adequate aeration (maintaining good structure in the bedding)
4. Adequate moisture (50-80%)
5. Protection from temperature extremes (keeping away from direct sun and wind

These and other considerations for setting up and maintaining a vermicompost are given below. These are based on our experiences in Kodaikanal (Tamil Nadu), Bir (Himachal Pradesh) and Auroville (Tamil Nadu).

1. Selecting the worms for composting

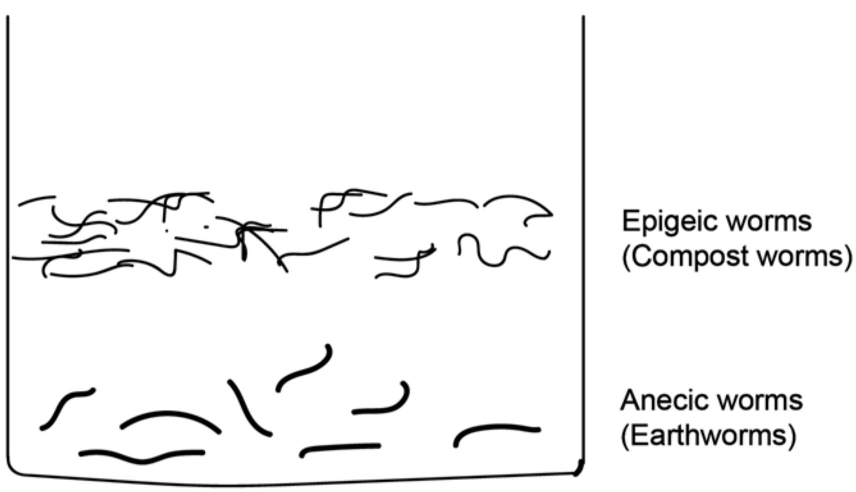
Epigeic worms like *E. foetida*, *E. eugeniae and P. excavatus* have long been used in composting and are very effective in decomposing organic wastes, but since they only thrive in rich organic matter, they do not survive if put in the soil, and therefore do not add significant benefits in improving soil structure. Anecic worms, however, like *L. mauritii* are useful both in decomposing organic wastes (though much slower than the epigeic worms) and modifying the structure of the soil.

Normally, only epigeic are used in composting, but more and more experiments are now being done to have a kind of polyculture of worms - a vermicompost system with both epigeic and anecic worms, offering both the niches for an integrated soil- worm process. The epigeic worms, which are often exotics- *E. foetida* or *E. eugeniae*, go through the organic matter ferociously and rapidly, while anecic worms like *L. mauritii,* which can be collected locally from the site, add the indigenous biology to the compost.

(We have had amazing results with our 'worm polyculture' set up at Auroorchard. *E. foetida* stays on the upper layers of the compost feeding mainly on the kitchen waste while *L. mauritii* live in the deeper layers, adding their richness and structure to the compost.)

Also, all available species of epigeic worms can be mixed together and added to the compost. This is good for the diversity of the microbial life in the finished vermicompost.

The selection of worms for the compost must be done keeping in mind the need and the context, giving preference to indigenous species. Worms collected on site or from a local farm are much more effective than from a far-off supplier, because of adaptability to climatic conditions.



Worm polyculture

2. Siting the compost

The best place for a vermicompost unit would be a place that worms like naturally. The following should be considered:

- Shaded from the sun either by trees or a roof, to protect the worms from direct light and heat
- Protected from the rain to prevent water logging
- Composting unit located on an elevated land or on stones to protect from stagnating water in the monsoon
- Protected from the wind to prevent evaporation and drying
- Close to a water source to maintain optimum moisture
- Protection from ants, termites, rats and other animals where necessary

3. Selecting a container

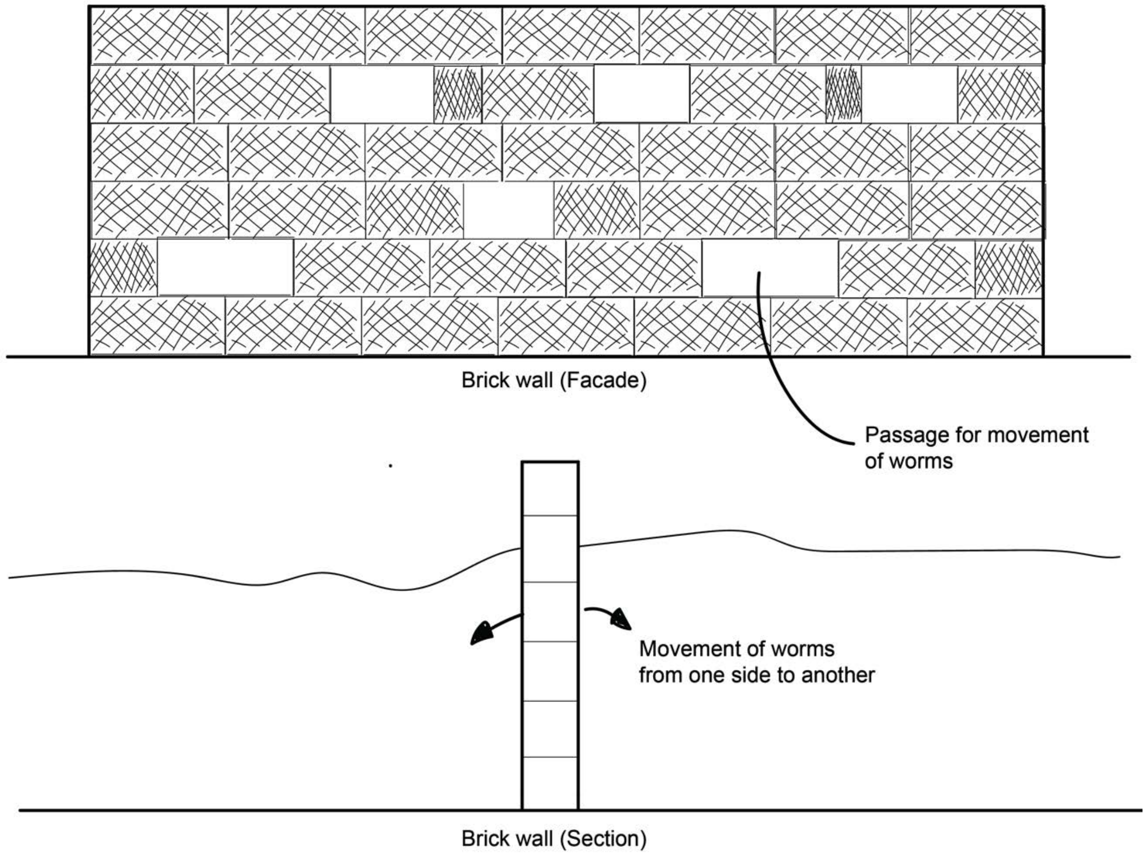
Vermicompost can be made in any container (concrete, plastic, wood etc.) with the possibility of drainage at the bottom to avoid stagnant water. It is preferable to have a small tray or bucket under the vermicompost container to collect the excess water and *leachate.*

The following are some commonly used systems for preparing vermicompost. These, however, are not the only ones.

a. Tank system

A tank system can be made using bricks and cement/lime/mud mortar. The number of tanks depends on the availability of organic matter to be composted. They are an effective solution for dairies, farms, etc.

The size of the tank too can vary with the volume required for the waste being generated. Normally, the width and height are 1m each and the length can be extended as needed. The 1m x 1m gives a unform structure to the compost, allowing for even temperature and moisture conditions.
Often the tanks are constructed with shared walls and the walls are built with gaps in between to allow migration of worms from one tank to the other depending on availability of food.



Porous walls in vermicompost tanks

Tank composting system at Shunya farm, Bir, Himachal Pradesh, November 2018

b. Concrete ring system

This system is simple and quick to setup. Concrete rings can be stacked one on top of another to create a bin. Generally, no more than two rings are used at a time. Placing more rings than that would create challenges for easy access and use. Similar rings of other material like plastic or terracotta can also be used.

Kitchen vermicompost unit, AuroOrchard, Auroville, November 2020

c. Box system

For this a rectangular deep box can be used. The dimensions of the box would depend on the desired size and capacity of the compost. This is usually more practical for urban spaces, individual houses and small-scale composting.

Box type vermicompost for kitchen waste at Coin de Terre, Pitchandikulam, Auroville, November 2020

d. Heap system

A simple heap system requires making compost layer by layer building a heap about 1 m wide and 1 m high and as long as needed. The bottom-most layer usually is made from twigs and woody material to create a strong base for the pile and also to lift the pile off the ground surface a little. This allows oxygen to enter the pile from the bottom and also for excess water to drain out. After the base, layers of dry leaves, twigs, chipped wood, etc. are alternated with layers of nitrogenous material like green leaves, grasses, animal dung etc. Water is added after every couple of layers (or light watering continuously) to keep the material moist.

The heap when ready is covered with a jute or a plastic cover to retain heat and moisture. Such a pile heats up quite a bit in the initial days.

Worms should only be introduced once the pile has passed through the peak temperatures and has reached more or less the ambient temperature.

Heap composts (on the right) at Sun farm, Kodaikanal, January 2016

4. Preparing the bedding

The bedding of the compost is the habitat and the starting condition created at the bottom of the tank/box/ring/pile. This is the lower most layer of the compost over which the food is added.

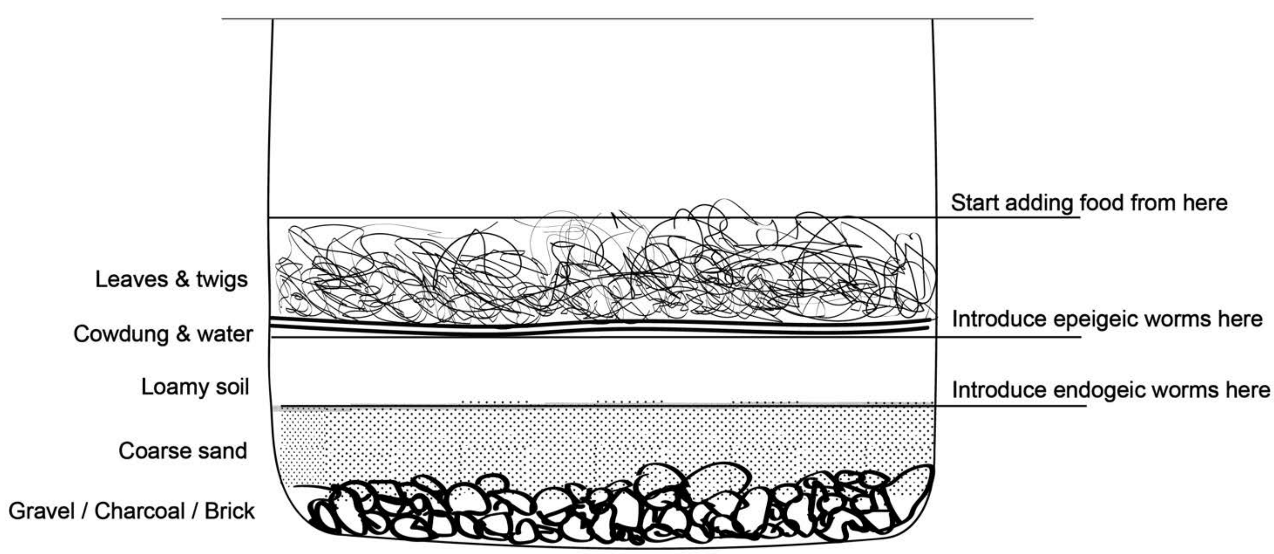
It is very important that the bedding is made with care and with all the required ingredients, as it is crucial for the health of the worms and the process of vermicomposting.

Some important characteristics of the bedding-

i) It has good structure (*bulking potential*) at the lowermost layer to allow aeration and avoid stagnant water saturating the bedding.
ii) It has spaces to allow worms to create habitat
iii) It has more dry material than green to prevent heating and last longer
iv) It can hold moisture (*absorbency*)

The selection of bedding materials is key to a successful vermiculture. Worms can be enormously productive and reproductive if the conditions are good. However, their efficiency drops off rapidly when their basic needs are not met. Good bedding mixtures are an essential element in meeting those needs. They provide protection from extremes in temperature, the necessary levels and consistency of moisture, and an adequate supply of oxygen.

A schematic of a bedding for a small-scale worm polyculture is given below. It can be changed with caution, keeping in mind the principles mentioned above. The system can be modified appropriately for only anecic or only epigeic worms.



From bottom up:

Broken bricks with charcoal: 5-10 cm
Coarse sand: 5-10 cm
Loamy soil: 15 cm
Add her the epigeic and anecic worms
Cowdung: 5-10 cm
Dry leaves: 10-15 cm

Instead of dry leaves, any of these could also be used- cardboard, paper, straw, chipped wood, sawdust etc.

Moisten the layers as you add by sprinkling water gently.
Cover the box, tank with mesh to protect from small animals, birds etc. and with plastic to protect from rain.

5. Collecting local earthworms

Earthworms can be collected easily from a place rich in organic matter.

In Bir (Himalayas), the worms were found naturally in abundance in cow dung heaps. These were of course epigeic worms and were highly effective in the compost.

In AuroOrchard (South of India), *L. mauritii* were easy to collect near the cow shed where cow urine and wash from cow dung flows out into the banana field. The soil in this area is moist, because of continuous water flow and shade from the banana and is rich from all the nitrogen waste and banana roots. We were not able to find any epigeic worms in the soil.

We also *harvested* worms from a location close to the new vermicompost at Auroorchard. A spot 1m x 1m was selected under a tree and a shallow pit (about 5-10 cm deep) was dug. Then, cowdung mixed with water was poured in this pit and covered with dry leaves and straw. The pit was watered to maintain moisture for about three weeks. Then, the soil was dug and sure enough the worms had come to the surface to feed on the cowdung. This method is common in the area and is also documented by Sultan Ahmed Ismail in his 'Earthworm book'.

6. Feeding the vermicompost

Any locally available organic waste can be fed to the vermicompost as long as it has a good balance of carbonaceous and nitrogenous materials. Earthworms prefer lower levels of lignin and tannin, and therefore it is important that carbon in worm food is maintained in balance with nitrogen. Also, too much carbon will slow down the decomposition process while too much nitrogen will create excess heat and suck oxygen out of the system, both of which will be detrimental for the worms and the overall compost ecology.

In the beginning, only small amounts of organic matter should be added to observe how fast the worms get through it. Gradually, the quantities can be increased as the worm populations increase. At any time, the layer of organic matter added must not be thicker than about 10 cm to prevent heating.

Another way is to fill the tank or box up to the brim with predigested waste (so that there is no risk of heating) and a significant number of worms introduced on the top. Gradually the worms go down on their own.

Organic matter can also be 'pre-digested' by keeping it in a pile for about 3 weeks and then feeding it to the worms. During this time, the organic matter loses excess heat and the bacteria already start the decomposition process making it easier for the worms to feed on it.

Kinds of foods that can be used:

- Kitchen waste (balance excess nitrogen by adding waste paper, cardboard etc.)
- Dung from animals (balance excess nitrogen if using fresh dung by adding dry leaves and straw)
- Green leaves from Moringa tree (*Moringa oleifera*) and Subabool tree (*Leucaena leucocephala*) can also be used as high nitrogen sources in farms without animals. (These can be balanced by carbon sources like dry leaves, think twigs etc.)

In ideal conditions, worms can eat up to their own body weight every day. But $1/3 - 1/2$ of their body weight/day can be considered as the average rate of feeding.
When earthworms ingest organic matter, they macerate it and pass it through their system as casts, most of which is changed very little chemically but has higher surface area which enhances microbial activity and accelerates decomposition.

Therefore, more than decomposing organic matter by themselves, worms help in breaking down matter and accelerate decomposition by stimulating microbial activity. Overall, this synergistic association makes nutrients available for the entire soil food web, increases diversity, facilitates nutrient cycling and supports life in and above the soil.

7. Maintaining temperature and moisture

The soil temperature and moisture are crucial in deciding the growth and activity of worms.
Different kinds of worms have different optimum ranges for moisture and temperature. However, the range for most is 50-85% moisture and 20-30 degrees C. temperature.
75-90% of the earthworms' body weight is water and they need good moisture in the soil to maintain their water content and prevent water loss.

The moisture requirement of epigeic worms is more than that of endogeic and anecic worms.

Temperature can be checked using thermometer probes. To check moisture, squeeze a handful of compost, if water escapes barely from between your fingers, the moisture is about 50%. Using this as reference, moisture percentage can be estimated. Watering should be done once in a while if required. While watering care should be taken that the compost doesn't become saturated as this will affect the worms.
Finally, the worms themselves are an indication of optimum temperature and moisture. If they are healthy, agile and reproducing, generally things are going okay.

8. Harvesting the vermicompost

When the container is getting full, the lower composted layers can be harvested. Carefully move the top layer where most of worms would be, to one side. Start digging the material that has changed its texture to powdery and colour to dark brown/black. This is the vermicompost. Be careful to not extract too many worms out of the system along with the compost. The intention should be to leave as many worms as possible back in the bin to be able to initiate a new cycle of the compost.

Sieving

Vermicompost is often sieved by hand or with a mesh to remove undecomposed organic matter and worms. This serves as the vermibed for the next compost cycle and helps to maintain culture populations, especially for epigeic worms (like E. *foetida*), which are exotic and hard to find. Anecic worms (like L. *mauritii*) could be added to the soil with the vermicompost. They are easy to harvest from the soil and introducing them in different locations could help develop soil structure and nutrition availability.

Trapping

To remove worms from the compost, they can also be *trapped.* Insert a few small balls of fresh cowdung in various spaces within the vermicompost. After a day or so, most worms would be around the balls. These can be removed added to the vermibed of the new compost(s).

Migration

If the vermicompost is exposed to light, the worms will escape to the lower layers. The upper layer can therefore be harvested. This process can be repeated till the desired quantity of the compost is harvested. Worm migration can also be facilitated in tank system with porous wall (see tank system above). Here, making a new pile of organic matter in the adjacent tank gets the worms to migrate out of a finished compost. This is the most elegant method but requires space to build at least a couple of tanks next to each other.

Worms in compost, Shunya farm, Bir, Himachal Pradesh, July 2018

Lampito *mauritii* collected at AuroOrchard, Auroville, September 2020

Lampito *mauritii* in vermicompost at AuroOrchard, Auroville, November 2020

Left: *Eisenia foetida*, Right: *Lampito mauritii*
in box vermicompost at Coin de Terre, Pitchandikulam, Auroville, November 2020

9. Application

The harvested composted could directly be added to the soil as a layer and covered with mulch. It can also be added to holes made to transplant young saplings. It is also beneficial when added to nursery soil as the rich biology in the compost inoculate the young roots which help them when they grow in the soil.

Vermicompost can also be made into an extract by adding water and mixing thoroughly. This mix could be used to water the plants, or spray on the leaves and directly on the soil.

10. Storing

It is best to use the compost as soon as it is ready. However, if it needs to be stored for a while, it should be in a cool, shaded places protected from sun and rain. It could be covered lightly by a gunny sack (preferable) or plastic. Water should be sprinkled on it regularly to maintain around 50% moisture. Compost can be stored for 6 months-1 year. However, as time passes the nutrients start oxidizing and the microbial population declines. It is best to use compost as fresh as possible.

A note on pH and temperature

Earthworms are sensitive creatures and while they adapt to pH changes within a range of 6 – 8, they don't tolerate sudden fluctuations. They thrive in close to neutral pH. When fresh food (kitchen waste, cowdung etc.) is added to a worm bin, it stimulates bacterial growth which raises both the temperature and pH of the system. Only once the microbial activity stabilises, and the pH and temperature normalise, worms start working on the organic matter. Therefore, it is advisable to add the food little by little to avoid generating excess heat and creating acidic conditions, and to balance the fresh, green, nitrogenous food with dry, brown, carbonaceous food.

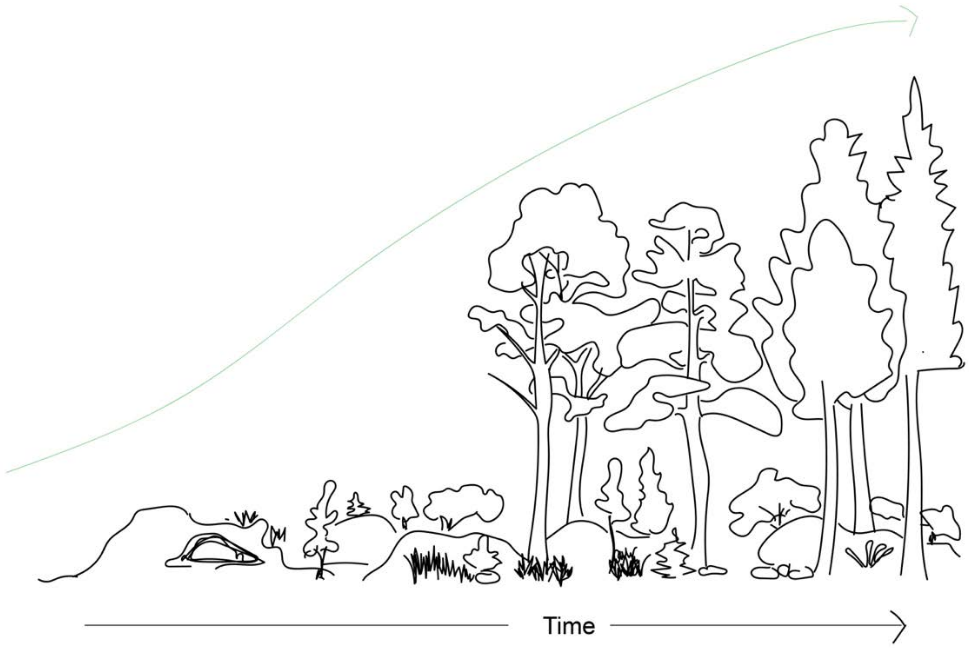
A note on Black soldier fly / White maggots

Black soldier flies appear because:

- Food available is more than what the worms can eat
- Food is mostly nitrogenous / Lack of enough carbon
- The compost is more than 80% wet

When the worms are not able to cope with the excess food, nature brings in the black soldier flies. They appear as white maggots. They are the larvae of the black soldier flies. They are voracious eaters and reproduce very quickly. They are not at all bad for the compost but they indicate that the compost has more biomass than what can be digested by the worms.
To bring back the balance- slow down the feeding of the compost, turn the compost a little to add more air to it (be careful not to disturb worm bedding), and add brown and dry material to create a good C: N balance. Even on its own the system will come back to balance as the black soldier flies grow and accelerate decomposition.

WORMS & ECOLOGICAL SUCCESSION



Natural succession of soil and plants over time

Succession is a natural process of a land going through evolution of soil and plant life. If left undisturbed, with time, the life on the land becomes more and more complex, develops more and richer relationships giving rise to higher forms of plants and animals. But this isn't a linear process. With disturbances like natural calamities, fires, floods, deforestation etc., the succession clock resets and once again life comes together to move forward in succession.

Different ecosystems will have different succession pathways depending on initial conditions, climate, water availability etc. and succession cycles can be of several hundred to thousand years.

The climax communities, so called because they are at the end of the succession cycles, are not static configurations but are relatively stable. Even in these rich and complex systems, nature keeps re-inventing itself, albeit at an even slower rate.

Agriculture, at least in the traditional-conventional sense is keeping land at an early succession stage, with abundant sunlight and high bacterial populations to support monocot, dicot and vegetable crops. Even fruit orchards are managed for vigorous growth and abundant flowering, a characteristic of early succession plants. Early succession soils (like of a grassland) are bacterial dominant while late successional soils (like of a forest) are fungal dominant. Since earthworms increase bacterial populations, and favour nitrification (Keller, 1893; Puh, 1941), they are more suited in an early to middle succession cycle. Their action of burrowing and aerating the soil is also a way of rehabilitating soils to create more oxygen and moisture which sets the template for higher succession. This is not to say that worms will not be present in a forest, but ecologically, they are more crucial and perhaps more significant in the early stages of natural succession.

WORMS & TERMITES

Earthworms, ants, termites, centipedes, beetles, grasshoppers, cockroaches and woodlice, may all be called "*ecosystem engineers*" (specifically earthworms, termites and some ants) because their activities modify the soil and enrich its productivity.
While all of them have fascinating characteristics of their own, I find earthworms and termites more intriguing than the others. In the colder areas (Kodaikanal and Bir), worms are more active, and termites, if present, are working in deeper layers, and in warmer areas the termites are more active while the activity of the worms vary depending on season.

In the case of Auroville, termites are the predominant soil macrofauna and responsible for most of the primary decomposition. Earthworms are present in the soil throughout the year but they are active mostly in the months from July- Feb, when the soil temperature is not as high and the soil moisture is above 50%.

Both the worms and the termites contribute to the soil structure and aggregation through castings and sheetings respectively. They also help in regulating the flow of air and water in the soil.

In understanding the work of worms, termites and ants, we can appreciate the role of soil invertebrates in managing and sustaining soil health and nutrient cycles. This invaluable knowledge can help us regenerate agroecological systems of both tropical and temperate nature.

FUTURE EXPERIMENTS

The documented range of applications such as animal feed, therapeutics, human food, waste decomposition, soil quality enhancement, bioremediation etc., where *Lampito mauritii* has been used is fascinating. Dr. Ismail calls it the wonder worm and we must be grateful to have this worm as an abundant resource at AuroOrchard. We must now learn to work with the worm and discover how it can help us make our integrated solutions richer. The following would be of immense interests in this area:

- Taking further the concept of 'worm polyculture' and setting up an experimental vermicompost unit for cowdung in the compost area at AuroOrchard.

- Exploring worm meal as a protein source for chickens as a substitute for commercial chicken feed.

- Collecting and using vermiwash. (diluted with water (10%) before spraying). Studies have found vermiwash to be very effective on several plants against pests and diseases. If need be, vermiwash may be mixed with cow's urine and diluted (1 liter of vermiwash, 1 liter of cow's urine and 8 liters of water) and sprayed on plants to function as an effecting foliar spray and pesticide.

As we have seen, earthworms play a major part in the soil ecosystem and are therefore of particular interest to agriculturists and ecologists. Their presence and function can reveal a lot about the health of the soil and the knowledge of working with them can benefit acceleration of decomposition processes and returning a rich biology to the soils. Though a lot has been written about earthworms, we are still in the infancy of understanding their behaviour and the vast interconnected web of life of which they are a small but significant part.

REFERENCES

- The Earthworm Book, Sultan Ahmed Ismail
  https://earthwormsofindia.com/

- Eco-science Research Foundation, India
  http://www.erfindia.org/local.asp

- Ecological considerations of earthworms used in vermiculture
  http://www.annelida.net/earthworm/Vermillennium%202000/Vermicology%20I.pdf

- The Earthworm Society, Britain
  https://www.earthwormsoc.org.uk/

- The Importance of Earthworms: Charles Darwin's Last Manuscript
  https://www.nypl.org/blog/2012/04/19/earthworms-darwins-last-manuscript

- Growth and reproduction performances of *Perionyx excavatus*
  https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7320800/#:~:text=Among%20them%2C%20earthworm%20Perionyx%20excavatus,The%20earthworm%20(P.

- Comparison between P. excavatus and E. foetida
  http://downloads.hindawi.com/journals/aess/2010/967526.pdf

- Lampito mauritii biology
  http://www.brainkart.com/article/Earthworm---Lampito-mauritii_33172/#:~:text=Lampito%20mauritii%20is%20commonly%20found,tinge%20at%20the%20anterior%20end.

- Perionyx excavatus biology
  https://shodhganga.inflibnet.ac.in/bitstream/10603/217243/2/c2.pdf

- Life cycle of E. foetida
  https://www.tandfonline.com/doi/abs/10.1080/02541858.1988.11448096

- Earthworms in forests
  https://fpr.vermont.gov/sites/fpr/files/Forest_and_Forestry/Forest_Health/Library/EarthwormsInForests_final.pdf

- Trouble with earthworms in the forest
  https://www.npr.org/templates/story/story.php?storyId=9105956

- Role of Earthworms in Soil Fertility Maintenance through the Production of Biogenic Structures: Tunira Bhadauria, Krishan Gopal Saxena
  https://www.hindawi.com/journals/aess/2010/816073/

- Effect of agricultural management on earthworms and termites
  https://www.sciencedirect.com/science/article/pii/S0167880910003129

- Higher local earthworm diversity in temperate regions than in the tropics
  https://www.sciencedaily.com/releases/2019/10/191024141227.htm

- Global distribution of earthworm diversity
  https://science.sciencemag.org/content/366/6464/480

- Earthworm species richness at higher latitudes
  https://www.labroots.com/trending/earth-and-the-environment/16047/earthworms-world

- The Role of Earthworms in Tropics with Emphasis on Indian Ecosystems
  https://downloads.hindawi.com/journals/aess/2010/414356.pdf

- Eisenia foetida adaptability with season
  https://www.sciencedirect.com/science/article/pii/S1631069106001922?via%3Dihub

- Comparative studies on biomass production, life cycles and composting efficiency of Eisenia foetida (Savigny) and Lampito mauritii (Kinberg)
  https://www.sciencedirect.com/science/article/abs/pii/S0960852403002372?via%3Dihub

  Effect of temperature on growth and reproduction of the epigeic earthworm, Eudrilus eugeniae (Kinberg)
  https://pubmed.ncbi.nlm.nih.gov/12017264/

  Influence of pH and temperature on the oxygen consumption of the earthworm, Lampito mauritii
  https://www.ias.ac.in/article/fulltext/secb/059/03/0145-0153

  About ANC
  https://wormfarmfacts.com/African-Night-Crawler.html

  Study on life cycle of E. eugeniae
  https://pharmaresearchlibrary.com/wp-content/uploads/2013/09/PRL2013-IJRPLS-1764.pdf

  Production of Worm Biomass (Vermiprotein) and Vermicompost by Using Epigeic Earthworms
  http://ijzi.net/Issue/1133663021IssueMS7.pdf

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