TEACHER&TRAINER GUIDE

VERMICOMPOSTING

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VERMICOMPOSTING

What you'll learn

You will learn how to produce and use vermicompost to obtain the nutrients needed by agricultural products. The guide was prepared to contribute to the development of your technical knowledge and skills on vermicomposting.

Key achievements

- Explains vermicomposting and its importance for a sustainable environment.
- Explains the terms and terminology related to vermicompost production.
- Compares vermicompost production methods.
- Classifies the advantages and disadvantages of vermicompost production methods over each other.
- Explains the role of earthworms in vermicompost production.
- Explains the importance of substrate type for the vital functions of earthworms.
- Analyzes the contribution of the substrate type to the composition of the final product, vermicompost.
- Illustrate the key parameters in the design of the living environment (beds) of earthworms.
- Plans the basic processes of vermicompost production.
- Classifies abiotic and biotic parameters affecting vermicompost production.
- Explains how to harvest vermicompost.
- Explains the importance of vermicompost for plants and soil.
- Explains the economic benefits of vermicomposting.
- Designs the requirements for the vermicompost production facility.
- Explains the current state of the market in vermicompost production as a commercial activity.
- Compares legal regulations and incentives for vermicompost production in different countries.
- Explains the functions, advantages and disadvantages of plant nutrients.

The Guide includes;

- A total of 15 video lessons,
- A total of 16 lessons,
- Downloadable educational materials,
- Certificate of completion

INTRODUCTION TO VERMICOMPOSTING

Increasing urbanisation, industrialisation and economic growth lead to the production of large quantities of solid waste worldwide. The management of this solid waste has become an ecological and technical problem. Sustainable solid waste management practices are indispensable for keeping the environment healthy and clean [1]. The situation of solid waste generation is worsening almost everywhere in the world. Studies indicate that by 2025, 1.8 million tonnes of solid waste per day will be generated in the Asia Pacific region alone [2]. According to different studies, an average of 0.77 kg of solid waste per person per day is generated in developing countries. It is estimated that the world's solid waste generation will increase to 3 billion tonnes by 2025 [3, 4].

The lack of appropriate technology for the economic recycling of solid waste in developing countries has resulted in large quantities of solid waste that pose significant technical, economic and environmental problems. Although there are many strategies for solid waste management, including waste minimisation, recycling at source, waste-to-energy, incineration and composting, it is known that some of these treatment and disposal methods can cause serious environmental problems. There are numerous scientific studies showing that waste disposed in landfills or open landfills causes groundwater contamination due to leaching of organic and inorganic compounds in the waste [5–7]. Landfilling and incineration processes are not preferred much considering their negative environmental impacts and low economic contribution. Waste sludge from treatment plants used as fertiliser can cause toxicity to soil, plants and soil microorganisms when applied directly to agricultural lands due to its high nitrogen (N) and phosphorus (P) content.

Considering all these adverse conditions, vermicomposting, which enables the conversion of solid wastes into organic-rich fertiliser, stands out as an ecologically sound and applicable technology. Vermicomposting is a waste management technology that involves the decomposition of the organic components of solid waste in an environmentally friendly manner to a level where they can be easily stored, processed and applied to agricultural fields without any negative impact [1, 5, 8]. Vermicomposting is a product of the collective work of microorganisms and earthworms under environmentally controlled conditions. In summary, it is a biotechnological process in which organic wastes are converted into nutrient-rich vermicompost using earthworms. The microorganisms present in the system are responsible for the biochemical breakdown of organic matter, while the earthworms are involved in improving the substrate and also in modifying the biological activity. This is a very low-cost technology for the treatment of organic waste using earthworms.

Composting is one of the feasible means for converting bio-degradable solid wastes into beneficial organic soil amendments for supporting environment friendly agricultural production system. Many beneficial organisms and microorganisms act as chemical decomposer in the process of formation of stable organic end-products (compost) during composting. Among them, decomposers like earthworms play significant role in stimulating the process of composting, enhancing nutrient value while fastening the process of stable organic end-product formation. This process of involvement of earthworms in preparing enriched compost is called vermicomposting. It is one of the simplest methods to recycle agricultural wastes and to produce quality compost. Earthworm acts physically an aerator, crusher and mixer, chemically a degrader and biologically a stimulator in the process of decomposition. Earthworms consume biomass (decaying organic matter) and excrete it in a digested form called as worm casts or worm manure. Worm casts are popularly called as black gold. They are rich in essential plant nutrients, plant growth promoting substances, beneficial soil micro flora and having properties of inhibiting pathogenic microbes. As a result, the organic endproducts produced by the use of earthworms i.e. vermicompost also inherits most of the beneficial properties (to soil health and crop productivity) of black gold. Vermicompost acts as an organic soil amendment- improves three dimensional soil health's (physical, chemical & biological properties). On application of vermicompost, it enhances the soil quality by improving its physicochemical and biological properties. The earthworm's underground burrows modify soil hydro-thermal and aeration regimes by making the soil more porous thus, allowing free movement of air, infiltration of water into deeper soil layers for better profile moisture recharge and root water uptake processes. Vermicompost is becoming popular as one the major components of the organic farming system because of its high nutritive value in addition to an important organic soil amendment [9].

LESSON 1

1. BASICS OF VERMICOMPOSTING: TERMS AND TECHNIQUES

Learning outcomes

- Trainees know the terms and expressions commonly used in vermicompost production.
- Trainees explain the term of compost.
- Trainees recognize the types of earthworms commonly used in vermicompost production.
- Trainees explain the term of bedding.
- Trainees associate the terms of bed, pile, windrow and pit with vermicompost production.
- Trainees explain the terms of anaerobic and aerobic.
- Trainees know the function of the Bokashi bin.
- Trainees explain the importance of $CaCO_3$ for vermicompost production.
- Trainees know clitellum, segment and cocoon.
- Trainees explain the difference between compost and vermicompost.
- Trainees explain the term of microorganisms.
- Trainees explain the function of protein as a substrate in vermicompost production.
- Trainees explain the term of vermicast, worm tea, worm castings.

Instructions for the trainer

Trainer, explain to students the terms commonly used in vermicomposting using Supplementary Material 1 (SM-1). The setup of the presentation was designed to display first the image of vermicompost production and then the term associated with the image.

- The trainer opens the presentation.
- The trainer reflects the image first in order.
- The trainer asks the trainees to give their opinions about the picture they see.
- The trainer expects the trainees to explain the picture.
- The trainer shows the term of the image to the trainees and explains the term.
- The trainer repeats this exercise for all terms.
- The trainer reflects the presentation again from the first image and waits for the trainees to make the correct identification.

Basic requirements: Computer, projector

1. BASICS OF VERMICOMPOSTING: TERMS AND TECHNIQUES

Acid : A liquid that tastes sour and smells somewhat sharp. Acids help dissolve rock and break down food. It is a normal product of decomposition. Redworms do best in a slightly acid soil (pH less than 7) environment. Below pH 5 can be toxic. Addition of pulverized egg shells and/or lime helps to neutralize acids in a worm bin (Figure 1).

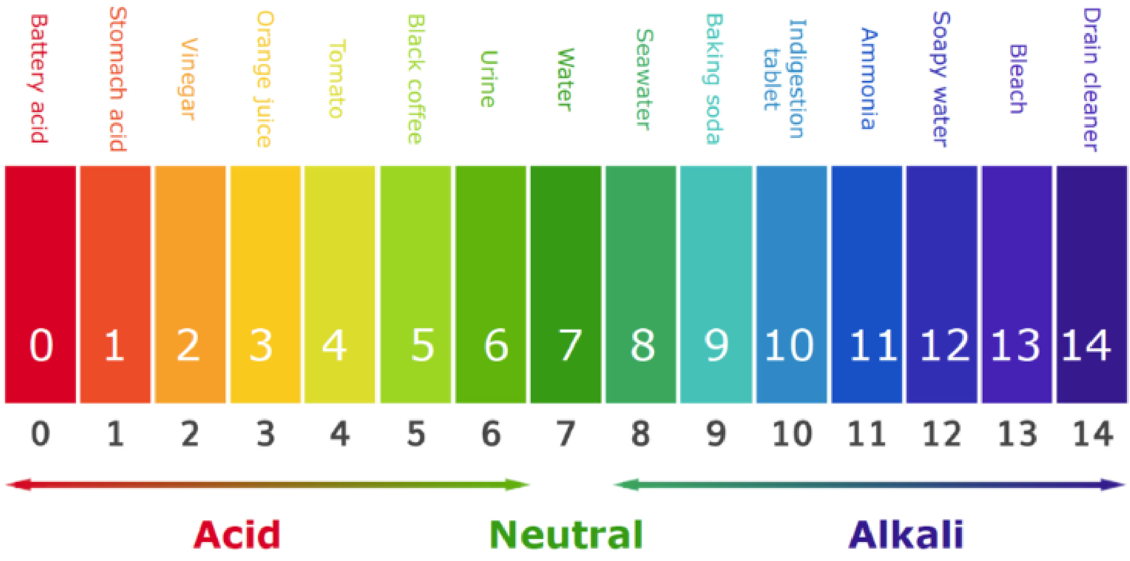

Figure 1. pH scale [10]

Aggregation : Clustering, as when soil particles form granules that aid in aeration and/or water penetration.

Aeration : Exposure of a medium to air which allows exchange of gases.

Aerobic : Pertaining to the presence of free oxygen. Organisms that utilize oxygen to carry out life functions.

Air : Mixture of atmospheric gases, including nitrogen, oxygen, carbon dioxide, and other gases in smaller quantities.

Albumin : A protein in cocoons that serves as a food source for embryonic worms. Found in egg whites.

Anaerobic : Pertaining to the absence of free oxygen. Organisms that can grow without oxygen present.

Animal : A living being capable of sensing its environment and moving about. Animals live by eating the bodies of other organisms, whether plant or animal.

Annelid : Term for a member of the Phylum Annelida containing segmented worms.

Anterior : Toward the front.

Aquatic : Living in or upon water.

Arctic : Pertaining to the region around the North Pole.

Bacteria : Plural for bacterium, a one- celled organism which can be seen only with a microscope. Bacteria may be shaped like spheres, rods or twisted springs. Some bacteria cause decay; others may cause disease. Most bacteria are beneficial because they help recycle nutrients.

Barrier : A geographic zone such as an ocean, desert, or glacier which would prevent the migration of an earthworm. Barriers may be different for other kinds of animals.

Bedding : Moisture- retaining medium which provides a suitable environment for worms. Worm bedding is usually cellulose- based, such as newspaper, corrugated cartons, leaf mold, or compost.

Bio-degradable : Capable of being broken down into simpler parts by living organisms.

Biologist : A scientist who studies living things.

Biological control : Management of pests within reasonable limits by encouraging natural predator/prey relationships and avoiding use of toxic chemicals.

Blood : A liquid medium circulating in the bodies of many animals. Blood carries food and oxygen to the tissues and carries waste products, including carbon dioxide, away from the tissues. Earthworms and humans both have a red, hemoglobin-based blood for oxygen transport.

Breathe : To carry on activities to permit gas exchange. Humans and land- dwelling vertebrates do this by expanding the lung cavity to draw air in, and reducing it to force air out. Worms conduct gas exchange through their moist skin, but do not actually breathe.

Breeders : Sexually mature worms as identified by a clitellum.

Bristles : Tiny rigid structures on most segments of earthworms which serve as brakes during movement. Known as setae, the patterns they form are a major distinguishing characteristic of earthworms.

Burrow : Tunnel formed when an earthworm eats its way through soil, or pushes soil aside to form a place to live and move more readily through the earth.

Carbon dioxide : Gas produced by living organisms as they utilize food to provide energy. Also produced through the burning of fossil fuels.

Castings : See worm castings.

Castings tea : A solution containing nutrients which dissolve in water in the presence of worm castings.

Cellulose : An inert compound containing carbon, hydrogen, and oxygen; a component of worm bedding. Cellulose is found in wood, cotton, hemp, and paper fibers.

Classify : To organize materials, organisms, or information based upon a defined set of characteristics.

Climate : The prevailing or average weather conditions of a place over a period of years.

Clitellum : A swollen region containing gland cells which secrete the cocoon materials. Sometimes called a girdle or band, it is present on sexually mature worms.

Cocoon : Structure formed by the clitellum which protects embryonic worms until they hatch.

Cold-blooded : Having blood that varies in temperature approximating that of the surrounding air, land, or water. Fishes, reptiles, and worms are cold- blooded animals.

Compost : Biological reduction of organic waste to humus. Used to refer to both the process and the end product. One composts (verb) leaves, manure, and garden residues to obtain compost (noun) which enhances soil texture and fertility when used in gardens.

Consumer : An organism that feeds on other plants or animals.

Contract : Action of muscle as it draws up, or gets shorter.

Culture : To grow organisms under defined conditions. Also, the product of such activity, as a bacterial culture. Vermiculture is growing worms in culture.

Cyst : A sac, usually spherical, surrounding an animal in a dormant state.

DDT : A toxic pesticide found to accumulate in the food chain and cause the death of animals which were only indirectly exposed.

Decompose : To decay, to rot; to break down into smaller particles.

Decomposer : An organism that breaks down cells of dead plants and animals into simpler substances.

Decomposition : The process of breaking down complex materials into simpler substances. End products of much biological decomposition are carbon dioxide and water.

Digestive tract : The long tube where food is broken down into forms an animal can use. It begins at the mouth and ends at the anus.

Dissect : To cut open in order to examine and identify internal structures.

Dissolve : To go into solution.

Dorsal : The top surface of an earthworm.

Earthworm : A segmented worm of the annelid group which contains some 3500 species. Most earthworms are terrestrial that is, they live in the ground. Earthworms have bristles known as setae which enable them to burrow in the soil. Earthworms help to aerate and enrich the soil.

Ecology : The science of the interrelationships between living things and their surroundings.

Egg : A female sex cell capable of developing into an organism when fertilized by a sperm.

Egg case : See cocoon.

Eisenia fetida **:** Scientific name for one of several redworm species used for vermicomposting. Color varies from purple, red, dark red to brownish red, often with alternating bands of yellow in between segments. Found in manure, compost heaps, and decaying vegetation where moisture levels are high. Frequently raised in culture on earthworm farms.

Environment : Surrounds, habitat.

Excrete : To separate and to discharge waste.

Experiment : To conduct research by manipulating variables to answer specific questions expressed as statements known as hypotheses.

Feces : Waste discharged from the intestine through the anus. Manure. Worm castings.

Fertilize : To supply nutrients to plants, or, to impregnate an egg.

Food chain : The sequence defined by who eats whom, starting with a producer (green plant).

Food web : The sequence defined by who eats whom, starting with producers and progressing through various levels of consumers, including decomposers and predators. Many organisms may be more than one level of consumer, depending upon whether they eat a plant, a microorganism which has consumed a plant, or an animal which ate the microorganism which ate the plant. A food web describes more complex linkages and interrelationships than a food chain.

Fungi : A large group of organisms which reproduce by spores. The group includes mushrooms, toadstools, molds and mildew.

Fungus : The plural of fungus is fungi.

Genus : A category of classification which groups organisms with similar characteristics. These are more general than species characteristics.

Heart : Muscular thickening in blood vessels whose valves control the direction of blood flow. Earthworms have several (commonly 5 pairs) of these blood vessels which connect the dorsal to the ventral blood vessels.

Heavy metal : Dense metal such as cadmium, lead, copper, and zinc which can be toxic in small concentrations. Build up of heavy metals in garden soil should be avoided.

Hemoglobin : Iron containing compound in blood responsible for its oxygen carrying capacity.

Humus : Complex, highly stable material formed during breakdown of organic matter.

Immigrate : To move into a region.

Inoculate : To provide an initial set of organisms for a new culture.

Larva : Early form of any animal that changes structurally before becoming an adult. A caterpillar is an insect larva which becomes a moth or butterfly as an adult.

Leach : To run water through a medium, causing soluble materials to dissolve and drain off.

Leaf mold : Leaves in an advanced stage of decomposition.

Lime : A calcium compound which helps reduce acidity in worm bins. Use calcium carbonate, ground limestone, egg shells, or oyster shells. Avoid caustic, slaked and hydrated lime.

Litter (leaf) : Organic material on forest floor containing leaves, twigs, decaying plants, and associated organisms.

Lumbricidae : Name of family group to which several redworm and nightcrawler species of earthworms belong.

***Lumbricus rubellus* :** Scientific name for a redworm species. Color is ruddy-brown or red-violet, iridescent dorsally, and pale yellow ventrally. It has been found in a wide variety of habitats, including under debris, in stream banks, under logs, in woody peat, in place rich in humus, and under dung in pastures. Grown in culture by worm growers.

***Lumbricus terrestris* :** Scientific name for large burrow- dwelling nightcrawler. Also known as the nightcrawler, Canadian nightcrawler, or dew worm.

Macro organism : Organism large enough to see by naked eye.

Membrane : A tissue barrier capable of keeping some substances out and letting others in.

Microorganism : Organism requiring magnification for observation. microscope, dissecting - an instrument permitting magnification of organisms too small to see clearly with the naked eye, but too large for a light microscope.

Mineral : A naturally occurring substance found on the earth which is neither animal nor plant. Minerals have distinct properties such as color, hardness, or texture.

Mineral soil : Soil that is mainly mineral material and low in organic material. Its bulk density is greater than organic soil.

Mold : A downy or furry growth on the surface of organic matter, caused by fungi, especially in the presence of dampness or decay.

Molecule : The smallest particle of an element or compound that can exist by itself. Two atoms of oxygen make up a molecule of oxygen. Two atoms of oxygen and one atom of carbon make up a molecule of carbon dioxide.

Mucus : A watery secretion, often thick and slippery, produced by gland cells. One function is to keep membranes moist.

Nematodes : Small (usually microscopic) roundworms with both free- living and parasitic forms. Not all nematodes are pests.

Nitrogen : An odorless, colorless, tasteless gas which makes up nearly four fifths of the earth's atmosphere. When it combines with oxygen through the action of nitrogen-fixing bacteria, it can become incorporated into living tissue as a major part of protein.

Nocturnal : Coming out at night.

Nourish : To promote or sustain growth.

Oligochaeta : Name of the class of annelids to which earthworms belong, characterized by having setae.

Optimal : Most favorable conditions, such as for growth or for reproduction.

Organic : Pertaining to or derived from living organisms.

Organic matter : Material which comes from something which was once alive.

Organism : Any individual living thing.

Oxygen : Gaseous element in the earth's atmosphere essential to life as we know it.

Pest : An organism which someone wants to get rid of.

Pesticide : A chemical, synthetic or natural, which kills pests.

pH : An expression for degree of acidity and alkalinity based upon the hydrogen ion concentration. The pH scale ranges from 10'to 14, pH of 7 being neutral, less than 7 acid, greater than 7, alkaline.

Posterior : Toward the rear, back, or tail.

Protein : Complex molecule containing carbon, hydrogen, oxygen, and nitrogen, a major constituent of meat. Worms are approximately 60% protein.

Protozoa : Plural for protozoan, a one- celled organism belonging to the animal kingdom. Most protozoa live in water and can be seen only with a microscope. Some move by means of tiny hairs called cilia, others by a whip-like tail called a flagellum, and others by false feet called pseudopodia like amebas have.

Redworms : A common name for *Eisenia fetida* and also *Lumbricus rubellus*. *Eisenia fetida* is a common worm used for vermicomposting, although in some parts of North America, *Lumbricus rubellus* is more common.

Respire : To exchange oxygen and carbon dioxide to maintain bodily processes.

Secrete : To release a substance that fulfills some function within the organism.

Segments : Numerous disc-shaped portions of an earthworm's body bounded anteriorly and posteriorly by membranes. People identify earthworm species by counting the number of segments anterior to the position of structures such as the clitellum, ovaries, or testes. Segmentation is a characteristic of all annelids.

Species : Basic category of biological classification, characterized by individuals which can breed together.

Springtail : A small, primitive insect with a turned-under projection on its abdomen which causes it to spring about. Sprintails are often found in worm bins.

Stress : To produce conditions which cause an organism to experience discomfort.

Subsoil : Mineral bearing soil located beneath humus-containing topsoil.

Ventral : Term for the underneath surface of an earthworm.

Vermicompost : Mixture of partially decomposed organic waste, bedding, worm castings, cocoons, worms, and associated organisms. As a verb, to carry out composting with worms.

Vermiculture : The raising of earthworms under controlled conditions.

Vibration : A rapid, rhythmic motion back and forth. Earthworms are sensitive to vibration.

Worm bedding : The medium, usually cellulose-based, in which worms are raised in culture, such as shredded corrugated cartons, newspaper, or leaf mold.

Worm bin : Container designed to accommodate a vermicomposting system.

Worm casting : Undigested material, soil, and bacteria deposited through the anus. Worm manure.

LESSON 2

2. VERMICOMPOSTING TYPES AND METHODS

Learning outcomes

- The trainee knows the scale-dependent method types/alternatives in vermicompost production.
- The trainee explains the batch/static system requirements.
- The trainee explains **c**ontinuous-flow system requirements.
- The trainee knows the advantages and disadvantages of batch/static system and continuous flow system.
- The trainee analyzes the superiority of the batch/static system and the continuous flow system over each other.
- The trainee customizes the application requirements for the bed/pile method.
- The trainee customizes the application requirements for the pit method.
- The trainee customizes the application requirements for the bin method.
- The trainee analyzes the superiority of the bed, pit, and bin over each other.
- The trainee analyzes application methods in terms of production times.
- The trainee designs the vermicompost production process that is suitable for physical conditions, climatic properties and cost.

Instructions for the trainer

- The trainer conveys technical information about vermicompost production types and methods to the trainees with a teaching approach through presentation (narrative technique).
- The trainer explains the types of vermicompost, namely batch system and continuous flow system, using appropriate visuals.
- Trainer explains vermicompost production methods, namely pile, pit and bin methods, using appropriate visuals.

Basic requirements: Computer, projector

2. VERMICOMPOSTING TYPES AND METHODS

2.1. Types

The type of system to be used in vermicompost production is classified under two main headings depending on whether the production is large or small scale, production of worms for vermicompost sale, manure harvesting time, availability of materials to be used as substrate, labor force and needs and environmental conditions. These are batch-static systems and continuous-flow systems (Table 1).

2.1.1. Batch-Static Systems

The batch system follows an application procedure where everything (worms, food and fertilizer) is added to the container/pile at once. The system is covered and left alone for 30 days. At the end of these days you can harvest the worms, liquid fertilizer (if waterproof) and vermicompost. The system provides low material investment costs, space optimization as batches can be stored vertically if made in boxes. The batch system can be disadvantageous as it is labor-intensive. All batches need to be changed every month, including the collection of worms from the system into another batch. The system is usually used to obtain liquid fertilizer in a waterproof box (IBC container) and to multiply the worms. However, some vermicompost can also be produced [11].

2.1.2. Continuous-Flow System

The continuous-flow systems are one of the systems used in the processing of biomass waste to produce vermicompost. The continuous-flow systems are characterised by dynamic operating conditions. It results in a simultaneous in-flow of fresh waste into the reactor and an out-flow of processed waste and vermicompost from the reactor. It can be designed with metal or plastic material. It is of two main types: reactors with continuous substrate feed and reactors with continuous worm and substrate feed.

In the Continuous-Flow system, food is constantly added to the heap and the worms are always active and moving towards the new food added. This can be open air heaps or open raised beds built on stilts, which both supply air from the top and are called bottoms as harvesting takes place from the bottom. The raw material is added from the "grid" on top after two months. Continuous process, can be harvested continuously. Investment costs are generally higher than for other systems. Also, since feeding and harvesting are continuous, more inputs (feed) and labour are required.

Table 1. The general summary of batch vermicomposting, continuous substrate and/or earthworms feed reactors and composite frame systems for continuous substrate feeding [11].

	Windrow vermicomposting or traditional vermicomposting	**Vermicomposting with continuous substrate and earthworms addition**	**Composite frame structured system for continuous substrate feed**
Advantages	It treats large quantity of waste	It also treat large quantity of waste	It treat large quantity of waste but in a consistent small quantities
	–	It require small area of land when composted in a container	It require very small area of land for its operation
	–	–	Its substrate treatment duration is short
	–	May not be affected by cold if carried out in a wooden container	Cold weather does not affect the system since it could be installed in door
	It has low capital requirement	Low capital is required	The cost of installation is relatively low
	–	–	Vermicompost is easily harvested since the worms migrate out of the mature vermicompost into the freshly added substrate in the upper compartment
	–	–	Operating conditions could easily be maintained via mechanical aeration, watering to maintain humidity and regulate the temperature
Disadvantages	It require large area of land	It may require large area of land if using the windrow method	–
	Its operation is labour intensive	Its operation is equally labour intensive	–
	Waste processing is slow	Waste processing is relatively slow but faster than windrow vermicomposting without regular earthworms addition	–
	Environmental conditions like cold slow down the treatment process and accelerate the time	Cold weather also affect the efficiency of the process if the vermireactor is material other than wooden container	–
	There is tendency to loose nutrients through leaching	Nutrients loss is inevitable	–
	Vermicompost harvesting is difficult since it requires earthworms separation	Earthworms separation makes this process tedious	–
	It could develop anaerobiosis if covered with plastic sheets	–	–
	Maintaining a constant operating condition is difficult	Here it is difficult to also maintain a uniform operating condition	–

2.2. Methods

Vermicomposting can be done in several ways (drum system, vegetable handle system, tree base), but bed, pit, and bin operations are the most popular, of which three are the main methods. The first of these is the bed method. In this method, organic matter is arranged in the form of a bed. The second method is the pit method. As the name suggests, pits made of cement are made to collect organic matter. This method is less common since organic matter cannot get enough air and water can also accumulate [12]. The most common method for small scale composting is bin composting method. The bin can be constructed of several materials such as wooden/plastic/recycled containers like bathtubs and barrels. These methods are explained in detail below.

2.2.1. Bed Method (Pile/Bed)

Composting is done by constructing a bed of organic mixture measuring 2 x 0.6 x 0.6m (~6 x 2 x 2 feet) in natural or raw ground (Figure 2 and 3). This technique is simple to maintain and use.

Figure 2. Vermicompost dual small beds [13]

Vermicomposting bed method is a composting method applied in open areas for the decomposition of organic waste using compost worms (species such as *Eisenia fetida* or *Eisenia andrei*). The method has some advantages and disadvantages:

Advantages:

- **Natural Composting:** The vermicompost bed made in the ground is used as a natural part of the garden soil and performs a natural composting process. This allows you to obtain a natural and environmentally friendly fertilizer for your plants.
- **Affordable Cost:** The vermicompost bed method is more cost-effective than other composting methods. No special equipment or closed systems are needed, and natural materials are used.
- **Easy Applicability:** The vermicompost bed made on the ground is a practical composting method and can be easily applied by everyone. It does not require special skills or knowledge.
- **Utilisation of Organic Wastes:** Organic waste decomposed in the bed becomes valuable vermicompost fertilizer and increases the productivity of your garden.

- **Natural Worms:** In an in-ground vermicompost bed, earthworms live in their natural environment and naturally decompose organic waste. Natural earthworm species are preferred in this method.

Figure 3. Vermicompost large bed [14]

Disadvantages:

- **Weather Dependence:** An outdoor vermicompost bed can be affected by weather conditions. Excessive rainfall or extreme heat can affect the efficient operation of the worms.
- **Risk of Contamination:** Beds made in the ground can be attractive to wild animals and pests and can threaten the earthworms or compost.
- **Adequate Space Requirement:** A vermicompost bed requires sufficient space to decompose the appropriate amount of organic waste. It can be difficult to implement in small gardens or limited spaces.
- **Decomposition Time:** Compared to some other composting methods, the vermicomposting bed method may carry out the decomposition process more slowly. It may take some time for full maturation and vermicompost to become ready.

As a result, vermicomposting bed method is a natural and environmentally friendly composting option. It provides a natural decomposition of organic waste in the open field and allows you to obtain valuable fertilizer for your plants. However, some disadvantages must be taken into account, such as dependence on weather conditions and the risk of contamination. When choosing a composting method, it is important to consider your space, your needs, and your possibilities.

2.2.2. Pit Method

This technique is simple to maintain and use. Composting is done in pits measuring 1.5 x 1.5 x 1 m (~5x5x3 feet) and made of cement. Straw grass or other locally accessible material is used to cover the structure. For the best pit composting, the pit depth should be at least 12 inches (30 cm) and the top of the pit should be covered with at least 8 inches (20 cm) of soil after the organic materials have been added (Fig 4a and 4b).

Figure 4. Methods in vermicomposting. a) Pit method application [15], b) Pit method example [16]

The vermicomposting pit method is the decomposition of organic waste within the pit using red composting earthworms (species such as *Eisenia fetida* or *Eisenia andrei*). The advantages and disadvantages of this method are given below:

Advantages:

- **Natural Composting:** In-pit vermicomposting encourages a natural composting process. Worms naturally decompose organic waste and create valuable vermicompost fertilizer.
- **Low Space Requirement:** The vermicomposting pit method requires less space than other composting methods. It can be applied in small gardens or limited areas.
- **Low Cost:** The pit method is a cost-effective composting option. It does not require special equipment or closed systems, just digging a pit is enough.
- **Natural Worms:** Natural earthworm species are used in the in-ground pit method. Earthworms live in a natural environment and decompose organic waste, providing valuable nutrients to the soil.
- **Easy Applicability:** Vermicompost pit is a practical and easy-to-use composting method. It requires no special knowledge or skills.

Disadvantages:

- **Risk of Contamination:** The pit method can lead to wild animals and pests attracting compost and threatening earthworms.
- **Dependence on Environmental Conditions:** Excessive rainfall or temperature changes can affect the efficiency of the earthworms and the decomposition process within the pit.
- **Limited Capacity of the Worm Bed:** The capacity of the worm bed within the pit may be limited. It may be necessary to create more than one pit to decompose large quantities of organic waste.
- **Slow Decomposition Process:** The pit method may have a slower decomposition process than some other composting methods.

As a result, the vermicomposting pit method is a convenient and cost-effective composting option for small gardens or limited spaces. It provides a natural decomposition of organic waste using natural earthworms and allows you to obtain valuable fertilizer for your plants. However, some disadvantages must be considered, such as the risk of contamination and dependence on environmental conditions. When choosing the composting method, you should choose the most suitable option according to the needs of your garden and your available space.

2.2.3. Bin Method

The most common method for small scale composting is bin composting method (Figure 5). The bin method is prepared to use in small scale such as home composting, in kitchen or garage and so on. The bin can be made of various materials, but wood and plastic ones are popular. Plastic bins, because of lightness, are more preferred in home composting. A vermicompost bin may be in different sizes and shapes, but its height must be more than 30 cm. bins with a height of 30-50 cm, and not so more than it, are perfect. Draining some holes in bottom, sides and cap of bin is so helpful to aeration and drainage. Around 10 holes with 1-1.5 cm in diameter is a good choice. Before feeding the worms by wastes it's needed to apply a worm's bed. A height of 20-25 cm bedding is appropriate. It may be a mixture of shredded paper, mature compost, old cow or horse manure with some soil [17].

Advantages:

- **Low Space Requirement:** The vermicomposting bin method requires less space than other composting methods.
- **Low Cost:** The bin method is a cost-effective composting option. It does not require special equipment or systems.
- **Easy Applicability:** Vermicompost bin is a practical and easy-to-use composting method. It requires no special knowledge or skills.
- **Productivity:** Bin system allows more airflow. It promotes a productive ecosystem.

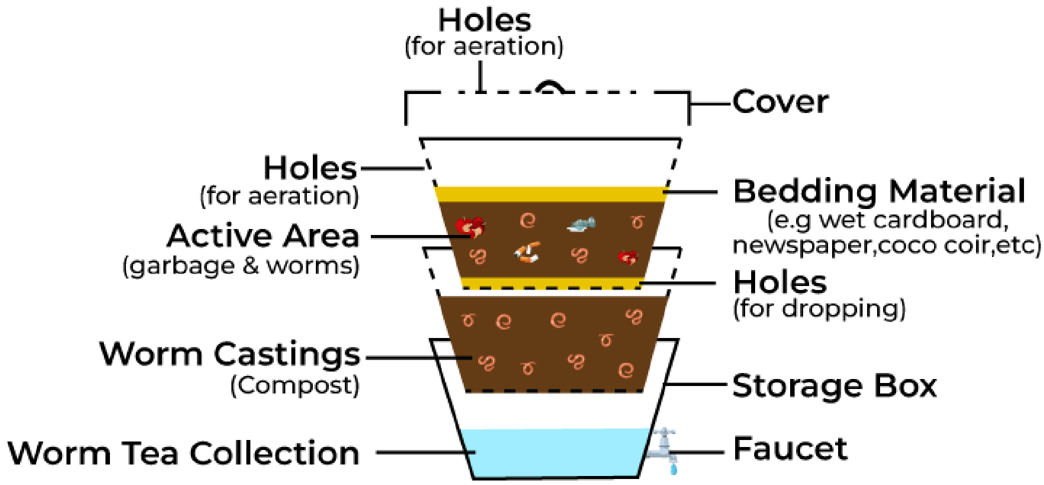

Figure 5. Bin method application [18]

Disadvantages:

- **Limited Capacity of the Worm Bed:** The capacity of the worm bed in the silo may be limited. It is not suitable for decomposing large amounts of organic waste.
- **Bad smell:** The leachate (extra moisture) leaks out the bottom holes in the bin and is messy to dump. If it is left to sit for awhile if goes anerobic and smells.
- **Frequent Feeding:** Since the space is small and limited, the worms require smaller amounts and frequent feeding.

LESSON 3

3. MATERIALS FOR VERMICOMPOST SUBSTRATES, BEDS, AND EARTHWORMS

Learning outcomes

- The trainee knows the substrates commonly used in vermicompost production.
- The trainee explains the substrates that increase or decrease the efficiency in worm compost production.
- The trainee explains the materials to be used to balance the pH of the environment in vermicompost production.
- The trainee knows the physical parameters (size, temperature, humidity, etc.) that the substrates must have for the earthworms to work efficiently.
- The trainee explains the bed term.
- The trainee knows the substrates that should not be present in the production environment.
- The trainee knows the commonly materials used for bed and their properties.
- The trainee knows the earthworm species used in vermicompost production.
- The trainee compares the physiological characteristics of the earthworm species used in vermicompost production and the characteristics of their living environments.
- The trainee determines the appropriate bed materials, earthworms and substrates for vermicompost production, taking into account the characteristics of the environment.

Instructions for the trainer

- The instructor shares theoretical knowledge through presentation.
- The trainer shows the students the materials brought to the class and asks whether they are suitable for worm compost production.
- The trainer asks the trainees to mark materials suitable for vermicomposting using the SM-2.
- The trainer asks the trainees to put the necessary components for vermicompost production into the bin in the appropriate order.

Basic requirements: Bokashi bin, dairy products, leaves, vegetable waste, meat, paperboard, paper waste, egg shells, cattle dung, plastic bag, coffee grounds, citrus waste, sawdust, bark-softwoods, corn-stalks, projector, computer, disposable gloves, paper checklist (SM-2)

3. MATERIALS FOR VERMICOMPOST SUBSTRATES, BEDS, AND EARTHWORMS

3.1. Substrates

Vermicomposting substrate can be made from a variety of materials. Organic wastes are an important substrate for vermicomposting in order to control waste while also producing alternative manure for soil fertility and plant growth. The waste is decomposed by earthworms through feeding, fragmentation, aeration, turnover, and dispersion, as well as enzymatic digestion by the associated microbes. According to estimates, India has the capacity to produce 4.3 million tons of compost per year. Municipal solid waste a problem, and solid municipal wastes containing at least 35%–40% organic material can be used for vermicomposting. City garbage, agricultural waste, industrial organic waste, cow and other cattle dung, kitchen waste, coir pith, grass, rice straw, food, animal waste, sewage waste, soil, etc. are the main substrate for Vermicomposting. Scotch broom (*Cytisus scoparius*), an invasive plant native to the Mediterranean basin, is a symbiotic nitrogen-fixing plant with high phosphorus, calcium, and potassium levels that can be used as a substrate for vermicomposting. It also has a high polyphenol content, making it phytotoxic. This vermicomposting procedure significantly reduces phytotoxicity, allowing this invasive plant to be used as manure. Many crop diseases are hosted by *Ageratum conizoides*, and *Lantana camara* is a weed plant that contains toxic phytochemicals that are toxic to grazing animals. These weed plants are also used in vermicomposting, which reduces the occurrence of plant disease and plant toxicity.

Both cow and goat dung is used for vermicomposting but it has been studied with *P. excavatus* that cow dung provides more nutrition to the vermicomposting substrate than the goat.

Poultry waste contains a diverse mixture of litter that is used for vermicomposting. Intensive breeding causes a huge deposal of bedding mixture, feather, food material, manures from the farms of broiler and layers of chicken, ducks, turkeys, quails, etc. Poultry waste contains a high amount of ammonia and organic salt which kills worms so, before the composting process starts, the addition of freshly prepared $CaCO_3$ is needed to neutralize them.

Fruits are the most wasteful food item due to an inefficient post-harvest system. Approximately 2.7 metric tons of bananas go to waste due to a lack of a cold chain system. Banana stems also contribute significantly to agricultural waste. Papaya's seed, skin, pomace, and rind contain a high amount of organic matter such as carotenoids, dietary fibers, vitamins, enzymes, carbohydrate, oils, and polyphenols. Together with these biologically active metabolites, a good substrate for vermicomposting that will form good peat-like manure can be produced. Furthermore, crop residue from cauliflower, cabbage, broccoli, and other crops is collected after harvesting and used as vermicomposting material. However, this materials should come from a field that has not been treated with insecticides or pesticides.

Paper is a versatile waste generated by municipal solid waste and industries. India accounts for approximately 1.5% of total global paper and paperboard production. There is a risky situation because there is no effective paper collection and management system. Paper is generally made from plants and contains a significant amount of organic material, making it an excellent material for composting.

Rice straw, mycostraw that is the residue after mushroom cultivation is left as waste material but is full of nutrition. So can also be a hospitable bedding material for vermicomposting. Rice hulls ash, coconut husk, tea waste, cotton balls are also used as the bed of vermicomposting [19]. However, the substrates (nutrients) commonly used in vermicomposting;

Kitchen Waste: Kitchen wastes such as vegetable and fruit peels, vegetable scraps, coffee grounds, and tea bags are suitable materials for compost.

Garden Waste: Garden waste such as grass cuttings, pruning residues, leaves, plant stems and flower residues can also be used in composting.

Leaves: Leave collected from the garden in autumn are valuable compost material.

Wood Crumbs: Wood chips, wood scraps, and wood pellets can also be used for compost.

Paper and Cardboard: Especially recyclable paper and cardboard materials can be suitable for composting. However, the use of colored and glossy paper should be avoided.

Animal Manure: Some animal manure, especially the manure of grazing animals such as horses, chickens, cows, and horses, can be used in composting. However, ineffective animal manure such as dog and cat manure should not be preferred in composting.

Food Waste: Food waste and vegetable waste are organic materials that can be used in compost.

Coffee Pulp: Used coffee pulp is a valuable material with its nitrogen content in compost.

Egg Shells: Egg shells are a suitable material for compost with their calcium content.

Grass Cutting: Grass cutting can be used as green material and with its nitrogen content it promotes rapid decomposition of the compost.

In addition, tea bags, hazelnut pulp and shell, indoor plants, stalks and straw, grain stalks, cotton and wool pieces, wood ashes, pistachio processing wastes, olive oil production wastes (except black water), tea processing wastes, fruit juice factory pulps, sugar beet heads and leaves, etc. materials can be counted.

Among the materials to be used for composting, it should be noted that animal wastes such as meat or fish residues, milk, and dairy products should not be used. Also, painted or treated wood, wastes containing chemicals, and diseased plant materials should not be used in composting. For healthy and high-quality compost, a balanced carbon/nitrogen ratio and a variety of organic materials should be used.

In general, compost contains food and plant waste, recycled organic matter, and fertilizers. The compost mix is also rich in plant nutrients and beneficial organisms such as bacteria, protozoa, nematodes, and fungi. Composting is an effective, environmentally beneficial method to reduce dependence on commercial chemical fertilizers. It is an important method to increase soil fertility in landscaping, urban agriculture, gardens, horticulture, and organic farming.

3.2. Beds

Bedding represents a suitable living environment for worms. Earthworm bedding should retain moisture, remain loose, and not contain much protein or organic nitrogen compounds that readily degrade (Table 2). These compounds would quickly degrade and release ammonia, and this might temporarily increase the pH of bedding material to 8 or higher, which is not good for the worms. The bedding material will heat up in the beds if it has not already substantially decomposed or if it contains excessive amounts of readily degradable carbohydrates. These conditions can cause the worms to die. Make sure all bedding materials are fully aged or composted before use. Place moist bedding in the beds to a depth of 6 inches. After adding worms, keep the upper 4 inches of the bedding moist but not soggy [20, 21]. Bedding is a material that provides the worms with a relatively stable habitat with following characteristics:

High absorbency: As earthworms breathes through their skins and therefore bedding must be able to absorb and retain water fairly well. Worms dies if its skin dries out.

Good bulking potential: Worms respire aerobically and different bedding materials affect the overall porosity of the bedding, including the range of particle size and shape, the texture, and

Table 2. List of some of the commonly used earthworm bedding material [20]

Bedding Material	Absorbency	Bulking Potential	C:N Ratio
Horse manure	Medium-good	Good	22–56
Peat moss	Good	Medium	58
Corn silage	Medium-Good	Medium	38–43
Hay–general	Poor	Medium	15–32
Straw–general	Poor	Medium-Good	48–150
Straw–oat	Poor	Medium	48–98
Straw–wheat	Poor	Medium-Good	100–150
Paper from municipal waste stream	Medium-Good	Medium	127–178
Newspaper	Good	Medium	170
Bark–hardwoods	Poor	Good	116–436
Bark–softwoods	Poor	Good	131–1285
Corrugated cardboard	Good	Medium	563
Lumber mill waste–chipped	Poor	Good	170
Paper fibre sludge	Medium-Good	Medium	250
Paper mill sludge	Good	Medium	54
Sawdust	Poor-Medium	Poor-Medium	142–750
Shrub trimmings	Poor	Good	53
Hardwood chips, shavings	Poor	Good	451–819
Softwood chips, shavings	Poor	Good	212–1313
Leaves (dry, loose)	Poor-Medium	Poor-Medium	40–80
Corn stalks	Poor	Good	60–73
Corn cobs	Poor-Medium	Good	56–123
Paper mill sludge	Good	Medium	54
Sawdust	Poor-Medium	Poor-Medium	142–750
Shrub trimmings	Poor	Good	53
Hardwood chips, shavings	Poor	Good	451–819
Softwood chips, shavings	Poor	Good	212–1313
Leaves (dry, loose)	Poor-Medium	Poor-Medium	40–80
Corn stalks	Poor	Good	60–73
Corn cobs	Poor-Medium	Good	56–123

the strength and rigidity of its structure. If bedding material is too dense or packs too tightly, then the flow of air is reduced or eliminated. This overall effect is referred as the material's bulking potential.

Low protein and/or nitrogen content/high Carbon: Earthworms consume their bedding as it breaks down and it is very important for this process to be slow. High protein/nitrogen levels can result in rapid degradation of bedding and its associated heating, creating inhospitable or fatal conditions. High carbon content is required as earthworms and microbes in the feed mixtures activate microbial respiration and degradation of organic wastes, thereby increasing the loss of organic carbon during the vermicomposting process [22]. Various bedding material according to absorbency, bulking potential and C:N are enlisted in Table 2.

Vermiculture bed: Vermiculture bed can be prepared by placing a first layer of saw dust, newspaper, straw, coir waste, sugarcane trash etc. at the bottom of tub/container. Newspaper is one of bedding material that high in absorbency whereas for the sawdust the level of absorbency is poor to medium. A second layer of moistened fine sand of 3 cm thick should be spread over the culture bed followed by a layer of garden soil (3 cm). The floor of the unit should be compacted to prevent earthworm's migration into the soil.

3.3. Earthworm

Earthworm is one of the major kinds and a key component of tropical and subtropical ecosystems. It helps is soil aggregation, nutrient recycling, litter decomposition, etc. Earthworm improves the soil environment by producing cast, pellets, and galleries. Mucus secretion from the gut of earth worm enhances microbial activity. Earthworms are terrestrial invertebrates comprising more than 3200 species, grouped into three categories according to their behavior in the natural environment: anecic, endogeic, and epigeic [21, 23] (Figure 6).

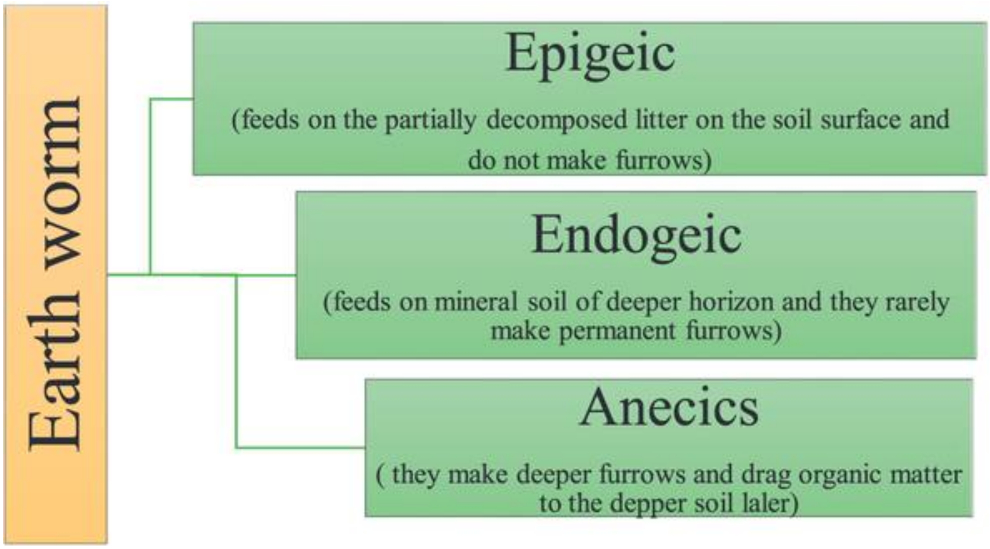

Figure 6. Earthworm classification [24]

Epigeics species are useful for biosolid waste management as these worms can hasten the composting process to a significant extent and produce better quality of vermicomposts, compared with those prepared through traditional methods [25].

Two tropical species, African night crawler, *Eudrilus eugeniae* (Kinberg) (Figure 7a) and Oriental earthworm, *Perionyx excavates* (Perrier) and two temperate ones, red earthworm, *Eisenia andrei* (Bouche), tiger earthworm, *Eisenia fetida* (Savigny) (Figure 7b), and *Lumbricus rubellus* are extensively used in vermicomposting [26, 27]. Most vermicomposting facilities and studies are using the worms *E. andrei* and *E. fetida* due to their high rate of consumption, digestion, and assimilation of organic matter, tolerance to a wide range of environmental factors, short life cycles, high reproductive rates and endurance and resistance during handling [28]. *Eisenia fetida* is used throughout the world for this purpose as it is ubiquitous, can tolerate a wide range of temperature and can live in wastes with good moisture content [29, 30]. *Eudrilus eugeniae* and *Perionyx excavatus* is the other commonly used worm. *Eudrilus eugeniae* is large in size, grows rapidly but has poor temperature tolerance, hence, may be suitably used in the areas with less fluctuation of temperature (tropical areas).

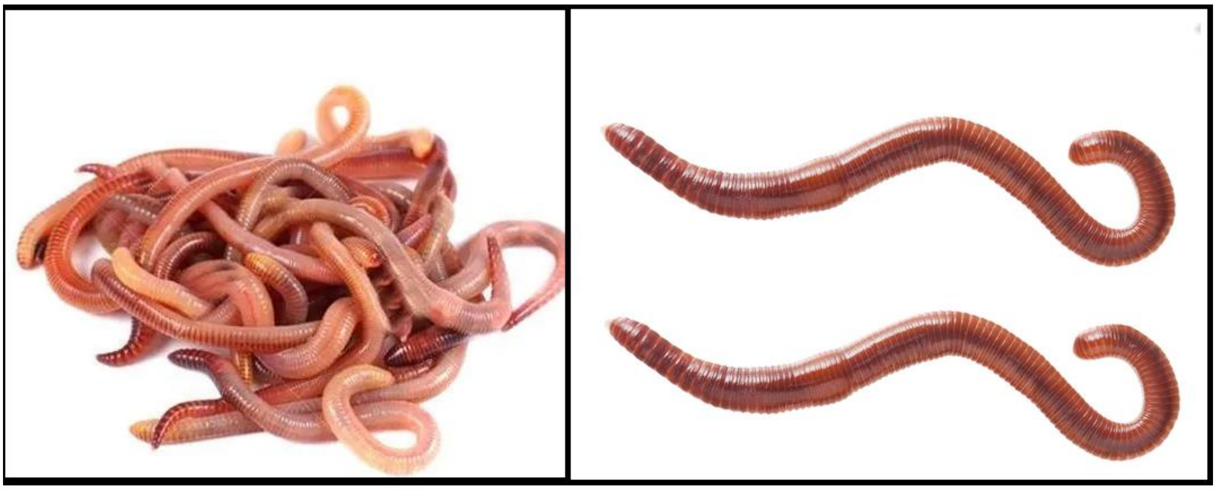

Figure 7. Earthworms, a) *Eudrilus eugeniae*, b) *Eisenia fetida*

Earthworms grow best on easily metabolised organic matter and unassimilated carbohydrates, which also support their reproduction. There was a positive correlation between the volatile solids content of the waste and growth and reproduction. Earthworm growth slows down when the C:N ratio and temperature are high. Biomass gain in *E. fetida* was found to depend on population density and food type during vermicomposting [31, 32]. Scientific studies have revealed that a single earthworm can gain biomass at a higher rate than those reared in groups. Some studies reported a decrease in worm biomass in some cases in worms that were continuously supplied with food [33, 34]. Thus, the physico-chemical or nutrient properties of the waste may be related to the temperature, pH and moisture content as well as the growth of the earthworm. The interaction between the palatability of these physico-chemical organic wastes and the feeding power by the earthworm is directly related to the interaction of these parameters and consequently affects the growth and reproduction of the earthworm.

Earthworms promote the growth of "beneficial decomposing aerobic bacteria" in organic waste material and also act as grinders, crushers, chemical degraders and biological stimulators of waste material [35]. The earthworm is home to millions of decomposing (biodegrading) microbes, hydrolytic enzymes and hormones, which help in the rapid decomposition of complex organic matter into vermicompost in a relatively short period of one-two months, compared to the traditional composting method, which takes about five months. The mechanism of vermicomposting by earthworms takes place in the following steps; The organic matter consumed by the worm is softened by the saliva in the worm's mouth. The food in the oesophagus is further softened and neutralised by calcium, and physical disintegration in the muscle gizzard results in particles $< 2\ \mu$ in size, thus providing an enhanced surface area for microbial processing. Finally, this ground material is exposed to various enzymes secreted in the lumen by the stomach and small intestine, such as protease, amylase, lipase, cellulase and chitinase [20, 35, 36].

3.3.1. Physiology and life conditions of earthworms

Earthworm body is almost cylindrical shape but may has end cross-sectional area of quadrilateral, octagonal or trapezoidal and in some species may be flat shape. Body length varies from 15 mm to 300 mm and its diameter varies from 1- 10 mm. External grooves, Furrow, on the worm body specify the place of internal curtains,Septa,. These curtains divide the body into a series of similar parts which called Somite or Metamere. External secondary grooves, Annuli, often form three rings. The secondary grooves is a virtual division and do not exist in internal anatomy of the body. The first body segment, Peristomiom, surrounds the mouth and on the dorsal area has a lobe which called Prostmium. How to connect the mouth and Prostmium in earthworm is variable depending on the species and are used for their classification. Earthworms are androgyny and have both male and female reproductive system which is mainly limited to the front parts of body. Earthworms have a simple digestive system. Earthworms eat almost everything such as plant roots, leaves and seeds, microscopic organisms such as protozoa, Larvae, the Rotifers, bacteria, fungi, and larger animals, especially cattle, feces. The food ingested with soil and passes along from the earthworms digestive canal. Earthworms continuously or semi-continuously do egg-laying most often along the year. Worm eggs are placed in the cocoon. The cocoon shape is different depending on the species of worm. In moist conditions and the temperature of 16 to 27 ° C for the eggs, within 14 to 20 days the small worms come forth. Natural life of many earthworms is short and some species in case of being protected from natural hazards live longer more than 1.5 Year.

Activity, metabolism, growth and reproduction of worms are strongly affected by the temperature. Temperature and humidity usually have an inverse relation. High temperature and dry environment are more limiting than low temperatures and water saturated environment, for the worms. Earth worms setting cocoon and coming out of egg are also affected by temperature. For example, setting cocoon in *Eisenia fetida* increases linearly with increasing temperature from 10 to 25 ° C, although the number of worms per cocoon out in 25°C is less than 20 °C. Cocoon opening period also is depends on temperature. Growth of new worm out of the eggs to mature at 18 ° C reaching in 9.5 weeks and at 28 ºC only 6.5 weeks is needed.

Worms are sensitive to hydrogen ion concentration which is stated as pH. According to sensitivity to pH in some texts have been divided them in three categories: resistant to soil acidity, sensitive and to soil acidity and a variety that can live in wide range of pH. However, many researchers have expressed that more species of earthworms show interest to live in neutral pH. *Eisenia fetida* is preferred life in the soils that pH is between 6.5 and 7.5. The role of organic carbon and inorganic nitrogen for synthesis of cell, growth and metabolism is essential in all organisms. Proper ratio of carbon to nitrogen is needed for optimal growth of earthworms [17, 37].

LESSON 4

4. MANAGING OF VERMICOMPOSTING PROCESS

Learning outcomes

- The trainee knows the five basic stages of vermicompost production.
- The trainee explains step by step the production of vermicompost.
- The trainee knows the materials that should not be present in the production environment.
- The trainee knows the prerequisite for adding animal manure to the production environment.
- The trainee knows the abiotic factors that need to be monitored in vermicompost production.
- The trainee knows the optimum moisture range for the production environment.
- The trainee explains the processes required to keep the production environment between optimum moisture values.
- The trainee knows the temperature range that the production environment should have.
- The trainee explains the relationship between temperature and moisture in the production process.
- The trainee explains the functional necessity of aerating the pile during the production process.
- The trainee knows the optimum pH range for the production environment.
- The trainee explains the relationship between the pH value of vermicompost and the physiological processes of the plant.
- The trainee knows pH regulator materials.
- The trainee evaluates the effects of the C:N ratio on the vermicompost process.
- The trainee explains the physiological importance of phosphorus, salt and ammonium for earthworms and plants.

Instructions for the trainer

- The instructor shares theoretical knowledge through presentation.
- The trainer introduces the equipment to be used to measure the abiotic parameters to be monitored during the vermicompost production process.

Basic requirements: Projector, computer, thermometer, moisture meter, bokashi bin.

4. MANAGING OF VERMICOMPOSTING PROCESS

Vermicompost production method is a complex process in which many physical, chemical and biological factors are effective. Many factors such as location, temperature, humidity, pH, composition, diversity and quantity of microbial elements and type and quantity of earthworms affect the vermicompost production process. The success of the vermicompost production process requires the production of fertilizer with physical, chemical, and biological content suitable for the demands of the market. For the production of vermicompost with these determined properties, it is an important requirement to keep all parameters that may affect the process under control. Vermicompost production indicates the management of five basic stages (Figure 8).

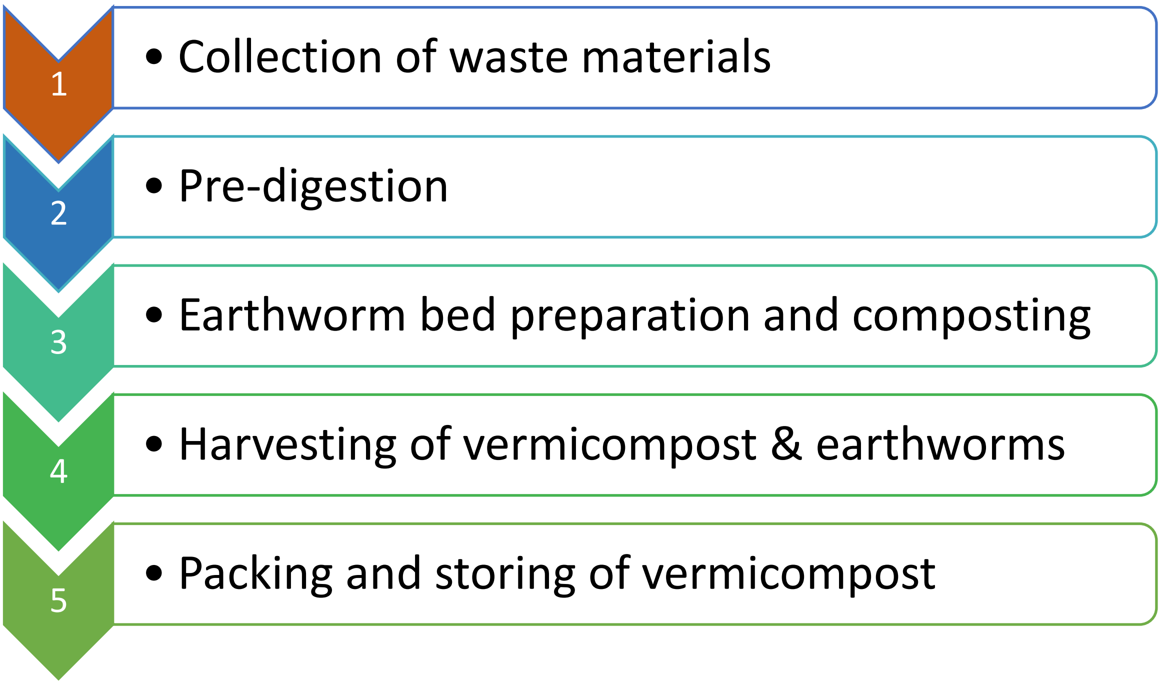

Figure 8. Basic process steps in the management of vermicompost production

Collection of waste material: The collected waste materials should be seperated from glass, plastic, ceramics, and some animal wastes (dairy wastes, fat, meat, etc.), reduced in size, and stored in a proper place.

Pre-digestion: Pre-digestion of organic waste should be done for at least 20-25 days by heaping the material along with cattle dung slurry and regular watering. This process partially digests the material and fit for earthworm consumption. Addition of higher quantities of acid-rich substances such as citrus wastes should be avoided. Any organic wastes – cow dung, crop residues, farm wastes, vegetable market wastes, and fruit wastes can be used as a raw material for composting. Use of wet dung should be avoided for vermicompost production. At least 20-25 days old cow dung should be used to avoid excess heat generation.

Earthworm bed preparation and composting: The earthworm bed prepared for vermicomposting must ensure the five basic things to obtain quality vermicompost from a short span of time. Vermicompost production can be done in any place which is having shades, high humidity and cool. Abandoned cattle shed, or poultry shed or unused buildings can also be used. If it is to be produced in the open area, artificial shading should be provided. The waste heaped for vermicompost production should be covered with moist gunny bags.

The five basic necessities are listed below:

- Hospitable living environment, called as bedding
- A food source
- Adequate moisture
- Adequate aeration
- Protection from extreme temperatures

Harvesting of vermicompost and earthworms: The vermicompost is ready within 75-90 days and ultimately the material becomes black, granular, lightweight, moderately loose, crumbly and humus-rich. Watering must be avoided two to three days before emptying the beds to facilitate the separation of worms from the compost. There are several different methods for harvesting vermicompost. These are inducing the migration of earthworms, screening or sieving, pyramidal heap, and manual harvesting.

Packing and storing of vermicompost: The harvested vermicompost should be stored in dark and cool place as sunlight will lead to loss of moisture and nutrient content. Moreover, harvested vermicompost material should be stored in open rather than packed in sacs. Packing should be done at the time of selling and laminated sac is always advisable. During compost storage in open place, periodical sprinkling of water should be done to maintain moisture level and beneficial microbial population. Vermicompost can be stored for longer periods of one year without loss of its quality, if its moisture is maintained at 40% level [20].

It can be follow up for step by step vermicomposting production process;

- Selection of suitable earthworm species.
- Choosing the site of vermicomposting unit in a cool and shady site.
- Organic waste with cowdung and chopped dried leafy materials are mixed in the proportion of 3: 1 ratio.
- A compost heap is structured and allowed to decompose for 15 to 20 days.
- Vermiculture bed of 3 cm is to be prepared by placing after saw dust or leaves or husk or coir waste or sugarcane trash in the bottom of application site.
- A layer of fine sand (3 cm) should be spread over the culture bed followed by a layer of garden soil (3 cm).

- All layers must be moistened with water.
- Partial decomposed materials obtained from first step is to be laded over the bed.
- Water is to be sprayed over it to make the moisture availability up to 50%.
- Adult earthworms are released in the upper layer of the bed.
- Beds should be kept moist by sprinkling of water (daily) and by covering with gunny bags/polythene.
- Earthworms should remain undisturbed for it's multiplication.
- Bed should be turned once after 30 days for maintaining aeration and for proper aerobic decomposition.
- The fully prepared vermicompost looks dark brown colored granules, appeared like a handful of dry CTC (crush-tear-curl) tea.
- The vermicompost is fully prepared within 75-90 days.
- When raw material is completely decomposed it appears black and granular.
- Then it is sieved further and should be separated from any contamination before use in crop field.

4.1. Maintenance for Vermicompost

The vermicompost production process requires monitoring and control of many abiotic and biotic parameters. The most important abiotic factors which affect vermicomposting process include moisture, pH, temperature, aeration, pH value, C:N ratio, ammonia and salt content.

4.1.1. Moisture: A strong relationship exists between the moisture content of organic wastes and the growth rate of earthworms. In a comparative study on vermicomposting process and earthworm's growth at different temperature and moisture ranges showed that 65–75% is most suitable range of moisture at all ranges of vermicomposting temperature [38]. The bedding used for vermicomposting must be able to hold sufficient moisture as earthworms respire through their skins and moisture content in the bedding of less than of 45% can be fatal to the worms. Although epigenic species, *E. fetida* and *E. andrei* can survive moisture ranges between 50% and 90%, but they grow more rapidly between 80% and 90%. The bacteria also plays vital role in vermicomposting. Its activity decreases in moisture content lower than 40% and it almost stops in lower than 10% [20, 39].

Vermicompost production process is always better to maintain a humid environment, but without becoming waterlogged, as this reduces the amount of oxygen available. Shuffling the substrate can help in the necessary aeration and distribution of any liquid that may accumulate. It should be wettest in the surface, to keep most of the activity there. You must pay attention to the ambient temperature, especially in warm periods, to prevent the worms from drying out.

Moistened rags or layers of cardboard or paper can be used to cover the vermicompost if the environment dries quickly.

Experience and observation will tell us if the humidity is correct. Worm skin must have a wet/fresh appearance. However, a stick hygrometer can be useful for measuring humidity, especially for the beginners. If you do not have a hygrometer, you can take a handful of compost in your hand; when you squeeze it hard, about 2 or 3 drops should drip from your fist. If there are many more, the humidity is excessive and it would be advisable to add some chopped paper or cardboard, mixing them in the compost. If, on the other hand, nothing comes out, the vermicompost would be too dry and it would be advisable to add some water.

Irrigation of worms should be done with non-chlorinated water (not from the tap), preferably by sprinkling. This can be done manually or through micro-sprinklers in a larger installation. Drip irrigation is another option, but obviously it can stress the worms. If you have to add water by hand, do it very gently.

The irrigation frequency will not always be the same and will depend on the ambient temperature, the interior of the pile, the texture of the compost, etc. So it can be every few days or weeks, or as short as hours in extreme temperatures. Fairly periodic observation is important.

Irrigation is related to temperature, so this can also be controlled somewhat by watering/sprinkling. The pile should not be kept below 10 degrees, if possible, nor above about 25 or 30 for most species. If we exceed these values too much, downwards or upwards, we run the risk of them dying.

4.1.2. Temperature: Earthworm's activity, metabolism, growth, respiration and reproduction are greatly influenced by temperature. The temperature for the stable development of earthworm population should not exceed 25°C. Although *E. fetida* cocoons survive extended periods of deep freezing and remain viable but they do not reproduce and do not consume sufficient food at single digit temperatures. It is generally considered necessary to keep the temperatures preferably 15°C for vermicomposting efficiency and 20°C for effective reproductive vermiculture operations. Temperatures above 35°C will cause the worms to leave the area or if they cannot leave, they will quickly die. Bacterial activity is also greatly depended on temperature as it multiplies by two per each 10°C increase in temperature and is quite active around 15–30°C.

4.1.3. Aeration: Earthworms are oxygen breathers and cannot survive in anaerobic conditions. They operate best when compost material is porous and well aerated. Earthworms also help themselves by aerating their bedding by their movement through it. *E. fetida* have been reported to migrate in high numbers from oxygen depleted water saturated substrate, or in which carbon dioxide or hydrogen sulfide has accumulated.

4.1.4. pH value: The pH value is also one of the important factors affecting the vermicomposting process. Epigenic worms can survive in a pH range of 5–9. The pH of worm beds tends to drop over time. If the food source/bedding is alkaline, than pH of bed drop to neutral or slightly alkaline and if the food source is acidic than the pH of the beds can drop well below 7. The pH can be adjusted upwards by adding calcium carbonate or peat moss for adjusting pH downward can be introduced into the mix. Although microorganisms which are active in vermicomposting which can maintain their activity even in lower pH of around 4 but recommended pH range for compost is around 6.5–7.5.

The pH of vermicompost plays a very important role in plant growth. When the pH of vermicompost is in the optimal range (usually around neutral), it provides an ideal environment for nutrient availability and microbial activity in the soil. This increases the plant's nutrient uptake and supports healthy root development. By maintaining the proper pH we can unlock the full potential of plant growth. The pH of vermicompost significantly affects nutrient availability in the soil. Different nutrients have varying solubilities at different pH levels. When the pH of vermicompost is balanced, it ensures that essential nutrients such as nitrogen, phosphorus and potassium are easily available to plants. However, if the pH is too acidic or too alkaline, some nutrients may become less accessible or even locked in the soil, leading to nutrient deficiencies in plants. Therefore, maintaining optimum pH through the use of vermicompost is vital to maximize nutrient availability and support plant health.

4.1.5. Ammonia and salt content: Earthworms cannot survive in organic wastes containing high levels of ammonia. Worms are also very sensitive to salts and they prefer salt contents less than 0.5%. However, many types of manures have high salt contents and if they are to be used as bedding, they should be leached first to reduce the salt content, it is done by simply running water through the material for a period of time.

4.1.6. Carbon:Nitrogen (C:N) Ratio: The major effect of C:N ratio in vermicompost is on bacterial activity, high C:N ratio decrease bacterial activity because of nitrogen shortage that is essential for bacteria and takes part in proteins, amino acids and other structural substances of bacteria. On the other hand low C:N ratio will led to loss of the nitrogen as in form of NH_3 to atmosphere. The worms also hate the high concentration of ammonia and will escape from it. Vermicompost process will progress properly by starting the process with a C:N ratio around 25-30 and it will decrease during the process. Carbon reduces because heterotrophic bacteria use organic material as source of electron and carbon is oxidized to CO_2 and releases to atmosphere. However, bacterial nitrogen usage is so less than carbon and some kind of bacteria can stabilize atmospheric nitrogen into compost such as Rhizobium. Also, autotrophic bacteria use ammonia as source of electron and convert it to nitrite and nitrate which remain in compost unless an anoxic condition occurs. In this condition nitrate and nitrite reduced and nitrogen releases to atmosphere as N_2 [23, 40].

4.1.7. Phosphorus: Phosphorus is an essential nutrient for plant growth and is utilised for protein formation, metabolism, photosynthesis, seed germination and flower and fruit formation. However, phosphorus in soil is in mineral form, readily available to plants, but the potential activity of earthworms and phosphate-solubilising microorganisms increases the availability of phosphorus for plants [41, 42].

The increase in total phosphorus during vermicomposting is thought to be due to the mineralization and mobilisation of phosphorus as a result of the bacterial and faecal phosphatase activity of earthworms. As organic matter passes through the worm intestine, some phosphorus is converted to a more useful form thanks to the enzyme phosphatase, and further release is thought to be due to microorganisms dissolving the phosphorus present in the castings. Earthworm activity is known to accelerate the conversion of organic phosphorus into the plant-available form of phosphorus. There are numerous scientific studies showing that the treatment of different waste materials with vermicompost leads to an increase in readily extractable phosphorus by 12–21% [43].

LESSON 5

5. HARVESTING METHODS AND UTILIZATION

Learning outcomes

- The trainee explains the harvesting methods of vermicompost.
- The trainee explains the appropriate harvesting method in small-scale production methods.
- The trainee knows the role of sunlight and temperature in the harvesting process.
- The trainee explains the role of nutrients added to the production environment in the harvesting process.
- The trainee knows the physical properties that vermicast must have.
- The trainee knows the chemical properties that vermicompost should have.
- The trainee knows the biological properties that vermicompost should have.
- The trainee explains the role of earthworms in heavy metal removal.
- The trainee knows the preservation and storage conditions of vermicompost before use.

Instructions for the trainer

- The instructor shares theoretical knowledge through presentation.
- The trainer shows the trainees the SM-3, which visualizes pit-type vermicompost production, and asks them to explain the appropriate harvesting method.
- The trainer shows the trainees the SM-4, which visualizes pile-type vermicompost production, and asks them to explain the appropriate harvesting method.

Basic requirements: Projector, computer.

5. HARVESTING METHODS AND UTILIZATION

The vermicompost is ready in 75-90 days and the resulting material becomes black, granular, light, moderately loose, crumbly and rich in humus. Watering should be avoided two to three days before emptying the beds to facilitate the separation of the worms from the compost. The general procedures for harvesting vermicompost are described below. Any method can only be adopted according to preference. In addition, two or more methods can be applied on the same pile. Except for the first method, the rest are intended for batch harvesting.

5.1. Manual collection of vermicompost

This method is applied when it is desired to collect small quantities of vermicast only a few days after the compost heap has been filled with compost worms. In this case only the top layer is covered with a thin layer of vermicast and the rest of the heap is not completely decomposed. The vermicast on the heap is collected by hand/trowel and transferred directly into a container. This method is recommended if organic soil amendment is needed in the preparation of a fertile potting mix. Over time, as vermicompost collects at the bottom of the heap, it is also collected by hand.

5.2. Vermicompost harvesting with pyramidal pile

Vermicompost is first collected to form a pyramid-like pile within the composting enclosure, provided the pile is exposed to light, or transferred on a plastic sheet or a sack to a flat surface elsewhere in the open sun. This method of vermicompost collection takes advantage of the worm's sensitivity to light because the worms will tend to move deeper into the pyramid. The vermicompost on the bottom, side and top surface of the heap is then collected by hand or with a trowel. After the first cycle of vermicompost collection, a few minutes are passed to allow enough time for the worms to go deeper and another cycle is started. The original pile is divided into several smaller piles for faster harvesting of the vermicompost.

5.3. Sieving or screening of vermicompost

The method of vermicompost harvesting is done manually with a device called a sieve, which consists of a wire mesh nailed to wood. A small portion of the vermicompost pile spread on flat ground is transferred to the sieve and shaken so that the fine vermicompost falls to the ground. All undecomposed substrates and worms are retained in the sieve and the worms are manually separated.

5.4. Harvesting vermicompost by promoting the migration of earthworms

The method of vermicomposting is based on the ability of worms to detect food sources. Worms have the habit of leaving the depleted food pile and moving towards fresher and more flavourful sources. Although there are many modifications to this technique, the basic principle remains the same, with the aim of providing fresh or more palatable food that will enable the worms to migrate from the depleted pile to the new food source.

5.5. Storage and packaging of vermicompost

Harvested vermicompost should be stored in a dark and cool place because sunlight will lead to loss of moisture and nutrient content. Also, the harvested vermicompost material should be stored in the open rather than packed in pouches. Packaging should be done at the time of sale and a laminated pouch is always recommended. During outdoor storage of compost, it should be periodically sprinkled with water to maintain the moisture level and beneficial microbial population. If the humidity of vermicompost is maintained at 40%, it can be stored for as long as one year without compromising its quality [20].

5.6. Utilization

The vermicompost obtained at the end of the vermicompost production process must have some physical, chemical, and biological properties in order to be used as an input in sustainable agricultural activities.

5.6.1. Physical properties

- A good vermicompost is always non-toxic, well decomposed, ecologically compatible and environmentally friendly.
- All types of green waste i.e. municipal waste, agricultural waste, sewage sludge, industrial waste and human excreta can be used for conversion by earthworms.
- When the turning of the soil takes place properly, it is symptomatic of aerobic decomposition, which will produce normal odour after preparation. In case of improper ventilation, bad odour may occur.
- The final result of vermicomposting will consist of fine particulate structure and granular form.
- Vermicompost plays the role of "soil conditioner" by improving soil porosity, drainage and water holding capacity.

5.6.2. Chemical properties

- Vermicompost is rich in almost all essential macro and micro plant nutrients. Various experiments indicate that the average nutrient content of vermicompost is higher than that of other conventional composts produced by other procedures.
- Among all secondary nutrients, the calcium content in vermicompost is higher than in other composts.
- Unlike other conventional compost, vermicompost contains worm mucus, which makes it easier to prevent the nutrients present there from washing away.
- Due to worm transformation, the heavy metal present in the feed material was found to decrease in worm castings due to its accumulation in the worm tissue. Depending on the feed used, the rate of heavy metal removal depends on vermicomposting techniques. This feature makes vermicompost less polluting than other composts. Thus, it becomes more environmentally sustainable.
- There are some differences between simple farm manure and vermicompost in terms of chemical properties. Vermicompost has a higher range of macro- and micronutrients as well as soil organic carbon status, as can be observed from Table 3.

5.6.3. Biological properties

- The by-product of soil breakdown is an inhabitant of various microorganisms, i.e. bacteria, fungi and actinomycetes. These microorganisms secrete various enzymes and phytohormones that help in improving plant growth. Thus vermicompost facilitates both microbial and enzymatic activity.
- The microbial population of nitrogen fixing bacteria and other symbiotic combining bacteria is expected to be in a good range of numbers in vermicompost.
- In addition, vermicompost harbours a large number of vesicular-arbuscular mycorrhiza (VAM) propagules. These propagules survive for up to 11 months after shedding and help to increase microbial activity to produce nitrogen and phosphorus in a form that the plant can readily utilise.

When applying vermicompost into the soil; between 120 and 150 grams of solid vermicompost should be used for each square metre of application area in agricultural areas or soils to be applied. The application should be repeated twice a year to guarantee successful results. Vermicompost should be mixed with the soil in the application area. Laying vermicompost on the application surface may make it difficult for plants to take useful nutrients from the soil. For this reason, it is necessary to mix the soil and vermicompost in such a way as to form a homogenous structure. To do this, use a shovel, pickaxe, or hoe to dig up the soil in the application area, mix the vermicompost and the excavated soil, and fill the pit again with the homogeneous mixture (soil and vermicompost).

Table 3. Chemical properties of vermicompost

Properties	Compost	Vermicompost
pH	7.16	7.72
EC (dSm^{-1})	3.65	6.88
OC	20.5	17.3
Total N (%)	2.42	3.5
Total P (%)	0.88	0.71
Total K ($mg.kg^{-1}$)	653.5	950.5
Total Ca (%)	2.9	3.5
Total Mg (%)	1.5	2.8
Total Fe ($mg.kg^{-1}$)	4467	6045
Total Zn ($mg.kg^{-1}$)	115.5	189.5
Total Cu ($mg.kg^{-1}$)	59	38
Total Mn ($mg.kg^{-1}$)	221.45	344.15
C:N	8.47	5.51

LESSON 6

6. THE ROLE OF VERMICOMPOST IN PEST AND DISEASE

Learning outcomes

- The trainee knows which plant diseases vermicompost are useful for.
- The trainee knows that vermicompost suppress parasitic organisms in the soil that cause disease in plants.
- The trainee knows that the use of vermicompost suppresses fungal activity.
- The trainee explains that the use of vermicompost reduces the use of chemicals in the fight against plant pests.

Instructions for the trainer

- The trainer shares theoretical knowledge through presentation.
- The trainer hands the SM-5 (table: relation between disease/pest and crop) to the trainee. Asks them to fill in the blank sections in the table. During this study, trainees should be encouraged to interact with each other.

Basic requirements: Projector, computer.

6. THE ROLE OF VERMICOMPOST IN PEST AND DISEASE

Vermicompost is known to be useful in the treatment of different plant diseases (Table 4). Many plant diseases caused by soil-borne, foliar plant pathogens and pests have been suppressed by vermicompost products, which have proven effective as organic fertiliser and biological control agents. The excessive and repeated use of chemical pesticides in conventional agriculture has resulted in "biological resistance" to crop diseases and pests. As a result, significantly higher doses are now needed to inhibit the growth of high-yielding crops that are more susceptible to pests and diseases [44]. The use of vermicompost has been shown to suppress disease-causing factors in many crops, such as chickpeas and tomatoes. It has been proven by numerous studies that the use of vermicompost as a substitute for chemicals yields successful results in the fight against plant diseases.

Earthworm has stimulatory effect on soil microbial activities thus it suppressed the plant diseases more potentially than aerobic compost. There is a lot of research on the suppression effect of organic matter amendments in soils, with gratifying levels of reduction in plant parasitic nematode infestations. There are few publications on the suppressing effect of solid vermicomposts on numbers and outbreaks of plant parasitic nematodes relative to OM and thermophilic compost additives. Solid vermicompost applications for control of plant parasitic nematode populations have been studied. Solid vermicomposts ranging from 2 to 8 $kg.ha^{-1}$ were applied to tomatoes, peppers, strawberries, and grapes in field treatments. They were able to suppress plant parasitic nematodes with great success. These researchers investigated the suppression capacity of plant parasitic nematodes in vermicomposts made from paper waste, food waste, and cattle manure under field circumstances and found considerable suppression [45].

Apart from using compost or biocontrol agents individually, the fortification of compost with bio-control agents has been suggested to increase the colonization process of biological agents in composts. Numerous composts and biofortified composts have been reported to decrease the number of pathogens and defend crops against soil borne pathogenic agents when applied as soil amendments [46, 47]. Antagonistic effect of vermicompost and vermicompost fortified with *Trichoderma harzianum*, *Bacillus subtilis* and *Pseudomonas fluorescens* was investigated against *Fusarium oxysporum* and it was shown that biofortification not only facilitated plant growth but also significantly reduced wilt disease. As these microbial strains have the potential to secrete antifungal metabolites, hydrolytic enzymes, and antibodies. A scientific study on the management of tomato Fusarium wilt with biofortified vermicompost revealed that vermicompost application alone or after fortification with microbes such as *Trichoderma harzianum*, *Pseudomonas fluorescens* and *Bacillus subtilis* significantly improved the growth and nutritional status of tomato plants. Furthermore, disease incidence was found to be lower in plants treated with vermicompost biofortified with biocontrol agents, especially *Trichoderma herzianum*, compared to control plants [48].

Table 4. Plant diseases and pests suppressed by the use of vermicompost [49]

No	Disease/pest	Crop
1	Jassid (Empoasca verri), aphid (*Aphis craccivora*)	Groundnut
2	Damping off and root rot	Cucumbers and Radishes
3	Damping-off	Tomatoes
4	Damping-off	*Impatiens walleriana*
5	Tetranychus urticae, Pseudococcus sp. *Myzus persicae*	Bush beans, Eggplant, tomato, Cucumber, and Cabbage
6	Collar rot	Chickpea
7	Fusarium wilt	Chick pea
8	*Helicoverpa zea* and *Pieris rapae*	Cabbage
9	Meloidogyne incognita	Brinjal
10	Earworm (Helicoverpa zea)	Corn plant
11	Aphid (*Lipaphis erysimi*)	Mustard
12	Fusarium wilt	Tomato
13	Damping- off	Cucumber
14	Polyphagotarsonemus latus	Chili
15	Late blight disease	Potato
16	Fusarium wilt	Cucumber

Vermicasts can also manage arthropod pests such as caterpillars: like tomato hornworms, cabbage white caterpillars and cucumber beetles including sucking arthropods such as aphids, spider mites and mealy bugs. Vermicomposts derived from food waste are known to significantly control mealybug attacks on cucumber and tomato, two-spotted spider mite (*Tetranychus urticae*) attacks on bush bean and egg crops, and aphid (*Myzus persicae*) attacks on cabbage, even at low amounts [50]. Vermicompost also has a positive effect on the occurrence and number of plant nematodes. It was reported that vermicast application at the rate of one kg per square metre significantly reduced the occurrence of *Meloidogyne incognita* in tobacco plants [51].

6.1. Vermicompost tea in pest and disease management

In agriculture, the use of vermicompost tea is increasing due to its potential to manage the diversity of air and soil-borne diseases (Table 5). With this in mind, liquid extracts of composts are seen as alternative options to the use of conventional chemical fungicides and pesticides in response to the growing need for agriculture and food protection for environmental sustainability. The efficacy of compost tea may be different depending on differences in the types of composts used, sources and preparation methods. However, it has been documented that the most excellent results are obtained by applying aerated tea instead of still tea. This is probably because dissolved oxygen favours microbial diversity and activity. In the last 10 years, the application of vermicompost tea as a biocontrol agent has increased significantly. Mycelial growth of *Botrytis cinerea*, *Sclerotinia sclerotiorum*, *Rhizoctonia solani*, *Corticium rolfsii*, and *Fusarium oxysporum* was significantly inhibited by liquid extracts from vermicomposts. The high potential of using vermicompost as a suitable substitution technique to control plant diseases is pointed out. It is recommended that farmers apply these liquid solutions directly to the leaves as a simple, cheap, and environmentally friendly plant protection method with high yield potential. In a study investigating disease prevention potential of vermicast tea against *Phytophthora infestans* on three varieties of tomato; it was revealed that vermicast tea reduced the susceptibility of leaves, stems and fruits of tomato plants to diseases caused by *Phytophthora infestans* [49].

Vermicompost teas have significant potential to kill or suppress pests. It is reported that drenching of vermicast tea suppresses spider mite damage. By applying vermicompost tea, the soluble phenolic compounds reach the plant and make the plant tissues unpalatable, thereby disturbing survival and reproduction rate of pests [50]. It is reported that earthworms take-up soil substances, swallow humic acids through their guts and finally excrete polychlorinated and monomeric phenols into the final vermicast. Vast microbial communities and their activities in vermicompost tea led to the release of nutrients in slow but balanced manner that reduces nitrogen inputs, improves phenol content of plants, thus resulting in plant tolerance against pests [52].

Table 5. Plant diseases and pests suppressed by the use of vermicompost tea [49]

No	Disease/pest	Crop
1	Powdery mildew	Pea and Balsam
2	Late blight	Tomatoes
3	Foot rot	Rice
4	*Acalymma vittatum, Manduca sexta*	Cucumber and Tomato
5	*Fusarium wilt*	Brinjal
6	*Reniform nematode*	Zucchini
7	*Sclerotium cepivorum*	Onion
8	*Meloidogyne incognita*	Zucchini and Cucumber
9	*Meloidogyne incognita and Rotylenchulus reniformis*	Cucumber
9	*Meloidogyne incognita*	Banana plant
10	*Meloidogyne incognita*	Tomato

LESSON 7

7. INFRASTRUCTURE AND EFFICIENT TIME MANAGEMENT

Learning outcomes

- The trainee explains the importance of mechanization in vermicompost production.
- The trainee explains the effects of substrate particle size on vermicompost yield.
- The trainee knows the machines and equipments used in reducing the substrate particle size.
- The trainee explains the necessity of mixing organic wastes in appropriate proportions and in sufficient variety to produce quality vermicompost.
- The trainee knows the appropriate tools and equipment for successful stack (pile) management.
- The trainee explains the requirements for controlling temperature, moisture and pH in the pile.
- The trainee explains the consequences of anaerobic and aerobic conditions.
- The trainee explains the functional role of the sifting process.
- The trainee knows the equipment used in the sifting.
- The trainee explains the requirements for packaging in vermicompost.
- The trainee knows the moisture content that vermicompost should have in the package.
- The trainee knows the approximate cost of vermicompost packaging equipment.
- The trainee knows the tools to be used in the packaging process.

Instructions for the trainer

- The trainer shares theoretical knowledge through presentation.

Basic requirements: Projector, computer.

7. INFRASTRUCTURE AND EFFICIENT TIME MANAGEMENT

Vermicomposting and composting production processes require a certain level of mechanization for effective time and cost management. Equipment that can be used in some basic processes to ensure that the production process results in high-quality outputs by consuming less labor and time are given below.

7.1. Crushing, Shredding, Size Reduction

Most materials used in farm composting do not require crushing or shredding. Newspapers, cardboard and other garden waste are crushed and shredded. Tree bark and other large objects are also reduced in size before composting. Thanks to shredding, materials such as newspapers can be shredded and used as bedding material before composting. However, crushing/shredding operations may create noise and dust problems. Equipment that can be used in this process are paper shredders, large garden shredders, lawn mowers and straw clippers. Some size reduction mechanisms can be used with auxiliary equipment such as balers, dust separators, conveyors and screens. Actual capacities depend on materials used, loading rate and other conditions. The cost varies depending on the power need and the equipment used. If a crusher or shredder is only needed for a few weeks a year, it is more profitable to rent this equipment. The primary types of crushing/shredding equipment used in composting systems are surface shredders, hammer axes, trough shredders and chippers [53].

7.2. Mixing and Batching

The most necessary step in the composting process; It is mixing the substances in appropriate proportions and then forming stacks with this mixture in a closed reactor. In most closed reactor methods, mixing is done within the system. Substances are loaded into the silo or hopper with conveyors, augers and/or bucket loaders. In windrow and aerated pile methods, mixing and stacking occur in separate steps. Initial mixing is especially important in aerated static pile systems. Once mixing is done, the quality of this mix lasts throughout the entire composting process. In the windrow method, in the first mixing step, the raw materials are proportioned and mixed until they reach a certain density. With subsequent mixing, the substance is completely mixed. Mixing and windrowing can be done in different ways depending on the compost method, the equipment available and the method of manure processing on the farm. For mixing materials and creating stacks; loaders, manure spreaders and other equipment on the farm are usually suitable. However, mixing and windrowing require more labor than other compost operations [53].

7.3. Maturation, Storage and Processing

Anaerobic conditions may be caused by excess moisture or water accumulating at the bottom of the pile. In mature compost, not enough heat is generated to evaporate moisture. Surface runoff in the maturation area is drained by directing it away from the piles. The height of the pile should be parallel to the base. The most effective way to prevent wet or anaerobic conditions in a compost pile is to mix the pile and spread the compost on an open field. This allows oxygen into the pile and aids in the aerobic decomposition or evaporation of anaerobic compounds. After aeration for a day or two, the compost is piled again, the pile warms up again and is composted in a short time. It takes a few days to a few weeks for the pH to return to its normal level. The use and sale of compost is generally seasonal. Microbial activity remains at a low level in finished compost that has been properly composted and matured. The height and width of the pile is determined by the use of bucket loaders, conveyors or other equipment. However, the height of storage piles should not exceed 3.6 m. As the size of the pile increases, the risk of compost deterioration and spontaneous combustion increases. Piles with a height of more than 2.4 m have low moisture, but due to poor drainage conditions, the bottom of the storage piles becomes wet. It is usually safe to stack large storage piles into smaller piles for a few weeks before using or selling. This allows natural aeration of the stored compost and removal of any phytotoxic compounds present. If the produced compost is applied to a field, maturation and/or storage piles are placed in a suitable part of the field. Poor drainage and steep land slopes should be avoided to reduce anaerobic conditions, compost loss, and nutrient loss from runoff [53].

7.4. Sifting

Sifting is done to separate substances of different sizes and/or shapes. By sifting;

- Most of the unwanted materials such as stones, metal, bottles and other garbage are removed,
- Composted materials are separated from non-composted ones,
- Compost residues and completely uncomposted materials are separated and brought to a quality suitable for sale or use,
- The bulking agent in the compost is recovered and reused.

The use of screening in on-farm composting systems allows the quality of the compost to be improved or the bulking agent to be recovered. The most important characteristics to consider when choosing a sieve are; The sieve's mouth opening, capacity, efficiency, cost and resistance to clogging. Clogging is the blocking of sieve openings with particles. Most sieves use equipment such as brushes or spheres to prevent this. The sieve opening to be used in composting should be between 0.60 - 1.30 cm, depending on the substances to be separated and the final use of the compost. Although small openings provide better separation, they reduce the capacity of the screen and cause clogging. The efficiency of the sieve is determined by its ability to separate particles in the desired distribution. If the size of the particles passing through the sieve is larger than desired or if the particles planned to pass through the sieve are retained in the sieve, the efficiency decreases. Efficiency and capacity are affected by the material fed as well as the sieve opening. The sieve works better with desiccant. It is generally preferred to sieve the substances after ripening and drying. To sift the compost without clogging and material buildup, the moisture content must be less than 50% or 45%. In practice, the maximum moisture content depends on the specific sieve opening. There are also sieves that can shred and mix. Such screens use abrasive belts or hammers to break up material residues before sifting. There are various types of sieves. These are rotary drum sieve, shaking sieve, shaker sieve, flexible belt sieve, disc sieve, augers and trough sieve, rotary sieves [53].

7.5. Packaging

Packaged compost is more expensive than openly sold compost. Compost customers can also be increased with packaging. It is not necessary to use special equipment for packaging small volumes. Although it is laborious, compost can be packed using a shovel. Work can be done faster by using package holders, package binders or closers. Metered valves, scales, package closers and conveyors are used in high-volume packaging operations. A packaging machine may also be required since most vendors package the package. An automatic package line costs a total of fifty thousands euros. This does not include labor and product storage. In a plastic package, the moisture content of the packaged compost must be at least 35%. Otherwise, the compost decomposed in the airtight package may turn sour. In compost labeling, the producer company/person, the properties of the compost, storage conditions, production code, date, intended use, instructions for use, and details about public health should be stated on the package [53].

LESSON 8

8. ESTABLISHING AN EFFECTIVE ORGANIC WASTE COLLECTION SYSTEM

Learning outcomes

- The trainee knows the average daily solid waste amount per person.
- The trainee knows how much of the solid waste produced is of organic origin.
- The trainee explains the forms of solid waste.
- The trainee knows the waste management hierarchy.
- The trainee explains the advantages of the central solid waste management strategy.
- The trainee explains the disadvantages of the central solid waste management strategy.
- The trainee explains the advantages of the local solid waste management strategy.
- The trainee explains the advantages of the central solid waste management strategy.
- The trainee explains the disadvantages of the local solid waste management strategy.
- The trainee customs the advantages of the central solid waste management strategy.
- The trainee customizes the management strategy appropriate to the solid waste potential.

Instructions for the trainer

- The trainer shares theoretical knowledge through presentation.

Basic requirements: Projector, computer.

8. ESTABLISHING AN EFFECTIVE ORGANIC WASTE COLLECTION SYSTEM

Huge amounts of solid waste are produced in urban areas. Average solid waste production is 0.6 kg per person per day. A look at the composition of solid waste from cities in low- and middle-income countries shows that readily biodegradable fractions range from 44 percent to 87 percent by weight. Levels of urbanization and modernization have a profound impact on the production and composition of municipal waste; However, some general trends, such as high organic matter content (50-90 percent), offer the opportunity for use through composting processes. The waste stream is not a homogeneous mass, but a combination of different materials (organic material, plastic, metal, textiles, etc.) that can be handled in different ways to maximize recovery. The organic waste fraction remains the largest fraction to be recovered [54]. Common forms of solid waste;

Solid waste: domestic and market wastes, food waste including vegetable and fruit peelings, charcoal ash. This also includes waste from institutions and commercial centres.

Horticultural and agricultural waste: garden refuse, leaf litter, cut grass, tree prunings, weeds, animal dung, crop residues, waste from public parks etc. Manure: poultry, pig, cow.

Agro-industrial waste: waste generated by abattoirs, breweries, processing and agro-based industries

Sludge and bio-solid: human faecal matter from septic tanks and treatment Plants.

There are many approaches to waste management (Figure 9). Solid waste is generally managed through landfilling, incineration, and recycling or reuse. But in developing countries, properly designed landfills are uncommon and the cost of modern incineration is unaffordable. Therefore, the most common method of waste disposal is some form of landfill, which includes variants such as uncontrolled dumping in undefined areas, collection and disposal in unmanaged open dumps, and collection/disposal in controlled landfills. It's common to find trash collectors going door to door or lining community trash cans to collect dry recyclables. However, these collectors are more interested in inorganic recyclable materials such as plastic and glass but not organic waste. Agenda 21, adopted in Rio in 1992, states that environmentally sound waste management should include safer disposal or recovery of waste and changes towards a more sustainable model introducing integrated life cycle management concepts. It introduced a phased approach to waste management in order of environmental priority [54]. The general principle of the waste management hierarchy (Figure 9) consists of the following steps:

- Minimizing waste;
- Maximizing the reuse and recycling of environmentally sensitive wastes;
- Promoting environmentally friendly waste disposal and treatment;
- Expanding the scope of waste service.

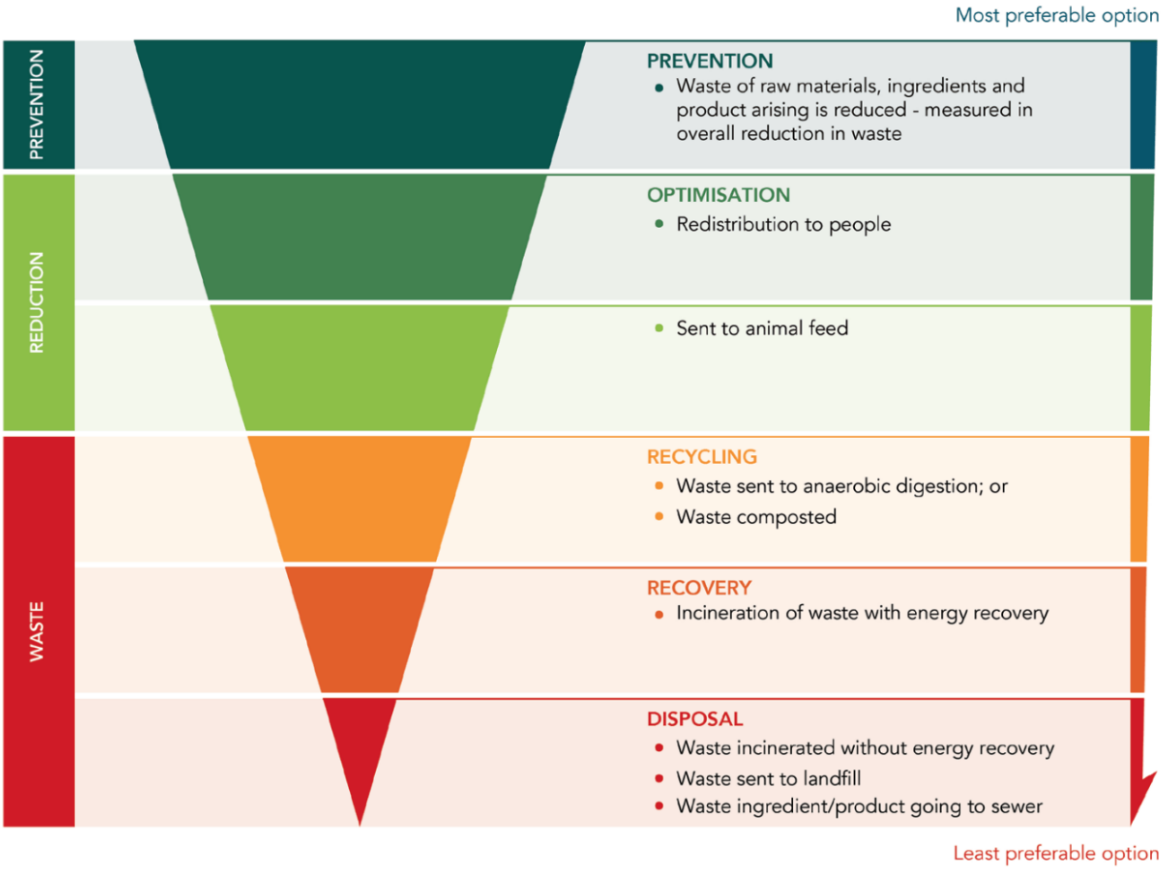

Figure 9. Solid waste management approaches [55]

After Rio, most countries generally accepted this hierarchy as a strategy towards an environmentally sound waste management system. Over the last decade, the concept of Integrated Waste Management (IWM) has evolved and is slowly becoming accepted by decision makers. IWM is based on a range of approaches to waste management, including all aspects of waste management from production to disposal and all stages in between, where technical, cultural, social, economic and environmental factors are taken into account as appropriate. Resource recovery is critical and part of this strategy [54, 56]. Current urban organic waste recycling practices include:

- Use of fresh waste from vegetable markets, restaurants and hotels and food processing industries as feed for urban livestock,
- Direct application of solid waste to and from the soil,

- Mining of old waste storage areas to be used as fertilizer in agricultural lands,
- Application of animal manure such as poultry/pig manure and cow manure;
- Direct application of human feces or biological solids to soil,
- Organized composting of solid waste or composting solid waste together with animal manure or human excreta.

Whichever method is used, the microbial decomposition process releases beneficial nutrients in organic waste for soil improvement and plant growth. Composting is the process of decomposing or breaking down organic waste materials (by microorganisms such as bacteria, single-celled organisms, fungi, and invertebrates) into a valuable resource called compost. Composting is done in urban areas at different scales (large, medium, small) by various people (municipalities, NGOs, communities, individuals) and for various purposes (gardening, landscaping, farming). In the 1970s, large-scale centralized fertilization came to the fore, especially in the world. However, this has proven unsuccessful. Collecting and transporting organic waste to centrally managed sites is expensive, time consuming and energy intensive; these processes are also dependent on fossil fuel inputs, which are often heavily subsidized to ensure fuel inputs are maintained, thus increasing economic inefficiency at the macro level. Where funding comes from donor agencies, the conditions that accompany such funding often act as a barrier to good practice. In developing countries, technological know-how on financial analysis, engineering design of compost facilities and transportation schedule modeling is very limited. In addition, technological transfers of composting processes and equipment from developed countries were often made in the past without regard to local constraints, and the transferred technologies were often not applicable in the receiving country. Additionally, comprehensively planned composting stations based on supply-demand analysis are not common. In fact, waste management authorities in many developing countries do not have the "luxury" of planning for recycling; Instead, they focus their limited resources on priority needs such as “waste collection” and “safe disposal,” which consume large portions of municipal budgets in low-income countries because their cost recovery is low. The irony is that waste disposal costs can be reduced through composting if planned well. But what seems like a logical win-win situation for city officials and farmers is rarely the reality in the developing world. This is due to various factors such as lack of affordable equipment, lack of technical personnel, frequent mechanical breakdowns and financial constraints. In the 1990s, small and medium-sized, decentralized composting-based initiatives developed. However, the transition from centralized to decentralized composting approaches is often further complicated by the lack of cross-sectoral planning (waste/planning/agriculture) in waste management. The failure of small-scale decentralized approaches to receive comprehensive government support at the national level has limited the success of studies carried out within this framework.

By far, the better composting options are those that are decentralized and use organic waste as close to the source as possible. Decentralized on-site (for commercial organic waste) and on-site (for domestic organic waste) are the preferred levels of intervention, with each intervention requiring appropriate technology at an appropriate scale. Essentially, the primary function is all about obtaining nutrients. Recycling organic matter from waste to the soil in the most efficient and effective way; hence the prioritization of backyard composting (home) and decentralized (community) approaches. Centralized municipal approaches do not have a good track record and potential economies of scale benefits have not been realized due to operational and marketing constraints.

As a result, the necessity of implementing small and regional scale, limited capacity waste management strategies stands out as the basis for establishing effective waste management systems. Collecting and recycling organic waste by each farm itself or by a cluster (network) of a certain number of farms coming together would be a correct and manageable approach. In urban areas, the establishment of small collection centers (in every street or neighborhood) by municipalities to separate organic waste at source may be a feasible solution (Figure 10 and 11).

Figure 10. City of Burnaby waste collection center [57]

Figure 11. Street-scale applications in organic waste collection [58]

With the mini-compost reactors to be established in these collection centers, the waste can be transformed into the fertilizer needed for the landscaping of that region. Or, the transfer of solid wastes, which shrink in volume at the end of the composting process, to agricultural enterprises creates less financial burden (Figure 12 and 13).

Figure 12. Organic waste collecting and logistics for composting in city-scale [59]

Figure 13. Compost reactors for different scales (home, street, waste collecting center) [60]

LESSON 9

9. BENEFITS AND ECONOMIC RETURNS

Learning outcomes

- The trainee explains the improvement in the physicochemical properties of the soil caused by the production of vermicompost.
- The trainee explains the positive effects of vermicompost on soil fertility and plant development.
- The trainee explains the improvement in the biological properties of the soil caused by the production of vermicompost.
- The trainee knows the economic benefits of vermicompost production.
- The trainee evaluates the economic benefits of waste recycling.

Instructions for the trainer

- The trainer shares theoretical knowledge through presentation.

Basic requirements: Projector, computer.

9. BENEFITS AND ECONOMIC RETURNS

9.1. Benefits

Vermicomposting has advantages at different levels. On the one hand, the benefit of applying worm castings, or vermicompot, to arable land to increase its fertility is well known, since at least ancient Egypt. Multiple studies show that worm castings have many beneficial properties:

- improves the composition of the soil, making it more spongy, aggregated and aerated, in addition to making it permeable to water, while helping to retain it. Also, chemically, vermicompost helps regulate, to a certain extent, an optimal pH for the plants. Biologically, the bacterial abundance and diversity of soil enriched with humus are easily verifiable. The increase in fertility of a soil supplemented with vermicompost is evident, with virtually zero side effects.
- It is also shown that the components of the mature vermicompost help the growth of the plants and their production. The acids, enzymes and hormones present in worm castings are of great help for the development of crops, from germination to their adult stage. Worm castings feed and make plants grow more vigorous, productive and resistant to pests and inclement weather.
- As if that were not enough, there is no chemical fertilizer comparable in results to vermicompost, a completely natural product, which reduces the possibility of harmful effects on health.Vermicomposting even helps in the elimination or degradation of chemicals, toxins or contamination existing in the waste that is fed to the worms.

On the other hand, vermicomposting is an activity that implies other indirect or less obvious benefits:

- Its educational potential for children, young people and adults has been known and has been applied for decades in educational systems. Conveniently introduced, vermicomposting is a living experiment that promotes countless values such as caring of fragile but fundamental living beings, the biological scientific aspects that it carries with it, the maintenance of the ecosystem, the analysis of its results...
- Waste management has a considerable social impact. Composting and vermicomposting are very welcome solutions for some of the problems of modern societies such as the management of certain organic waste. Often the excess of organic "garbage" from the individual or family level, to the communal level, in companies, schools, hospitals and many other environments, can be remedied with composting systems. The investments

and maintenance required are minimal, especially when verifying its low cost and maintenance and the high return in nutritional terms, health improvement and environmental balance.

- It is worth mentioning the level of consciousness that composting in all its forms introduces into our societies that are increasingly voraciously consumerist and disconnected from the environment. It is especially curious that the most profound and simple beings, from bacteria to worms, give us recycling lessons and help us reconnect with the nature that sustains us. Worms have taught us to convert waste into a resource and are the very link with our origin and sustenance, we cannot forget them.

9.1.1. The role of vermicompost on soil fertility

The main role of earthworm compost is the change of physical, chemical and biological properties of the soil by earthworm activities and therefore they are called soil managers. It significantly improves the structure, texture, aeration of the soil and prevents soil erosion. By increasing the macropore area between 50 and 500 μm, it causes the air-water relationship in the soil to improve and thus positively affects plant growth. It also positively affects soil pH, microbial population and soil enzyme activities. In addition, vermicompost is a rich source of nutrients such as nitrates, phosphates and exchangeable calcium and soluble potassium. Besides adding mineralogical nutrients, vermicompost is also rich in beneficial micro-flora such as N-fixers, P-solubilisers, cellulose-decomposing micro-flora, etc. It also reduces the proportion of water-soluble chemicals that cause possible environmental contamination. The mucus secreted by the digestive tract of the earthworm produces certain antibiotics and hormone-like biochemicals, thereby accelerating plant growth and increasing the decomposition of organic matter in the soil. Vermicompost has been reported to have favourable effect on growth and yield parameters of various crops like paddy, sugarcane, brinjal, tomato and okra. Thus, vermicompost acts as a soil conditioner and a slow-release fertiliser, ultimately improving soil structure, soil fertility, plant growth and suppressing diseases caused by soil-borne plant pathogens, increasing crop yields [20, 61–63].

9.1.2. The role of vermicompost on the soil physiochemical properties

Vermicompost improves the physiochemical characteristics of soil, such as soil structure, soil water holding capacity, penetration resistance, bulk density, soil organic carbon, aggregation, nutrient content, etc. According to the findings of various long term research addition of vermicompost reduces the bulk density of the soil and increases the water holding capacity of soil [64]. It is found that when vermicompost was added in the soil, the mean bulk density, and mean total porosity were the least. Air permeability rose and penetration resistance reduced dramatically as wet aggregate stability improved and bulk density reduced. Increased microbial population and activity led in the development of aggregates and increased soil porosity, resulting in decreased particle and bulk densities. Physicochemical characteristics such as pH, electrical conductivity (EC), porosity, moisture content, water holding capacity, and chemical properties like nitrogen, phosphorous, potassium, calcium, and magnesium were all found to be significantly improved in vermicompost treated soil, while the corresponding physicochemical values in control soil were minimal in rice crop [65]. Vermicompost has indeed been found to have significant concentration of total and bioavailable nitrogen, phosphorus, potassium (NPK), and micronutrients, as well as microbial and enzyme activity and growth regulators. Polysaccharides appeared to be abundant in vermicompost. Polysaccharide worked as a cementing ingredient in the soil, causing aggregate stability, which helped to establish and maintain the soil structure for improved aeration, water retention, drainage, and aerobic conditions. The preservation of soil structure is essential for root elongation and nutrient uptake. The inclusion of mucus secretion and microorganisms from the earthworm's gut improves the soil's aggregate stability. The absorbent organic matter in vermicomposts increases the soil's water retention capacity by holding only the quantity of water required by the plant roots [66, 67]. Vermicomposts have been found to have a higher base exchange capacity and a higher oxidation potential rise [68]. The C/N ratio of vermicompost is usually lower, indicating that it is more suited for use as a soil amendment. By altering the physiochemical parameters of the soil, vermicompost was able to limit the loss of nutrients through leaching [69]. Humic acid and biologically active compounds like plant growth regulators are abundant in vermicompost. Humic acid has been proven to improve nutrient accretion in situations where nutrients are scarce or when additional nutrients are provided. Humic acids may have a hormone-like effect on plant growth and productivity as a result of their involvement in cell respiration, photosynthesis, oxidative phosphorylation, biogenesis, and a variety of other enzymatic functions [24, 70].

Table 6. Effect of vermicompost on physiochemical properties of soil on different crops [24]

Crop	Treatments	pH	EC (dSm^{-1})	BD ($g.cm^{-3}$)	Porosity (%)
Rice	Control	7.4 ± 2 01	2.0 ± 1.0	—	39 ± 2.0
	Vermicompost	7.1 ± 0.01	1.01 ± 1.0	—	41 ± 1.0
	Vermi-wash	7.2 ± 1.02	2.0 ± 1.1	—	40 ± 1.1
	Vermicompost + Vermi-wash	7.0 + 0.03	0.02 ± 0.01	—	44 ± 1.0
Wheat	Soil sample	8.56	25.82	1.52	25.38
	Vermicompost / 5 $g.kg^{-1}$ soil	7-6	4.65	1.42	26.85

Table 7. Comparison between the effect of vermicompost and conventional compost on different nutrient content of the *Amaranthus viridis* production [71]

Parameters	Compost ($g.m^{-2}$)			
	Vermicompost		Conventional compost	
	100	150	100	150
Nitrogen (%)	0.61	0.72	0.54	0.62
Phosphorus (%)	0.0057	0.0077	0.0039	0.0047
Potassium (%)	11.11	11.17	10.41	10.48
Calcium (%)	1.443	1.683	0.561	0.641

9.1.3. Effect of vermicompost on the soil biological properties

Biological properties of soil can be enhanced through application of vermicompost. Recent studies founded that soil biological characteristics viz. soil organic carbon as well as soil microbial biomass, enzymatic activity, population of different beneficial microorganism, hormones, etc. significantly enhanced with application of vermicompost. The activity of the dehydrogenase enzyme, which is commonly employed to quantify the respiratory activity of microbial communities, was shown to be higher in vermicompost than in commercial medium. Application of vermicompost improved the nitrogen status of soil by introducing the beneficial microorganism in the rhizosphere of the plant which ultimately enhances the nitrogenase activity in soil, which is the enzyme responsible for nitrogen fixation [24, 72, 73].

9.1.4. Effect of vermicompost on plant growth and development

Vermicompost promotes the growth and development of a variety of plant species, especially various horticulture crops, that is, sweet corn, tomato, strawberry [74], cereals crop rice [65], wheat, sorghum [69], fruit crops papaya [75], and pineapple [76]. Several growth and yield metrics viz. stem diameter, plant height, marketable yield per plant, mean leaf number, and total plant biomass of tomato plant were recorded significantly higher with the application of vermicompost. The increase in growth and development of plant is due to the improving action of vermicompost application on soil physical, chemical, and biological properties which ultimately improves the overall soil fertility, which enhances the plant growth and development. Vermicompost has been demonstrated to improve plant dry weight and uptake of plant N serve as a naturally available, slow released sources of plant nutrients [24].

9.2. Economic Returns

Vermicomposting offers several economic benefits. Firstly, it is an efficient and cost-effective method of converting organic waste into valuable compost, which can be used as a nutrient-rich manure for crop cultivation [77]. This reduces the reliance on chemical fertilizers, which can be expensive. Additionally, the demand for vermicompost has been increasing rapidly, creating a potential market for its commercialization [78]. This presents an opportunity for farmers and small-scale entrepreneurs to generate revenue by producing and selling vermicompost. Furthermore, vermicomposting has the potential to reduce the cost associated with food waste disposal, as demonstrated by a financial analysis. By utilizing vermicomposting, the cost of waste treatment can be significantly reduced, making it an economically viable option. Overall, vermicomposting offers economic benefits through the production and sale of vermicompost, as well as cost savings in waste management [79].

The economic benefits of vermicomposting include a potential reduction in the cost associated with food waste disposal from $57 to $18 per ton. In today's world, where the total amount of global waste is 20 billion metric tons and municipal solid waste is 2.7 billion metric tons, the transformation of waste into economic value is also important in terms of the circular economy [80]. Considering that 70% of the municipal solid wastes generated are of organic origin [81], the contribution of reprocessing these wastes with environmentally friendly approaches such as vermicomposting to the world economy is approximately 73.7 billion dollars. The amount of solid waste from small-scale farms can often vary depending on the size of the farm, type of production, and processing methods.   Regardless of size and scale, recycling organic wastes through vermicomposting will reduce the solid waste management costs of small agricultural enterprises by at least 70%.

The positive effect of vermicompost on plant growth and development and its protective effect against plant diseases and pests make it a powerful fertiliser and a successful plant protection component. Considering that the average annual fertiliser and plant protection product costs of small-scale agricultural enterprises/farmers are 22.175 and 15.915 dollars [82], respectively, it is obvious that, in addition to the 70% cost reduction provided by vermicompost in the field of waste management, a cost reduction of approximately 38.000 dollars will be a significant gain for small farm enterprises/farmers.

LESSON 10

10. INFORMATION AND COMMUNICATION TECHNOLOGY SOLUTIONS

Learning outcomes

- The trainee knows the self learning tools on vermicompost production.
- The trainee knows how to access the WWOOF Vermicompost online training interface.
- The trainee knows how to access the ILA Vermicompost online training interface.
- The trainee knows how to access the MTU Vermicompost online training interface.
- The trainee evaluates in which processes of vermicompost production the Internet of Things technology can be used.

Instructions for the trainer

- The trainer shares theoretical knowledge through presentation.
- The trainer demonstrates the registration and login process to the WWOOF vermicompost online training interface.
- The trainer demonstrates the registration and login process to the ILA vermicompost online training interface.
- The trainer demonstrates the registration and login process to the MTU vermicompost online training interface.
- The trainer shows the SM6 video (Vermicomposting Monitoring System) to the trainees. After the video, the trainer asks the trainees, "What digital solutions can be developed at other stages of the worm castings production process?"
- The trainer guides the trainees on the introduction and use of the Powerworms mobile application.

Basic requirements: Projector, computer, internet connection.

10. INFORMATION AND COMMUNICATION TECHNOLOGY SOLUTIONS

The landscape of dedicated digital solutions solely focused on vermicomposting is limited. However, there have been some developments in the realm of online education courses and research papers addressing related aspects, particularly in the domain of Automatic Monitoring and Correction via the Internet of Things (IoT). In recent years, there have been online education courses and mobile applications available that delve into the intricacies of Vermicomposting [83, 84]. These courses might cover topics ranging from the basics of setting up a vermicomposting system to more advanced techniques for optimizing compost quality and worm activity. These educational platforms might offer video tutorials, instructional guides, or interactive modules, providing enthusiasts and practitioners with comprehensive insights into effective vermicomposting practices. Additionally, academic research and published papers explore the integration of IoT in waste management and composting. These studies discuss concepts and prototypes for automatic monitoring and correction systems that utilize IoT sensors to track crucial parameters in composting, such as temperature, moisture, pH levels, and oxygen content. These papers might propose methodologies or experimental setups for leveraging IoT to optimize composting conditions automatically [85–89]. The absence of specific digital solutions dedicated entirely to vermicomposting could be attributed to several factors. Firstly, the field of vermicomposting, while gaining attention for its environmental benefits, might not have yet garnered sufficient commercial interest to prompt the development of standalone digital solutions. The diverse nature of vermicomposting methods, varying based on location, available resources, and specific needs, might pose challenges in creating a universally applicable digital solution. Moreover, the complexity of vermicomposting processes and the range of variables involved, including environmental conditions, worm species, and waste materials, might have deterred the immediate development of dedicated digital tools. Developing a comprehensive and effective digital solution that addresses these intricacies could require significant research, resources, and expertise. In essence, while there might not have been prevalent digital solutions exclusively dedicated to vermicomposting, the existence of educational courses and research papers exploring IoT applications in composting indicates a growing interest and potential for technological advancements in this field. These resources lay the groundwork for future innovations and the development of specialized digital solutions tailored to vermicomposting practices.

LESSON 11

11. PRACTICAL IMPLEMENTATION ON SMALL FARMS

Learning outcomes

- The trainee defines the requirements for small-scale bed/pile-type vermicompost production.
- The trainee establishes the production environment by using the components in the appropriate order for bed/pile type production.
- The trainee defines the requirements for small-scale pit-type vermicompost production.
- The trainee establishes the production environment by using the components in the appropriate order for pit type production.

Instructions for the trainer

- The trainer briefly summarizes the process steps.
- An open area should be preferred for this application. Like a practice garden.
- Large pieces are reduced into smaller pieces using garden shears.
- Egg shells are ground.
- Egg shells and coffee grounds are laid between layers of organic waste.
- The trainer tells the trainees step by step what they need to do and asks them to use the appropriate material to build the vermicompost production environment.
- At the end of the day, the instructor asks the trainees to write down all the actions taken.

Basic requirements: Organic waste (leaves, vegetable wastes, sawdust, grass, cattle dung, etc.), egg shells, coffee grounds, newspaper and cardboard waste, earthworms (*Eisenia fetida*), three spades, gardening shears, bucket, grinder.

11. PRACTICAL IMPLEMENTATION ON SMALL FARMS

In this section, bed and pit methods for vermicomposting production on small-scale farms are presented step by step.

11.1. Bed/Pile method

Composting is done on the pucca / kachcha floor by making a bed (dimension: 6 x 2 x 2 feet) of organic mixture. This method is easy to maintain and to practice.

Procedure:

- Processing involves collection of wastes, shredding, mechanical separation of the metal, glass and ceramics and storage of organic wastes.
- Pre-digestion of organic waste for twenty days by heaping or dumping the material along with cattle dung slurry. This process partially digests the material and fit for earthworm consumption.
- Preparation of earthworm bed. A concrete base is required to put the waste for vermicompost preparation. Loose soil will allow the worms to go into the soil and also while watering; all the dissolvable nutrients go into the soil along with water.
- A layer of 15-20 cm of chopped dried leaves/grasses should be kept as bedding material at the bottom of the bed.
- Beds of partially decomposed material of size 6x2x2 feet should be made. Each bed should contain 1.5-2.0 q of raw material and the number of beds can be increased as per raw material availability and requirement.
- Red earthworm (15-20 worms per kg of bed material) should be released in the upper layer of the bed.
- Water should be sprinkled with can immediately after the release of worms.
- Beds should be kept moist by sprinkling of water (daily) and by covering with gunny bags/polythene.
- Bed should be turned once after 30 days for maintaining aeration and for proper decomposition.
- Compost gets ready in 75-90 days.
- The weight of the finished product is about 75% of the raw materials used [9].

11.2. Pit method

Composting is done in the cemented pits, wooden boxes, plastic buckets, silpaulin bag, baskets, etc. The unit is covered with thatch grass or any other locally available materials.

Procedure:

- Pit size of dimensions 10′x 4′ x 2′ of either cement or vermibag is maintained. The length and width can be increased or decreased depending upon the availability of material but not the depth because the earthworms' activity is confined to 2 feet depth only.

  1st layer: bedding material of 1" thick with soft leaves

  2nd layer: 9" thick organic residue layer finely chaffed material

  3rd layer: dried cattle dung + water equal mixture of 2" layer.

  The layer is continued until the pile is filled up.
- On 25 days old unit, 795-820 worms are introduced into the pit (15-20 worms per kg of bed material) without disturbing the pit.
- Proper moisture and temperature is maintained by frequent watering, turnings and subsequent staking.
- The turnover of the compost is 75% (If the total material accommodated in the pit is 1000 kg; the out turn will be 750 kg).
- The filled materials are watered and turned at regular interval [9].

LESSON 12

12. MARKET-RELATED INFORMATION

Learning outcomes

- The trainee knows the leading vermicompost producers.
- The trainee knows the countries that have a say in worm compost production.
- The trainee knows the countries that use high amounts of vermicompost in agricultural production.
- The trainee knows the approximate size of the vermicompost market.
- The trainee knows the consumer groups for vermicompost.
- The trainee knows the expectations and demands of the market for vermicompost.

Instructions for the trainer

- The trainer shares theoretical knowledge through presentation.

Basic requirements: Projector, computer.

12. MARKET-RELATED INFORMATION

With the global population increase around the world, more agricultural production is needed to meet food and nutritional needs. For this reason, humankind has tried to find more efficient resources in line with the demand of the ever-increasing population, and as a result, agricultural systems in which fertilizers are used for various plants have been developed. Fertilizers are generally defined as chemical compounds applied to stimulate plant growth and are substances applied to the soil or leaves. Fertilizers are basically divided into two classes: natural (organic) and chemical (inorganic) fertilizers. Natural fertilizers are natural compounds produced by natural processes; Chemical fertilizers are substances produced as a result of chemical processes of natural sediments, that is, substances that have undergone chemical transformation.

In recent years, there has been intense interest in worm compost and the benefits this fertilizer provides. As the interest in question increases day by day, worm compost has started to become an industry. Vermicompost can be used in all areas of agriculture, in all kinds of agricultural activities using organic or chemical fertilizers, and in the nutrition of garden, greenhouse and living room plants. It also serves as a soil regulator due to its high aeration and high water retention capacity. While protecting plant roots from extreme temperatures, it reduces the development of weeds and the risk of erosion. Since the nutrients taken by the worm in liquid form after aerobic digestion are further broken down in the digestive system, they are rich in nutritional elements that are beneficial to the plant. It provides economic benefits because it supports sustainability in plant production. It is also intensively applied in the degradation and processing of solid organic waste, which has become an important environmental problem with rapid industrial development and population growth. This technique is used extensively around the world as it has both commercial and environmental value. Since fertilizer is one of the most important inputs of agriculture, the sector is directly affected by developments in the field of agriculture.

Vermicompost attracts the attention of many producers, institutions and organizations around the world interested in sustainable and organic agriculture because it is in the organic fertilizer group, is produced naturally and does not leave waste in the soil. In the report published by the International Fertilizer Association (IFA) on the medium-term course of the sector, it is stated that the supply and demand imbalance in Latin America and East Asia will lead to an import-dependent situation in the medium term, despite the decrease in fertilizer demand as a result of the new policies implemented by China. It is emphasized that it indicates growth. It is predicted that imports from some key consumer countries in Southeast Asia (India, Indonesia and

Malaysia) and Africa have the potential to increase. Vermicompost production has a very messy structure. Most vermicompost producers are located in India and Southeast Asia. India's share in the global vermicompost production value is 9.5%. The share of the New Zealand company MyNOKE, which is the leading manufacturer in the world, in the world market was 8.8% in 2015. With the expansion of the vermicompost market, the company's sales, which were 30 million dollars in 2014, reached 38 million dollars in 2018, with an increase of 24.89%.

The world's leading companies in worm castings production;

- MyNOKE; (New Zealand) produces 150,000 tons of vermicompost with 1.2 billion worms
- Nutri Soil; (Australia) produces liquid worm compost
- Davo's Worm Farms (Australia)
- Worm Power; (USA) It produces organic liquid worm compost. Their products are CDFA certified by the California Department of Food and Agriculture Organic Program
- Kahariam Farms (Philippines)
- Sri Gayathri Biotec (India)
- Dirt Dynasty (USA)
- AgriLife (India)
- Suman VermiCompost (India)

HS (The Harmonized Commodity Description and Coding Systems) code 31.01: “animal or vegetable fertilizers (whether or not mixed together or chemically treated); World imports of "fertilizers obtained from chemical treatment or mixing of fertilizers of plant or animal origin" amounted to $920 million in 2020. The USA, France, the Netherlands, Vietnam and Spain are at the top of the list in world imports. The shares of these countries in imports are 9.6%, 8.7%, 7%, 5.1% and 4.9%, respectively. World animal or herbal fertilizer exports amounted to 928 million dollars in 2020. The Netherlands, Belgium, Italy, Spain and France rank first in world exports. The shares of these countries in exports are 20.8%, 15.6%, 14.7%, 5.6% and 4.7%, respectively. Turkiye is the 19th largest exporter of animal or herbal fertilizers in the world, with exports of approximately 8 million dollars in 2020.

A key to the success of a vermicomposting operation is a marketing or distribution program for compost products. To develop long-term markets, the products must be of consistently high quality. Other essential marketing factors include planning, knowledge about end-users, following basic marketing principles, and overcoming possible regulatory barriers and product stigma. Compost characteristics desired by end-users vary with intended uses, but most compost users look for the following elements (in order of importance):

- Quality (moisture; odor; feel; particle size; stability; nutrient concentration; product consistency; and a lack of weed seeds, phytotoxic compounds, and other contaminants)
- Price (should be competitive with other composts, although high quality and performance can justify a higher price)
- Appearance (uniform texture, relatively dry, earthy color)
- Information (product's benefits, nutrient and pH analysis, and application rates and procedures)
- Reliable supply

How compost is sold depends on the amount, quality, appearance, and seasonal availability. Most compost is used in spring and early summer. Consider whether to sell compost in bulk, in bags, or both. Bagging expands the potential market because bags can be sold at retail outlets. Bagged compost may be sold at a higher price, which justifies higher transportation costs, and thus, can support a larger market area. The bulk market usually stays at the local level due to high transportation costs. The best markets for bulk sales are local nurseries, landscapers, and home gardeners. The following are potential end-users for compost:

- Growers (greenhouse, container, sod, field, agriculture, silviculture)
- Landscapers/turf managers (commercial properties, sports turf, residential lawns, cemeteries)
- Government agencies (parks, schools/universities, roadsides/highways, sports turf)
- Companies conducting land reclamation (landfills, sand/gravel pits, strip mines)
- Blenders/resellers (topsoil dealers/brokers, garden centers)
- Companies or agencies involved in environmental projects (wetlands, biofilters, erosion control, soil remediation, water filters)
- Farmers (fruit, vegetable, field crops, organic)
- Owners of golf courses and cemeteries
- Homebuilders and buyers (new home builders, renovators, organic gardeners, homeowners)

Rapidly expanding markets include homeowner use, custom topsoil blending, environmental applications, and agricultural uses. There are a number of ways to improve the marketing of your compost product. Hire staff who can talk about your products and their uses. Try selling to high-profile markets to get others interested in your products. Plant flower and vegetable gardens at your facility to show compost in action. Exhibit at industry trade shows and get involved with local trade associations. Promote a positive public reaction by conducting tours of your facility and offering hands-on activities for school children, such as planting things using compost. Lastly, contact local radio and television gardening shows about the possibility of interviews [90–92].

LESSON 13

13. STRENGTHENING COOPERATION WITH EDUCATIONAL INSTITUTIONS

The institutional structure of the agricultural sector is a complex socio-economic system that includes economic, organisational, legal, moral, and ethical elements. The development of society in the process of market transformation leads to a change in the role and importance of individual agricultural institutions. Throughout the world, there is an agricultural structure dominated by small family enterprises based on private property. Over time, the number of enterprises has also increased with the expansion of the cultivated lands. Farm activities carried out with traditional perspectives and teachings are the biggest obstacle to the sustainability of small agricultural enterprises. Climate change, decrease in irrigable land, decrease in water resources, inappropriate crop rotation and unconscious use of chemicals threaten sustainable agricultural activities. The fact that agricultural production is carried out consciously by people with a certain education, regardless of scale, whether small or large scale, will increase productivity in agricultural production and product losses caused by the practices of uninformed people will be prevented. It is important to establish cooperation between organisations carrying out education and training activities in the field of agricultural production and people/institutions carrying out farm activities.

High schools, vocational school, agricultural faculties, soil science departments, environmental engineering departments, associations and foundations that aim to disseminate good practices in the field of agricultural production can play a role in disseminating the correct technical information in the field of vermicompost production, which is an important approach in terms of sustainability in agricultural production. Short-term skills and competence-building courses at Continuing Education Centers , Adult Education Centers and Lifelong Learning Centers will promote the dissemination of good practices in agricultural production and vermicompost production and usage.

LESSON 14

14. DEVELOPING INVESTMENT PLANS FOR VERMICOMPOSTING

Learning outcomes

- The trainee knows the variables that define the scale for the vermicompost production facility.
- The trainee knows the technical equipment required for the vermicompost production facility.
- The trainee customizes the equipment required for vermicomposting depending on the variables available.

Instructions for the trainer

- The trainer shares theoretical knowledge through presentation.
- The trainer asks the trainees to list the infrastructure and equipment required to produce 2 tons of vermicompost.
- The trainer asks the trainees to list the infrastructure and equipment required to produce 360 tons/year of vermicompost.

Basic requirements: Projector, computer.

14. DEVELOPING INVESTMENT PLANS FOR VERMICOMPOSTING

Many variables need to be taken into consideration when determining the scale of investment for vermicompost production. These;

- Whether it is for commercial or personal farm needs,
- Amount of accessible input organic waste,
- Financial resources owned,
- Environmental and climate conditions,
- Logistics and technical facilities,
- Traditional approach or technology usage preferences,
- Continuity of demand for Vermicomposting.

14.1. Small-Scale Investment

Small farms use pits and bins of various sizes (or IBC tanks) to meet their worm compost needs. These systems, which do not require advanced mechanization, make sustainability possible for small agricultural enterprises with low investment costs. In this section, the requirements for annual 5 tons of vermicomposting production with IBC tanks are reported (Table 8).

14.2. Large Scale Investment

This section will provide an overview of the investment requirements and costs for a large-scale vermicomposting plant (Table 9). People who are considering investing in this field can increase or decrease the technical equipment needed depending on the production scale, mechanization preference, amount of solid waste, and human resources. Windrow, raised bed and continuous flow (flow through) systems are commonly used techniques in large-scale vermicompost production.The presented facility will have a production capacity of 720 tons/year of solid vermicomposting (Table 10). Creating a process with a continuous flow system in the facility was simulated. The most important advantages of this system are that it enables the fertilizer to be supplied continuously at the desired time and also saves time by performing the sifting process. The return of investment is 2.1 years. The internal return rate of the investment is 41%.

Table 8. Investment budget for small-scale vermicomposting facility

Equipment&Material	Quantity	Unit Price	Total Price (Euro)
IBC Tank	10	40	400
Transport IBC	1	200	200
Gravel (150 kg)	1	150	150
Sand (100 kg)	1	50	50
Wood for lids	10	25	250
Palets	20	3	60
PVC Pipes (3 meter)	10	5	50
Manure (kg) (farm waste)	4.000	0	0
Irrgigation pipes (3 meter)	2	5	10
Earhworms (*E. fetida*) (kg)	10	90	900
Sprinklers	50	0,4	20
Haystacks	4	25	100
Thermometer	1	84	84
Hygometer	1	106	106
		Total Budget	2.380

Table 9. Machinery and equipment required for worm compost production in continuous flow system

Material/Equipment name	Quantity (Piece/Kg)	Total Price (Euro)
Earthworm	500.000	5.000
Continuous Flow System	5	54.000
Heat Treatment Furnace	1	8.000
Fertilizer Mill / Crusher	1	4.800
Vibrating Fertilizer Screening Machine	1	1.900
Fertilizer Packaging Machine	1	9.100
Pellet Machine	1	6.900
Forklift	1	31.650
Office Furnishing	1	3.200
Total	**-**	**124.550**

Table 10. Investment cost

No	Investment Table	Price (Euro)	Detail
1	Preliminary Work Expenses	4.405	It is envisaged as 3% of the total construction cost.
2	Engineering and Project Expenses	3.126	It is envisaged as 2% of the total construction cost.
3	Land and Landscaping	2.936	It is the cost required for the excavation of the area where the facility will be established and the transportation of the excavation by trucks. It was determined as 3% of the construction cost.
4	Construction Work Expenses	146.840	The total closed area is 800 m^2.
5	Main Facility Machinery and Equipment Expenses	124.550	It is the cost of machinery and equipment and furnishing, the details of which are given in Table.
6	Vehicles, General Expenses	20.000	The facility will need 1 forklift to transport and store the products produced by the business.
7	Working Capital Need	25.000	Investment period working capital requirement
	Investment Amount	**326.857**	

LESSON 15

15. UNDERSTANDING POLICIES AND INITIATIVES SUPPORTING VERMICOMPOSTING

Learning outcomes

- The trainee knows the legal regulations regarding solid waste management in Turkey, EU and America.
- The trainee knows the limits of heavy metal in the soil Turkey, EU and America.
- The trainee knows the quality parameters followed in vermicompost.
- The trainee knows the physical, chemical and biological qualities that composts must have in Turkey, EU and America.
- The trainee knows the financial and technical support provided to vermicompost production and organic agriculture.

Instructions for the trainer

- The trainer shares theoretical knowledge through presentation.

Basic requirements: Projector, computer.

15. UNDERSTANDING POLICIES AND INITIATIVES SUPPORTING VERMICOMPOSTING

15.1. Türkiye

15.1.1. Policies

Although there is no specific legal regulation on vermicomposting in Turkey, the first legal restriction on the composting of solid wastes was determined in the Regulation on Solid Waste Control published in the Official Gazette dated 14.03.1991 and numbered 20814. After that, the Regulation on Soil Pollution Control was published in the Official Gazette dated 10.12.2001 and numbered 24609 and then the Regulation on Amendment of the Regulation on Solid Waste Control was published in the Official Gazette dated 25.04.2002 and numbered 24736 and some provisions in this regulation were subjected to the provisions in the Regulation on Soil Pollution Control.

Article 36 of the by-Law on Control of Solid Wastes, which determines the quality criteria of compost intended to be used in agriculture, and Article 37, which determines the heavy metal content and limit values of compost, have been combined in the by-Law on Soil Pollution Control and regulated under Article 10.

While Article 37 of the by Law on Solid Waste Control stipulates that heavy metal analyses in soil should be carried out on lands larger than one hectare, Article 10 of the by-Law on Soil Pollution Control does not stipulate such a condition for heavy metal analyses, and stipulates that such analyses should be carried out on lands of any size.

While the limitation on the heavy metal load of the soil in the by-Law on Solid Waste Control is valid in case of repeated application of the compost to the land, this statement is corrected in the by-Law on Soil Pollution Control as the application of the compost to the land every year in a 10-year period and the application period is tied to a certain period.

The heavy metal limit values in the by-Law on Solid Waste Control were reorganised in the by-Law on Soil Pollution Control. While the limit values of heavy metals in soil were stated as a single value in the by-Law on Solid Waste Control, these values are regulated according to two different conditions according to the pH of the soil being greater than 6 and less than 6 in the by-Law on Soil Pollution Control published later. The heavy metal limit values in the Regulation on Soil Pollution Control and the Regulation on Solid Waste Control are given below in comparison (Table 11).

Table 11. Comparison of heavy metal limit values in soil

Type	by-Law on Solid Waste Control		by-Law on Soil Pollution Control
	PH<6 mg/kg	PH>6 mg/kg	mg/kg
Bullet	50	300	100
Cadmium	1	3	3
Chromium	100	100	100
Copper	50	140	100
Nickel	30	75	50
Zinc	150	300	300
Mercury	1	1,5	2

There is not yet a specifically developed standard for compost quality in our country. In by-Law on Solid Waste Control and by-Law on Soil Pollution Control, it is insufficient for high quality compost and there are some gaps. The statement stated in Article 10 of by-Law on Soil Pollution Control that the compost should be hygienically perfect and not threaten the health of humans and all living things is insufficient. The reason for this is that there is no criterion for whether the compost is hygienically perfect and the standard does not clearly state the parameters by which perfection will be determined. Especially if the processed compost will be used for various purposes, limit values of parameters such as pH, mineral content and particle distribution of the final compost should be determined, compost quality classes suitable for various purposes should be developed and expressed according to the compost quality class in the standard.

Organic fertilizers and soil enrichers of animal origin must be produced within the framework of the criteria specified in the "Regulation on Animal By-Products Not Intended for Human Consumption" published in the Official Gazette dated 24.12.2011 and numbered 28152 and the Communiqués and Instructions based on this Regulation (Official Gazette, 2018). The criteria of the fertilizer are evaluated within the scope of the 'Regulation on Organic, Mineral and Microbial Source Fertilizers Used in Agriculture' published by the Ministry of Food, Agriculture and Livestock in the Official Gazette dated 23 February 2018 and numbered 30341. In accordance with this regulation, enterprises must obtain a license and registration certificate. Companies that do not have these documents cannot supply vermicompost to the market. Companies that do not have these documents must obtain the necessary documents within ten months. Penal action is initiated for businesses that do not complete their documents during the specified transition period. One of the developments regarding vermicompost production in our country is the Turkish Vermicompost Producers Association (TOSGEB), a professional organization established by certified and non-certified producers.

Market placement conditions and product specifications of worm castings are regulated by-law 30341 and 28152. The qualifications that solid and liquid vermicompost must have in order to be marketed are given below (Table 12).

Table 12. Specifications for solid and liquid vermicompost

	Solid vermicompost	**Liquid vermicompost**
Information about the method of obtaining the organic product and its main components	The final product obtained from ground-independent worm beds as a result of passing wastes of plant and/or animal origin through the digestive system of the worm and processed in accordance with the relevant legislation.	The product in solution or suspension form obtained as a result of physical and/or chemical and/or biological processing of solid vermicompost.
The product's raw material content, quantity, plant nutrient content and other criteria	Organic matter at least 20% Total nitrogen at least 0.5% Organic nitrogen $N+P_2O_5+K_2O$ up to 7% Maximum humidity 35% C/N: 8-22	Organic matter at least 5% Organic nitrogen
Other information such as EC, pH etc. that should be declared on the product label	pH EC (dS/m)	pH EC (dS/m)
Mandatory content to be declared on the label	Organic matter Total nitrogen Organic Nitrogen Maximum humidity C/N Optional: Water-soluble potassium oxide (K_2O) Total phosphorus pentoxide (P_2O_5) Total humic acid+fulvic acid can be declared.	Organic matter Organic nitrogen Shelf life cannot exceed one year Optional: Total nitrogen Water-soluble potassium oxide (K_2O) Total phosphorus pentoxide (P_2O_5) Total humic acid+fulvic acid can be declared.

15.1.2. Initiatives Supporting

In Turkey, some financial support is provided by the state depending on the socio-economic development level of the region where vermicompost production will take place. These supports are investment incentive supports provided through the Ministry of Treasury and Finance and entrepreneurship supports provided by the Small and Medium Scale Industry Development and Support Administration (KOSGEB).

Basic supports provided to investors through the investment incentive support program; Tax exemption up to 50% of the total investment, exemption of all expenditures made for investment from value added tax and customs duty, free land allocation for investment, payment of employees' insurance premiums by the state for up to 10 years, 7% discount on interest rates on bank loans to be used for investment. (2% for foreign currency loans).

The fully non-refundable supports provided by KOSGEB for organic fertilizer, which is evaluated within the scope of Medium-High Technology Investments, are as follows; company establishment support (10.000 TL), consultancy-mentoring support (10.000 TL), machinery-equipment purchasing support (200.000 TL), product certification support (5.000 TL) and performance support (20.000 TL).

15.2. Composting Regulations in The United States and Europe

According to organic waste activities, Europe is examined in four classes. It is found in Austria, Belgium, Germany, Switzerland, Luxembourg, Italy, Spain (Catalonia), Sweden and the Netherlands in the first class. These countries have spread their policies throughout the country and have established their policies. These countries recover 80% of their organic waste collected separately at source by composting. Refutation is used sparingly. Denmark, England and Norway are in the second grade. These countries have established the quality and organization policy required for separate collection and composting. Finland and France are in the third grade. These countries have defined their composting strategies and are at the starting point of implementation. In the fourth grade, countries such as Spain, Greece, Ireland and Portugal are collected separately and have not done any work on composting management at the source of organic waste. In these countries, waste is mixed collected and composted [53].

Quality assurance of the final product is important in composting. Final product quality, composting processing and composting techniques should be carefully considered when planning composting. In countries with an established compost system, such as Austria, Germany, Denmark, the Netherlands and Belgium, the role of quality assurance is great. A quality system has been established in these countries. In many countries such as Sweden, Norway, Italy and France, this system is under design. The quality assurance organizations are Compost Quality Assurance Organization (CQAO) in Germany, KGVO in Austria, VLACO in Belgium and VVAV in the Netherlands, respectively. In Europe, the quality assurance system consists of raw materials, input control, quantity of harmful substances, quality criterion of valuable substances in compost, composting production, external control (of product and/or production), product quality label, plant or product certification, declaration of compost properties, operator training and ability, operation and maintenance of facilities, and certificates. The quality assurance status of compost quality in Europe and the quality assurance status of composting and rotting plants in Europe are given below, respectively [53].

520 large compost and digestion plants in Austria, Belgium (Flanders), Germany, Luxembourg, the Netherlands and Sweden are controlled by a quality monitoring system. In Germany, the quality of the final compost is determined by the RAL mark. Two different attitudes prevail in the Netherlands and Belgium. Here final product control is combined with production control. In Belgium, the application period for a quality mark for a new compost facility is two years. In the first year, production is constantly monitored. In the second year of the application, only the compost produced is checked.

It can be seen that regulations regarding composting in Europe focus especially on the heavy metal content of compost. Especially in Austria, compost quality classes are determined according to heavy metal content. In Germany, compost classes are determined according to the properties or use of the compost. In Belgium (Flanders); Compost quality is determined by the raw material used. Mainly the quality of the final compost; It depends on the raw material used, heavy metal content and intended use. In America, special limits apply for sewage sludge compost. These limits are quite flexible (Table 14). Heavy metal limits in American and European countries are shown below [53].

In European countries, compost limits also apply to sewage sludge. Heavy metal limits of compost are different in each country. In America, the limits are quite high, whereas in Europe, the limits are quite low and it is very difficult to meet them. While the limits in American standards are determined according to health risk, the limits in European standards are determined close to the natural limits of these heavy metals in the soil and are not flexible. Thus, compost prevents soil pollution and is safer for public health. The required temperatures during the biological process during compost production in Europe and the anticipated holding times to ensure hygienic conditions at this temperature are shown in Table 15. In addition, since the usage areas of compost are different, the limits that compost must meet are different [53].

Table 13. Compost Organizations in Europe and America

Quality Labeled Organizations			Without-Quality Labeled Organizations		
Country	**Abbrv.**	**Organisation name**	**Country**	**Abbrv.**	**Organisation name**
Austria	KGVÖ	Austrian Compost Quality Association	Austria	ARGE	Compost and Biogas
Belgium	VLACO	Flemish Compost Organization	Czech Republic	CZ	Biom
Germany	BGK	Bundesgütegemeinschaft Compost	Ireland	Crè	Irish Compost Association
Sweden	RVF	Swedish Waste Management Association	Italy	CIC	Italian Compost Association
Holland	VVAV	Dutch Waste Processing Association	Japan	JORA	Japanese Organic Waste Recovery Association
England	CA	Compost Union	Switzerland	VKS	Verband Kompostwerke Schwez
New-Zelland	NGIA	Nursery and Garden Industry Association	Europe	ECN	European Compost Network
			Canada	CCC	Compost Council of Canada
			California		California Compost Quality Council
			America		United States Compost Council
			Türkiye		Vermicomposting Producers Association
			Türkiye		Vermiculture Association

Table 14. Heavy metal limits in European countries and America, mg/kg

Countries	Quality Standard	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Austria	Biowaste Regulation Class A	1	70	150	0.7	60	120	500
Belgium (FL)	Ministry of Agriculture	1.5	70	90	1	20	120	300
Denmark	Ministry of Agriculture	0.4	-	1000	0.8	30	120	4000
Germany	Biowaste Regulation Type II	1.5	100	100	1	50	150	400
Ireland	Draft	1.5	100	100	1	50	150	350
Luxembourg	Ministry of Environment	1.5	100	100	1	50	150	400
Holland	Second Class Compost	1	50	60	0.3	20	100	200
Spain	A Class	2	100	100	1	60	150	400
Sweden	Quality Assurance Organization	1	100	100	1	50	100	300
England	TCA Quality Label	1.5	100	200	1	50	150	400
Türkiye	By-law 30341	3	350	450	5	120	150	1100
America	ABD EPA 503	39	-	1500	17	420	300	2800

Table 15. Holding times at the required temperature to hygiene compost to be used during biological process in some European countries and America

Countries	Hygiene Temperature, °C	Holding Time, Day
Belgium	60	4
Denmark	55	14
Italy	55	3
Holland	55	4
Austria	65	6
Cuba	55	3
Korea	55	3
England	55	3
Spain	55	3
America	55	3

The standard for labeling compost was prepared in the European Union on December 31, 1994. In this context, standards have been developed for soil improvers. On the label of the compost produced according to this standard, the manufacturer, the person, the properties of the compost, storage conditions, production code, date, intended use, instructions for use and details about public health must be stated. In addition, compost should not cause any odor after application, in terms of human health; It should not contain glass, wire, metal and hard plastic. The limits in the standard are shown in Table 16.

In Austria, the Ö-NORM S 2200 standard was developed for compost quality. This standard was developed by research institutes and universities in Austria, Germany, the Netherlands and Switzerland. Experts have not determined a limit value for organic substances in compost and accept that these substances have a self-limiting feature because they stop the compost process. In Austria, there is a procedure that must be implemented to maintain the quality of compost, and according to this procedure, the quality of compost is checked every two months by government organizations or institutions authorized by the state. The use of compost as fertilizer is limited to 7 tons/ha/year, and as a soil improver to 10 tons/ha/year by Ö-NORM S. Austria's Ö-NORM standard is shown in Table 17. In Austria, all waste is collected by municipalities. Centers are established to collect organic waste, and organic waste is accumulated in these centers. These centers are close to living centers. Transfer stations have also been established for compost facilities with a distance of more than 30 km. Waste is first collected at these transfer stations, and from there it is transported to solid waste compost facilities [53].

Table 16. Limit values of EU standard compost ingredients

Parameters	**Limits of EU Standard**
Dry matter (DM)	>%25
Nitrogen	8 g/m^2
K_2O	12 g/m^2
Salmonella	<25 g
E.coli	<1000 MPN(most probable number)
	Heavy metal, mg/kg
Zn	300
Cu	75
Ni	50
Cd	1,5
Pb	140
Hg	1
Cr	140
Mo	2
Se	1,5
As	7
Fl	200

Table 17. Austria Ö-NORM 2200 standard compost limits

Organic contents(DM%)	
Parameters	Ö-NORM S 2200 Limits
Volatile solids	> 20
Total carbon	> 12
Macronutrients	
Total nitrogen (DM%)	< 0,2
Total nitrate ($N\text{-}NO_3$) (DM%)	< 0,1
Total ammonia ($N\text{-}NH_4$) (DM%)	Determined by the manufacturer
Phosphorus (total P_2O_5)	Determined by the manufacturer
Phosphorus (possible)	Determined by the manufacturer
Calcium (total CaO)	Determined by the manufacturer
Potassium (total K_2O)(DM%)	Determined by the manufacturer
Potassium (possible)(DM%)	Determined by the manufacturer
Manganese (total MgO)(DM%)	Determined by the manufacturer
Boron (mg/kg DM)	< 10
Carbon/Nitrogen (C:N)	Determined by the manufacturer
Heavy metals, mg/kg	
Chrome	70
Nickel	42
Copper	70
Zinc	210
Cadmium	0,7
Mercury	0,7
Lead	70
Lindane	0,1
Phsical properties	
Moisture content (%raw weight)	25-50
Moisture capacity (DM%)	> 100
Raw density (kg 1 raw weight)	< 0,85
pH (H_2O) (-)	Determined by the manufacturer
EC (pS/cm)	< 2,0
Particle size > 25 mm (DM%)	< 3
Total physical contamination (DM%)	< 0,5
Will include plastics > 200 (DM%)	0,2
Will include plastics > 20 mm (DM%)	0
Plant tolerance margin, %15 compost	
Plant biomass (% reference mass)	100
Germination delay (days)	0
Germination number (%)	100
Plant tolerance, %30 compost	
Plant biomass (% reference mass)	100
Germination delay (days)	0
Germination number (%)	100
Plant tolerance, %30 compost	
Plant biomass (% reference mass)	90
Germination delay (days)	1
Germination number (%)	100

15.3. Greece

In the sector of sustainable agriculture and waste management, vermicomposting appears as a innovative practice, combining environmental management with agricultural innovation. INNOPOLIS's contribution to the "Powerworms:Vermicomposting" project underscores the significance of integrating vermicomposting within the European context, particularly through the Greek national legislation and policy frameworks. This initiative seeks to navigate the complex legal landscape, identifying the synergies and gaps in existing regulations that impact the adoption and effective implementation of vermicomposting practices.

Central to INNOPOLIS's analysis is the exploration of the Greek legal framework, which encompasses a broad spectrum of regulations from waste management to environmental protection, and agricultural practices. Key legislative pieces, such as Law 4685/2020, highlight Greece's commitment to harmonizing its environmental policies with EU directives and the Green Deal, fostering a conducive environment for renewable energy projects and sustainable waste management practices, including vermicomposting. This legal framework provides a foundation for examining the categorization of vermicompost, the regulatory status of worms in the composting process, and the relationship between different regulatory domains such as waste, environmental, and agricultural regulations.

The challenges of incorporating vermicomposting into Greece's existing legal and policy frameworks are multifaceted. They underscore the need for legislative clarity and adaptability to embrace innovative waste management solutions. INNOPOLIS's contribution is geared towards highlighting these challenges while proposing pathways for integrating vermicomposting more seamlessly into national strategies. This involves a detailed analysis of the potential legal adjustments required to support vermicomposting, addressing issues such as the classification of vermicompost under current waste and fertilizer regulations, the legal status of bio-waste management practices, and the promotion of circular economy principles within the agricultural sector.

Moreover, INNOPOLIS's engagement with Greek authorities, including the Ministry of Environment and Energy and the Ministry of Rural Development and Food, is instrumental in fostering a dialogue on sustainable waste management practices. This collaborative approach not only enhances the knowledge base around sustainable agricultural practices but also paves the way for legislative reforms that align with environmental sustainability goals and the broader objectives of the "Powerworms: Vermicomposting" project.

Through this initiative, INNOPOLIS seeks to contribute to the development of a more resilient and sustainable agricultural sector in Europe, supported by legal and policy framework for vermicomposting.

Greek Law 4951/2022, although not directly addressing vermicomposting, plays a significant role in the broader context of renewable energy and environmental sustainability in Greece, which can indirectly influence sustainable practices like vermicomposting. This law focuses on further simplifying and accelerating the permit-granting process for renewable energy projects, building on the foundation set by previous legislation (such as Law 4685/2020). By enhancing the legal and regulatory framework for renewable energy initiatives, Law 4951/2022 aims to facilitate Greece's transition to a more sustainable and environmentally friendly energy mix. The streamlined processes and supportive environment for renewable energy development underscore the country's commitment to sustainability and climate change mitigation, principles that are also central to the practice of vermicomposting.

The relevance of Law 4951/2022 to vermicomposting, while indirect, lies in its contribution to creating a more favorable regulatory landscape for sustainable practices. Vermicomposting, as a method of recycling organic waste into nutrient-rich compost, aligns with the objectives of environmental sustainability and reduction of carbon footprint that Law 4951/2022 seeks to promote through the support of renewable energy projects. Although the law specifically targets the energy sector, its broader implications for sustainability can encourage the adoption and integration of circular economy practices, including vermicomposting, within Greece's environmental policy framework. This legislation highlights the interconnectedness of renewable energy development, waste management, and agricultural practices in achieving overall environmental sustainability goals.

Greek Law 4685/2020 - Environmental Protection and Enhancement: This comprehensive environmental law, approved in May 2020, significantly reforms Greece's legal framework towards harmonization with EU law and the Green Deal. It covers a wide range of environmental issues, aiming to simplify the environmental licensing process, maximize renewable energy projects, and update the Forest Charter. Key provisions include extending the Environmental Conditions Approval Decision (AEPO) duration, simplifying the procedure for AEPO renewal/modification, and introducing an Electronic Environment Register for streamlined processing.

Law 4685/2020, a comprehensive piece of legislation on Environmental Protection and Enhancement in Greece, plays a significant role in shaping the legal landscape for sustainable practices like vermicomposting. Specifically, it simplifies the environmental licensing processes and introduces measures aimed at promoting renewable energy sources, which indirectly supports the infrastructure necessary for vermicomposting projects.

Through these regulations, vermicomposting initiatives, which transform organic waste into valuable compost using earthworms, can gain momentum by aligning with the law's objectives of sustainable development and environmental protection.

Moreover, the emphasis Law 4685/2020 places on the circular economy and the sustainable management of bio-waste presents opportunities for vermicomposting to be integrated into national waste management strategies. The law's provisions for waste reduction, recycling, and the valorization of organic waste echo the principles of vermicomposting, which not only diverts waste from landfills but also transforms it into a resource for agricultural use. By fostering an environment that values the recycling of organic waste and the reduction of environmental footprints, this law underpins the relevance and importance of vermicomposting within Greece's framework for environmental stewardship and sustainable agriculture. This alignment with national and EU environmental goals underscores the potential for vermicomposting to contribute significantly to Greece's sustainable development objectives, leveraging legal support to enhance its implementation and impact.

Legal Framework in Environmental Governance and Decentralization: Greece has a decentralized system of environmental governance, with significant efforts made to increase transparency, accountability, and reduce the regulatory burden on enterprises. However, challenges remain in effectively implementing environmental law and utilizing good regulatory practices, particularly in compliance assurance.

Greek Law 4414/2016 establishes a comprehensive framework for the promotion of renewable energy sources (RES) in alignment with the country's commitments to environmental sustainability and the reduction of greenhouse gas emissions. This legislation is pivotal in setting the support schemes for renewable energy projects, detailing the financial incentives, and outlining the operational framework for the production, transmission, and distribution of energy from renewable sources. It is designed to accelerate the adoption of renewable energy within Greece's energy mix, contributing to the national and European targets for sustainable development and climate change mitigation. The law's emphasis on clean energy and its mechanisms for supporting RES projects underscore the government's dedication to transitioning towards a low-carbon economy.

The relevance of Law 4414/2016 to vermicomposting is found in its broader objectives of sustainability and environmental protection. While the law directly addresses the renewable energy sector, its implications for sustainable practices, like vermicomposting, are significant. Vermicomposting, as an eco-friendly method of waste management, aligns with the principles of sustainability and resource efficiency promoted by the law. By encouraging the reduction of waste and the utilization of organic materials as resources, vermicomposting contributes to the environmental goals that Law 4414/2016 seeks to achieve through the promotion of renewable energy sources. This interconnection highlights the importance of integrating various sustainable practices, including renewable energy development and organic waste recycling, in achieving comprehensive environmental sustainability objectives.

Greek Law 3851/2010 - Accelerating the Development of Renewable Energy Sources to Confront Climate Change: Although primarily focused on renewable energy, this law contributes to a broader environmental governance framework that supports sustainability initiatives, including waste management. By promoting the use of renewable energy and setting ambitious targets for its integration into the national energy mix, the law indirectly supports the energy efficiency and sustainability of operations like vermicomposting facilities. It underlines the Greek government's commitment to sustainable development and environmental protection, which are essential for practices that contribute to a circular economy and sustainable agriculture.

Greek Law 3851/2010, aimed at accelerating the development of renewable energy sources to confront climate change, indirectly supports sustainable practices like vermicomposting through its emphasis on environmental sustainability and energy efficiency. By fostering a legal and regulatory environment that encourages the adoption of renewable energy and the sustainable management of resources, this law enhances the feasibility and attractiveness of vermicomposting projects. These projects, in turn, contribute to the law's objectives by promoting the recycling of organic waste into valuable compost, thereby reducing greenhouse gas emissions associated with waste decomposition in landfills. Vermicomposting aligns with the spirit of Law 3851/2010 by integrating sustainable waste management with the broader goals of energy efficiency and environmental protection. This synergy underscores the relevance of the law to vermicomposting initiatives, as both seek to mitigate climate change impacts through innovative and sustainable practices.

Renewable Energy Legislation and Incentives: Greece has made substantial advancements in renewable energy (RES), holding a global rank for its use in gross final energy consumption. Laws such as 4685/2020, 4951/2022, and 4414/2016 regulate the development and operation of RES projects, aiming to simplify and accelerate the permit-granting process. These laws support the transition to a low-carbon economy, in line with EU guidelines and national goals for climate neutrality and reducing dependency on fossil fuels. Incentive programs for energy upgrading and self-production, such as the installation of rooftop PV systems and net-metering, are promoted to increase RES penetration and support citizens becoming "prosumers".

This legislative and regulatory framework forms the basis of Greece's national efforts to promote sustainable environmental practices, including vermicomposting, by fostering a supportive context for renewable energy and environmental protection. These initiatives are integral to achieving broader sustainability goals, enhancing the legal and operational environment for vermicomposting projects by emphasizing renewable energy use, environmental conservation, and participatory governance.

15.4. Holland

The legal framework generally highlights issues such as the categorisation of vermicompost, the status of worms used in the composting process, and the complex interplay between different legal frameworks like waste, environmental, and agricultural regulations. Specific regulations include the Waste and Environment Legislation, Regulation on Animal By-products, Feed Regulation, Fertilizers Law, Animal Law, and Environmental Law. The challenges in integrating vermicomposting into existing legal frameworks emphasise the need for clarity and possible adjustments in legislation to support this sustainable waste management practice. The Ministry of Agriculture, Nature and Fisheries, including the Agro Desk and the Dutch Food and Consumer Product Safety Authority, for their knowledge of the legal frameworks in this case.

15.4.1. Dutch national laws and regulations on vermicomposting

Waste and Environmental Legislation (Wet Milieubeheer): In the Netherlands, organic waste processing, including vermicomposting, must comply with strict waste management laws. These laws aim to reduce landfill use and encourage recycling. They impact the categorisation and handling of organic waste for vermicomposting and dictate how organic waste should be collected, treated, and processed.

Regulation on Animal By-Products (Verordening dierlijke bijproducten) (1069/2009 and 142/2011): This set of regulations is particularly important in scenarios where vermicomposting uses or produces animal by-products. It details how these materials should be handled, processed, and utilised, ensuring they meet health and safety standards.

Feed Regulation (Regeling diervoeders): Governs the use of organic material as animal feed. In vermicomposting, this regulation affects what types of organic waste can be fed to the worms.

Fertilisers Act (Meststoffenwet): This law sets the standards for fertilisers in the Netherlands, including those produced through vermicomposting. It ensures that the compost is safe for use in agriculture by regulating its nutrient content, contaminants, and other properties.

Animal Health and Welfare Act (De Wet Dieren): This law considers the status and welfare of the animals. It refers to regulations regarding breeding, treatment, and use in composting processes.

Composting commercial organic waste is subject to a permit requirement under Article 3.185 Bal, because the activity is not excluded from the list in paragraph 3. Under the Environmental Act, collected or delivered household waste is regarded as industrial waste. Given this, the permit requirement applies under Article 3.185 Bal. Where applicable, a permit requirement may apply for the composting of animal fertilisers.

From a legal point of view, the waste stream is always an 'animal by-product'. However, feeding animal by-products to production animals or transporting organic waste to locations with production animals is not permitted.

15.4.2. Policies and initiatives promoting vermicomposting

In the Netherlands, a framework of policies and initiatives promotes vermicomposting as part of the broader strategy to foster a sustainable and environmentally conscious society. These policies and initiatives are anchored in several key areas. Firstly, the Circular Economy Action Plan positions the Netherlands as a pioneer in advocating for a circular economy where waste is minimised and resources are continuously reused. Within this framework, vermiculture, the process of using earthworms to convert organic waste into nutrient-rich compost, plays a significant role in recycling organic waste. This approach reduces waste that would otherwise end up in landfills and provides a sustainable source of fertiliser.

Furthermore, the Dutch government offers Subsidies and Financial Support to encourage sustainable waste management practices, including vermicomposting. These financial incentives are designed to stimulate the adoption of eco-friendly practices by businesses and individuals, making vermicomposting a more viable and attractive option for waste management.

Another critical aspect is Public Awareness and Education. The Dutch authorities and non-governmental organisations raise public awareness about the benefits of composting. These campaigns aim to educate the public on how composting can contribute to environmental sustainability and encourage participation in local community composting initiatives. Lastly, significant Research and Development efforts are ongoing to optimise vermicomposting processes and enhance the compost quality produced. This includes investing in scientific research to improve the efficiency of vermicomposting, exploring innovative methods, and developing better techniques to produce high-quality compost.

15.5. North Macedonia

The agricultural policy in North Macedonia, outlined in the National Agriculture and Rural Development Strategy (NARDS), is primarily governed by the Law on Agriculture and Rural Development (LARD). The Ministry of Agriculture, Forestry and Water Economy (MAFWE) oversees policy planning and regulation related to organic products, while the Agency for Financial Support in Agriculture and Rural Development (AFSARD) handles policy implementation. The State Agricultural Inspectorate and the Food and Veterinary Agency conduct general supervision of organic agriculture. The National Extension Agency (NEA) is responsible for disseminating information to agricultural producers.

For the period of the National Agriculture and Rural Development Strategy 2014−2020, organic production is encouraged to gain traction in the domestic market. Support measures focus on ensuring market-sustainable organic production and promoting the agri-environmental approach. These measures include direct payments per arable land for various organic crops, as well as support for existing orchards, vineyards, cattle, sheep, and goats. Additionally, special payments are allocated for expert control, certification, and analysis of organic production.

Funds allocated for organic production beneficiaries in the 2014−2020 programming period totaled 7.5 million EUR, with an increasing trend year by year. The proportion of support for organic production within the total agricultural policy budgetary transfers ranged from 0.4% in 2014 to 1.1% in 2019. The recently adopted National Agriculture and Rural Development Strategy 2021−2027 continues to provide support for organic agricultural production through measures such as green cover, crop rotation, and organic farming. Control of organic producers, processors, and traders is conducted by registered inspection bodies, with two accredited certification bodies currently authorized by the MAFWE.

15.5.1. Waste Management Legislation: The Law on Waste Management plays a crucial role in establishing the legal framework for the management of different types of waste, including organic waste suitable for composting. It sets out regulations and guidelines for the proper handling, treatment, and disposal of waste materials to promote sustainable waste management practices in North Macedonia.

15.5.1.1. Environmental Protection Act: The Environmental Protection Act establishes regulations for environmental protection, including guidelines for sustainable waste management practices like composting. This legislation provides a framework for effective waste management and encourages composting and vermicomposting as eco-friendly approaches to divert organic waste from landfills.

15.5.1.2. National Organic Farming Policy: The National Organic Farming Policy encourages the adoption of organic farming practices, which may include composting, to enhance soil fertility and reduce reliance on chemical fertilizers. This policy actively promotes the integration of composting and vermicomposting into organic farming systems, providing guidelines, support, and incentives for farmers to utilize these practices, recognizing their significant contributions to soil health, fertility, and sustainable agriculture.

15.5.1.3. Strategy for Sustainable Development: This strategy may include elements related to sustainable waste management, environmental protection, and incentives for eco-friendly agricultural practices like composting. The Strategy prioritizes organic farming and vermicomposting as key strategies for achieving long-term agricultural and environmental sustainability. It sets targets for increasing organic farming practices, highlights vermicomposting as a crucial soil enrichment technique, and advocates for policy measures to incentivize and support sustainable agricultural methods.

15.5.1.4. National Biodiversity Strategy: This strategy may promote sustainable waste management approaches like composting as part of broader biodiversity conservation efforts. The National Biodiversity Strategy of North Macedonia actively promotes composting as a critical element in sustainable waste management practices, aligning it with broader efforts to conserve biodiversity. By diverting organic waste through composting, the strategy aims to reduce environmental impacts, safeguard ecosystems, and support diverse plant communities, while also advocating for policy measures to incentivize composting initiatives.

Understanding the legal and policy framework surrounding vermicomposting in North Macedonia is crucial for individuals and businesses looking to engage in sustainable waste management practices. By being aware of existing laws, policies, and support programs, participants can navigate the regulatory landscape effectively.

15.5.2. Financial Support in Agriculture: This law includes provisions for financial support and incentives in agriculture, which could extend to organic farming practices and composting. The Law on Agency for Financial Support in Agriculture and Rural Development of North Macedonia includes provisions to incentivize the adoption of organic farming and vermicomposting practices. Eligible farmers may access grants for setup costs, subsidized loans for infrastructure, subsidies for organic certification, and funding for training initiatives, all aimed at promoting sustainable agriculture.

15.6. Spain

There is no national approach plan to composting, much less vermicomposting. In Spain there are Autonomous Communities (Political and Geographic Subdivisions) that can independently promote and legislate to a greater or lesser extent, composting in all its formats. Most of the experiences or initiatives launched at the regional level are developed in Catalonia, Galicia, Navarra, Madrid, although there are often other projects distributed throughout Spain.

There is no national information on community composting or vermicomposting programs. Special mention would be some consortia of multidisciplinary Organizations: Public and private Institutions, Associations, Training Centers such as: https://www.recompostaje.com/ and https://www.compostaenred.org with a continued activity of exchange of experiences, knowledge, training meetings, published or selected quality material.

The experiences that are in operation are local and often require the social involvement of the group covered by the program. The community composting experience almost always starts with institutional home composting campaigns. Finally, it can be stated that the culture of community composting is quite small, even less so when talking about vermicomposting.

Legal Framework: Compost and vermicompost are included in the royal decrees 506/2013 and 865/2010 regarding fertilizers and substrates, where they are described and defined, including the characteristics they must comply with. Also regarding inputs in organic farming it is applicable the Norm UNE 142500:2017

Regarding operating composting sites, there doesn't seem to be any specific legislation or regulations in place. It would be considered as any industrial waste treatment plant, similar to composting facilities. Therefore, the Autonomous Communities would have the authority to determine the requirements that apply to them.

LESSON 16

16. PLANT NUTRITION

Learning outcomes

- The trainee knows the roles of nitrogen in plant growth, development and health.
- The trainee knows the roles of phoshorus in plant growth, development and health.
- The trainee knows the roles of potassium in plant growth, development and health.
- The trainee knows the roles of calcium in plant growth, development and health.
- The trainee knows the roles of magnesium in plant growth, development and health.
- The trainee knows the roles of sulphur in plant growth, development and health.
- The trainee knows the roles of iron in plant growth, development and health.
- The trainee knows the roles of manganese in plant growth, development and health.
- The trainee knows the roles of copper in plant growth, development and health.
- The trainee knows the roles of zinc in plant growth, development and health.
- The trainee knows the roles of molybdenum in plant growth, development and health.
- The trainee knows the roles of boron in plant growth, development and health.

Instructions for the trainer

- The trainer shares theoretical knowledge through presentation.

Basic requirements: Projector, computer.

16. PLANT NUTRITION

Today, the close relationship between health and nutrition is increasing day by day. The Covid-19 pandemic, which has recently caused great deaths around the world, is a very good example of this. Because Covid-19, which has various effects on health and nutrition, is a respiratory disease and affects individuals with weak immune systems or chronic health problems more, health and nutrition measures have increased their importance. Therefore, it is known that the soil, which is the production environment, must first be recognized very well. It is a fact that plant nutrition, which affects plant development, yield, and quality, is very important in terms of plant and soil management. For this purpose, it has become a necessity to increase plant yield and reduce chemical inputs [93]. Plant nutrition is the sum of chemical elements and compounds necessary for plant growth and reproduction, and plant metabolism, in other words, plants need some plant nutrients for healthy growth. In their absence, the plant cannot complete a normal life cycle. Plants take a large number of nutrients from the environment in which they develop with their above- and below-ground organs. Seventy-four elements can be taken up by plants. However, only some of these elements are essential for plants. These mineral substances that plants need for their development are called absolute essential plant nutrients.

Necessary plant nutrients are divided into two. These are macro and micronutrients. Macronutrients: carbon (C), oxygen (O), hydrogen (H), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), sulfur (S), magnesium (Mg). Micronutrients (or trace minerals): iron (Fe), boron (B), chlorine (Cl), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), nickel (Ni). In recent years, it is reported that sodium (Na), cobalt (Co), vanadium (V) and silicon (Si) have also been included in the classification of absolute essential elements [94].

The role of each plant nutrient element in the plant is different. Therefore, each element is necessary for the plant. So what are these benefits, what are the damages in case of excess, and what are the changes seen in the plant when it is deficient? Let's examine the most important ones one by one.

16.1. Nitrogen

Nitrogen is vital for plants and is an essential nutrient. Plants always need nitrogen for healthy reproduction, growth, and development [95].

Protein and Enzyme Production: Nitrogen is an essential component for protein synthesis in plants. Plants need protein to grow and develop, and this enables the formation of the plant's cellular structures and organelles. It also helps regulate metabolic reactions by taking part in the structure of enzymes.

Chlorophyll Synthesis: Chlorophyll is the green pigment found in chloroplasts, the cell organelles in plants where photosynthesis takes place. Photosynthesis is an important process in which plants use solar energy to convert carbon dioxide and water into glucose and oxygen. Chlorophyll contains nitrogen in its structure and therefore plants need nitrogen for photosynthesis.

Formation of Nucleic Acids: Nitrogen is found in the building blocks of nucleic acids (DNA and RNA) in plants. Nucleic acids store the hereditary information of plants and are vital for the synthesis and transmission of genetic material.

Formation of Amino Acids: Nitrogen is the building block of amino acids in plants. Amino acids are the basic building blocks for protein synthesis and are critical for the growth and development of plants.

Plant Growth and Productivity: Nitrogen supports the development and growth of root, leaf, and stem tissues of plants.

16.1.1. Deficiency and excess of nitrogen

Nitrogen deficiency is mostly seen in young leaves. Leaves develop light green color, in case of further progression, leaves turn yellow, and a lack of photosynthesis is observed. Chlorosis (yellowing) is first seen in old leaves and then in young leaves. Cell size and cell division decrease and plants become stunted. In excess nitrogen, premature aging of leaves is observed.

16.2. Phosphorus

Phosphorus is an essential nutrient element that is vital for plants. Plants need phosphorus for growth, energy transfer, cell structure, and formation of genetic materials [96]. The main functions of phosphorus in plants are as follows:

Energy Transfer: In plants, energy transfer takes place inside the cell through ATP (adenosine triphosphate) molecules. Phosphorus is one of the basic components of ATP molecules and plants need phosphorus where energy is required for their cellular activities and biochemical reactions.

DNA and RNA Synthesis: Phosphorus is one of the building blocks of DNA and RNA in plants. DNA and RNA store the genetic material of plants and are vital for protein synthesis and the transfer of genetic information.

Cell Membrane Structure: Phosphorus is involved in the basic structure of cell membranes in plants. Cell membranes are important structural components that separate the cell interior from the external environment and phosphorus plays an important role in the formation of these membranes.

Photosynthesis Phosphorus plays an important role in the regulation of photosynthetic reactions and energy transfer in plants. Photosynthesis is a critical process in which plants use solar energy to convert carbon dioxide and water into glucose and oxygen.

Plant Growth and Development: Phosphorus supports the development of the root, leaf, and stem tissues of plants. Phosphorus deficiency negatively affects root development in plants and slows down the growth of plants.

Reaction Catalyst: Phosphorus functions as a catalyst for biochemical reactions in plants. It regulates metabolic reactions by taking part in the structure of enzymes and provides physiological functions to plants.

Phosphorus deficiency or excess in the plant is one of the important problems that adversely affect plant health. Both can adversely affect plant development and cause yield losses. Here are the effects of phosphorus deficiency and excess in the plant:

16.2.1. Phosphorus Deficiency

Problems in Root Development: Phosphorus deficiency negatively affects the root development of plants. Roots weaken and cannot get enough nutrients and water.

Slow Growth: The growth rate of plants slows down due to phosphorus deficiency. Plants may have smaller and weaker leaves.

Yield Loss: Phosphorus deficiency reduces the crop yield of plants. Especially fruit and seed formation can be affected.

Color Changes: Leaves may turn purple or dark green and leaf margins may be reddish.

Ripening Delay: Due to phosphorus deficiency, the ripening of fruits or seeds of plants may be delayed.

Seed Formation Problems: Phosphorus deficiency can affect the seed formation of plants and reduce seed quality.

16.2.2 Phosphorus Excess

Mineral Imbalance: Phosphorus excess can cause mineral imbalances in plants and inhibit the absorption of other nutrients.

Toxicity: Phosphorus excess can lead to plant toxicity and cause symptoms such as burns or chlorosis (yellowing of leaves).

Nutrient Poisoning: Phosphorus excess can reduce the bioavailability of other nutrients in the soil and damage plants.

Environmental Pollution: Excess phosphorus can cause environmental pollution in agricultural fields and irrigation water. The leaching of excess phosphorus into water bodies can adversely affect aquatic ecosystems and lead to algal blooms.

Therefore, it is important to ensure a balanced supply of phosphorus in the plant. In case of phosphorus deficiency, fertilizers containing appropriate phosphorus can be applied to the plants. In case of phosphorus excess, measures should be taken to improve the soil and to provide phosphorus in balance with other nutrients. It is important to carry out regular soil analyses and to ensure the balance of nutrients to protect plant health.

16.3. Potassium

Potassium is an important macronutrient for plants and is vital for plant growth, development, and metabolism [97]. The main functions of potassium in plants are as follows:

Water Balance and Osmoregulation: Potassium regulates the water balance in plant cells. Potassium ions inside the cell regulate the turgor pressure (tension) of the cell by controlling the entry of water into the cell. This allows plants to regulate the uptake and loss of water, ensuring a regular transport of water.

Photosynthesis and Respiration: Potassium affects the processes of photosynthesis and respiration in plants. In chloroplasts (the organelle where photosynthesis takes place), potassium is involved in the structure of chlorophyll molecules and photosynthetic enzymes. Therefore, it regulates photosynthesis processes and enables plants to produce food by using solar energy.

Protein Synthesis and Enzyme Activity: Potassium plays an important role in protein synthesis and activation of enzymes. It regulates the metabolic processes of plants by increasing the activity of enzymes.

Cell Division and Growth: Potassium affects cell division and growth processes in plants. It supports the development of root, leaf, and stem tissues of plants.

Disease Resistance: Potassium increases plant resistance to disease. It helps thicken and strengthen the walls of plant cells, thus preventing the entry of diseased organisms into the plant.

Ripening and Fruit Formation: Potassium affects the fruit formation of plants and the ripening of fruits. This increases crop yield and quality of plants.

Deficiency or excess of potassium in the plant is one of the important problems that adversely affect plant health. Both can negatively affect plant development and cause yield losses. Here are the effects of deficiency and excess potassium in the plant:

16.3.1. Potassium Deficiency

In potassium deficiency, the edges appear burnt on older leaves.

Slow Growth: Potassium deficiency negatively affects the growth rate of plants. Plants may have smaller and weaker leaves.

Leaf Yellowing: Due to potassium deficiency, yellowing (chlorosis) can be seen on the leaves. Yellowing leaves are first affected from the edges.

Susceptibility to Desiccation: Potassium deficiency weakens the ability of plants to regulate water balance and can cause plants to be more susceptible to desiccation.

Yield Loss: Potassium deficiency reduces crop yield in plants. Fruit and seed formation may be affected, thus yield may decrease.

Drying of Leaf Tips: Potassium deficiency can cause drying and burns on leaf tips.

Plants become susceptible to insects and disease.

16.3.2. Potassium Excess

Mineral Imbalance: An excess of potassium can cause mineral imbalances in plants and inhibit the absorption of other nutrients.

Toxicity: Excess potassium can lead to plant toxicity and cause symptoms such as burns or chlorosis (yellowing of leaves).

Nutrient Poisoning: An excess of potassium can reduce the bioavailability of other nutrients in the soil and damage plants.

16.4. Calcium

Calcium is an essential nutrient for plants and is vital for their growth, development, and healthy functioning [98]. The main functions of calcium in plants are:

Cell Wall Formation: Calcium plays an important role in the structure of the cell walls of plants. Cell walls provide the structural support of plants and determine the shape and rigidity of the cells.

Cell Division: Calcium regulates cell division in plants and supports the development of root, leaf, and stem tissues.

Ion Balancing: In plants, calcium regulates the ion balance inside and outside the cell. Calcium ions inside the cell regulate the functioning of the cell membrane and water movement.

Enzyme Activation: Calcium plays a critical role in the activation of many enzymes in plants. Enzymes are involved in the regulation of metabolic reactions in plants and calcium activates these reactions.

Cell Signalling: Calcium is an important part of cellular signaling in plants. Calcium levels within the cell can change in response to environmental stimuli and hormonal signals, allowing plants to respond.

Stomatal Control: Stomata are small holes in the leaves of plants that allow gas exchange and water vapor loss. Calcium is part of the mechanisms that regulate the opening and closing of stomata and controls water loss.

Disease Resistance: Calcium increases disease resistance in plants and activates plant defense mechanisms against pathogens (disease-causing organisms).

These functions of calcium in the plant are vital for the healthy growth and development of plants. Calcium deficiency can cause problems in plants such as weak cell walls, edge curling of leaves, and poor resistance to diseases. It is therefore important in agriculture and horticulture to provide plants with sufficient amounts of calcium. Plants are usually fed with calcium-containing fertilizers to meet their calcium needs. In addition, calcium increases the fixation of atmospheric nitrogen by bacteria and increases the availability of molybdenum.

16.4.1. Calcium Deficiency

In calcium deficiency, the tips of the growing roots and leaves turn brown and die. The quality of the fruit is also affected and the fruits develop flower nose rot.

Problems in Root Development: Calcium deficiency negatively affects the root development of plants. Roots weaken and not enough water and nutrients can be taken.

Cell Wall Weakness: Calcium is involved in the structure of cell walls and therefore calcium deficiency causes the cell walls of plants to weaken. This reduces the structural support of the plants and collapse and sagging of the plants can occur.

Leaf Disturbances: Calcium deficiency can cause symptoms such as marginal curling, necrosis (tissue death), and curling of leaves.

Fruit Rot Calcium deficiency may cause rotting and deformation in fruits. There may be loss of quality especially in rind fruits.

Stomatal Control Disorder: Calcium deficiency prevents stomata (leaf holes) from functioning normally and can increase water loss in plants.

16.4.2. Calcium Excess

It can inhibit the absorption of other nutrients: An excess of calcium can reduce the absorption of other nutrients in the soil and cause nutrient deficiencies in plants.

Salinity and Toxicity: Calcium excess can cause salinity and high pH in the soil. This can cause toxicity in plants and negatively affect root development.

Nutrient Imbalance: An excess of calcium can disturb the balance of other nutrients and lead to mineral imbalances in plants.

16.5. Magnesium

Magnesium is a macronutrient element of vital importance for plants [99]. The main functions of magnesium in plants are as follows:

Chlorophyll Synthesis: Magnesium is an essential component of chlorophyll molecules in plants. Chlorophyll is the green pigment in which plants convert water and carbon dioxide into glucose and oxygen using solar energy in the process of photosynthesis. Without magnesium in the structure of chlorophyll, photosynthesis cannot take place and plants cannot produce nutrients.

Energy Transfer: Magnesium is an essential component of ATP (adenosine triphosphate) molecules in plants. ATP is the main molecule used for energy transfer of cellular activities in plants. Magnesium ensures efficient synthesis of ATP and cellular energy transfer.

Enzyme Activation: Magnesium plays a critical role in the activation of many enzymes in plants. Enzymes play an important role in the regulation of metabolic reactions and the synthesis of nutrients in plants. Magnesium is involved in the structure and function of these enzymes and helps many biochemical reactions to occur in plants.

Protein Synthesis: Magnesium plays an important role in protein synthesis in plants. Plants need proteins to grow, develop and fulfill their life functions. Magnesium plays an active role in ribosomes (structures of protein synthesis).

Synthesis of Nucleic Acids: Magnesium is involved in the synthesis of DNA and RNA (nucleic acids) in plants. Nucleic acids are critical for the storage and transfer of genetic material in plants. Magnesium plays an important role in the regulation of these processes.

Deficiency or excess of magnesium in the plant is one of the important problems that adversely affect plant health. Both can negatively affect plant development and cause yield losses. Here are the effects of deficiency and excess of magnesium in the plant:

16.5.2. Magnesium Deficiency

In magnesium deficiency, in old leaves of plants, interveinal veins turn yellow and veins remain green (Interveinal chlorosis).

Leaf Yellowing: Yellowing of leaves (chlorosis) can be seen due to magnesium deficiency. The yellowing leaves are first affected by the edges and may cover all leaves over time.

Slow Growth Magnesium deficiency negatively affects the growth rate of plants. Plants may have smaller and weaker leaves.

Decrease in Photosynthesis Efficiency: Since magnesium is present in the structure of chlorophyll molecules, its deficiency negatively affects the photosynthesis process. This reduces the ability of plants to produce nutrients using solar energy.

Decrease in Flower and Fruit Formation: Magnesium deficiency can affect the flower and fruit formation of plants and cause low yields.

Problems in Root Development: Magnesium deficiency can adversely affect the root development of plants and interfere with nutrient and water uptake.

16.5.2. Magnesium Excess

It may inhibit the absorption of other nutrients: Magnesium excess can inhibit the absorption and transport of other nutrients in plants. This can cause mineral imbalances in plants.

Cellular Disruptions: Magnesium excess can lead to deterioration and toxicity in plant cells. Disruption of cell membranes and organelle structures can be seen.

Decreased Photosynthesis: Magnesium excess can also negatively affect photosynthesis efficiency and reduce the nutrient production of plants.

Inhibiting Root Development: Magnesium excess can negatively affect the root development of plants and inhibit the growth of roots.

16.6. Sulphur

Sulphur is a micronutrient for plants and is essential for the healthy growth and development of plants [100]. The main functions of sulphur in plants are as follows:

Formation of Amino Acids and Proteins: One of the main functions of sulphur is to ensure the formation of amino acids and proteins in plants.

Chlorophyll Synthesis: Sulphur has an important role in the synthesis of chlorophyll in plants.

Synthesis of Plant Hormones: Sulphur is thought to be effective in the synthesis of some plant hormones in plants.

Participation in Cell Membrane Structure: Sulfur participates in the structure of the cell membrane in plants and supports the strength and functionality of the cell membrane.

Activates the Defense Mechanisms of Plants: Sulphur activates the defense mechanisms of plants against diseases and harmful organisms. It especially increases the resistance of plants against some diseases.

Deficiency or excess of sulphur in the plant is one of the important problems that adversely affect plant health. Both can adversely affect plant development and cause yield losses. Here are the effects of deficiency and excess sulphur in the plant:

16.6.1. Sulphur Deficiency

In case of sulphur deficiency, the interveinal yellow color between the veins and the veins remains green (Interveinal chlorosis).

Slow Growth Sulfur deficiency negatively affects the growth rate of plants. Plants may have smaller leaves and their development may be slow.

Leaf Yellowing: Yellowing of leaves (chlorosis) may occur due to sulphur deficiency. The young parts of the leaves are affected, and the leaves may turn pale green or yellow.

Decreased Protein and Amino Acid Synthesis: Sulphur deficiency reduces protein and amino acid synthesis in plants. This situation negatively affects the normal growth and development of plants.

Problems in Chlorophyll Synthesis: Chlorophyll is the pigment that plants need for photosynthesis. Sulfur deficiency can reduce the photosynthesis efficiency of plants by affecting chlorophyll synthesis.

16.6.2. Sulfur Excess

May inhibit the absorption of other nutrients: An excess of sulphur can inhibit the absorption and transport of other nutrients in plants (such as calcium and potassium). This can cause mineral imbalances in plants and lead to deficiencies of other nutrients.

Toxicity: Excess sulphur can cause toxicity in plants. Symptoms such as burns on leaves, curling of leaf margins and plant death can be seen.

16.7. Iron

Iron is a micronutrient element of vital importance for plants [101]. The main functions of iron in plants are as follows:

Chlorophyll Synthesis: Iron is an essential component in the structure of chlorophyll molecules in plants.

Takes Part in Electron Transport Chain: Iron is involved in the structure of important proteins and enzymes such as cytochromes in the electron transport chain in plants. This chain ensures the transport of electrons in energy production processes such as photosynthesis and respiration.

Nitrate Reduction: Iron plays an important role in the conversion of nitrate to nitrite and then to ammonia in plants. This process is important for plants to take up nitrogen and form proteins and other compounds.

DNA and RNA Synthesis: Iron plays an important role in DNA and RNA synthesis in plants. DNA and RNA are critical for the storage and transfer of genetic material in plants.

Enzyme Activation: Iron plays a critical role in the activation of many enzymes in plants.

Deficiency or excess of iron in the plant is one of the important problems that adversely affect plant health. Both can negatively affect plant development and cause yield losses.

16.7.1. Iron Deficiency

Chlorosis (leaf yellowing): Iron deficiency affects chlorophyll synthesis in plants and causes yellowing of leaves (chlorosis). Yellowing of the leaves first appears on the young leaves and between the leaf veins. In severe cases, the whole plant may be light green.

Slow Growth: Iron deficiency negatively affects the growth rate of plants. Plants may have smaller leaves and less branched stems.

Restricted Photosynthesis and Nutrient Production: Iron deficiency reduces the photosynthetic efficiency of plants by reducing chlorophyll synthesis and restricts nutrient production.

Respiration Problems: Iron deficiency can affect the regulation of respiratory processes in plants and affect the energy production of plants, negatively affecting growth.

16.7.2. Iron Excess

Food Poisoning Iron excess can cause nutrient poisoning in plants. High iron levels can produce symptoms of toxicity in plants and cause spots, drying, and burns on leaves.

Mineral Imbalance: Iron excess can lead to mineral imbalances in plants by affecting the absorption and transport of other nutrients.

Negatively Affecting Root Development: Iron excess can negatively affect the root development of plants and prevent the roots from growing healthily.

In excess of iron, tanning, tiny brown spots appear on the leaves.

16.8. Manganese

Manganese is an important micronutrient for plants and has various functions in plants [102]. The main functions of manganese are as follows:

Chlorophyll Synthesis: Manganese is present in the structure of chlorophyll molecules in plants and plays an important role in chlorophyll synthesis. Chlorophyll is the green pigment that enables plants to produce nutrients by using solar energy in the process of photosynthesis.

Antioxidant Activity: Manganese is involved in the activation of antioxidant enzymes in plants. These enzymes help plants fight oxidative stress and prevent damage to cells.

Enzyme Activation: Manganese plays an important role in the activation of many enzymes in plants. It is especially involved in the structure of enzymes that catalyze redox reactions and regulates the metabolism of plants.

Nitrate Reduction: Manganese plays an important role in the reduction of nitrate to nitrite and then to ammonia in plants.

Phosphoric Acid Metabolism: Manganese plays an important role in phosphoric acid metabolism in plants and regulates phosphorus absorption and transport by plants.

Increases the availability of P and Ca in plants.

16.8.1. Manganese Deficiency

Chlorosis (Leaf Yellowing): Manganese deficiency, chlorosis (yellowish green) can be seen in the leaves of plants. Intermediate veins of leaves and young leaves are affected. Manganese deficiency is similar to iron deficiency in plants. Grey spots and streaks appear on the leaves. If severe, plants become stunted.

Decrease in Photosynthesis Efficiency: Manganese deficiency can reduce nutrient production by negatively affecting the photosynthesis process in plants.

Growth Retardation: Manganese deficiency adversely affects the normal growth and development of plants. Plants may have smaller leaves and poorly branched stems.

16.8.2. Manganese Excess

Toxicity: Excess manganese can cause toxicity to plants. High manganese levels can cause spotting, burns, and drying of leaves. Older leaves will show a chlorotic zone and brown spots surrounded by a circle.

It may inhibit the absorption of other nutrients: Manganese excess can lead to mineral imbalances in plants by inhibiting the absorption and transport of other nutrients.

16.9. Copper

Copper is one of the micronutrients required in trace amounts for plants and has various functions in plants [103]. The main functions of copper are:

Enzyme Activation: Copper plays an important role in the activation of many enzymes in plants. It is especially involved in the structure of enzymes that catalyze redox reactions and regulates the metabolism of plants.

Supporting Cell Wall and Tissue Structure: Copper helps support cell walls and tissue structure in plants. This is important for maintaining the structural integrity of plants.

Phosphorus Metabolism: Copper regulates phosphorus metabolism in plants, allowing plants to absorb and transport phosphorus.

Chlorophyll Synthesis: Copper is present in the structure of chlorophyll molecules in plants and contributes to chlorophyll synthesis. Chlorophyll is the green pigment that enables plants to produce nutrients by using solar energy in the photosynthesis process.

It is a catalyst for respiration. Provides balancing of water movement in the plant.

16.9.1. Copper Deficiency

In copper deficiency, plant growth slows down, and plants begin to deteriorate. Young leaves and the death of the growth point are experienced. Copper deficiency, chlorosis (yellowish green) can be seen in the leaves of plants. This is due to the effect of chlorophyll synthesis.

Slow Growth and Development: Copper deficiency can negatively affect the growth rate and development of plants. Plants may have smaller leaves and poorly branched stems.

16.9.2. Copper Excess

Toxicity: Excess copper can cause toxicity to plants. High copper levels can cause spotting, burns, and drying of leaves.

It may inhibit the absorption of other nutrients: Copper excess can lead to mineral imbalances in plants by inhibiting the absorption and transport of other nutrients (such as Fe).

16.10. Zinc

Zinc is one of the micronutrients required in trace amounts for plants and has several important functions in plants [104]. The main functions of zinc are as follows:

Enzyme Activation: Zinc plays an important role in the structure and activation of many enzymes in plants.

Hormone Regulation: Zinc plays an important role in the regulation of some hormones in plants. It regulates auxin hormone concentration.

Protein Synthesis: Zinc plays an important role in protein synthesis in plants.

Chlorophyll Synthesis: Zinc is present in the structure of chlorophyll molecules in plants and is an important component in chlorophyll synthesis.

Cell division promotes shoot elongation. It provides flower eye formation and proper development of fruits.

16.10.1. Zinc Deficiency

Chlorosis (leaf yellowing): Zinc deficiency, chlorosis (yellowish green) can be seen in the leaves of plants. Intermediate veins of leaves and young leaves are affected. If the deficiency progresses, the leaves turn white.

Short, Curled, and Narrow Leaves: Zinc deficiency can cause leaves to be shorter, curled, and narrower than normal in plants.

Problems in Root Development: Zinc deficiency can negatively affect the root development of plants and prevent healthy root growth.

16.10.2. Zinc Excess

Toxicity: Excess zinc can cause toxicity in plants. High zinc levels can cause spotting, burns and drying of leaves.

It may inhibit the absorption of other nutrients: Excess zinc can inhibit the absorption and transport of other nutrients, leading to mineral imbalances in plants.

16.11. Molybdenum

Molybdenum is a micronutrient required in trace amounts for plants and has important functions in the plant. The main function of molybdenum is to play a critical role in nitrogen conversion processes in plants [105]. The function of molybdenum in plants are:

Nitrogen Fixation: Molybdenum plays an important role in nitrogen fixation in plants. Molybdenum is involved in the structure of enzymes (nitrogenases) that are effective in nitrogen fixation and helps plants to utilize nitrogen in the atmosphere.

It helps nitrogen fixation by rhizobium bacteria. Root nodule bacteria also require Mo.

Reduction of Nitrate: Molybdenum is also involved in the conversion of nitrate to simpler compounds, e.g., ammonia, in plants.

Increases the availability of P and S in the soil. Takes part in vitamin synthesis.

16.11.1. Molybdenum Deficiency

Molybdenum deficiency symptoms are often similar to nitrogen deficiency. Older and middle leaves first undergo chlorosis. In some cases, leaf curling, growth, and flower formation are restricted.

Problems in Nitrogen Fixation and Nitrate Reduction: Molybdenum deficiency reduces the efficiency of nitrogen fixation and nitrate reduction in plants. Therefore, nitrogen uptake and protein synthesis of plants may be affected.

Slow Growth and Development: Molybdenum deficiency can cause slow growth and development in plants. Leaves of plants may be small and pale in color.

16.11.2. Molybdenum Excess

Toxicity: Excess molybdenum can cause toxicity in plants. High molybdenum levels can cause spotting and burns on leaves (chlorosis with orange color and pigmentation).

It may inhibit the absorption of other nutrients: Molybdenum excess can lead to mineral imbalances in plants by inhibiting the absorption and transport of other nutrients.

Molybdenum deficiency is usually seen when the soil pH is high or the soil in which the plants grow is deficient in molybdenum.

16.12. Boron

Boron is a micronutrient required in trace amounts for plants and has several important functions in plants [106]. The main functions of boron are:

Contribution to Cell Wall Structure: Boron contributes to the regulation of the permeability of the cell wall structure in plants.

Cell Division and Elongation: Boron plays an important role in the processes of cell division and elongation in plants.

Carbohydrate and Protein Metabolism: Boron is involved in carbohydrate and protein metabolism in plants and regulates the processes of energy production and nutrient synthesis.

Activation of Hormones: Boron can be effective in the activation of some hormones in plants. These hormones regulate processes such as the growth and flowering of plants.

It provides the transport of photosynthesis products from leaves.

16.12.1. Boron Deficiency

Abnormal development of growth points (meristematic tissue) occurs, and apical growth points are stunted and die in boron deficiency. Flower and fruit formation does not occur. For some cereals and fruits, yield and quality are significantly reduced.

Cell Wall Weakness: Boron deficiency can cause cell wall weakness and structural problems in plants. This can negatively affect the growth and development of plants.

Spot Formation on Leaves: Boron deficiency can cause brown spot formation on leaves in plants.

Slow Growth and Development: Boron deficiency can cause slow growth and development in plants. Plants may have smaller leaves and poorly branched stems.

16.12.2. Boron Excess

Boron excess can cause toxicity in plants. High boron levels can cause burns and drying of leaves. It may inhibit the absorption of other nutrients: Boron excess can lead to mineral imbalances in plants by inhibiting the absorption and transport of other nutrients.

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