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VERMICOMPOST., A BACKBONE FOR SUSTAINABLE AGRICULTURE – REVIEW ARTICLE

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ABSTRACT
Vermicompost is produced through interaction between earthworm and microorganism by the breakdown of organic wastes. Vermiculture and vermin-composting are a self-promoted, self-regulated, self-improved and self-enhanced, low or no-energy requiring zero-waste technology, and easy to construct, operate and maintain. It excels all 'bio-conversion' technologies by the fact that it can utilize organics that otherwise cannot be utilized by others and also excels all 'bio-treatment' technologies because it achieves greater utilization than the rate of destruction achieved by other technologies. It involves about 100-1000 times higher 'value addition' than other biological technologies. The best part is that vermicomposting by worms decrease the proportion of 'anaerobic to aerobic decomposition', resulting in a significant decrease in the greenhouse gas methane (CH_4) which plagues the conventional composting methods by microbes. All organic wastes by their very nature (chemical composition) are bound to disintegrate anaerobically in environment and generate greenhouse gas methane (CH_4). Only if they are allowed to degrade completely under aerobic conditions (which is readily facilitated by earthworms) that this can be prevented. Vermicomposting is saving over 13,000 cum of landfill space every year in Australia. Some city councils in Australia were committed to 'no landfills' by 2008 and planned to achieve this target by vermi-composting the entire organic wastes of the residents. Thus the vermicomposting process helps in the disposal of organic waste and industrial waste in a safe, economic and useful manner.

KEYWORDS: Vermicompost, Earthworms, Nutrients, Decomposition.

INTRODUCTION
Vermes is a Latin word for worms and Vermicomposting is basically composting with worms. In nature all organic matters eventually get decomposed. In vermicomposting the process of decomposition is at fast rate and end up with a rich end result called castings. Since vermicomposting can be done virtually anywhere, it has the added benefit of allowing to create compost indoors during the winter and outdoors during the summer.

Vermicomposting is a 100% pure ecofriendly organic fertilizer, rich in nitrogen phosphorus, potassium, organic carbon, sulphur, hormones, vitamins, enzymes and antibiotics which help to improve the quality and quantity of yield. It excels all other waste conversion technologies by the fact that it can utilize waste organics that otherwise cannot be utilized by others. It excels all other biological or mechanical technologies for production of 'bio-fertilizer' because it achieves 'greater utilization' than the rate of 'destruction' achieved by other technologies and the process becomes faster with time as the army of degrader worms and the decomposer microbes multiply in millions in short time (Sinha *et al*., 2008).

Earthworms involve about 100-1000 times higher 'value addition' in any medium (composting wastes or soil) wherever it is present (Appellof *et al.*, 2003).

Mainly vermicomposting is a simple biotechnological process of composting, in which certain species of earthworms are used to enhance the process of waste conversion and produce a better product. Vermicomposting differs from composting in several ways (Gandhi *et al*., 1997). It is a mesophilic process that utilizes microorganisms and earthworms that are active at 10°C to 32°C (not ambient temperature but temperature within the pile of moist organic material). The process is faster than composting; because the material passes through the earthworm gut where a significant but not fully understood transformation takes place, which results in earthworm castings (worm manure) that are rich in microbial activity and plant growth regulators, and fortified with pest repellent attributes as well. In a nutshell earthworms through a type of biological alchemy are capable of transforming garbage into "gold" (Vermi Co, 2001, Tara Crescent 2003).

GENERAL CHARACTERISTICS OF VERMICOMPOST

Vermicompost is the excreta of earthworms, which are capable of improving soil health and nutrient status. Vermiculture is a process by which all types of biodegradable wastes such as farm wastes, kitchen wastes, market wastes, bio-wastes of agro based industries, live stock waste etc. are converted into nutrient rich vermicompost while passing through the gut of the worm. Vermi worms are used here act as biological agents to consume those wastes and to deposit excreta in the process called vermicomposting.

REQUIREMENTS OF VERMICULTURE AND VERMICOMPOSTING

Culturing of selected species of earthworm as well as using them for biodegradation of organic wastes to turn them into dark, nutrient rich vermicompost requires the following.

1. Selection of proper species.
2. Physical factors such as moisture, temperature, aeration and shelter.
3. Chemical factors such as pH, nutrient status and C/N ratio.
4. Biological factors such as availability of soil microorganisms and absence of predators.(Ranganathan, 2006).

VERMICOMPOSTING IN DAY TO DAY LIFE

Vermicomposting system should be included in teaching courses of educational institutes as it forms part of skill development programme. Various aspects of this system will bring us near to learn about environment. The biological and environmental issues associated with vermicomposting are quite evident. The process includes various aspects like types of container, filling it with moist bedding, introducing worms and feeding them on a regular basis, active phase of worms and attention to ensure optimum living environment. Some potential markets for worms and castings include: bait and tackle shops, bird breeders, boarding kennels, dairy farms, exotic bird breeders, feedlots, fisheries, fishing clubs, food processing companies, fruit and vegetable markets, garden clubs, home waste disposal, hotels, landscape gardeners, agriculture farms, national parks, nurseries, orchardists, pig farms, poultry growers, pulp mills, racing stables, restaurants, schools, supermarkets, and worm growers.

NUTRIENTS IN VERMICOMPOST

Vermicompost is an excellent soil additive made up of digested compost. Worm castings are much higher in nutrients and microbial life and therefore, are considered as a higher value product. Worm castings contain up to 5 times the plant available nutrients found in average potting soil mixes. Chemical analysis of the castings was conducted (Ruz-Jerez *et al*., 1992, Parkin and Berry, 1994) and found that it contained 5 times the available nitrogen, 7 times the available potash and 1.5 times more calcium than that found in 15 cm of good top soil. In addition, the nutrient life is up to 6 times more in comparison to the other types of potting mixes. It is reported that phosphorous while passage through gut of worms is converted to the plant available form (Reinecke *et al*., 1992). Phosphorous is usually considered as a limiting element for plant growth. Therefore, any process that significantly increases phosphorous availability through plants and organic matter will be very important for agriculture. The average potting soil mixes that is found in the market are usually sterile and do not have a microbial population. The combination of nutrients and microbial organisms are essential for growing healthy and productive plants. Vermicompost not only adds microbial organisms and nutrients that have long lasting residual effects, it also modulates structure to the existing soil, increases water retention capacity. Vermicompost may also have significant effects on the soil physical properties. It was observed that addition of vermicompost @ 20 t·ha−1 to an agricultural soil in two consecutive years significantly improved soil porosity and aggregate stability (Ferreras *et al*., 2006). The number of large, elongated soil macro pores in- creased significantly after a single application of a dose of vermicompost equivalent to 200 kg·ha−1 of nitrogen to a cornfield (Marinari *et al.*, 2000). Similarly, a significant decrease in soil bulk density and a significant increase in soil pH and total organic carbon after application of vermicompost in two consecutive growing seasons, at a rate equivalent to 60 kg·ha−1 of N. Together these changes in soil properties improve the availability of air and water, thus encouraging seedling emergence and root growth (Gopinath *et al*., 2008).

Vermicompost contains an average of 1.5% - 2.2% N, 1.8% - 2.2% P and 1.0% - 1.5% K. The organic carbon is ranging from 9.15 to 17.98 and contains micronutrients such as Sodium (Na), Calcium (Ca), Zinc (Zn), Sulphur (S), Magnesium (Mg) and Iron (Fe).

Earthworms consume various organic wastes and reduce the volume by 40% - 60%. Each earthworm weighs about 0.5 to 0.6 g, eats waste equivalent to its body weight and produces cast equivalent to about 50% of the waste it consumes in a day. The moisture content of castings ranges between 32% to 66% and the pH is around 7.0.

From various studies it is also, evident that vermicompost provides all nutrients in readily available form and enhances uptake of nutrients by plants. Soil available nitrogen increased significantly with increasing levels of vermicompost and highest nitrogen uptake was obtained at 50% of the recommended fertilizer rate plus 10 t·ha−1 vermicompost. Similarly, the uptake of nitrogen (N), phosphorus (P), potassium (K) and magnesium (Mg) by rice (*Oryza sativa*) plant was highest when fertilizer was applied in combination with vermicompost (Jadhav *et al.*,1997). The production of potato (*Solanum tuberosum*) by application of vermicompost in a reclaimed sodic soil in India was studied and observed that with good potato growth the sodicity (ESP) of the soil was also reduced from initial 96.74 kg/ha to 73.68 kg/ha in just about 12 weeks. The average available nitrogen (N) content of the soil increased from initial 336.00 kg/ha to 829.33 kg/ha (Ansari, 2008). Vermicompost contains enzymes like amylase, lipase, cellulase and chitinase, which can break down the organic matter in the soil to release the nutrients and make it available to the plant roots (Chaoui *et al*., 2003).

Table 1: Nutrient composition of vermicompost and garden compost are given.

Nutrient element	Vermicompost (%)	Garden compost (%)
Organic carbon	9.8 - 13.4	12.2
Nitrogen	0.51 - 1.61	0.8
Phosphorus	0.19 - 1.02	0.35
Potassium	0.15 - 0.73	0.48
Calcium	1.18 - 7.61	2.27
Magnesium	0.093 - 0.568	0.57
Sodium	0.058 - 0.158	<0.01
Zinc	0.0042 - 0.110	0.0012
Copper	0.0026 - 0.0048	0.0017
Iron	0.2050 - 1.3313	1.1690
Manganese	0.0105 - 0.2038	0.0414

EARTHWORMS 'NATURE'S PLOWMAN'

Ecology

Earthworms are considered as natural bioreactors which proliferate with other microorganisms and provide required conditions for the biodegradation of waste. Earthworms are burrowing animals and form tunnels by literally eating their way through the soil. The distribution of earthworms in soil depends on factors like soil moisture, availability of organic matter and pH of the soil. They occur in diverse habitats specially those which are dark and moist. Organic materials like humus, cattle dung and kitchen wastes are highly attractive sites for some species. Earthworms are generally absent or rare in soil with a very coarse texture and high clay content or soil with pH < 4. Earthworms are very sensitive to touch, light and dryness. As worms breathe through their skin proper ventilation of air in soil medium is necessary. Water logging in the soil can cause them to the surface. Nearly worms are tolerate a temperature range between 5° C to 29°C. A temperature of 20°C to 25°C and moisture of 60-75% is optimum for earthworm function.

Biology

Earthworms are long, narrow, cylindrical, bilaterally symmetrical, segmented animals without bones. The body is dark brown, glistening and covered with delicate cuticle. They weigh over 1400-1500 mg after 8-10 weeks. On an average, 2000 worms weigh 1 kg and one million worms weigh approximately 1 ton. Usually the life span of an earthworm is about 3 to 7 years depending upon the type of species and the ecological situation. Earthworms harbor millions of 'nitrogen-fixing' and 'decomposer microbes' in their gut. Their body contains 65% protein (70-80% high quality 'lysine rich protein' on a dry weight basis), 14% fats, 14% carbohydrates and 3% ash.

Enormous Rate of Multiplication

Earthworms multiply very rapidly. They are bisexual animals and cross-fertilization occurs as a rule. After copulation the clitellum (a prominent band) of each worm eject lemon-shaped 'cocoon' where sperms enter to fertilize the eggs. Up to 3 cocoons per worm per week are produced. From each cocoon about 10-12 tiny worms emerge. Studies indicate that they double their number at least every 60 days. Given the optimal conditions of moisture, temperature and feeding materials earthworms can multiply by 2^8 i.e. 256 worms every 6 months from a single individual. Each of the 256 worms multiplies in the same proportion to produce a huge biomass of worms in a short time. The total life-cycle of the worms is about 220 days. They produce 300-400 young ones within this life period.

A mature adult can attain reproductive capability within 8- 12 weeks of hatching from the cocoon. Red worms takes only 4-6 weeks to become sexually mature. Earthworms continue to grow throughout their life and the number of segments continuously proliferates from a growing zone just in front of the anus. (Sinha and Sinha, 2008).

About 3000 species of earthworms are found worldwide. Out of which, approximately 384 species are reported to be found in India and their detail taxonomic studies have been done already (Julka,1983). The most effective use of earthworms in organic waste management could be achieved when a detailed understanding of biology of all potentially useful species and their population dynamics, productivity and the life cycles of earthworms are known. Detail studies on Indian species (Julka, 2001) and tropical species (Dash and Senapati, 1980) and knowledge about the reproductive strategies of earthworms have been done. Earthworms belong to the family Lumbricidae. Earthworms are hermaphrodites but self-fertilization is rare.

The doubling time *i.e.* the time taken by a given earthworm population to double in its number or biomass, specifically depends upon the earthworm species, type of food, climatic condition, etc. For example, the mean doubling time of *Lampito mauritii* in different organic inputs ranges from 33.77 - 38.05 days while the value for *Perionyx excavatus* is 11.72 - 16.14 days (Ismail, 1997). The adult worm might live for about two years. Full grown worms could be separated and dried in an oven to make "worm meal" which is a rich source of protein (70%), and are often used as animal, poultry and fish feed. *E. eugeniae* is a manure worm, which has been extensively used in North America and Europe for vermin composting because of its voracious appetite, high rate of growth, and reproductive ability (Gajalakshmi *et al*., 2001). A few years back it was brought to India and it has been progressively increasing application in the vermicomposting of animal manure and other forms of biomass (Garg *et al.*, 2006). The other epigeic species used in large-scale vermin culture is *E. foetida*, which has high potential for bio-converting organic waste into vermin casts (Garg *et al.*, 2006).

Table 2: Characteristics of earthworms of different ecological categories.

Characteristics	**Epigeic**	**Endogeic**	**Anecic**
Habitat	Litter dwellers	Naturally found in upper organic rich soil layers	Deep burrowing
Food	Litter and humus feeder	Litter and organic rich soil feeder	Litter and soil feeder
Burrow formation	Do not construct burrows and remains active in litter layers	Constructe horizontal burrows lined by mucus and excretory products	Construct vertical burrow
Microbial communities in burrows	-	Well documented in literature	Positive evidences are available
Cocoon production rate	Highest	Moderate-high	Low
Life cycle	Short	Intermediate	Long
Efficiency in waste recycling	Well established	Well established in some species	Efficiency data is not available
Species adopted in waste management	*Eisenia fetida* *Bimastos parvus* *Dendrobaena rubida* *Eisenia hortensis*	*Eudrilus eugeniae*	*Pheretima elongate* *Megascolex megascolex* *Perionyx excavates* *Lumbricus terristris* *Amnthus diffringens* *Lampito mauritii* *Perionyx sanibaricus* *Lumbricus rubellus*

Sources: Bouche 1977; Munnoli 2007; Suther 2008.

FEED FOR WORMS

Under optimum conditions, red worms can eat their own weight in food scraps and bedding in one day. On the average, however, it takes approximately 2 pounds of earthworms (approximately 2,000 breeders) to recycle a pound of food waste in 24 hours. The same quantity of worms requires about 4 cubic feet of bin to process the food waste and bedding (1 cubic foot of worm bin/500 worms).

SUBSTRATE - FOOD AS A WASTE

Earthworms eat all kinds of food and yard wastes, including coffee grounds, tea bags, vegetable and fruit waste, pulverized egg shells, grass clippings, manure and sewage sludge. Avoid bones, dairy product and meats that may attract pests and garlic, onions and spicy foods. Limited amounts of citrus can be added, but too much can make the compost too acidic. The compost should be kept at a p^H of 6.5 if possible, with upper and lower limits at 7.0 and 6.0, respectively. Overly acidic compost can be corrected by adding crushed eggshells.

Avoid adding chemicals (including insecticides), metals, plastics, glass, soaps, pet manures and oleanders or other poisonous plants, or plants sprayed with insecticides to the worm bin.

Food wastes should be added to the bin by pulling back the bedding materials and burying it. Be sure to cover it well to avoid attracting flies and other pests. Successive loads of waste should be buried at different locations in the bin to keep the food wastes from accumulating. Grinding or blending the food waste in a food processor speeds the composting time considerably. (Gupta, 2003).

CONSUMPTION BY EARTHWORM

Usually 2 kg of earthworms will recycle 1 kg of organic waste in 24 hours. In absolutely ideal conditions of comfort and ground up, moist food, the herd will recycle their own weight in wastes every 24 hours.

FEEDING OF EARTHWORMS

The earthworms will need a little help in the preparation of some of the materials. When feeding the scraps if at all possible chop or break them into small pieces as it will be easier for the worms to process. Leave the scraps in a container for a few days so bacteria will start forming because worms love bacteria. Be sure the overall mix, (or any individual waste), is moist, about like a blueberry muffin or sponge cake.

MULTIPLICATION OF WORMS

Earth worms can be multiplied in 1:1 mixture of cow dung and decaying leaves kept in a cement tank or wooden box or plastic bucket with proper drainage facilities. The nucleus culture of the worms needs to be introduced into the above mixture at the rate of 50 worms per 10 kg of organic wastes properly mulched with dried grass or straw in a wet gunny bag. The unit should be kept under shade. Sufficient moisture level should be maintained by occasional sprinkling of water. Within 1 - 2 months, the worms multiply 300 times, which can be used for large scale vermin composting. Suitability of dry olive cake, municipal biosolids and cattle manure as substrates for Vermicomposting was evaluated and reported that larger weights of newly hatched earthworms were obtained in substrate containing dry olive cake (Garg *et al.*, 2006). In another study, maize straw was found to be the most suitable feed material compared to soybean (*Glycine max*) straw, wheat straw, chickpea (*Cicer arientinum*) straw and city refuse for the tropical epigeic earthworm, *Perionyx excavatus* (Manna *et al.*, 1997).

BIOREACTIONS BETWEEN EARTHWORMS AND MICROORGANISMS

Earthworms are considered as `ecosystem-engineers` and they can be efficiently employed as nature`s unpaid labour force in the `decomposer-industry` since earthworms in conjunction with microorganisms can decompose dead biomass (Fisher *et al.*, 1995). This process can also be initiated by the deliberate introduction of earthworms into a stack of biomass, the process being called as vermicomposting. Earthworms are very effective in initiating the decomposition processes and paving the way for subsequent microbial action (Pearson *et al*., 1963). Thus there exists a strong relationship between invertebrates and microorganisms to make use of soil organic matter (Reyes *et al*., 1976).

The earthworm intestine contains about twice the quantity of water as found in the soil and this could be a factor that might be the most rate-limiting relative to the activity of soil and earthworm associated microbes (Jonathan, 2006). In addition, the increased organic carbon and nitrogen content of the worm gut might also stimulate the microbial activity (Blanchart *et al*., 1997). Microbes play an important part as a diet of earthworms which even prefer organic matter with high concentration of microbial life.

DIFFERENT SOURCES OF VERMICOMPOST

Worms are used to convert organic waste into dark brown nutrient rich humus. Worms leave behind while reducing the household wastes turn into a good source of manure for plants the excreta. In specific cases, worms could degrade specific pollutants and might allow community formation of useful microorganisms. Due to low cost nature of inputs, the price of vermicompost in the market is usually low in South Asian countries like India. Earthworms bio engineering principles which could potentially act as a substitute to thermophilic composting is becoming increasingly common and numerous studies have shown that increased plant growth and yield could be achieved when plants grown in the presence of vermicompost (Atiyeh *et al*.,2000, Arancon *et al*.,2004, Arancon *et al*.,2004, Lee *et al*.,2004).

Vermicomposting from Household Wastes

Following methods could be adopted for making vermicompost from household wastes. A wooden box of 45 × 30 × 45 cm or an earthen/plastic container with broad base and drainage holes should be used for this purpose. A plastic sheet with small holes should be placed at the bottom of the wooden box. 3 cm layer of soil and a 5 cm layer of coconut fiber for draining of excess moisture are kept inside the box at the bottom. A thin layer of compost along with worms as inoculums was placed above it. About 250 worms are sufficient for the box. Vegetable wastes should be added in layers daily on top of the inoculums in daily basis. The top of the box should be covered with a piece of gunny bag to provide dim light inside the box. When the box is full, the box should be left undisturbed for a week. When the compost seems to be ready, the box should be kept in light for 2 - 3 hours so that the worms go down to the lowermost coconut fiber layer. The composted materials should be removed from the top of the box and gradually down and sieved for use in the urban or intensive horticultural and agricultural systems.

Vermicomposting of Farm Wastes

Pits of sizes 2.5 m × 1 m × 0.3 m (length, breadth and depth) are taken in thatched sheds with sides left open. The bottom and sides of the pit are made hard by compacting with a wooden mallet. At the bottom of the pit a layer of coconut husk is spread with the concave side upward to ensure drainage of excess water and for proper aeration. The husk is moistened and above this, bio- waste mixed with cow dung in the ratio of 8:1 is spread up to a height of 30 cm above the ground level and water is sprinkled daily. After the partial decomposition of wastes for 7 to 10 days, the worms are introduced @ 500 to 1000 in numbers per pit. The pit is covered with jute bags. Moisture is maintained at 40 to 50 per cent population density and a temperature of 20°C - 30°C by sprinkling water over the bed. At higher temperature the worms are found to aestivate and at lower temperature, they will hibernate. When the compost is ready, it is removed from the pit along with the worms and heaped in shade with ample light. The worms will move to bottom of the heap. After one or two days, the compost from the top of the heap is removed. The undecomposed residues are put back to the pit with worms for further composting.

Vermicompost Harvesting

Harvesting the compost means removing finished castings from the beds. The finished product is black or dark brown and is called crumbly worm compost. Harvesting the compost and adding fresh bedding, at least twice a year is necessary to keep the worms healthy. The compost can be harvested by spreading a sheet of plastic under a bright light or in the sun. The contents of the bed leaving the bedding materials are divided into a number of heaps on the sheet. The worms will crawl away from the light into the center of each heap and the worm compost can be brushed away on the outside by hand. The crawling worms will be collected for reuse.

Table 3: Details of physical- chemical process of vermicomposting in soil

S.No	Characteristics	Vermicomposting
	physical	
1.	Degree of composition	Complete, resulting in small uniform particles
2.	Formation of aggregation	Significantly more
3.	Porosity of soil	Significantly increased
4.	Aeration	Significantly enhanced
5.	Bulk density	Reduced
6.	Particle density	Reduced
7.	Heat and odour	No heat generation (no thermophilic stage) and removes all bad odours
8.	Texture and structure of soil	Significantly improved
9.	Water penetration and Retention in soil	Good
	Chemical	
1.	P^H	Reduced, near neutral
2.	C/P, C:N ratio	Narrow and optimal
3.	Mineralisation	Greater
4.	Available NPK	Greater
5.	Form of N release	In the form of nitrate
6.	Solubilization of P	Greater because of more P solubilizing microbes
7.	Availability of Zn, Fe, S, Mn, Mg	Greater
8.	Electrical conductivity	Optimally changed
9.	Humification, oxidation and stabilization	Significantly increased
10.	Cation exchange capacity of soil	Significantly increased
11.	Time taken for decomposition	Less
	Biological	
1.	Agents of decomposition	Earthworms together with microorganisms facilitate better and faster decomposition
2.	Secondary agents of decomposition	Nil
3.	Plant growth promoting factors	More hormones (auxins, indole acetic acid, gibberellins) vitamins
4.	Propagation of useful microorganisms	Propagates, selectively useful microorganisms
5.	Pathogenic microbes	Most of the pathogenic organisms are destroyed
6.	Population of N- fixation and P-solubilizing microbes	More
7.	Symbiotic mycorrhizal association	Promoted significantly
8.	Nodulation	More and active
9.	Antibiotic property	Virucidal, bactericidal
10.	Release and retention time of nutrients	Slower and longer release
11.	Nutrients uptake by the plants	Promoted significantly
12.	Microbial biomass	Increased greatly
13.	Microbial activity	Greatly increased
14.	Soil enzymes	Greatly increased
15.	Nematode control	Good control
16.	Plant nutritive value	Greatly more
17.	Development of plant resistance to decrease	Resists more
	Environmental,Economical and Social	
1.	Eco-friendliness	More eco-friendly
2.	Pollution control	Effective
3.	Bioremediation	Effective
4.	Support to other industry	Supports live stock, piggery, fisheries, sports
5.	By –product	Vermiprotein, vermiwash
6.	Socio economic potential	Greater
7.	Economic value of plant product	Significantly more
8.	Aesthetics	Appealing

VERMIWASH – (WORM TEA)

Vermiwash is a brown coloured liquid collected after the passage of water through a column of worm culture. This liquid partially contains water from the body of earthworms (as worm's body contain plenty of water) and is rich in amino acids, vitamins, nutrients like nitrogen, potassium, magnesium, zinc, calcium, iron, and copper, as well as some growth hormones like auxins and cytokinins. It also contains plenty of nitrogen fixing and phosphate solubilizing bacteria (nitrosomes, *Nitrobacter*, and actinomycetes) (Fayez *et al.*, 1985). As per Prabu (2006), it is alkaline in nature and contains nitrogen, phosphorus, potash, calcium, magnesium and zinc in appreciable quantities. Subasashri (2004) stated that vermiwash has enzymes that stimulate plant growth and yield, and enables the development of resistance in crops.

PROBLEMS IN USING VERMIWASH

The fluid matter is collected from the decomposing organic waste and is not passed through microbial filters, therefore, such extract may contain microbial flora and may have negative effect on plant growth.

PREVENTIVE MEASURES DURING THE PROCESS

The following precautions should be taken during vermicomposting.

The African species of earthworms, *Eisenia fetida* and *Eudrilus eugenae* are ideal for the preparation of vermicompost. Most Indian species are not suitable for the purpose.

Only plant-based materials such as grass, leaves or vegetable peelings should be utilized in preparing vermicompost.

Materials of animal origin such as eggshells, meat, bone, chicken droppings, etc. are not suitable for preparing vermicompost.

Gliricidia loppings, tobacco leaves, onion, garlic, chilli etc. of kitchen wastes are not suitable for rearing earthworms.

The earthworms should be protected against birds, termites, ants and rats.

Adequate moisture should be maintained during the process. Either stagnant water or lack of moisture could kill the earthworms.

After completion of the process, the vermicompost should be removed from the bed at regular intervals and replaced by fresh waste materials.

ROLE OF VERMICOMPOST IN WASTE MANAGEMENT

Red worm castings contain a high percentage of humus. Humus helps soil particles form into clusters, which create channels for the passage of air and improve its capacity to hold water. Presence of worms regenerate compacted soils and improves water penetration in such soils by over 50%. (Ghabbour, 1973, Bhat and Khambata, 1996, Capowiez *et al*., 2009).

A worm casting (also known as worm cast or vermicast) is a biologically active mound containing thousands of bacteria, enzymes, and remnants of plant materials that were not digested by the worms.

Castings contain slow released nutrients that are readily available to plants. Castings contain the plant nutrients that are encased in mucus membranes that are secreted by the earthworms. They dissolve slowly rather than allowing immediate nutrient leaching. The product has excellent soil structure, porosity, and aeration and water retention capabilities. Castings can hold 2 - 3 times more water than their weight in soil. Worm castings do not burn root systems.

Plant Growth Regulating Activity: Positive effects of vermicompost include stimulated seed germination in several plant species such as green gram (Karmegam *et al*.,1999) tomato plants (Atiyeh *et al*., 2000, Zaller, 2007), petunia (Arancon *et al.,* 2008) and pine trees (Lazcano *et al.,* 2010).

Ability to develop Biological Resistance in Plants, Minimize Pests Attack and Suppress Plant Disease.

TRAILS OF VERMICOMPOST IN CROP PLANTS

There have been several reports that earthworms and their vermicompost can induce excellent plant growth and enhance crop production.

Cereal Crops

Glasshouse studies made at CSIRO Australia found that the earthworms (*Aporrectodea trapezoids*) increased growth of wheat crops (*Triticum aestivum*) by 39%, grain yield by 35%, lifted protein value of the grain by 12% and resisted crop diseases as compared to the control. The plants were grown in a "red-brown earth" with poor nu- tritional status and 60% moisture. There were about 460 worms per m–2 (Baker *et al.,*1997). They also reported that in Parana, Brazil invasion of earthworms significantly altered soil structure and water holding capacity. The grain yields of wheat and soybean was increased by 47% and 51%, respectively (Baker *et al*., 2006). Some studies were made on the impact of vermicompost and garden soil in different proportion on wheat crops in India. It was found that when the garden soil and vermicompost were mixed in 1:2 proportions, the growth was about 72% - 76% while in pure vermicompost, the growth increased by 82% - 89% (Krishnamoorthy and Vajranadhaiah, 1986). Another study coincide with earthworms and their vermicast improve the growth and yield of wheat by more than 40% (Palanisamy, 1996). Similarly that reported better yield and growth in wheat crops applied with ver micompost in soil (Roberts *et al*.,2007, Suthar, 2005,2010). Studies made on the agronomic impacts of vermicompost on rice crops (*Oryza sativa*) reported greater population of nitrogen fixers, actinomycetes and mycorrhizal fungi inducing better nutrient uptake by crops and better growth (Kale *et al*.,1992). Finding of made on the impact of vermicompost on rice legume cropping system in India. Integrated application of vermicompost, chemical fertilizer and biofertilizers (*Azospirillum* and phosphobacteria) increased rice yield by 15.9% over chemical fertilizer used alone. The integrated application of 50% vermicompost, 50% chemical fertilizer and biofertilizers recorded a grain yield of 6.25 and 0.51 ton/ha in the rice and legume respectively. These yields were 12.2% and 19.9% higher over those obtained with 100% chemical fertilizer when used alone (Jeyabal and Kuppuswamy, 2001). Studies from Philippines also reported good response of upland rice crops where grown on vermicompost (Guerrero, 2008).

Fruit Crops

Worm waste (vermicompost) boosted grape yield by two-fold as compared to chemical fertilizers. Treated vines with vermicompost produced 23% more grapes due to 18% increase in bunch numbers. The yield in grapes was worth additional value (Buckerfield and Webster, 1998). Farmer in Sangli district of Maharashtra, India, grew grapes on "eroded wastelands" and applied vermicasting @ 5 tons/ha. The grape harvest was normal with improvement in quality, taste and shelf life. Soil analysis showed that within one year pH came down from 8.3 to 6.9 and the value of potash increased from 62.5 kg/ha to 800 kg/ha. There was also marked improvement in the nutritional quality of the grape fruits (Sinha *et al*., 2009). Study was made on the impacts of vermicompost and inorganic (chemical) fertilizers on strawberries (*Fragaria ananasa*) when applied separately and in combination. Vermicompost was applied @ 10 tons/ha while the inorganic fertilizers (nitrogen, phosphorus, potassium) @ 85 (N):155 (P):125 (K) kg/ha. Significantly, the yield of marketable strawberries and the weight of the largest fruit was 35% greater on plants grown on vermicompost as compared to inorganic fertilizers in 220 days after transplanting. Also there were 36% more "runners" and 40% more "flowers" on plants grown on vermicompost. Also, farm soils applied with vermicompost had significantly greater "microbial bio mass" than the one applied with inorganic fertilizers (Bhat and Khambata, 1996). Vermicompost increased the yield of strawberries by 32.7% and drastically reduced the incidence of physiological disorders like albinism (16.1% → 4.5%), fruit malformations (11.5% → 4%), grey mould (10.4% → 2.1%) and diseases like Botrytis rot. By suppressing the nutrient related disorders, vermincompost use increased the yield and quality of marketable strawberry fruits up to 58.6% (Singh et al., 2008). Impact of vermicompost on cherries found that it increased yield of "cherries" for three (3) years after "single application" inferring that the use of vermicompost in soil builds up fertility and restore its vitality for long time and its further use can be reduced to a minimum after some years of application in farms. At the first stage of harvest, trees with vermicompost yielded an additional $63.92 and $70.42 per tree and after three harvests profits per tree were $110.73 and $142.21, respectively (Webster, 2005).

Vegetable Crops

Important vegetable crops like tomato (*Lycopersicum esculentus*), eggplant (*Solanum melangona*) and okra (*Abelmoschus esculentus*) have yielded very good results(Sinha *et al*.,2009, Atiyeh *et al*., 1999, Gupta *et al*.,2008, Guerrero,2006). Usuage of vermicompost on the growth impact of earthworms (with feed materials), vermicompost, cow dung compost and chemical fertilizers on okra (*Abelmoschus esculentus*). Worms and vermicompost promoted excellent growth in the vegetable crop with more flowers and fruits development. But the most significant observation was drastically less incidence of "Yellow Vein Mosaic", "Color Rot" and "Powdery Mildew" diseases in worm and vermicompost applied plants (Agarwal *et al*.,2010). Study was made on the production of potato (*Solanum tuberosum*) by application of vermicompost in a reclaimed sodic soil in India. The overall productivity of potato was significantly high (21.41 tons/ha) on vermicompost applied @ 6 tons/ha as compared to control which was 04.36 tons/ha. The soul infinite of the soil was also reduced and nitrogen (N) contents increased significantly (Ansari, 2008). Study was made on the growth impacts of organic manure (containing earthworm vermicast) on garden pea (*Pisum sativum*) and compared with chemical fertilizers. Vermicast produced higher green pod plants, higher green grain weight per plant, higher percentage of protein content and carbohydrates and higher green pod yield (24.8% - 91%) as compared to chemical fertilizer (Meena *et al*., 2007). Studies made on the effects of vermicompost and chemical fertilizer on the hyacinth beans (*Lablab purpureas*) it was found that all growth and yield parameters e.g. total chlorophyll contents in leaves, dry matter production, flower appearance, length of fruits and fruits per plant, dry weight of 100 seeds, yield per plot and yield per hectare were significantly higher in those plots which received vermicompost either alone or in combination with chemicals. The highest fruit yield of 109 ton/ha was recorded in plots which received vermicompost @ 2.5 tons/ha (Karmegam and Daniel, 2008).

Increasing plant growth and productivity, vermicompost may also increase the nutritional quality of some vegetable crops such as tomatoes (Gutierrez-Miceli *et al*., 2007), Chinese cabbage (Wang *et al*., 2010), spinach (Peyvast *et al*., 2008), strawberries (Singh *et al*.,2008) and lettuce (Coria-Cayupan *et al*., 2009). Due to physical, chemical, biological properties of soil, earthworm nature, vermicompost used to promote sustainable agriculture and also for the proper solid waste management.

TROUBLESHOOTING

Death of worms in large and small numbers

Worms are dying for the following reasons:
If they are not getting enough food, therefore food should be buried into the bedding.
Food may be too dry, so moisture should be maintained until it is slightly damp.
Food may be too wet, in which case bedding should be added.
The worms may be too hot, so the bin or she should be put under the shade.

Bad smells from the vermicomposting grounds

It is due to that there is not enough air circulation. In this case, add dry bedding under and over the worms. Turning of the food may give better result.

There may be the presence of some materials such as meat, pet feces, or greasy foods, which are harmful in the compost, pit. These should be removed.

Important practical points for vermiculture

No smell if the right products or bedding and feed are used.
No need to turn the compost as the worms act like little ploughs turning the bedding and food.
Air is circulating on a continuous period.
Composting time is short in comparison to other composts.
Composting can be done year round.

FOE OF VERMICOMPOST

Ants, lizards, birds, hedgehogs, frogs, toads, rats, shrews, bandicoots, snakes and centipedes are enemies of earthworm. Various biocides such as fungicides, nematicides, insecticides, weedicides and heavy metals are toxic to earthworms. Adequate protective measures have to be taken to protect earthworms from being eaten away by this animals. In organic farming practice, Ismail (1997) recommended spraying of a native decoction containing 20 L water wherein 100 g chilly powder, 100 g turmeric powder, 100 g salt and a little soap powder are added or 0.5% neem oil around the units of vermicomposting.

ENVIRONMENTAL AND ECONOMIC ASPECTS OF VERMICULTURE

Sustainable agriculture is a process of learning new and innovative methods developed by both farmers and the farm scientist and also learning from the traditional knowledge and practices of the farmers and implementing what were good in them and also relevant in present times. Vermiculture was practiced by traditional and ancient farmers with enormous economic benefits for them and their farmlands. There is need to revive this 'traditional concept' through modern scientific knowledge-a 'Vermiculture Revolution'. Sir Charles Darwin called the earthworms as 'farmer's friends'. There is great wisdom in this statement of the great visionary scientist who advocated to use the earthworms, the 'nature's gift' in farm production. It is necessary to adopt and implement food and agriculture production system which must ensure.

(i)High productivity and stability of yield achieved over the years.
(ii) Productivity with minimum use of water and even sustain dryness or heavy rainfall.
(iii) Maintenance of crop diversity (biotopes).
(iv) Preservation of soil, water and air quality in the farm ecosystem.
(v) Preservation of benevolent organisms (predators) flora and fauna in the farm ecosystem.
(vi) Preservation of groundwater table.
(vii) Preservation of good health for all.
(viii) Reduction of water and energy use.
(ix) Produce growth regulators.
(x) Increase soil fertility.

Sustained vermiculture practices and use of vermicompost in farm soil over the years would meet several of the above requirements for a truly sustainable agriculture. Vermicompost rich in microbial diversity and plant available nutrients; improve the moisture holding capacity of soil reduces water for irrigation. It also improves physical, biological and chemical properties of soil; soil porosity and softness. There are also ample opportunities in the reduction of uses of energy and GHG emissions in vermicompost production locally at farms by the farmers themselves, (Singh, 1993).

CONCLUSION

Global organic farming and sustainable agriculture can massively bring in 'economic prosperity' for the farmers, 'ecological security' for the farms and 'food security' for the people. This will promote on a 'Second Green Revolution' and this time through 'Vermiculture Revolution' by the earthworms. This practice will ensure economic empowerment and environmental sustainability. Vermicompost is the best agromanager, and without proper management of waste may cause serious threat to our life and environment. This review paper describes the strategies, dynamics of vermicompost between the soil, earthworm, plant relationship. The slogan reveals that 'Don't waste, waste becomes Art' help to create the healthier environment thus condemning them as waste.

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