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A review of the new technologies in vermicompost production

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Abstract— Organic agriculture can be defined as an integrated agriculture production management system that promotes sustainability in global food production and enhances soil health, ecological balance, and biological diversity. In the world, the use of organic amendments (compost, vermicompost, cow dung, etc) as nutrient inputs to the soil is currently increasing, and it is becoming an alternative agricultural practice to sustain, an eco-friendly agriculture production with low environmental contamination. It is widely acknowledged that using vermicomposts as amendments, rather than industrialized fertilizer, could improve soil health, biodiversity, and animal welfare reduce reliance on non-renewable resources, and sustainably adopt practices. Vermicomposts are composed of finely divided, black color, peat-like materials that are produced through a non-thermophilic process involving the biodegradation and stabilization of organic materials by earthworms and microorganisms. This review paper emphasizes the fundamentals of vermicomposting, the new vermicomposting techniques, vermicompost production, and factors that affect the quality and quantity of vermicomposting. The previous studies revealed that the positive effects of plant growth and vermicompost can also increase soil organic carbon, nitrates, phosphates, exchangeable calcium, and some other nutrients for plant growth. Vermicompost production can improve farmers' livelihoods as a replacement for chemical fertilizers, cost savings, income generation, market opportunities, etc.

Index Terms- Earth worms, New technologies, Organic agriculture, Vermicompost, Vermicomposting

1 Introduction

Organic agriculture can be defined as an environment-friendly agriculture production management system for the enhancement of soil fertility, maintenance of the soil biological activity, biological diversity of the species, and the ecological balance of the environment which enhances and ensures agro-ecosystem health [1]. In the world, 72, 213 000 ha (1.5% of total area) of agriculture land area is cultivated under organic agriculture [2]. In organic agriculture management systems, inorganic fertilizers play a vital role in ensuring the availability of nutrients in soil. When considering economic factors, inorganic fertilizers are more profitable than inorganic fertilizers. Sometimes, inorganic fertilizers aren't available in the market at the right time which leads to the farmers not being able to apply inorganic fertilizers to the crop field in optimum time. When compared with inorganic fertilizers, organic fertilizers are low-cost and easily available [3]-[5].

In the organic agriculture technology concept, vermicompost is a microbiologically active organic amendment that results from the interactions between earthworms and microorganisms during the breakdown of organic matter, and also it is an attractive green waste proper disposal method to increase the organic matter content in soil. Vermicompost is a product of stable finely divided peat-like material with a low C: N ratio, high porosity, and high water holding capacity that enriches with macro and micro plant nutrients resulting from earthworm digestion and aerobic decomposition using the activities of micro and macro organisms [6].

Vermicast (worm casting, worm humus, worm feces) is the end product of the breakdown of organic matter by earthworms [7]. Vermicomposting is the bio-oxidation and stabilization process that involves the interaction between earthworms and microorganisms. Vermiculture is the culture of earthworms. The purpose of vermiculture is to continually increase the number of worms to obtain a sustainable harvest [8].

In this process, microorganisms are biochemically degrading the organic matter and earthworms are the crucial drivers of the process, as they aerate and fragment the substrate thereby drastically altering the microbial activity and increasing the surface area for increasing microbial activity and further decomposition [9]-[10].

2 VERMICOMPOSTING

2.1 Principle of vermicomposting

Pre-composting

In the vermicomposting production system, pre-composting practice can be identified as the best earthworm protection practice because it provides many benefits as waste stabilization, pH stabilization, and thermal stabilization. Organic wastes containing high levels of ammonia can become acceptable after the removal of ammonia by a period of pre-composting. The pre-composting period helps to initiate microbial degradation, eliminates disease-causing pathogens, and also improves the quality of the final vermicompost [11]-[13].

vermicomposting

when compared with conventional composting which requires mesophilic, thermophilic, and psychrophilic phases vermicomposting only involves the mesophilic phase and consists of two stages active and maturation phases involving the activity of earthworms [14].

Active Phase

In the active phase, the earthworms are mainly involved in the decomposition process than microbes. The decomposition process consists of different modifications of their physical state and microbial composition. In this phase, gut-associated processes (GAPs) are processes that include all the modifications for decaying organic matter and the microorganisms undergo during transit through the earthworm’s intestine. Earthworms directly act on the rotting of organic matter throughout the gut-associated processes via the impact of ingestion, digestion, assimilation of the organic matter and microorganisms in the gut, and trimming.

The organic waste is softened by the saliva in the mouth of earthworms. After that, organic compounds become softened and neutralized by calcium (excreted by the inner walls of the esophagus) and passed on to the gizzard for further action in the esophagus region of the worm body. Finally, the organic compounds are finely ground into small particles in the muscle gizzard. In the stomach, the organic compounds are digested by a proteolytic enzyme. The various enzymes involved in the decomposition of pulped organic material components including proteases, lipases, cellulases, chitinase, etc. secreted in the intestine then the digested material is absorbed in the epithelium of the intestine. Excretion of undigested food material from worm castings. During passage through the gut, some bacteria are triggered, whereas others remain untouched and others are absorbed in the intestinal tract thus modification of the microfaunal population [15]. These modifications include the addition of sugars and other substances, modification of the microbial diversity and activity, homogenization, and the intrinsic processes of digestion, assimilation, and production of mucus and excretory substances such as urea and ammonia, which constitute a readily assailable pool of nutrients for microorganisms. The first instance is due to gut-associated processes (GAPs). These processes include all the modifications that the decaying organic matter and the microorganisms undergo during transit through the earthworms' intestines. In earthworm gut, enzymatic activities lead to toxic metal immobilization, which suggests that terotechnology is an efficient process for the remediation of heavy metal from industrial organic waste [16], [17].

Maturation–like phase

After completion of Gut-associated processes, the resultant casts undergo cast-associated processes (CAPs), which are more closely associated with the aging processes, the action of the microflora and microfauna present in the substrate, and the physical modification of the egested materials. The microorganisms mainly fungal and protozoan spores and some resistant bacteria are accessible for colonization of newly formed earthworm casts, after passing through the earthworm gut. These freshly deposited casts are generally rich in ammonium nitrogen and relatively digested organic matter and thus provide a good substrate for microbial growth. Then higher involvement microbes than earthworms during the aging process, vermicompost reaches its optimum in terms of biological properties that promote plant growth and suppress plant diseases [18].

Factors affecting the vermicompost production

1. Moisture

In vermicomposting, adequate moisture content is one of the most important factors that affect the quality of vermicompost. The optimum moisture content is 70% -90%. The earthworm prefers moist environments because they need to keep their skin wet because they respiration through their skins. The moisture content is less than 50% which negatively affects the bacterial activity. The bacteria need water to begin reactions and many of the essential substances are solved in water for transmission through membranes into bacterial cytoplasm. Bacterial activity extremely decreases in a moisture content lower than 10%.

2. Aeration

Biologically, the earthworm respires through its skin. Air dissolves on the mucus of their skin, so the skin should be moist. Then oxygen is drawn into the worm's circulatory system and the worm's hearts pump the oxygenated blood to the head area. Especially, high levels of oily/greasy materials should not be included in the feedstock of vermicomposting because the high levels of oily/greasy materials or excessive moisture combination lead to an anaerobic environment. Under anaerobic conditions, the different types of anaerobic microbes can produce toxic substances. Then, both depletion of oxygen and toxic substances negatively affect the worms. This is one of the main reasons for meat or other greasy/ oily wastes must be included in worm feedstock after pre-composting. As an advantage, vermicomposting requires the lack of need to turn the material because the worms do that work. In vermicomposting, the feedstock is not packed too dense to prevent this movement.

3. Temperature

The earthworms prefer a temperature range of 15 ^{O}C - 25 ^{O}C for growth vermicomposting efficiency and productivity. Above 35 ^{O}C, it will cause the worms to leave the area. If they can't leave, they will quickly die. Most of the cocoons were laid at 25°C. Temperature below 10°C generally results in reduced feeding activity. In temperatures below 4°C condition, cocoon production and development of young earthworms cease completely. Earthworms can also acclimate to temperature in autumn and survive the winter, but they can't survive long periods under freezing conditions unless they are in protective cells.

4. pH

Earthworms are very sensitive to pH. Previously studies found that the range of 5.0 to 8.0 was the optimum pH range. The pH can be adjusted upwards by adding calcium carbonate.

5. Ammonia and Salt

Earthworms are very sensitive to ammonia and can't survive in organic wastes containing high levels of this cation. They also die in wastes with large quantities of inorganic salts. Both ammonia and inorganic salts have very sharp cutoff points between toxic and nontoxic ($<1mgg^{-1}$) ammonia and <0.5% salts. Organic wastes containing high levels of ammonia can become acceptable after the removal of ammonia by a period of pre-composting. According to Gunadil et al (2002), earthworms are very sensitive to salts, preferring a salt content of less than 0.5%.

6. Toxic components

detergent cleansers, industrial chemicals, pesticides, and oily materials are toxic to the earthworms.

Vermicompost production

Select a bedding

A hospitable living environment is usually called "bedding". Bedding is any material that provides the worms with a relatively shaded habitat. This habitat must have the following characteristics.

High absorbency

worms breathe through skins and therefore must have a moist environment in which to live. If a worm's skin dries out, it dies. The bedding must be able to absorb and retain water fairly well if the worms are to thrive.

Good bulking potential

if the material is too dense to begin with, or packs too tightly, then the flow of air is reduced or eliminated. Worms require oxygen to live. Different materials affect the overall porosity of the bedding through a variety of factors including the range of particle size and shape, texture, and the strength and rigidity of its structure.

C: N ratio

the vermicompost process properly by starting the process properly by starting the process with a C: N ratio around 25:1-30:1 and it will decrease during the process.

Conventional vermicompost methods

1. Windrow

Windrow vermicomposting can be carried out in many different ways. The 3 most common are described here.

2. Static pile windrow (batch)

Static pile windrows are simply piles of mixed bedding and feed (or bedding with feed layered on top) that are inoculated with worms and allowed to stand until the processing is complete. These piles are usually elongated in a windrow style but can also be squares, rectangles, or any other shape. But they should not exceed 1m in height (before settling). Maintenance and care must be taken to provide a good environment for the worms. So the selection of bedding type is very important. Although the windows don’t require turning. They are required watered and covered [19].

3. Top-fed windrows (continuous flow)

Top-fed windrows are set up as continuous flow operations. This means that bedding is placed first, then inoculated with worms, and then covered repeatedly with thin (less than 10cm) layers of feedstock. The worms tend to consume the feed stock at the bedding interface and then drop their castings near the bottom of the windrow. A layered windrow is created over time, with the finished product on the bottom, partially consumed bedding in the middle, and the fresher feed stock on top. Layers on new bedding should be added periodically to replace the bedding material gradually consumed by the worms. Harvesting is usually accomplished by removing the top 10-20cm first, usually with a front end loader or tractor outfitted with a bucket. This is the system used by North America’s largest vermicomposting facility, a 77acre operation run by America Resources Recovery in Northern California that processes 300 tons of paper waste per day [20].

As an advantage, Top feeding have mainly to do with the greater control the operator has over the worms environment, since the food is added on regular basis, the operator can easily assess conditions at the same time and modify such things as feeding rate, pH, moisture content etc, as required. This high-efficiency system with greater vermicompost production.

As a disadvantage, top-feeding windrow require continuous feeding and sometime difficult to operate specially in the winter season. In addition, if windrow covers are used, they must be removed and replaced every time the worms are fed, creating extra work for the operator.

4. Wedges (continuous flow)

The vermicomposting wedges, an initial stock of worms in bedding is placed inside a corral-type structure (3-sided) of not more than 3 feet or 1m in height. The sides of the corral can be concrete, wood or even bales of hay or straw. Fresh material is added on a regular feeding schedule through the open side by using bucket loader. The worms follow the fresh feed stock over time, leaving the processed material behind. When the material has reached the open end of corral, the finished material is harvested by removing the back of the corral and scooping the material out with a loader. A4th side is then put in place and the direction reserved.

Using this system, the worms don't need to be separated from the vermicompost and the process can be continued indefinitely. During the coldest months, a layer of insulating hay or straw can be placed over the active part of the wedges. The corrals can be any width at all, the only constraint being access to the interior of the piles for monitoring and corrective actions, such as adjustment of moisture content or pH level. A corral width of about 6 feet, with space between adequate for foot travel, would be ideal. The ideal length will depend on the material being processed, the size of the worm population, and other factors affecting processing times [21].

The sides of the corrals can be made of any material at all, although insulating value is a consideration, hay or straw bales will gradually break down over time and be consumed by the worms. However, it can be added to the contents of the wedge and replaced with a fresh one. As a problem, operating the wedge system over the winter is challenging, though not impossible. As a solution, the regular addition of fresh manure to the operating face can create enough heat to produce a "temperate zone" behind the face within which the worms will continue to thrive and reproduce, another option would be to load up the face with fresh manure in late autumn, cover all of the material within a thick layer of straw, and uncover and begin operations again in the spring [22].

5. Top-fed beds (continuous flow)

A top-fed bed works like a top-fed windrow. The main difference is that the bed, unlike a windrow is contained within 4 walls and usually a floor, and is protected to some degree from the elements, often within an unheated building as a barn. The beds can be built with insulated sides, or bales of straw can be used to insulate them in the winter. If the bins are fairly large, they are sheltered from the wind and precipitation and feedstock is reasonably high in nitrogen, the only insulation required may be an insulating "pillow" or layer on top. These can be as simple as bags or bales of straw.

Harvesting vermicompost can be most easily accomplished by taking advantage of horizontal migration. The beds were built end to end, with metal screens separating the different beds. To harvest, the operator simply stops feeding one of the beds for several weeks, allowing the worms time to finish that material and then migrate to the other beds in search of fresh feed. The "cured" bed is emptied and refilled with bedding, after which feeding is resumed, this is repeated on a regular rotating basis. As an advantage, the beds or bins have more controllable environmental conditions. As a disadvantage: the system is the extra cost of building and maintaining the beds, as well as the cost of shelter [23].

6. Stacked bins (batch or continuous flow)

A stacked bin requires limited space because it uses the vertical dimension for vermicomposting. The feedstock can be introduced as a batch type or continuously but the batch process is most suitable for economical route of vermicompost production. It requires an unheated shelter for bins.

Preparation of vermicompost pit or tank

Vermicompost tank may be a single tank or a combination of more tanks of any size (manageable size is 2 m x 1 m x 0.75 m) that consist of proper water outlets to combat the ant menace and have a water column in the center of the parapet wall of the vermins. The four-chamber pit will facilitate easy and continuous movement of earthworms from one chamber with fully composted matter to the one with pre-processed waste in the chambers.

Novel vermicomposting techniques

1. Flow through reactors

In flow-through reactors, the raised boxes are used that are rectangular and not more than 3m in width. Feedstock is added to the top and vermicompost can be collected through a grid at the bottom. Especially, this is a type of “flow-through” because there is no disturbance to earthworm bedding material. The material goes in the top, flows through the reactor (and the worm’s guts), and comes out the bottom (*Eisenia fetida* tends to eat at the surface and drop castings near the bottom of the bedding). The method for pushing materials out the bottom is usually a set of hydraulically powered “breaker bars” that move along the bottom grate, loosening the material so that it falls through. The properly managed flow-through unit of approximately 1000 ft^2 surface area can process 2 to 3 t per day of organic waste [24].

Phosphate and microbial-enriched vermicompost

This enriched method is similar to the above-mentioned slurry method, but during the preparation of the slurry of cow dung and biowaste, 25 kg of rock phosphate (RP) was also added (5% of the total weight) and mixed well and the mixture was kept undisturbed. When the vermicompost matured (appearance of blackish brown color), after 5-7 days, the mixture was stirred with little addition of water followed by the addition of 2 kg of earthworms and covered with gunny bags, and moisture was maintained as mentioned in the above method. After 50- 55 days (appearance of brown-black color), a consortium of biofertilizers viz., phosphate solubilizing bacteria (PSB), N-fixing bacteria viz., *azospirilum and acetobacter* (1kg each/100 kg vermicompost) were added to the vermicompost and kept undisturbed for 15-20 days and the enriched vermicompost was removed from the tank and the earthworms were separated following heap method and by sieve screening. The vermicompost was air-dried, sieved, and estimated for the above-mentioned parameters following the standard procedure mentioned [25]

Sour crop or protein poisoning – this disease is the result of too much protein in the bedding. This happens when the worms are overfed. Protein builds up in the bedding and produces acids and gases as it decays. Keeping pH neutral to prevent this.

End Product of vermicomposting:

i. Finely divided peat-like material

ii. High porosity

iii. High water holding capacity

iv. Low C: N ratio

v. Contain many nutrients in forms that are readily taken up by the plant

vi. High rates of mineralization occur in the organic matter–rich earthworm casts, which greatly enhances the availability of inorganic nutrients such as Ammonium, Nitrates, Phosphorus, Potassium, Calcium Magnesium

3. Conclusion

Vermicomposting provides a sustainable green solution for organic waste management problems and also it offers numerous environmental, agricultural, social, and economic benefits. Vermicompost could improve soil nutrient status and soil health. Furthermore, research, studies, and innovations are required to improve vermicompost production.

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