Chapter 14

Vermicomposting for Soil Fertility Improvement and Solid Waste Management in Plantations

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Sustainable agriculture (including forestry) involves the successful management of agricultural resources to satisfy human needs, while maintaining or enhancing environmental quality and conserving natural resources for future generations. Improvement in agricultural sustainability requires, alongside effective water and crop management, the optimal use and management of soil fertility and soil physical properties. Both rely on soil biological processes and soil biodiversity. This calls for the widespread adoption of management practices that enhance soil biological activity and thereby build up long-term soil productivity and health.

The goal of efficient agriculture is, therefore, to develop agro-ecosystems with minimal dependence on agrochemicals and energy inputs in which agroecological interactions and synergy among biological components provide the mechanisms for the system to sponsor their own soil fertility and crop production functions. The array of organisms in the soil also partially determines soil resilience, the desirable ability of a given soil to recover its functions after a disturbance such as fire, compaction and tillage.

I. Soil biodiversity and sustainable agriculture

Soil is a dynamic, living matrix that is an essential part of the terrestrial ecosystems. Soil contains enormous number of diverse living organisms assembled in complex and varied communities. Soil biodiversity includes invisible microorganisms like bacteria, fungi and actinomycetes to the more familiar macro-fauna such as earthworms and termites. Plant roots can also be considered as soil organisms in view of their symbiotic relationships and interactions with soil components. Each of these organisms has a specific role in the complex web of life under the soil.

- The activities of certain organisms affect soil structure–especially the so-called "soil engineers," such as earthworms and termites-through mixing soil horizons, organic matter and augmenting porosity. This directly determines vulnerability to soil erosion and availability of soil profit to plants;
- The functions of soil biota are central to decomposition processes and nutrient cycling. They, therefore, affect plant growth and productivity as well as release of pollutants in the environment, leaching of nitrates in water resources, methane emission;
- Certain soil organisms can be detrimental to plant growth, for example, nematodes under certain cropping practices. However, they can also protect crops from pest and disease outbreaks through biological control and reduced susceptibility.
- The activities of certain organisms determine the carbon cycle, the rates of carbon sequestration and gaseous emissions and soil organic matter transformation;
- Plant roots, through their interactions with other soil components and symbiotic relationships, especially *Rhizobium* bacteria, P-solubilizers, PGPRs and mycorrhizae, play a key role in the uptake of nutrients and water and contribute to the maintenance of soil porosity and organic matter content through their growth and biomass.
- Soil organisms can also be used to reduce or eliminate environmental hazards resulting from accumulations of toxic chemicals or other hazardous water.

II. Role of earthworms in improving soil fertility

Earthworms are so called because they are almost always terrestrial and burrow into moist-rich soil, emerging at night to forage. Charles Darwin (1981) had written that earthworms are great benefactors of soil and agriculture and the earthworm casts are good fertilizer. These worms continuously till and aerate the soil, supply it with organic matter, and help moisture reaching it via the burrows they make. The earthworm activity in soil is known to reduce plant pathogens (Szczeck, 1999) and releases enzymes and hormones in their excreta which are beneficial for plant growth (Tomati *et al.*, 1987, Spain *et al.*, 1992, Chaoui *et al.*, 2003). Thus earthworms that constitute highest biomass among tropical macrofauna and have been indicated as potential indicators of sustainability of agroecosystems (Christenson, 1991) play a vital role in restoring the degraded soil fertility (Joshi and Kelker, 1951; Lavelle, 1988).

III. Distribution and classification of earthworms

There are more than, 1800 known species of earthworms (Minnich, 1977) which are found in most parts of the world with exception of deserts, areas under snow and ice mountain ranges, areas bereft of soil and vegetation. Species of earthworms which are widely distributed are described as peregrine earthworms,and species which occur in specific areas have been termed endemic (Michaelson, 1910).

a) Classification based on habitat

Earthworms have been classified into 3 broad categories based on the ecological habitat (Bouche, 1977), These forms are (i) *epigeics*, (ii) *anecics* and (iii) *endogeics*. The different characteristics used for distinguishing the 3 ecological types are given below in Table-1

Table 1. Characteristics used for distinguishing different ecological types of earthworms (Bouche, 1977)

Character	Ecological type		
	Epigeics	Anecics	Endogeics
Body	small	moderate	large
Burrowing	reduced	strongly developed	developed
Longitudinal contraction	absent	present	least developed
Hooked chetae	absent	present	absent
Sensitivity to light	feeble	moderate	strong
Mobility	rapid	moderate	feeble
Skin moistening	developed	developed	feeble
Pigmentation	homochronic	dorsal and anterior	absent
Fecundity	high	moderate	limited
Maturation	rapid	moderate	slow
Respiration	high	moderate	feeble
Survival in adverse condition	as cocoons	true diapause	by quiescence

(i) *Epigeics*: Epigeic earthworms live above the mineral soil surface (Lee, 1985). They are phytophagous and generally have no effect on the soil structure, as they cannot dig into the soil. They are small in size with uniform coloration.

(ii) *Anecics*: These worms live in burrows in mineral soil layer, but come to surface to feed on dead debris/litters, which they drag into their burrows. They are geophytophagous as they ingest both soil as well as plant litter. Presence of vertical tunnel in soil indicates the activity of anecic earthworms.

(iii) *Endogeics*: These species inhabit the mineral soil zones feeding on soil which is enriched with organic matter (Lee, 1985), They are geophagous and construct horizontal branching burrows in soil. They are not pigmented.

The endogeics were further categorised into mesohumic endogeics, polyhumic endogeics and oligohumic endogeics based on their preference of soil with organic matter content (Lavelle, 1981). However, such demarcation could not be made with respect to earthworms in Indian tropics where majority of the worms are endogeic and only few are epigeics or anecics (Kale and Krishnamoorthy, 1978).

b) Classification based on diet

Earthworms are generally known to consume food every day equivalent to their body weight (Minnich, 1977). The bulk of their diet consists of decaying organic waste of almost any origin. Living organisms like fungi and bacteria are also ingested (along with decaying organic matter) and this forms an important part of their diet (Lee, 1985). Lee (1985) described earthworms, which feed on plant debris that is only slightly decomposed as *humus formers* and those which feed on plant debris that is already much decomposed as humus feeders. Besides these, Lee also classified worms that feed on a high proportion of raw humus as *detrivorous* and those that feed on amorphous humus and mineral material as *geophagous*.

IV. Environmental requirements for earthworms

Earthworms like all life forms require particular environmental parameters within which they flourish. Most important among these are soil moisture, pH and temperature. Food requirements, limiting light and soil composition are also important.

Soil moisture: Earthworms have very few mechanisms to preserve their body moisture. Their moist bodysurface requires moist environment without which they perish in short time. Optimum cocoon production occurs between 28 and 42 per cent soil moisture (Evans and Guild, 1982) and population densities are usually the highest between 12 and 30 per cent soil moisture (Minnich, 1977). In practice this means keeping the earthworm medium moist but not wet. These are the reasons why earthworms do not thrive well in dry soils or during drought season and heavy flooding. Moisture also governs the growth, maturation and cocoon production of worms (Veljoen and Reinecke, 1989).

Soil pH: Earthworms are very sensitive to pH. They prefer a soil with a neutral pH, or slightly alkaline (Lee, 1985). Acidic soils do not harbour earthworms in large numbers.

Temperature: It has been reported that the structure of earthworm community is mainly determined by temperature (Lavelle, 1983) and tropical countries harbour more species. In temperate countries, the most favourable temperature for most of the earthworms is between 13 to 18°C (Minnich, 1977). However, in tropical country like India, the earthworms particularly *Eudrillus euginiae*, have been reported to perform well between 25.9 and 27.7°C (Amoji et al., 1999). However, there is very less information available on the life cycle of the earthworm under tropical and subtropical climatic conditions (Kale *et al.*, 1982).

Light: Light can injure or kill earthworms, especially ultra-violet light. The only concern this will pose is keeping the earthworm 'farm' away from intense crop light.

Earthworm population: Earthworms are capable of growing at very high population densities. The best natural ecosystem (Nile Valley) has roughly a million earthworms per area which works to 5000/m^2 (Hopp and Slater, 1948). Commercial growers can support densities of 100,000 earthworms/m^3 (Minnich, 1977).

V. Earthworm activity: Earthworms perform three main activities viz. burrowing, feeding and casting which are responsible for improving the soil health and fertility.

i) **Burrowing**: Earthworms create horizontal and vertical tunnels in soil as they move. Burrows range from 3-12 mm in diameter. These are cemented internally by secretion of worms cutaneous glands. Soil porosity, aeration and friability are significantly improved due to burrowing activity.

ii) **Feeding**: Earthworms mainly feed on the decaying organic matter found in the soil. The food is moistened by alkaline enzymatic secretion, which digests starch, making it easier to shred.

iii) **Castings**: The organic matter consumed by the earthworms is degraded by microorganisms and enzymes present inside the gut of the worm. After getting digested in the gut, the food emerges as a compact concentrated mass termed as 'casting' or 'vermicast'. These casts are rich in microorganisms, inorganic minerals and organic matter in a form available to plants. These are also rich in enzymes such as protease, amylase, lipase, cellulase and chitinase, which continue to disintegrate organic matter even after they have been excreted. Table-2 gives the details of earthworm casts and soil from a cultivated field.

Table 2. Properties of earthworm casts and soil from a cultivated field (Lunt and Jacobson, 1944)

Compound	Casts	Cultivated soil	
		0-6'	8-16' depth
Total N	0.035	0.24	0.08
Organic carbon (%)	5.17	3.35	1.11
C:N ratio	14:7	13:8	13:8
NO_3 Nitrogen (ppm)	21.9	4.7	1.7
Available P (ppm)	150.0	20.8	8.3
Exchangeable calcium (ppm)	2,793.0	1993.0	418.0
Exchangeable magnesium (ppm)	492.0	162.0	69.0
Exchangeable potassium (ppm)	358.0	32.0	27.0
Total calcium (%)	1.19	0.88	0.91
Total magnesium (%)	0.54	0.511	0.54
Percent saturation	92.9	71.1	55.5
pH	7.0	6.36	6.05
Moisture equivalent	31.4	27.4	21.1

VI. Vermicomposting for solid agricultural waste management

Vermicomposting (Vermes, a Latin word = worm) is a kindered process to composting, featuring the addition of certain species of earthworms used to enhance the process of waste conversion and produce a quality end product. It differs from composting in several ways. Chiefly, vermicomposting is a mesophilic process, utilizing micro-organisms and earthworms that are active in temperature range of 50-90° F (not the ambient temperature but temperature within the pile of moist organic material). Common composting on other hand is produced entirely by the activity of micro-organisms on organic matter. Vermicomposting process is considered faster than composting as the material passes through the earthworm's gut where transformation takes place, whereby the resulting earthworm castings (vermicast, worm manure), abundant in microbial activity and plant growth regulators and fortified with pathogen suppressing attributes. In recent years, earthworms have been increasingly employed in vermicomposting of agricultural wastes (Edward *et al.*, 1985; Amoji et al., 1998). A wide variety of agricultural wastes beginning with straw (Curry and Byrne, 1992), vegetable wastes, fruit rinds, leaf-litter, grass clippings, weeds (Rao, 2005) and neem leaves (Gajalakshmi and Abbesi, 2004) have been successfully converted to vermicompost by earthworms which are being used for improving soil fertility and increasing plant productivity in an ecologically safe and sustainable way.

VII. Systems of vermicomposting

Vermicomposting can be carried out in indoor systems and outdoor systems based on the availability of facilities.

1. Indoor systems

This method is used for commercial exploitation of earthworms for vermicompost production. Vermicomposting can be carried out inside permanent or temporary structures such as sheds. The indoor systems have the advantages in providing the optimal conditions for vermicomposting and proper protection for the worms from predators like rodents, wild boars and birds. Small scale vermicomposting at individual house level can also be carried out in plastic buckets, wooden boxes or cement tubs. Medium to large scale composting can be done in cement rings or tanks built of bricks or cement. Large scale vermicomposting is carried out by heaping the soil wastes in the shape of a cone under roof. This has been found to favour fast composting by ensuring proper aeration, allowing the worms to feed from all sides.

2. Outdoor systems

In this, composting is done at the source of organic wastes such as orchards and plantations with grown up trees and proper shade.

These systems have the advantages that the wastes as well as compost require very little transport, thus saving a lot of labour. The free space available in the garden may also be utilized for composting by heaping method. Vermicomposting in irrigated gardens and indoor composting systems have been exploited to achieve three benefits.

1. Management of organic wastes and abatement of pollution by rapid reduction in bulk density and elimination of foul odour.
2. Production of vermicompost containing easily available nutrients and plant growth promoting microbes and biochemicals.
3. Production of vermiprotein as feed for poultry and fishes.

VIII. Plantation waste management by vermicomposting

Plantation crops are high value commercial crops which are valued for their contribution to the national exchequer by way of export earnings. It covers a variety of crops like coconut, arecanut, cocoa, cashew, oil palm, spices, besides well known conventional crops like coffee, tea and rubber. These crops are cultivated in diverse farming systems and are known for their high socio-economic relevance. The major area under these crops belong to small holder sector with notable exception of tea. Plantation crops, being perennial in nature, provide vegetative cover and prevent soil erosion and foster the ecological balance. Apart from the economic product, the plantation crops produce large quantities of lignocellulosic biomass, which are often wasted in plantations without proper use. Considerable success has been achieved in bioconversion of the lignocellulosic biomass from the plantation crops to acceptable organic manure using different species of epigeic earthworms. Successful technologies have been developed to vermicompost wastes from plantations such as coconut leaves (Prabhu *et al.*, 1998), coconut coir waste (Ramesh and Gunathilegeraj, 1996), arecanut and cocoa wastes (Chowdappa *et al*, 1999) and coffee pulp (Orozco *et al.*, 1996). The vermicomposting technology and characteristics of vermicompost obtained from waste biomass of plantation crops such as coconut, arecanut, cocoa and coffee are described below:

VIII. 1. Vermicomposting of coconut palm wastes

The coconut palm is an important oil yielding plantation crop grown in an area of 18.92 lakh hectares in coastal regions of the country. It is a small holders plantation crop mostly grown in homestead gardens. Studies conducted at Central Plantation Crops

Research Institute, Kasaragod have revealed that one hectare of coconut plantation produces about 8000 kg dry organic biomass per year in the form of leaves. As the use of this biomass as fuel and thatching material has declined over the years, its disposal in a meaningful way has become a problem in many coconut gardens. If we can recycle all the organic wastes available from a plantation, it can supply the major portion of nitrogen and apart of other nutrients required by the palms. This waste is rich in ligno-cellulosic complexes and polyphenols which have the potential to produce humus, nitrification and urease inhibitors respectively. These biochemicals can influence soil health and long-term soil fertility. But, because of high proportion of lignin, these wastes undergo decomposition rather slowly. The possibility of using earthworms to enhance the decomposition rate was examined, as it is known that the action of earthworms is more important and pronounced on recalcitrant wastes than easily decomposable ones.

a) Earthworm species suitable for coconut palm wastes

Among the local earthworms tested for their ability to multiply and produce vermicompost from coconut palm wastes, a strain of *Eudrilus* was the best and hence more studies were conducted. *Eudrilus* sp. was located from a heap of coconut palm wastes, which were seen fully converted into vermicasts, leaving behind only mid-ribs of the leaves. Methods for maintenance and large-scale mutliplication have been standardized. It can be multiplied fast in 1-1 mixture of cow dung and decayed leaves mulched properly with grasses.

Studies conducted have revealed that this strain of *Eudrilus* is different from *Eudrilus eugeniae,* the African night crawler, which has its origin in tropical and subtropical Africa. The strain of *Eudrilus* located at Kasaragod differs from the African strain in its colour, vigour, behaviour, cocoon colour and reproductive rate on coconut wastes. It is also capable of active feeding on soil and digested soil in the form of pellets which are deposited around burrow holes.

(b) Vermicomposting technology for coconut leaves: A low cost technology has been standardized for vermicomposting, the biomass from coconut palms left exposed to the action of weather in the field for about 3 months. (Prabhu *et al.,* 1998). The weathered wastes obtained during rainy seasons is preferred. This waste can be used without chopping thus saving a lot of a labour. The coconut wastes used for oyster mushroom cultivation were also found suitable for vermicomposting. These organic wastes are treated with cow dung at the rate of 10% by weight, in the form of slurry to undergo a preliminary decomposition for about 2-3 weeks. The earthworms at the rate of 1000 worms per ton of coconut leaves are introduced. The compost bed should be mulched properly using any locally available plant material or gunny bags and has to be protected from direct sunlight. Watering is done periodically to maintain enough moisture. As full leaves are used for composting, compact mass is not formed thus allowing free movement of air of the bed. In about 60-75 days, compost will be ready, leaving behind only mid ribs of the leaves. This method was tested in cement tanks and under the root of a shed by heaping. Composting was after in heaps and earthworms were seen feeding and castings from all the sides, may be due to better aeration and exposure. On an average, 70% recovery of vermicompost was obtained. Similar technology for vermicomposting was also tested in large pits taken in the inter spaces of four coconut palms ine sandy loam and coastal sandy soils and was found to work well. As composting is done in the itself, lot of labour required for transportation of the biomass and compost can be saved. This technology can be tried even in plantations with very limited irrigation facilities, as only limited number of pits or trenches need to be watered. The coconut palm waste was also vermicomposted in the basins and inter spaces and these methods are suited for irrigated garden. If all the available biomass from a plantation is recycled through vermicomposting, itcan meet a part of nutrient requirements and especially in coastal regions it could improve soil organic matter content.

c) Characteristics of vermicompost from coconut leaves

The average nutrient composition of the vermicompost recovered was: N% (1.8), P% (0.216), K% (0.16), Organic carbon % (17.84), and C/N ratio (9.96). Total microbial counts and beneficial microbial population were also more in the compost compared to the base material. Two types of active nitrogen fixing bacteria not commonly isolated from soils have also been found regularly associated with vermicast.

d) Vermicomposting of coconut waste (coir pith)

Coir pith accumulates as a waste material near coir processing factories after extraction of coir fibre from coconut husk. Application of coir pith as manure in crop production has not been recommended due to its high C:N ratio and high lignin and polyphenol contents. Vermicomposting of coir pith using a local strain of *Eudrilus sp.* has been found to be effective for bioconversion of these waste materials to useful organic manure (Prabhu *et al.*, 2001; Thomas *et al.*, 2001). Pre treatment with lime and rock phosphate makes the coir pith amenable for earthworm activity. Layering with uncut coconut leaves was also found to be necessary to facilitate aeration. A granular vermicompost with 1.2% nitrogen and a C:N ratio of 16.7:1 could be obtained in two months. Other epigeic or compost worms such as *Perionyx excavatus* (Ramesh and Gunathilagaraj, 1996) and *Eudrilus eugeniae* (Patil *et al.*, 1999) have also been utilized for vermicomposting of coir pith.

VIII. 2. Vermicomposting of areca and cocoa wastes

Arecanut (*Areca catechu L*) is an important commercial plantation crop grown in humid tropics of India. Cocoa (*Theobroma cacao L.*), a shade-loving crop is an ideal mixed crop in arecanut garden (Bhat and Leela, 1968; Bhat, 1978). The area under arecanut cultivation in India is 2.54 lakh hectares (1995-96); while cocoa is cultivated in 14100 ha. Arecanut is generally grown in laterite soils with acidic nature and low nutrient retention capacity.

Successful conversion of available organic wastes of arecanut (*Areca catechu L.*) and cocoa (*Theobroma cacao L.*) gardens into quality vermicompost, using African night crawler (*Eudrilus eugeniae*) was reported by Chowdappa *et al.*, (1999). The level of various nutrients in dry leaves and corresponding vermicompostare presented in Table 3. The recovery of vermicompost was 74.65 to 87.75% in a composting period of 3 months. Earthworm biomass doubled irrespective of organic waste used in a period of two months. Macro nutrients (NPK) and micronutrients (Cu, Zn, Fe and Mn) were slightly higher in all the vermicompost samples than that of normal compost. Vermicompost had lower C: N ratio and pH than normal compost irrespective of the source of organic waste. The population of beneficial micro-organisms was considerably higher in vermicompost than in normal compost. Vermicompost was found to be a profitable venture to enhance income from their holdings. Economics of vermicompost production revealed that the profit of Rs.1.51 to 1.69 could be realized from 1 kg of the compost. Estimated cost of commercial vermicompost production showed that a profit of Rs.11,114/- could be obtained from the vermicompost production from organic wastes available in 1 hectare of arecanut plantation.

Table 3. Nutrient composition in two organic wastes and vermicompost produced from them.

	Cocoa leaves		Areca leaves	
Nutrients	Dried leaves	Vermicompost	Dried leaves	Vermicompost
Organic carbon (%)	47.10	24.4	44.20	33.1
N %	1.27	1.65	0.71	1.38
P %	0.17	0.19	0.08	0.35
K %	0.27	0.32	0.94	0.98
C:N ratio	37.00	14.78	62.25	23.18
Cu (ppm)	32.66	83.60	100.59	120.18
Fe (ppm)	1157.41	2593.0	1745.61	2561.00
Zn (ppm)	228.39	367.7	307.08	395.68
Mn (ppm)	363.1	679.84	81.73	241.68
Moisture		29.94		31.82
pH		7.5		7.3

VIII. 3. Vermicomposting of coffee pulp.

Coffee pulp, comprising the outer hull of the fruit and some of the juices after extraction of the seed, is produced in large quantities as waste material. The transformation of these wastes into a useful organic fertilizer utilizing the earthworm. *Eisenia fetida* has been reported (Orozco *et al.*,1996). A study on the influence of bed depth and time indicated that the C and N contents of the compost were not affected by the depth of the bed whereas time affected both. An increase in the fractionation ratio and low values of humic-like substances were recorded during vermicomposting. The ingestion of the pulp by the earthworms resulted in an increase in available P, Ca and Mg but a decrease in K. The mean increase in available P in the vermicompost compared with the original pulp was about 54%.

IX. Conclusion

Vermicomposting has gained importance as an alternative method for a conversion of degradable organic wastes generated in agriculture and agro industries into manure by the activity of selected species of earthworms. The findings from a number of research institutions and many non-governmental organizations have promoted vermicompost production in rural areas in a manner that is suitable to the local conditions with respect to the availability of waste. Efficient technologies have also been developed for bioconversion of plantation wastes to acceptable organic manure with the utilization of particular species of earthworms suitable for the type of waste material. The vermicompost produced from different agro wastes proved to be a promising soil amendment with respect to nutrient content, growth promoting properties and occurrence of beneficial microbial communities. There is enormous potential for the management of solid wastes generated from agriculture and agro-waste industries in an eco-friendly and cost effective way by vermicomposting.

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