COMPOSTING EFFICIENCY OF INDIGENOUS AND INTRODUCED EARTHWORMS

By

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DECLARATION

I hereby declare that this thesis entitled "Composting efficiency of indigenous and introduced earthworms" is a bonafide record of research work done by me during the course of research and that the thesis had not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other university of society.

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CERTIFICATE

Certified that this thesis entitled "Composting efficiency of indigenous and introduced earthworms" is a record of research work done independently by Smt. JIJI, T. (93-21-07) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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INTRODUCTION

Agriculture in order to be truly productive should have long-term sustainability by way of sustenance of natural resources, economic viability and social acceptability of production systems and protecting environment (Paroda, 1996). However, the basic natural resources for agricultural development like land, water, fauna and flora are subject to several deteriorating influences.

Continuous application of inorganic chemical fertilisers disturbs soil structure, soil aeration, pH and even soil biology. The unbalanced use of synthetic fertilisers and chemicals has resulted in the deterioration of soil health and increased environmental pollution. The residues of pesticides contaminate both surface water and ground water. They may enter the life chain through aquatic organisms resulting in bio-magnification. A fast deteriorating natural resource base cannot support agricultural development. Hence it is imperative to develop strategies for conservation and improvement of resources.

Organic farming is a production system which avoids the use of synthetic fertilisers, pesticides and growth regulators. It involves a holistic approach for sustainable yield, environmental safety and ecological protection. The principle of

organic farming is to produce human food of optimum quality and quantity, using methods like vermitechnology which seek to co-exist with natural system.

Status of soil organic matter in humid tropical countries is generally low. Its maintenance is very important for sustaining crop productivity. Vermicomposting can be an important component of organic farming since it can be used for converting urban and rural wastes into nutrient-rich compost. Recycling of available biowaste is also helpful in reducing environmental pollution. Thus vermitechnology offers a cost-effective method for efficient composting of organic wastes, useful for obtaining organic fertiliser and reducing environmental pollution.

Earthworms play a key role in soil biology as versatile bioreactors. They effectively harness the beneficial microflora *viz.* bacteria and fungi which constitute the prime work force in soil. The presence of vermicompost enhances the uptake of macro- and micro-nutrients for plants, harbours rich amount of microbes and degrades and mobilises the nutrient to available form. Vermicompost also helps to improve soil structure and texture and water holding capacity of the soil.

There are several reports on the use of detritivorous terrestrial and aquatic Oligochaeta worms in the decomposition of organic wastes (Edwards, 1984). Many workers had suggested vermitechnology as an ideal option for organic waste management in India (Senapati and Dash, 1982; Ismail, 1985; Kale, 1991). The scope of earthworm in the recycling of biowastes has been proposed by many workers (Kale *et al.*, 1982; Edwards and Bater, 1992).

Earthworms differ in their feeding habits, composting efficiency, tolerance to stress conditions and multiplication rate. Screening of earthworm species with respect to their composting efficiency will help to identify useful species for vermiculture. Standardisation of techniques for mass multiplication of such species will be useful for large scale local adoption of vermitechnology. A comparative study of the efficacy of vermicompost and farm yard manure as well as inorganic fertilisers will be useful for reducing / dispensing with the use of the latter two inputs. Knowledge of the effect of biopesticides and insecticides on earthworm will also be useful for utilisation of *in situ* vermiculture.

In this context the present study was formulated with the following objectives:

(i) to collect and identify earthworms from different soil types,

(ii) to measure the composting efficiency and breeding potential of identified species,

(iii) to study the comparative bionomics of the exotic species *Eudrilus eugeniae* and one promising indigenous species,

(iv) to assess the effect of applying vermicompost on pests, diseases and yield of crops,

(v) to evaluate the effect of bio-pesticides and synthetic pesticides on indigenous and exotic earthworm species, and

(vi) to estimate quantitatively, CO_2 evolution and microflora during composting.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Organic farming is a production system which avoids the use of synthetic fertilisers, pesticides and growth regulators. The principle of organic farming is to produce food of optimum quality and quantity, using technologies like vermi-technology, which seek to co-exist with natural system.

There are several reports on the use of detritivorous terrestrial and aquatic Oligochaeta worms in the decomposition of organic wastes (Hartenstein *et. al.*, 1979; Collier and Livingstone, 1981; Graff, 1981; Kale *et. al.*, 1982; Tomati *et al.*, 1983; Edwards, 1984). The usual practices of composting dung material were found to be inefficient due to significant loss of nitrogen during the process (Chandra and Seckler, 1980). Many workers suggested vermi-technology as an ideal option for organic waste management in India (Senapati *et al.*, 1980; Dash and Senapati, 1986; Kale and Bano, 1988; Senapati, 1988; Bhawalkar, 1990; Bhagyalakshmi *et. al.*, 1994 and Padmaja *et. al.*, 1996).

The use of earthworms for composting has been studied by many workers (Atlavinyte, 1971; Senapati and Dash, 1982; Bano *et al.*, 1984; Bhawalkar, 1993; Madhukeshwara *et al.*, 1996; Swami and Rao, 1996). Kale *et al.* (1982) reported that the earthworm *P. excavatus*, *E. eugeniae* and *Eisenia foetida* could degrade organic wastes and convert into nutrient-rich manure. Tomati *et al.* (1985 and

1988) discussed the feasibility of vermiculture as an economic option in organic waste recovery for agricultural purposes, with particular emphasis on sludge and solid urban wastes. They found that earthworm could consume all the organic wastes and reduce their volume by 40-60 per cent. As a result, castings with a high fertility value could be produced. Remarkable quantities of mineralisable or available nutrients, a large microbial population and biologically active metabolites, particularly gibberellins, cytokinins and auxins were also found. Edwards and Bater (1992) discussed the use of earthworms in organic waste management. They studied the life cycle and productivity of *Eisenia foetida*, *E. eugeniae*, *P. excavatus* and *Dendrobaena veneta*. Kale (1991) established the possibility of using earthworms under semi-natural conditions. Padmaja *et al.* (1994) standardised techniques for converting garden waste and kitchen waste into vermicompost. Gunathilagaraj and Ravignanam (1996 a) reported that sericulture wastes could be converted to nutrient rich vermicompost using *P. excavatus*.

2.1. Survey

Soil characteristics can determine earthworm activity and *vice versa*. Earthworm can be a key component in the biological strategies of nutrient cycling in soil. The structure of the communities of the earthworms gives indication of the system they inhabit (Lavelle, 1988).

The modern agricultural practices and denudation of forests exerted an impact on the soil as a habitat, affecting soil fauna and species diversity (Evans and Guild, 1948; Graff, 1953). Although agricultural practices affected earthworm population in general, they could also favour the growth of some species (Edwards and Lofty, 1975). Large population of earthworms was observed in the uncultivated areas as well (Edwards and Lofty, 1977).

There are several reports documenting the variety and diversity of earthworm fauna in our country (Aiyer, 1926; Dash and Patra, 1977). Aiyer (1926) conducted a detailed survey of Oligochaeta of Travancore and reported 49 species belonging to three families. Earthworms in and around Bangalore were reported by Kale and Krishnamoorthy (1978). Kale and Krishnamoorthy (1981 b) discussed the factors affecting distribution and abundance of earthworms in soil.

From southern Karnataka Bano and Kale (1991) reported 44 earthworm species belonging to seven families. Environmental factors and soil conditions determine the density and distribution of earthworm. *Allolobophora rosea* was the most wide spread and abundant earthworm species in pasture cereal rotation in South Australia and Western Victoria (Baker *et al.*, 1993). Singh and Rai (1996) reported 384 species of earthworms in India inhabiting different soil strata.

2.2. Composting efficiency and breeding potential of earthworms

2.2.1. Composting efficiency of *Eudrilus eugeniae*

In the tropical and subtropical soils, majority of the earthworms feed on soil mixed with humus. Such worms are of the least importance in the composting process. The worms which directly feed actively on the decomposing organic matter are required for the purpose. Such worms are categorised under `epigeic' which live on the soil surface in the organic debris. *E. eugeniae* is a promising epigeic species.

Graff (1981) reported that poultry manure with straw is unacceptable for the earthworm. Bano *et al.* (1984) found that *E. eugeniae* could be cultured for cast production. Bano and Kale (1988) suggested that poultry manure in the form of biogas sludge could be used for the multiplication of the earthworm. The poultry manure with cowdung (1:1 w/w) was found preferable. There are reports that *E. eugeniae* could be used efficiently for vermicomposting in Kerala (Jiji *et. al.*, 1995; Prabhakumari *et al.*, 1995; Zacharia and Prabhakumari, 1996).

The earthworms feed actively on semi-decomposed sericultural wastes and produced vermicasts in a short span of 4-5 weeks. The vermicompost was rich in plant nutrients containing 1.9 per cent N, 0.6 per cent P_2O_5 and 1.0 per cent K_2O

besides various micronutrients like zinc, copper and iron (Das *et al.*, 1996). Feed material with low C:N ratio was required for faster multiplication and vermicomposting (Krishnakumar *et al.*, 1993). They also found that the rate of multiplication was faster with kitchen waste followed by forest leaf litter and cardamom trash.

Madhukeshwara *et al.* (1996) found that the growth and fecundity of earthworms and the rate of compost production showed variations with respect to the substrate used in the feed mix. Maximum biomass and compost production was in the spent leaves. In a pot culture experiment conducted for one year (1.5 kg wastes and 25 worms) the time taken for composting varied between 50 and 75 days (Prabhakumari *et. al.*, 1996). Singh and Rai (1996) found that *E. eugeniae* was good for vermicomposting garbage, especially kitchen wastes mixed with cattle dung.

2.2.2. Composting efficiency of *Perionyx* spp.

Culturing and use of *Perionyx excavatus* as a protein source was reported by Guerro (1981). Kale *et al.* (1982) studied the composting efficiency of indigenous species *P. excavatus*. It is known to degrade organic waste and convert them into nutrient rich organic manure. Shanthi *et al.* (1993) reported that *P. excavatus* was the appropriate species for vegetable waste composting. Vermicomposting using *P.*

excavatus increased the nitrogen content of mulberry leaf litter and silkworm larval litter. Phosphorus content was increased in cowdung and sericultural wastes. It also enhanced the potassium, manganese, zinc and iron content of the mulberry leaf litter (Gunathilagaraj and Ravignanam, 1996 a). Singh and Rai (1996) found that *P. sansibaricus* was good for vermicomposting kitchen waste mixed with cowdung.

2.3. Bionomics

2.3.1. Bionomics of *Eudrilus eugeniae*

Evans and Guild (1947) reported that many species of earthworms were known to be reproductively active throughout the year. However, seasonal variations are known to affect productivity. Olive and Clark (1978) found that, in general, earthworms are reported as iteroparous and reproduction is of semi-continuous type. Cocoon productivity among earthworm has been related to ecological type, available nutrients and environmental factors (Graff, 1981; Kale *et al.*, 1982; Senapathi and Dash, 1982; Lavelle, 1988). Bano and Kale (1988) reported that *E. eugeniae* has an endogenous rhythm on reproduction. Usually three worms emerge out of each cocoon. The maximum number that could be laid under ideal condition was about 100 cocoon by a pair of worms in three to six months time.

Density pressure greatly influences the biomass production. An area of 1000 cm^2 can hold a maximum of 200 reproducing adults at a time (Kale and Bano, 1988). The young ones emerged had to be removed into the new culture beds. The culture bed had to be changed once in six months. Viljoem and Reinecke (1992) reported that *E. eugeniae* was sensitive to low temperature and could thrive well up to 30°C. The optimum temperature range for growth and fecundity was found to be 22 to 25°C. Effect of worm density on cocoon production of *E. eugeniae* was studied by Reinecke and Viljoem (1993).

2.3.2. Bionomics of *Perionyx* spp.

Hallatt *et al.* (1992) found that moisture influenced the growth and reproduction of *Perionyx excavatus* and the most favourable moisture content was 80 per cent. Reinecke *et al.* (1992) found that in the southern sub regions of Africa, the winter temperature seems to be the limiting factor in applying *E. eugeniae* and *P. excavatus* in out door vermiculture. Shanthi *et al.*. (1993) found that the worms of *P. excavatus* survived in a moisture range of 20-80 per cent and temperature range of 20-40°C. Maximum survival of *P. sansibaricus* was noticed in slaughter home waste followed by vegetable market waste and the least was recorded in FYM + soil (3:1). The increase in count of *P. sansibaricus* was recorded from 5.1 to 9.6 times at 90 days. Cocoon production ranged from 40 to

45 among the treatments in 90 days. It increased to 102 with vegetable + soil waste and to 120 with slaughter home waste + soil at 180 days starting from an initial count of 10 earthworms (Raut *et al.*, 1996).

2.4. Effect of vermicompost on plant growth

Increasing the use of organic sources of nutrients is important in the context of organic farming and sustainable Agriculture. It is well known that earthworm influence physical and chemical properties of soil (Georghengan and Brain, 1948). Their role in improving the soil fertility has been advocated by several early workers (Evans and Guild, 1947; Nielson, 1951, 1953, 1964; Nijhawan and Kanwar, 1952; Richards, 1955; Barley and Jennings, 1959; Rhee and Van, 1965; Dash and Patra 1979; Stockdill, 1982; Lee, 1985; Krishnamoorthy and Vajranabhaiah, 1986).

Nitrogen excretion is an essential contribution of earthworms to soil fertility (Satchell, 1967; Edwards and Lofty 1980; Lal and Akinene, 1983; Christensen, 1987). Earthworm casts have been reported to contain more soil exchangeable cation (Lal and Akinene, 1983). The importance of earthworms in the soil nitrogen cycle apparently lies in the fact that they increase either directly or indirectly, the proportion of mineral nitrogen available for plants at any given time. This effect was proved in coniferous forests where the soil was commonly

low in nutrients (James and Seastedt, 1986). Tiwari *et al.* (1989) found that earthworms increased availability of nitrogen. Exchangeable K was significantly higher in soils with earthworms than without earthworm (Basker *et al.*, 1992).

Earthworms produce plant growth stimulating substances. Nielson (1964) demonstrated the presence of IAA in the earthworm tissues. Tomati *et al.* (1983) related the beneficial influence of worm cast to the biological factors like gibberellins, cytokinins and auxins released due to metabolic activity of the microbes harboured in the cast. Grapelli *et al.* (1987) reported that chemical exudates of the worms and those of the microbes in the cast influenced the rooting layer or shoots.

The nitrogen levels of vermicompost ranged from 1.40 to 2.17 per cent and carbon levels from 23.6 to 30.0 per cent. The nitrogen and potassium levels of vermicompost were significantly higher than that of Farm Yard Manure and cattle dung (Bano and Suseela Devi, 1996). Ushakumari *et al.* (1996) reported that vermicompost produced from banana wastes and cattle manure in the ratio 8:1 v/v had an average of 1.5, 0.4 and 1.8 per cent NPK, respectively. Sarawad *et al.* (1996) reported that application of one tonne vermicompost could substitute 25 to 50 per cent recommended dose of fertilizers. The study also revealed that physical properties of vertisol was improved with vermicompost application.

Organic carbon and available phosphorus were also increased by vermicompost application.

Kale and Bano (1986) reported that paddy seedlings showed significant increase in growth by vermicompost application. They also found that by using wormcast as a fertiliser in fields it was possible to bring down the use of chemical fertilizer. Vermicompost use was economical and helped to improve the physico-chemical and biological properties of the soil. In rice the grain yields were significantly high in the treatments consisting of vermicompost from sugar trash, ipomea, parthenium, neem leaves and banana peduncle + NPK at recommended levels than in the treatment with NPK alone. The results further showed that the organic carbon content and fertility status as reflected by the available status of N, P, K, Ca, Mg and micronutrients were higher in the treatment consisting of vermicompost + NPK than in the treatment with NPK alone (Vasanthi and Kumaraswamy, 1996).

The improved growth in pastures and crops like rye and barley had been attributed to the richness of the earthworm fauna and linked to the chemical exudates of the associated worms and microbes (Atlavinyte and Zimkuviene, 1985). Ross and Cairns (1982) found that earthworm increased fodder production by increasing biochemical activity and nutrient recycling in the soil. Jimenez and Alvarez (1993) observed that vermicompost increased dry matter

yield, soil mineral nitrogen and plant nitrogen in rye grass. The uptake was proportional to the applied rate. They also reported that this pattern of nitrogen availability in highly matured municipal refuse compost, with positive net mineralisation, but partial immobilisation, was similar to the pattern of N availability in biologically active soil and was important for the conservation of nitrogen in agro-ecosystem. With both vermicompost and farm yard manure, addition of each incremental dose of fertilizer caused significant increase in the uptake of nutrients in guinea grass plants (George and Pillai, 1996).

In cabbage, after the application of 4.0, 6.0 and 8.0 kg per m^2 of vermicompost, the dry matter yield increased from 1-60 per cent. High dry matter yield in leek also was reported by vermicompost application (Saciragic and Dzelilovic, 1986). Ushakumari *et al.* (1996) reported that when cattle manure was substituted by vermicompost in bhindi summer crop, the yield was 105.0 per cent more. The yield obtained was 69.4 per cent when inorganic fertilisers were reduced to 3/4 of the recommended dose. In a pre-monsoon experiment to compare vermicompost along with full and 3/4 to recommended dose of inorganic fertilisers, bhindi yielded 43 and 26 per cent more of fruits, respectively than that in plots grown according to the Package of Practices recommendations. Shivananda *et al.* (1996) found that in French bean var. Arka Komal uptake of sulphur was increased in vermicompost-treated plots. Residual availability of sulphur was the highest in vermicompost treated soil at flowering stage (402

ppm) and at harvest (415 ppm) compared to farm yard manure treated soil (284 ppm) at three stages, respectively. In coriander vermicompost application increased the germination percentage, growth, herbage and seed yield, compared to non-application. Twenty tonnes/ha of vermicompost was required to maximise yields in local and Bulgarian variety, while only 15.0 t/ha of vermicompost was superior and recorded more yield compared to the highest yield of other two varieties. The highest seed yield in all the three varieties of Rer-41, Bulgarianand Local was with 20 t/ha of vermicompost (Vadiraj *et al.*, 1996). There are reports that vermicompost increased yield in chillies (Ismail et al., 1993; Rajalekshmi, 1996). Twenty five tonnes of vermicompost along with full inorganic fertilizer influenced the growth of chilli to the maximum extent (Pushpa and Prabhakumari, 1997).

Krishnakumar *et al.* (1994) reported that use of vermicompost in potting medium helped better growth and development of seedlings in cardamom nursery. In vanilla, total root length, sprout length, number of leaves and leaf area per vine were found to be the highest when vermicompost was used as the rooting medium (Siddagangaiah *et al.*, 1996). In turmeric also the effect of vermicompost was pronounced. The varieties Armour and Surome when treated with vermicompost had 30 per cent increase in plant height and 70 per cent increase in leaf area over the control. However, the variety Surome recorded 25 per cent

more fresh yield of turmeric, compared to only 10 per cent in other varieties over the control plots (Vadiraj *et al.*, 1996).

In cotton var. NH-44, yield was high in plots that received vermicompost (100, 50 and 75 per cent of dose of NPK), compared to 100 per cent of the recommended dose of NPK through inorganic fertilizers (Jambhekar, 1996).

In mulberry, cutting and treating with IBA 50 ppm and vermicompost slurry recorded significantly higher number of roots and root length (Dorigol and Gauda, 1996). Gunathilagaraj and Ravignanam (1996 b) reported that the larval litter after vermicomposting significantly increased the length and weight of shoot, root, shoot/root ratio and NPK uptake in mulberry. Patil *et al.* (1996) found that application of vermicompost enhanced the root colonisation of VAM fungi.

2.4.1. Effect of vermicompost on pest and disease incidence

There are several reports showing that the level of pest and disease incidence is less in crops when vermiculture is adopted.

Inhibition of plant parasitic nematodes by earthworms was discussed by many workers (Dash *et al.*, 1980; Senapati, 1992). Earthworm mucus stimulated oviposition in predatory Anthomyiid fly (Morris and Pivnick, 1991). Senapati

(1992) emphasised the importance of soil fauna in ecological agriculture through fauna interaction. Upward dispersal of *Steinernema feltiae* and *S. carpocapsae* was increased in presence of earthworm (Shapiro *et al.*, 1995).

Szczech *et al.* (1993) revealed a suppressive effect of commercial earthworm compost on pathogenic fungi. The effectiveness of compost appeared dose-dependent and increased with an increase in the rate of substrate amendment with compost.

Attack of bollworm was significantly less in plots where vermicompost was applied in radish, spinach and green peas (Jambhekar, 1996). Attack by amaranthus weevil *Hypolixus truncatulus* was reduced in *in situ* vermiculture (Alfred and Gunathilagaraj, 1996).

2.5. *In situ* Vermiculture

In situ vermiculture has been found effective for enhancing the growth and yield of crops (Gupta and Sakal, 1967; Rhee, 1977; Kale and Krishnamoorthy, 1981 a; Sharma and Madan, 1988; Edwards and Bater,1992; Curry *et al.*, 1995; Singh and Rai, 1996). Earthworms have also been shown to increase the availability of plant nutrients in soils, to alter the soil pH, to increase the production of plant growth regulators and to reduce the influence of soil borne

plant pathogens (Shuxin *et al.*, 1991; Lee, 1992). Curry and Byrne (1992) reported a density of 408 earthworms /m^2 (biomass 61 g/m^2) from a cultivated field in Ireland and found that the population mineralised 3.2 g N annually by excretion and tissue turn over and further 3.3 g through enhanced mineralistion in faeces. The decomposition rate was increased by 26-47 per cent within 8-10 months, compared to the treatments in which the earthworms were excluded. McCredie and Parker (1992) found that there was potential for introducing exotic species to improve soil fertility in many wheat belt soils. Earthworm inoculation in combination with heavy mulching proved a successful practice in grape cultivation (Gunjal and Nikam, 1992; Barve, 1993. Phule, 1993). Stephens *et al.* (1994) reported that earthworms could increase the foliar concentration of iron, manganese and zinc.

There were significant differences in the establishment of *Amaranthus dubius* in soils with earthworms and without earthworms. Seed germination was more in beds with earthworms (67 per cent) than in beds without earthworms (59 per cent). The mean height of plants in beds with earthworms was more than the normal. Plants raised in bed with earthworms had more N, P and K content than in bed without earthworms (Alfred and Gunathilagaraj, 1996).

In situ introduction of *E. eugeniae* in the field and application of half the recommended dose of inorganic fertilisers with 12 tonnes of vermicompost produced comparatively good yield in bhindi (Ushakumari *et al.*, 1996).

In situ vermiculture was found effective for mulberry growth and yield. Incorporation of worms @ 50,000 /ha and @ 11,00,000 / ha, one year before the experiment was equally good as that of application of recommended dose of fertilisers (Rajashekar *et al.*, 1996).

In mulberry the number of leaves, leaf area, leaf weight contents of total chlorophyll, nitrogen, potassium and iron were stimulated in the treatment which received recommended doses of N, P and K fertilisers and earthworm + cowdung + mulch. The worm used for *in situ* vermiculture was *P. exavatus* (Ravignanam and Gunathilagaraj, 1996 a & b).

2.6. Effect of bio-pesticides on earthworms

Bio-pesticides have been gaining importance for insect control in recent times. Compared to synthetic insecticides they are safe and eco-friendly. Kale *et al.* (1986) studied the suitability of neem cake as an additive in earthworm feed. *E. eugeniae* was found tolerant (0.4 to 1.6 per cent) in the medium and had a positive effect on the worm biomass production. In another report (NRC, 1991)

when neem leaves and neem kernels were incorporated into the potting medium containing the earthworm *Eisenia foetida*, the number of young worm produced increased by 25 per cent.

2.7. Effect of synthetic pesticides on earthworms

Pesticides have become an integral part of modern agriculture. A significant portion of the pesticides, even when applied on the crops, reaches the soil through wind and rain (Brown, 1978). Moreover, the introduction of granular insecticide formulation resulted in a massive increase in the quantities of insecticides reaching the soil environment. The soil is the natural habitat of numerous macro and microorganisms like nematodes, earthworms, mites, springtails, millipedes, antipedes, insect larvae, termites, fungi and bacteria. Organophosphates and carbamates are known to be toxic to several non-target organisms (Davis, 1968; Gish, 1970; Edwards and Lofty, 1972; Martin, 1976; Rajukkannu *et al.*, 1977; Agnihotrudu and Mithyantha, 1978; Beevi, 1987).

2.7.1. Carbamates

Kring (1969) found many dead earthworms (*Lumbricus terrestris*) on the soil surface on application of carbofuran 2.3 kg/ha in tobacco field. Thompson (1971) observed that soil samples collected from pasture plots three weeks after

insecticide application (carbofuran 4.48 kg ai /ha) showed a large reduction in earthworm population. Stenersen *et al.* (1973) tested the toxicity of carbofuran to the same earthworm species and found that the LD 50 of injected material was 1.3 mg/kg. They also found that the recovery was faster for carbofuran treated worms than for worms treated with dasanit granules. Gilman and Vardanis (1974) reported that application of carbofuran 2.24 kg ai/ha reduced the earthworm population to 42 per cent in a pasture soil. Sileo and Gilman (1975) found that carbofuran on topical application induced muscle necrosis in *L. terrestris.* When the worms were maintained in treated soil, they became swollen, rigid and immobile. Martin (1976) reported that earthworm population was initially reduced to 50 per cent of the control population, when carbofuran was applied as granules to the surface of a pasture at 2.24 kg ai/ha, but recovered apparently by immigration between five and eighteen weeks.

Tomlin and Gore (1976) reported that carbofuran applied at the rate of 3.4 kg ai/ha in pasture land reduced earthworm population tremendously. Ruppel and Loughlin (1977) tried different concentrations of carbofuran (0.75 to 5.5 kg ai/ha) on earthworm and found that pesticides at all levels were toxic to the worms. Kale and Krishnamoorthy (1979) reported that survivability, activity and fecundity of the worms were greatly influenced by Sevin residues. The pesticidal effects of Sevin on the survivability and abundance of earthworm *Pontoscolex*

corethrurus revealed that concentrations up to 100 ppm were not inhibitory to life activities and above this level it affected the population. Stenersen (1979) found that carbofuran even at low concentrations caused death of the earthworm species *Allolobophora caliginosa*, *A. chlorotica* and *Lumbricus terrestris*. Veeresh (1983) found that application of carbofuran 0.75 kg ai/ha was toxic to earthworms in tobacco nursery, betelvine garden and paddy fields.

When the earthworm *Pheretima posthuma* was exposed in moist soil to carbaryl 2-8 mg/kg for upto 24 h, the alpha amylase activity in the intestine was reduced (Gupta and Sundararaman, 1988). In a study conducted by both in summer and spring seasons, carbofuran significantly reduced annelid biomass (Parmelee *et al.*, 1990). Stenersen *et al.* (1992) also reported carbaryl as a strong poison for earthworm. Exposure to carbofuran decreased cocoon production in *Eisenia foetida* (Brunninger *et al.*, 1994). Maurya and Chattoraj (1993) reported that carbaryl was toxic to earthworms. All the earthworms were killed after 24 hrs of treatment at a concentration of 100 ppm in solution. The earthworms did not survive when introduced to insecticide (carbofuran and phorate) treated potting medium (0.5, 1.0 and 1.5 kg ai/ha) seven and fourteen days after insecticide application (Jiji *et al.*, 1994).

Ramesh and Gunathilagaraj (1996) found that carbofuran, being a soil insecticide, was more toxic (LC 50 1.77) than endosulfan to earthworm *P. excavatus*. The relative toxicity ratio between endosulfan and carbofuran was 5.48.

2.7.2. Organophosphates

Raw (1965) found that granular organophosphate insecticide affected the earthworm population in sugarbeet field. Edwards *et al.* (1967) reported that phorate applied @ 4.0 1b/acre almost eliminated earthworms from garden soils. Way and Scopes (1968) found that phorate 250 ppm killed almost all earthworms in sandy loam of pH 6.1. Phorate 2.0 kg ai/ha caused reduction in earthworm population up to 55 per cent, four months after treatment and 25 per cent one year after treatment. The immature stages of *Allolobophora* sp. was more susceptible than *Lumbricus rubellus* (Saunders and Forgi, 1974).

Bharathi and Subbarao (1986) found that phosphamidon, monocrotophos and dichlorvos at 10.34, 4.87 and 0.22 ppm, respectively, increased both acid and alkaline phosphatase activity of *Lampito mauriti* as indicated by cell damage, protein deficiency and disruption of cellular activity. Phosphatase activities were decreased at sub-lethal concentration of the insecticide.

Phorate was highly toxic to earthworms present in paddy fields even at the lowest dose of 1.0 kg ai/ha (Beevi, 1987). Population counts of earthworms were in the decreasing trend on the 2nd and 7th day. But from the 14th day onwards a gradual increase of the population was observed in the treated plots. The population however, remained less than that in the untreated plots Visalakshi *et al.* (1988) reported that earthworm population declined by 89.4, 84.2 and 75.6 per cent in the carbofuran, phorate and quinalphos treated plots, respectively. Recovery of the population was noticed from third week onwards. Reddy and Reddy (1992) found that the adult, juvenile and total populations of earthworms were reduced by 52-58 per cent after 40 days of treatment with the high dose of methyl parathion and 15-52 per cent with the normal dose. The biomass of the earthworms was significantly reduced with treatment of either dose of both insecticides (methyl parathion, carbaryl).

2.8. Microbial studies

Many scientists have reported the presence of micro organisms in the gut of earthworm (Hutchinson and Kamel, 1956; Khambata and Bhat, 1957; Parle, 1963 a and b; Satchell, 1967; Citernesi *et al.*; 1977; Contreras, 1980; Sacheu, 1987;). Stockli (1928) found that there was increased number of bacteria and actinomycetes in the earthworm gut, compared to those in the soil. The number increased, exponentially from anterior to the posterior portions of the gut.

Ponomareva (1953) found an increase in the number of actinomycetes, pigmented bacteria and other bacteria of the *Bacillus cereus* group, after passage through the earthworm intestine. The number of bacteria in the earthworm faeces was observed to be 13 times higher than in the surrounding soil (Ponomareva, 1962).

Atlavinyte and Lugauskas (1971) observed that earthworms increased the number of micro organisms in soil as much as five times. They concluded that earthworms were important in inoculating the soil with micro organisms, harboured in their casts. Svensson *et al.* (1987) observed about 16 per cent higher carbon dioxide evolution in the casts of *Lumbricus terrestris* than in the surrounding soil. Many other workers reported that microflora of cast soil was larger than that of the surrounding soil.

Kale *et al.*(1988) reported high metabolic rate and microbial load in worm-worked soil. Cellulolytic organisms were more, which led to high degradation of cellulose. The microbial load of the gut of earth worms showed intense colonisation in the anterior part of the intestine than in the other regions. The earthworm *E. eugeniae* stimulated microbial respiration by 15-18 per cent, whereas *Dendrobaena octaedra* stimulated it only slightly. The worms also raised the pH of the leaching water and the humus (Haimi and Huhta, 1990). Harinikumar *et al.* (1991) found that mycorrhizal propagules in earthworm cast varied from 2.0 to 54 per cent per gram. Reddel and Spain (1991) reported that

earthworms could act as vectors of viable propagules of mycorrhizal fungi. Kale *et al.* (1992) observed that vermicompost application enhanced the activity of beneficial microbes like nitrogen fixers and mycorrhizal fungi. It played a significant role in nitrogen fixation and phosphate mobilisation, leading to higher nutrient uptake by plants. Presence of vesicular arbuscular mycorrhizal (VAM) fungi in the cast of *Lumbricus terrestris* casts was demonstrated by the successful inoculation of sterile grown onion plants (Harinikumar and Bagyaraj, 1994).

In paddy variety Madhu there was significant increase in nitrogen fixers, actinomycetes, spore formers, and VAM in the experiment plot which received vermicompost along with half the recommended dose of fertilisers (Kale *et al.*, 1992). The symbiotic association of VAM in the roots was significantly increased (10.0 per cent) compared to the control plots (2.9 per cent). The total nitrogen in the experimental plot was also more. This was attributed to the higher count of N-fixers (3.48×10^3) in the experimental plots, compared to the control plots (2.16×10^3). Earthworm cast material contained more number of spores and infective propagules of VAM than the nearby field soils (Gange, 1993). Zachmann and Molina (1993) found viable bacteria co-existing with developing embryos in egg capsules (cocoons) of the earthworm *Eisenia foetida*.

The role of micro organisms, *viz.* actinomycetes, bacteria and fungi in the decomposition of organic matter was discussed by Goodfellow and Cross (1974), Gyllenberg and Eklund (1974) and Dwivedi and Shukla (1977).

The decomposition of organic material in the soil was observed to be accelerated in the presence of earthworms (Barley and Jennings, 1959). The cast material of earthworms was rich in nitrogenous compounds. Earthworms helped to decompose organic material by ingestion, disintegration and transport. They also stimulated microbial decomposition (Tiwari *et al.*, 1989).

Earthworm gut constitutes a micro habitat, enriched in microbes capable of anaerobic growth and activity. Karsten and Drake (1995) found that the ratio of microbes capable of growing under obligate anaerobic conditions to those capable of growing under aerobic conditions was higher in the worm intestine than in the soil. Earthworm encouraged mutualism and biodiversity in soil. Mobilisation of nutrient and organic resources through mutualism with soil microflora was encouraged by earthworm (Lavelle *et al.*, 1995). Indira *et al.* (1996) reported that population of beneficial organisms like phosphorus solubilising bacteria, nitrogen fixing organisms and entomophagus fungi was in the range of 10^5 and 10^6 in vermicompost. Amongst the phosphorus solubilising organisms like *Bacillus* and *Aspergillus*, and nitrogen fixing organisms like *Azotobacter* and *Azospirillum* were prominent among the species present.

MATERIALS AND METHODS

MATERIALS AND METHODS

A study was conducted on various aspects of vermiculture at the College of Agriculture, Vellayani, Thiruvananthapuram during 1994-97. The study covered aspects such as collection and identification of earthworms from different soils, assessment of the composting efficiency, breeding potential and bionomics of the earthworm species, the effect of vermicompost on pests, diseases and yield of vegetables and the effect of biopesticides and synthetic pesticides on earthworms. The materials and methods of the study are described below:

3.1. Collection and identification of earthworms

3.1.1. Collection

Earthworms from the following soil types were collected and identified :

i. Forest soil (Mollisols) of Palode

ii. Laterite soil (Oxisols) of Thiruvananthapuram district

iii. Sandy soil (Entisols) of Kayamkulam

iv. Alluvial soil (Entisols) of Moncompu

v. Red soil (Ultisols) of Vellayani

Ten samples from each soil type were collected and earthworm populations were estimated. One meter square wooden frame was used for marking the sampling area. Digging was done up to about 10 cm depth (Bano and Kale, 1991). The soil lumps were broken and the soil passed through the fingers to sort out the worms. The smaller worms were collected by passing through a sieve of 3-4 mm size. The worms were then sorted out species-wise, counted and preserved in jars containing 70 per cent ethanol.

3.1.2. Identification

The preserved specimens were identified with the help of expertise available at the Department of Zoology, University of Agricultural Sciences, Bangalore. Three to five earthworms were put in a petri dish containing water. Then absolute alcohol was added drop by drop and the petri dish was covered. and kept for 5-10 minutes. When the worms were narcotised, they were kept in straight position in 10 per cent formalin overnight. Cotton was dipped in sufficient quantity of 10 per cent formalin and the worms were kept in between the cotton layers, covered with polythene sheets and sent for identification.

The following observations were recorded:

a. Number of earthworms per m^2

b. Particle size distribution of the soil

c. Organic carbon content of the soil

d. Moisture holding capacity of the soil

e pH of the soil

Organic carbon was estimated by the method of Walkley and Black (1934). Particle size distribution, moisture holding capacity and pH of the soil samples were determined by standard procedures (Jackson, 1973).

3.2. Composting efficiency and breeding potential of identified earthworm species

3.2.1. Composting efficiency and breeding potential of identified earthworm species in culture media in pots

Composting efficiency and breeding potential were assessed using primed waste mixture consisting of banana leaves and cow dung (1:1w/w). The pot culture study was carried out in completely randomised design. There were four replications. Indigenous species *Megascolex cochinensis, Pontoscolex corethrurus* and *Perionyx sansibaricus* and the exotic species *Eudrilus eugeniae* were used for the study. The worms were selected for the study based on the preliminary observations. Twenty five worms were introduced into the pots having 2.0 kg

waste mixture. The pots were kept in shade and adequate moisture level was maintained by watering. Observations on the number of adults, juveniles and cocoons of earthworm species were taken when composting was over.

3.2.2. Field evaluation of the composting efficiency of *Eudrilus eugeniae* and *Perionyx sansibaricus*

The field experiment was repeated with eight replications. Pits of 1.0 m x 1.0 m x 0.4 m size were used for the study. The bottom of the pit was made compact by malloting. Coconut husks were placed with their concave side up. Fifty kilograms of the waste mixture (5:1 w/w) was put in the pit. One hundred grams of worms were put in the pit 10 days after the application of waste. *Eudrilus eugeniae* and *Perionyx sansibaricus* were used for the study. Completely randomised design was adopted for the study. Time taken for composting, count of population per kg compost, total biomass and the quantity of compost recovered were estimated.

3.3. Bionomics of *Eudrilus eugeniae* and *Perionyx sansibaricus* under the humid tropical conditions of Kerala

3.3.1. Effect of seasons on the earthworm population and consequent biomass production

Effect of seasons on the earthworm population and consequent biomass production of one promising indigenous species *Perionyx sansibaricus* and one exotic species *Eudrilus eugeniae* was studied. The experiment was done with 2.0 kg waste mixture and 25 worms. The experiment was set up on the first day of each month. Observations were recorded for a period of one year. Count of worms, compost recovery and period required for composting in each case were observed when composting was over. The treatments were replicated three times. The findings were correlated to environmental factors such as temperature, rainfall, and relative humidity (Appendix I).

3.3.2. Cumulative increase of biomass of *Eudrilus eugeniae*

The cumulative increase of biomass for a period of one year was also recorded. The experiment was started with two kilograms waste and twenty five worms. Two types of containers were used. Container I was plastic basin of 40 x 20 x 30 cm size. . Container II was plastic basin of 60 x 20 x 30 cm size. When the composting was over the composts were sieved through 2.0 mm sieve and fresh wastes were added. A field experiment was conducted during the same period. Pits of 2.0 x 1.0 x 0.4 m) were used for the study. The bottom of the pit was made compact by malloting. Coconut husks were placed with their concave side up. Over that 240 kg of banana waste-cow dung mixture (5:1 w/w) was spread.

Earthworm species (0.5 kg) were introduced into the pits 10 days after the application of wastes in the pit. The treatments were replicated thrice. The period of composting was observed. Data on the number of worms per kilogram of compost and total biomass were recorded.The experiment was continued for a period of one year. The increase in the biomass of worms for a period of one year was observed.

3.3.3. Biology of *Eudrilus eugeniae* and *Perionyx sansibaricus*

Biology of the most promising indigenous species *Perionyx sansibaricus* and exotic species *Eudrilus eugeniae* was studied. The experiment was initiated when the hatchlings emerged from the cocoon.

Five grams of the partially decomposed organic matter (chopped banana leaves : cow dung 1:1w/w) was kept on a moist filter paper in a petri dish and six cocoons were kept over it. The petri dishes were then placed in shallow earthen pots which were covered with wet sack pieces. There were eight replications.

The hatchlings emerged from the cocoons were introduced into the glass jar. Fifty grams of the waste mixture was put in the glass container (10.0 x 5.0 x 20.0 cm size). Time taken for attaining clitellate stage was observed.

After attaining the clitellate stage, a pair of worms was introduced into earthen pots containing 100 g waste mixture (banana leaves : cow dung 1:1 w/w). Observation on the number of cocoons laid per week was recorded.

Newly laid cocoons were taken and placed over wet filter paper containing five grams of partially decomposed banana leaf-cow dung mixture in a petri dish. Time taken for the hatching of the cocoons was also recorded. Six cocoons were kept in each petri dish. The treatments were replicated eight times.

3.4. Effect of the application of vermicompost on the incidence of pests, diseases and yield in bittergourd

A field experiment was carried out with six treatments and five replications in completely randomised design. Cowpea var. Malika and bittergourd var. Preethi were used for the study. A plot size of 2.0 m x 2.0 m was kept. The treatments included vermicompost (equal quantity of farmyard manure) with half, three fourth and full dose of inorganic fertilizers, vermicompost (instead of farm yard manure) alone and vermicompost having total nitrogen supply as per POP through vermicompost. A treatment as per the recommended manurial schedule (KAU, 1993) was also kept as control. The treatments were:

T1 Package of Practices (POP) Recommendations

T2 Vermicompost (instead of farm yard manure) alone

T3 Vermicompost + 1/2 inorganic fertilizers as per the Package of Practices Recommendation

T4 Vermicompost + 3/4 inorganic fertilizers as per the Package of Practices Recommendation

T5 Vermicompost + nitrogen requirement as per Package of Practices Recommendation through vermicompost

T6 Vermicompost + full inorganic fertilizers as per the Package of Practices Recommendation

Observations on pests, diseases and yield were recorded.

3.4.1. Scoring of pests and diseases of bitter gourd

Fruit fly

The total number of fruits per pit was assessed and the percentage of fruits affected by fruit fly per pit was determined.

Jassids

Five leaves per pit were selected at random and the population of jassids was assessed.

Epilachna beetle

From each pit, five leaves were selected at random and the total number of beetles of all stages was assessed.

Leaf spot

The number of plants affected by leaf spot disease was assessed.

Mosaic

The number of plants affected by mosaic was assessed.

Pumpkin beetle

The total number of adult population per plant was assessed.

3.4.2. Scoring of pests and diseases of cowpea

American serpentine leaf miner

The number of leaves affected by American serpentine leaf miner was recorded in five observational plants per plot and the percentage was worked out.

Aphid

The number of aphids on five centimeter length of the affected shoot portion of five randomly selected plants was recorded and the percentage was worked out.

Pod borers

The number of pods infested by pod borers in the five observational plants was recorded and the percentage was worked out.

Pod bugs

The number of pods infested by pod bugs in the five observational plants was recorded and the percentage was worked out.

3.5. Effect of vermicompost (prepared from different wastes) incorporated in the potting mixture on the growth and yield of bhindi

Potting mixture was prepared incorporating vermicompost (prepared from different wastes *viz.* banana leaves, neem cake, neem leaves, mahua cake, glyricidia leaves, eupatorium leaves, thevetia leaves, clerodendron leaves and calotropis leaves), soil and sand in 1:1:1 ratio. Vermicompost was prepared from banana leaves-cowdung mixture 1:1 w/w alone, banana leaves-cowdung mixture 1:1 w/w and biopesticides in the ratio of 6:1. The treatments were:

T1 Potting mixture using cow dung (Control)

T2 Potting mixture incorporating vermicompost from banana leaves

T3 Potting mixture incorporating vermicompost containing neem cake

T4 Potting mixture incorporating vermicompost containing neem leaves

T5 Potting mixture incorporating vermicompost containing mahua cake

T6 Potting mixture incorporating vermicompost containing glyricidia leaves

T7 Potting mixture incorporating vermicompost containing eupatorium leaves

T8 Potting mixture with vermicompost containing thevetia leaves

T9 Potting mixture with vermicompost containing clerodendron leaves

T10 Potting mixture with vermicompost containing calotropis leaves

Bhindi plants were raised in the above potting media. Observations on the height of the plants, number of leaves, flowers, yield and pest and disease incidence were recorded.

3.5.1. Scoring of pests and diseases in bhindi

Leaf roller

Average number of leaf rolls / plant was counted.

Shoot and fruit borer

Average number of shoots and fruits affected / plant was assessed.

Aphids

The total number of aphids on one upper, one middle and one lower leaf was assessed.

Jassids

The total number of jassids on one upper, one middle and one lower leaf was assessed.

White fly

The total number of white flies on one upper, one middle and one lower leaf was assessed.

Yellow vein mosaic

The plants affected by yellow vein mosaic were recorded.

3.6. Effect of *in situ* vermiculture on the incidence of pests and diseases and yield of bhindi crop

A field experiment was carried out with five treatments and four replications to assess the impact of *in situ* vermiculture on bhindi using the indigenous species *Perionyx sansibaricus*. Plot size was 2.0 X 2.0 m. A control plot was also maintained as per the Package of Practices Recommendation. The variety of bhindi used was Arka Anamika.

T1 Package of Practices Recommendations

T2 Vermicompost (instead of farm yard manure) + Package of Practices Recommendations

T3 FYM + banana wastes having nitrogen as per Package of Practices Recommendations + 150 worms /plot

T4 FYM + banana wastes having nitrogen as per Package of Practices Recomendations + 250 worms / plot

T5 FYM + vermicompost containing nitrogen as per the Package of Practices Recomendations

Biometric observations on plant height, number of leaves and branches were recorded.

3.7. Effect of biopesticides on indigenous and exotic species

Effect of organic soil ameliorants and biopesticides such as neem cake, mahua cake, leaves of plants like neem, calotropis, thevetia, eupatorium, glyricidia, clerodendron and calotropis on the indigenous species *Perionyx sansibaricus* and the exotic species *Eudrilus eugeniae* was studied. A pot culture study with three replications was carried out in completely randomised design. Shallow earthen pots were used. A mixture of cow dung and banana leaves (1:1w/w) was used as the culture medium. Twenty worms were introduced into the pots having 1.5 kg waste mixture. The biopesticides were applied at the rate of 250 g per pot, seven days after the introduction of worms. A control treatment with banana cow dung mixture (1:1 w/w) alone was also tried. All the treatments

were replicated thrice. The pots were kept in shade and adequate moisture level was maintained in the medium by watering. Observations on the number of adults, juveniles and cocoons of the earthworm were taken one month after their introduction.

Treatments

T1 Control

T2 Neem cake 250g/pot

T3 Mahua cake 250g/pot

T4 Neem leaves 250g/pot

T5 Glyricidia leaves 250g/pot

T6 Eupatorium leaves 250g/pot

T7 Thevetia leaves 250g/pot

T8 Clerodendron leaves 250g/pot

T9 Calotropis leaves 250g/pot

3.8. Effect of synthetic pesticides on the survival of earthworms

The earthworm *Eudrilus eugeniae* was used for the study. Shallow earthen pots were filled with soil (2.0 kg). Cow dung-banana leaves mixture (1:1 w/w) was put over the soil. Carbofuran, phorate and quinalphos were applied at 0.5, 1.0 and 1.5 kg ai/ha, respectively to the mixture. Twenty clitellate worms were introduced into the pots on 1st, 3rd, 7th, 14th, 21st and 28th days after the

application of insecticides. Survival of the worms was recorded on the third day and mortality was worked out. Standard procedures were adopted for estimating residue levels of carbofuran (Gupta and Diwan, 1974), phorate and quinalphos (Getz and Watts, 1964; Jain *et al.*, 1974) in the medium.

3.8.1. Estimation of carbofuran

Twenty five grams of the sample (mixture of organic matter and soil) were taken in 500 ml flask containing 250 ml of 0.25 N HCl. It was transferred to a 500 ml separating funnel and shaken with 45 ml of dichloromethane and six drops of 4.0 per cent sodium lauryl sulphate. The lower layer was transferred through anhydrous sodium sulphate. It was shaken two more times and collected in the same bottle and the volume was made up to 100 ml. From the filtrate 10 ml was evaporated to almost dryness using an air condenser. Sides of the beaker were rinsed with 3.0 ml methanol and 7.0 ml freshly prepared coagulating solution. The solution was allowed to stand for 10 minutes with occasional shaking and then was filtered through Whatman No.42 filter paper. Five milli litre of the filtered solution was transferred to a test tube and placed in an ice bath, below 4^0C. Two milli litres of 1.5 N methanolic KOH was added to the solution, mixed

well and allowed to stand. After five minutes 0.2 ml of cold chromogenic reagent was added and shaken well and kept on the ice-bath for two more minutes. The optical density was read at 550 nm using a Spectronic-20 spectrophotometer.

3.8.2. Estimation of phorate and quinalphos

Samples for residue analysis were taken at different intervals. Twenty gram of each sample was taken in 100 ml beaker and 0.5 ml ammonia solution was added. It was stirred well with a glass rod and kept till the smell of ammonia disappeared. Activated charcoal 0.5 g and florisil 0.5 g were mixed thoroughly with the sample in the beaker. This was packed in a chromatographic column and eluted with 100 ml acetone. The extract was concentrated to 10 ml. This was taken in a graduated test tube with B-19/26 joint to which a drop of propylene glycol was added and the tube was dried over an oven at 40^0C. Then 0.4 ml each of 2.0 per cent benzyl pyridine and 2.0 per cent cyclohexyl amine in acetone were added. Air condenser was fitted over the tube which was then heated in an oil bath at 175-180°C for three minutes. The reaction tube was then taken out and cooled immediately in an ice-bath for 30 seconds. The condenser was taken out and 3.0 ml of ethyl acetate was added. The colour intensity was measured at 540 nm using a Spectronic-20 spectrophotometer (Getz and Watts, 1964).

3.9. Microbial studies

Microbial activity during the period of composting was estimated at weekly intervals. It was estimated by measuring carbon dioxide evolved during the period of composting. The microbial population was estimated by dilution pour plate technique using the compost suspension in different media, appropriate for bacteria, fungi and actinomycetes.

3.9.1. Estimation of carbon dioxide evolution

The CO_2 evolved was estimated using standard procedure (Anderson and Ingram, 1983). The CO_2 evolved during a given period of time was absorbed in potassium hydroxide and it was later precipitated as carbonate. The excess of KOH was titrated against standard HCl solution using phenolphthaline as indicator. The volume of KOH thus consumed was calculated by deducting the titer value from the amount added.

Two kilograms of cow dung-banana leaf mixture (1:1 w/w) was kept in shallow pots having 30 cm x 15 cm size. Twenty five worms each of *Eudrilus eugeniae* and *Perionyx sansibaricus* were introduced into the pots. Waste mixture without worms was kept as control. Each treatment was replicated thrice. The

CO_2 evolution was estimated by keeping 100 ml 0.1 N KOH solution in beaker. Then the pots were tightly closed with same sized pots and plastered with mud. After 24 h the beaker was taken out and titrated against 0.1 N HCl after adding saturated barium chloride solution (2.0 ml per 25 ml KOH). More of KOH was added since the alkali became saturated during the exposure period. The absorbed CO_2 was calculated on the basis that 1.0 ml of 0.1 N HCl is equivalent to 2.2 mg CO_2 or 1.0 ml of 1.0 N HCl is equivalent to 22 mg CO_2 .

3.9.2. Estimation of microbial population in the compost

The microbial population was estimated at fortnightly intervals. Martin rose bengal streptomycin agar medium for fungi, Compost extract agar medium for bacteria and Kenknight's and Munaier's medium for actinomycetes (Appendix II) were used for the study.

3.9.2.1. Preparation of compost extract agar medium

One kilo gram of the vermicompost was mixed with 2.0 l tap water and steamed in the autoclave for 30 minutes. The supernatant solution of the compost extract was filtered and kept aside. Fifteen grams of agar agar was dissolved in 900 ml of water by steaming for an hour. Then 100 ml of the supernatant compost extract solution as well as previously weighed nutrients (Appendix II)

were added to the dissolved agar agar and mixed well. The pH was adjusted to 6.8.

3.9.2.2. Estimation of microbial population

One gram of compost was initially suspended in 100 ml sterile water in a conical flask by shaking on a mechanical shaker for 30 minutes. One milli litre of the suspension was transferred to 99 ml of sterile distilled water blanks to obtain 10^{-4} dilution. One milli litre of the aliquot was then transferred to 99 ml sterile distilled water blanks to obtain 10^{-6} dilution. 10^{-4} dilution was used for the estimation of fungi and actinomycetes while 10^{-6} dilution was used for the estimation of bacteria. The flask containing suspension was shaken for five minutes each time before taking samples for serial dilution (Rao, 1975).

One milli litre of the diluted suspension was pipetted out into a sterile petri dish and about 20 milli litre of the appropriate agar medium (cooled just above the solidifying temperature) was added to each petri dish . The dishes were gently rotated by hand so that the diluted compost suspension was uniformly dispersed in the medium. The plates were incubated at 28 $\pm$ 2^0C. The observations on the number of fungi, bacteria and actinomycetes were taken on the 3rd, 5th, 7th, 9th and 11th days after the inoculation. The dry weight of the sample was measured.

The average number of colonies per dish was multiplied by the dilution factor and expressed as number of colonies / g in the original soil sample. The fungal colonies were transferred to nutrient agar slants and identified.

RESULTS

RESULTS

4.1. Collection and identification of earthworms

The results of the survey conducted to study the diversity and species distribution of earthworms are presented in Table 1. Eight earthworm species belonging to three families *viz.* Megascolecidae, Moniligastridae and Glossoscolecidae were observed in the five soil types. *Megascolex cochinensis M. konkanensis, M. trivandranus, M. trilobatus, P. sansibaricus*, and *Pheretima heterochaeta* (family Megascolecidae), *Pontoscolex corethrurus* (Glossoscolecidae) and *Drawida* sp. (Moniligastridae) were found to occur in the areas surveyed.

Among the earthworms collected, two species *viz. Megascolex cochinensis* (Plate I) and *Pontoscolex corethrurus* (Plate II and III) were ubiquitous. *P. sansibaricus* (Plate IV) was confined only to forest and red soils. *Megascolex konkanensis* (Plate V) was present in laterite and alluvial soils and their counts were on par. *Pheretima heterochaeta* (Plate VI) was found in all soil types, except laterite soil. *Megascolex trilobatus* (Plate VII) was found in sandy soil and alluvial soil. *Megascolex trivandranus* (Plate VIII) was present in forest and laterite soils. Except in the cases of *P. sansibaricus*, *Drawida* sp. (Plate I) and *M. trivandranus*, the count variation was not significant.

Table 1. Population distribution of earthworm species in five soil types of Kerala

Earthworm species	Population density (number of earthworms per m^2) *					
	Forest soil	Laterite soil	Sandy soil	Alluvial soil	Red soil	CD (0.05)
Megascolex cochinensis	8.2	1.5	5.4	0.8	4.9	-
Megascolex konkanensis	0	0.5	0	1.8	0	-
Megascolex trilobatus	0	0	0.5	1.6	0	-
Megascolex trivandranus	10.0	1.1	0	0	0	6.46
Pontoscolex corethrurus	10.2	3.6	12.6	2.2	7.2	-
Perionyx sansibaricus	7.0	0	0	0	2.5	5.07
Pheretima heterochaeta	5.7	0	2.3	0.2	4.0	-
Drawida sp.	0.3	0	0	6.0	0.3	3.08

* The data represent the mean values of ten samples

Table 2. Number of species and population density of earthworms in five soil types of Kerala

Item	Soil type					CD (0.05)
	Forest soil	Laterite soil	Sandy soil	Alluvial soil	Red soil	
Number of earthworm species	1.70	1.10	1.90	1.50	1.60	-
Number of earthworms per m^2	41.30 (40.20)	8.20 (11.80)	22.30 (19.62)	13.10 (13.57)	18.30 (17.99)	9.29

The data represent the mean values of ten samples
Data in paranthesis are adjusted means

Fig. 1. Population distribution of earthworm species in five soil types of Kerala

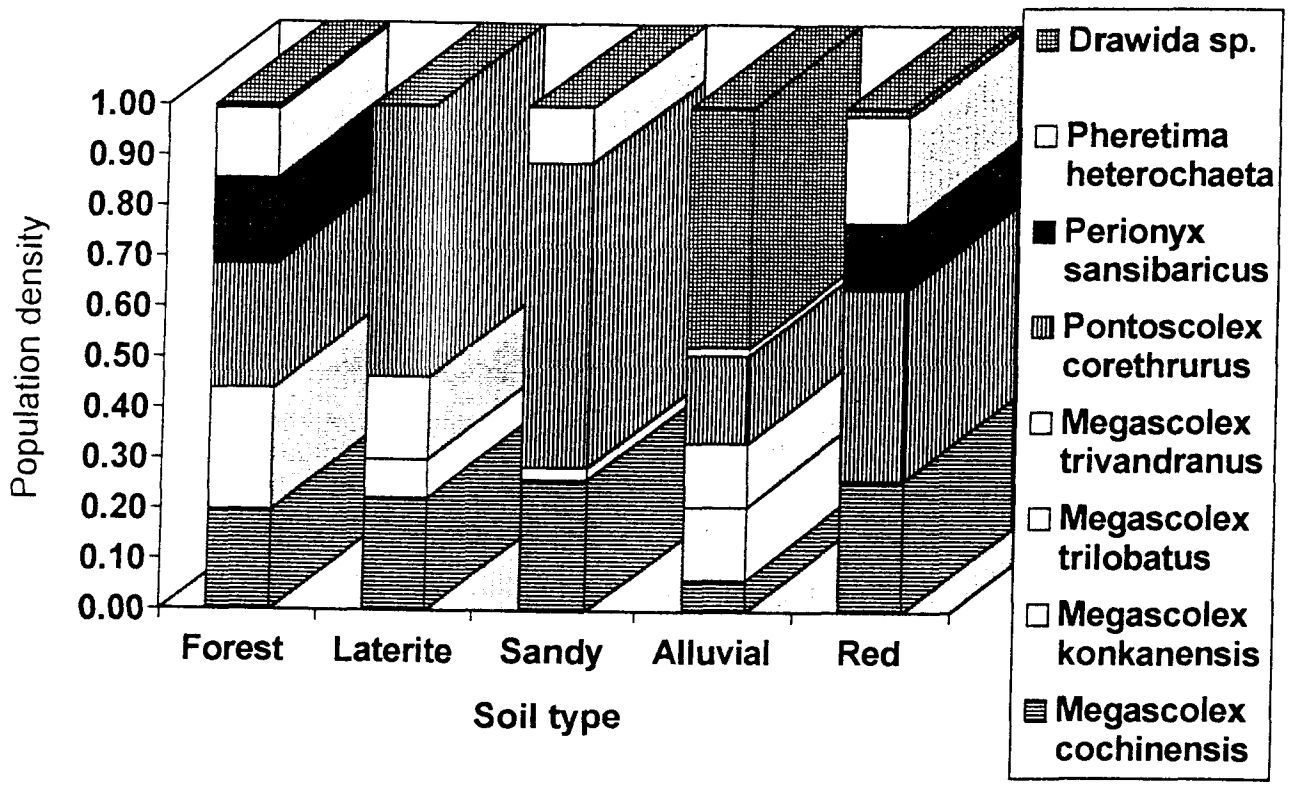


Table 3. Physical and chemical properties of soil types surveyed

Physical / chemical properties of soil	Soil type					CD (0.05)
	Forest soil	Laterite soil	Sandy soil	Alluvial soil	Red soil	
pH	4.83	5.21	5.57	4.37	5.42	0.36
Water holding capacity (%)	44.52	32.35	22.30	38.50	28.85	-
Organic carbon (%)	4.05	0.82	1.15	2.07	0.79	0.50
Particle size distribution (%)						
a. Coarse sand	46.5	54.0	68.0	48.5	49.1	-
b. Fine sand	11.1	15.2	13.1	26.1	15.4	-
c. Silt	11.5	8.1	6.0	31.0	7.1	-
d. Clay	30.5	22.1	12.0	43.3	17.6	-

The data represent the mean values of ten samples

Plate I. Adult worms of *Drawida* sp. (a) and *Megascolex cochinensis.* (b)

Plate II. Juveniles of *Pontoscolex corethrurus*


b

Plate III. Adult worms of *Pontoscolex corethrurus*

Plate IV. Adult worms of *Perionyx sansibaricus*

Plate V. Adult worms of (a) *Megascolex konkanensis* and (b &c) *Pontoscolex corethrurus*

Plate VI. Adult worm of *Pheretima heterochaeta*


a b c

Plate VII. Juveniles and adults of *Megascolex trilobatus*

Plate VIII. Adult worm of *Megascolex trivandranus*

Population distribution of earthworm species in five different soil types of Kerala is presented in Table 1. The highest species diversity (six species) was observed in forest soil and alluvial soil, eventhough the total count was less in the latter (Table 2; Fig. 1). Laterite soil, with low organic carbon content and water holding capacity (Table 3), recorded the lowest total count of worms (Table 2). In all cases more than one species was observed in the same habitat (Tables 1 and 2).

The ubiquitous earthworm *Pontoscolex corethrurus*, the single representative of Glossoscolecidae, co-existed with *Megascolex* spp., and *Drawida* sp. Among Megascolecidae *Megascolex cochinensis* had a wider range of distribution than *Megascolex konkanensis*, *M. triolobatus* and *M. trivandranus*.

4.2. Composting efficiency and breeding potential of indigenous and exotic earthworm species

4.2.1. Composting efficiency and breeding potential of indigenous and exotic earthworm species in culture media in pots

The results of the experiment to evaluate the comparative efficiency of exotic and indigenous species on composting are presented in Table 4.

Table 4. Population growth, compost recovery, biomass production and period for composting of four earthworm species cultured in pots

Earthworm species	Population growth			Compost recovery (kg)	Biomass production (g)	Period for composting (days)
	Adults	Juveniles	Cocoons			
Perionyx sansibaricus	40.23* (6.34)	160.75** (12.69)	28.35** (5.4)	1.40	34.35 (5.85)	84
Megascolex cochinensis	13.5 (3.64)	0 (1.0)	0 (1.0)	-	8.82 (2.9)	-
Pontoscolex corethrurus	6.75 (2.58)	0 (1.0)	0 (1.0)	-	4.67 (2.16)	-
Eudrilus eugeniae	28.0 (5.28)	104.75 (10.21)	18.75 (4.43)	1.35	49.60 (7.04)	56
CD	0.38	0.48	0.24		0.43	

The data represent the mean values of four replications
The values in parentheses are transformed values
* $\sqrt{x}$ transformation ** $\sqrt{x+1}$ transformation

Table 5. Composting efficiency of *Eudrilus eugeniae* and *Perionyx sansibaricus* under field conditions

Species	No.of worms/ kg of compost	Weight of worms/ kg compost (g)	Recovery of compost (kg)	Period for composting (days)	Decomposition ratio
Eudrilus eugeniae	38.75	24.4	25.78	59	11.5
Perionyx sansibaricus	67.50	19.98	26.25	59	12.33
CD (0.05)	6.58	2.47	-	-	-

Fig. 2. Population growth, biomass production and period for composting of four earthworm species cultured in pots

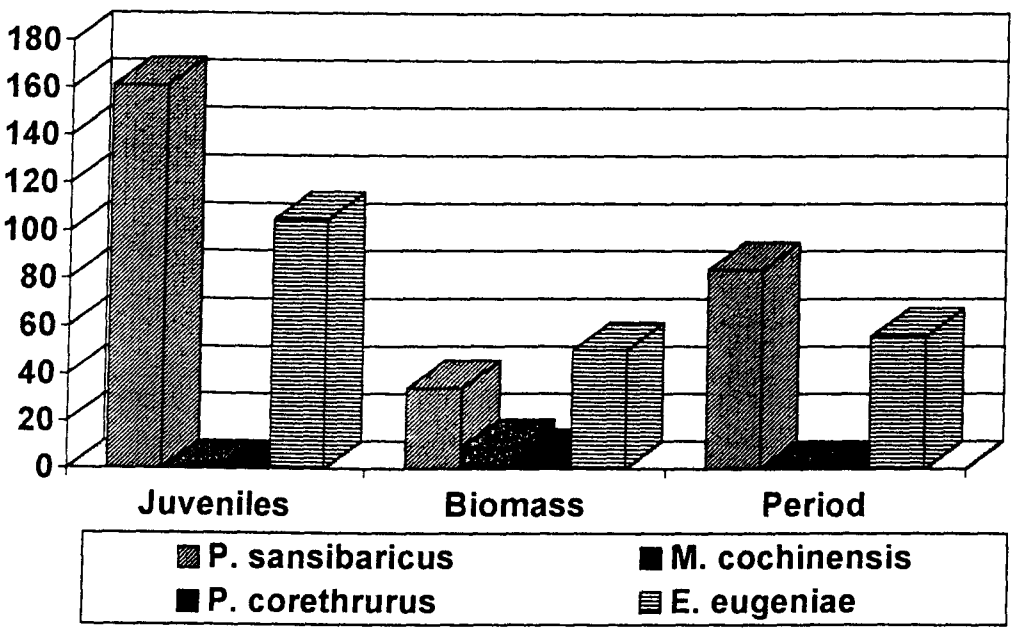


Plate IX. *Perionyx sansibaricus* feeding on banana wastes

Plate X. Banana waste in the pit before composting

E. eugeniae was relatively more efficient for composting in terms of duration for composting (56 days) and biomass production (49.6g), compared to *P. sansibaricus* which took 84 days for compost maturity and recorded 34.35g weight (Table 4; Fig. 2). However, the counts of both adult (40.23) and juvenile worms were significantly higher than that of *E. eugeniae,* having an adult and juvenile count of 28.00 and 104.75, respectively. The indigenous species *Megascolex cochinensis* and *Pontoscolex corethrurus* did not come up well in pots in the banana-cowdung mixture (1:1 w/w). There was a decrease in the count of adults towards the end of the experiment. They failed to produce juveniles or cocoons in the experimental conditions. The other species collected during survey were not found good for composting, based on the preliminary studies.

4.2.2. Composting efficiency and breeding potential of indigenous and exotic earthworm species in the field

The result of the field experiment to assess the performance of *E. eugeniae* and *P. sansibaricus* is presented in Table 5. When equal quantity (weight) of worms of the two species was used for composting, the period required for composting was equal. There was no significant difference in the compost recovery and the undecomposed fraction in the compost. In the present

experiment the counts of worms (adults and juveniles) were high in *P. sansibaricus* (Plate IX), compared to *E. eugeniae*. However, the weight of worms/ kg compost was significantly higher in *E. eugeniae,* than in *P. sansibaricus* .

4.3. Bionomics of *E. eugeniae* and *P. sansibaricus*

4.3.1. Effect of seasons on the growth and multiplication of *E. eugeniae* and *P. sansibaricus*

The effect of species, month, and species-month interaction on adult, juvenile and cocoon production of *E. eugeniae* and *P. sansibaricus* is presented in Table 6 and 7.

4.3.1.1. Species difference on adult, juvenile and cocoon production.

The indigenous species *P. sansibaricus* was superior to the exotic species *E. eugeniae* with respect to adult and juvenile worm production. However, cocoon production was more in *E. eugeniae* and the effect was significantly superior (Table 6).

4.3.1.2. Effect of month on adult, juvenile and cocoon production in *E. eugeniae* and *P. sansibaricus*

Experiment set in May recorded the highest count of adult worms (38.83). The observations in October (37.5), June (35.00) and September (33.83) were on par. The lowest count of adult worms (29.17) was observed in August and December (Table 6).

With respect to juveniles the counts were significantly superior (Table 6) in the experiments set in July (134.67), June (134.5) and September (126.67) and the lowest count was in March (45.67).

The mean cocoon counts were the lowest in February (14.8) and the highest in October (28.33). The observations in September and June were on par.

4.3.1.3. Effect of species-month interaction (*E. eugeniae*)

The adult count was the highest (35.67) in experiments set in October with respect to *E. eugeniae*. Observation in May (Table 6) was on par (35.0). The other treatments recorded lesser worm counts. July, followed by June and August, produced higher juvenile counts (109, 105 and 98.67, respectively). The other months recorded significantly lesser worm counts. The highest cocoon count

Table 6. Interaction effect of season on the growth and multiplication of *Eudrilus eugeniae* and *Perionyx sansibaricus*

Treatments		No. of adults	No. of juveniles	No.of cocoons
S1	(*Eudrilus eugeniae*)	29.56(5.51)	60.31 (7.60)	23.94 (4.94)
S2	(*Perionyx sansibaricus*)	35.75(6.04)	103.33 (9.90)	15.72 (3.99)
CD (0.05)		0.174	0.440	0.234
M1	May	38.83 (6.28)	98.33 (9.37)	21.83 (4.74)
M2	June	35.00 (5.96)	134.50 (11.56)	23.67 (4.94)
M3	July	32.67 (5.76)	134.67 (11.59)	21.83 (4.74)
M4	August	29.17 (5.48)	94.00 (9.72)	20.17 (4.48)
M5	September	33.83 (5.90)	126.67 (11.15)	24.83 (5.05)
M6	October	37.50 (6.20)	67.33 (7.82)	28.33 (5.30)
M7	November	33.50 (5.86)	50.00 (7.02)	16.83 (4.11)
M8	December	29.17 (5.48)	54.00 (7.32)	17.33 (4.25)
M9	January	29.50 (5.52)	48.33 (7.02)	15.50 (3.98)
M10	February	28.67 (5.44)	47.33 (6.89)	14.80 (3.87)
M11	March	31.33 (5.67)	45.67 (6.82)	17.70 (4.14)
M12	April	32.67 (5.78)	80.50 (8.72)	15.17 (4.00)
CD (0.05)		0.419	1.073	0.574

	No.of adults		No. of juveniles		No. of cocoons	
	S1	S2	S1	S2	S1	S2
M1	35.00 (5.96)	42.67 (6.59)	35.00 (5.96)	162.67 (12.79)	24.01 (5.02)	19.00 (4.40)
M2	28.00 (5.38)	42.00 (6.55)	105.00 (10.29)	164.00 (12.83)	19.00 (4.47)	28.33 (5.41)
M3	25.00 (5.09)	40.33 (6.42)	109.00 (10.49)	160.33 (12.69)	17.00 (4.24)	26.67 (5.24)
M4	25.33 (5.13)	33.00 (5.83)	98.67 (9.98)	89.33 (9.47)	28.67 (5.42)	11.67 (3.54)
M5	30.33 (5.59)	37.33 (6.18)	87.00 (9.37)	166.33 (12.93)	29.00 (5.44)	20.67 (4.65)
M6	35.67 (6.05)	39.33 (6.35)	28.00 (5.38)	106.66 (10.26)	38.67 (6.29)	18.00 (4.31)
M7	33.00 (5.83)	34.00 (5.89)	48.33 (6.83)	51.67 (7.21)	24.33 (5.01)	9.33 (3.21)
M8	27.00 (5.29)	31.33 (5.67)	39.33 (6.34)	68.67 (8.29)	18.00 (4.35)	16.67 (4.15)
M9	28.70 (5.44)	30.33 (5.59)	48.33 (7.02)	48.33 (7.02)	21.67 (4.75)	9.33 (3.21)
M10	28.70 (5.44)	28.67 (5.44)	38.33 (6.25)	56.33 (7.53)	21.00 (4.65)	8.67) (3.10)
M11	29.67 (5.53)	33.00 (5.81)	42.00 (6.55)	49.33 (7.09)	27.67 (5.35)	7.67 (2.94)
M12	28.33 (5.41)	37.00 (6.16)	44.67 (6.75)	116.33 (10.67)	17.67 (4.31)	12.67 (3.69)
CD (0.05)	0.594		1.520		0.290	

The data represent the mean values of three replications

The values in parentheses are transformed values ($\sqrt{x}$ transformation)

(38.67) was obtained in October which was significantly superior to those in experiments set in the other months. Higher cocoon counts were also observed in the experiments set in September, August and March. The lowest count (Table 6) was recorded in July (17.00) followed by December (18.00) and June (19.00). No defenite trend could be identified in the cocoon counts of *E. eugeniae.*

4.3.1.4. Effect of species-month interacion (*P. sansibaricus)*

The adult counts of *P. sansibaricus* were high in May, June, July, October, September and April. The counts of May, June, July, October, September and April were 42.67, 42.0, 40.33, 39.33, 37.33 and 37.0, respectively. The figures were significantly higher, compared to that obtained in the experiments set in the other months. The lowest adult count (28.67) was recorded in the experiments set in February (Table 6).

The count of the juveniles was the highest in experiments set in September (166.33), followed by June (164.0), July (160.33) and April (116.33). The observations in September, June and July were significantly superior to all other treatments. The lowest count (48.33) was obtained in the experiment set in January. The numbers of juveniles from November to March were significantly lower.

The cocoon counts were high in experiments set in June (28.33), July (26.67) and September (20.67). The count was the lowest in November (9.33). In summer months the counts were significantly lower.

4.3.1.5. Correlation studies with environmental factors

E. eugeniae

There was no significant correlation between adult counts and environmental characters. But, there was positive correlation between juvenile count and rainfall. However, the correlation between juvenile count and cocoon count expressed with maximum temperature was negative (Table 7).

P. sansibaricus

Adult and juvenile counts expressed positive correlation with rainfall and humidity. However, the correlation between adult and juvenile and cocoon counts and maximum temperature was negative. Cocoon count showed positive correlation with rainfall (Table 7).

4.3.1.6. Effect of month on the time required for composting

The time required for composting when the experiment was set in different months is presented in Table 8.

The time required for composting was more in *P. sansibaricus* than in *E. eugeniae*. In both cases the period required for composting in summer season was more, compared to rainy season (Fig. 3).

In *E. eugeniae* the highest decomposition rate was observed in the experiments set in June. The observation in May, July and August were on par with this. In the other months the decomposition rates were significantly lower, compared to the observation in June. The lowest decomposition rate was observed in the experiments set in February (Table 8).

With respect to *P. sansibaricus* the highest decomposition rate was observed in the experiments set in May. The observations in June, July, August and September were on par. Experiments set in the other months recorded significanty lower rates. The lowest rate of decomposition was observed in January (Table 8).

Table 7. Coefficients of correlation of adult, juvenile and cocoon counts of *Eudrilus eugeniae* and *Perionyx sansibaricus* with climatic factors *viz.* maximum temperature, minimum temperature, rain fall and relative humidity.

Adult (E)	1.00									
Juvenile (E)	-0.412	1.00								
Cocoon (E)	0.258	-0.200	1.00							
Adult (P)	0.447	0.297	0.059	1.00						
Juvenile (P)	0.118	0.486	-0.043	0.640	1.00					
Cocoon (P)	-0.053	0.508	-0.040	0.527	0.791	1.00				
Max. Temp	-0.126	-0.510 **	-0.347 *	-0.531 **	-0.652 **	-0.512	1.00			
Min. Temp	0.238	-0.288	-0.008	0.059	-0.070	-0.140	0.016	1.00		
Rain fall	-0.262	0.817 **	-0.107	0.462 **	0.697 **	0.687	-0.660	-0.057	1.00	
RH	0.193	0.302	0.018	0.420 **	0.384 *	0.214	-0.550	0.409	0.491	1.00

* Significant at 5 % level
** Significant at 1 % level
E. *Eudrilus eugeniae*
P. *Perionyx sansibaricus*

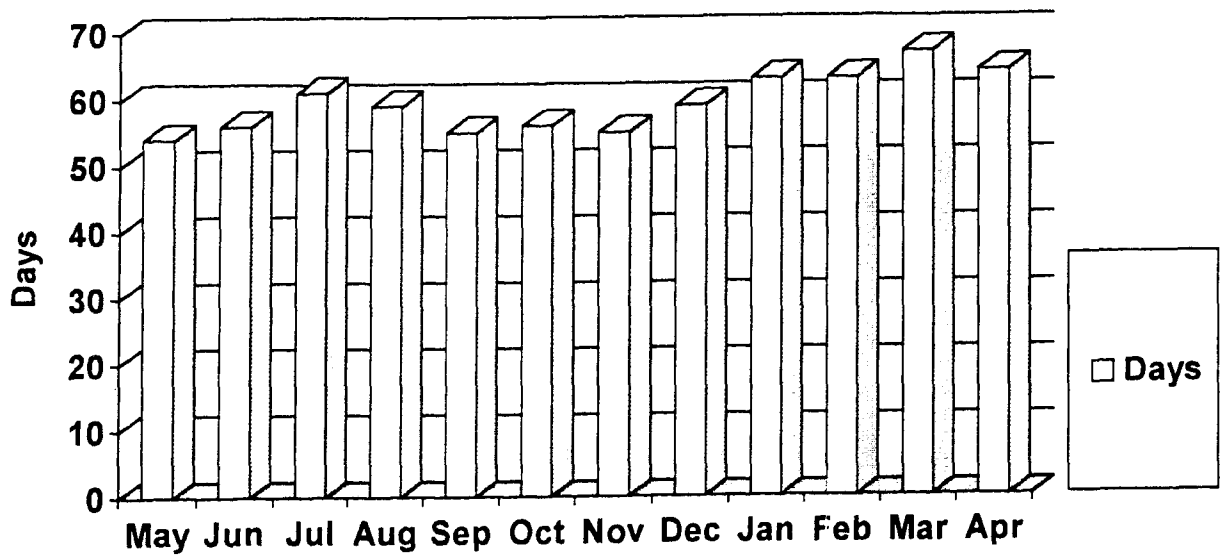
Table 8. Effect of months on the time required for composting and the decomposition ratio of compost, using *Eudrilus eugeniae* and *Perionyx sansibaricus*

Month of starting the experiment	*E. eugeniae*		*P. sansibaricus*	
	Duration	Decomposition ratio	Duration	Decomposition ratio
May	54	12.96 (3.60)	71	13.32 (3.65)
June	56	14.03 (3.74)	74	12.43 (3.52)
July	61	13.03 (3.61)	75	13.03 (3.61)
August	59	13.03 (3.61)	73	11.84 (3.44)
September	55	12.09 (3.47)	72	12.08 (3.47)
October	56	11.26 (3.35)	75	10.86 (3.29)
November	55	11.93 (3.45)	81	11.93 (3.45)
December	59	10.56 (3.25)	84	9.55 (3.09)
January	63	8.69 (2.95)	83	7.83 (2.79)
February	63	8.12 (2.85)	84	8.69 (2.94)
March	67	8.69 (2.95)	82	9.36 (3.05)
April	64	10.17 (3.18)	84	10.57 (3.25)
CD (0.05)		0.174		0.265

The data represent the mean values of three replications.

The values in parentheses are transformed values ($\sqrt{x}$ transformation)

Fig. 3. Effect of months on the duration of composting using *E. eugeniae*



4.3.2. Cumulative increase of the biomass of *E. eugeniae*

The results of the experiment to assess the cumulative increase of the biomass of *E. eugeniae* are presented in Table 9 to12.

With respect to container I (plastic basin of 40 cm x 30 cm x 20 cm size) containing 2.0 kg waste and 25 worms), there was gradual increase in adult count upto 217 days (optimum 223.43 day). However, there was no increase in the juvenile count with time. Moreover, there was a decline in the cocoon count and the regression model did not fit with the data. The highest biomass was also observed at an interval of 217 days (optimum 219.33 days). The increase in biomass at this period was only 6.89 times (Table 9 and 12).

With respect to container II (plastic basin of 60 cm x 30 cm x 20 cm size) using the same initial quantity of worms and waste there was an increase in the adult count up to 264 days. The increase in biomass at this period was 12.73 times (Table 10 to 12), optimum being 250.54 days.

In the field condition (pit size 2.0 m x 1.0 m x 0.4 m, with 250 kg banana waste-cowdung mixture (5:1 w/w 0.5 kg worm) (Plates X and XI) the population increase and biomass production was superior to the first two situations. In field

Table 9. Cumulative increase of biomass of *Eudrilus eugeniae* in container I (Plastic basin small)

Biomass	64 days	117 days	168 days	217 days	272 days	323 days
No. of adults	34.66	96.66	119.33	164.33	128.66	103.00
No. of juveniles	68.66	31.00	45.66	37.00	34.66	14.66
No. of cocoons	28.33	15.33	24.66	17.33	10.33	4.33
Total biomass (g)	45.33	109.66	142.50	172.33	139.00	113.33

The data represent the mean values of three replications

Table 10. Cumulative increase of biomass of *Eudrilus eugeniae* in container II (Plastic basin big)

Biomass	62 days	114 days	161 days	212 days	264 days	325 days
No. of adults	39.66	94.66	155.66	229.00	296.66	282.33
No. of juveniles	87.00	102.66	75.00	106.33	74.00	65.60
No. of cocoons	18.00	25.00	34.00	51.66	20.33	8.33
Total biomass (g)	51.00	121.83	156.33	245.66	318.33	293.00

The data represent the mean values of three replications

Table 11. Cumulative increase of biomass of *Eudrilus eugeniae* in field condition

Biomass	76 days	140 days	198 days	261 days	321 days
No. of adults	30.00	45.33	52.00	53.66	51.66
No. of juveniles	39.66	40.66	47.00	29.66	18.33
No. of cocoons	8.33	9.00	9.66	6.00	5.33
Biomass per kg compost (g)	34.00	57.60	61.43	63.33	53.00
Total biomass (kg)	4.42	7.20	7.86	8.17	7.01

condition there was 16.34 times increase in the biomass (Table 11 and 12) in a period of 261 days (optimum 224.12 days).

4.3.3. Biology and biometrics of *E. eugeniae*

The observations on the biology and biometrics of *E. eugeniae* (Plates XV and XVI) are presented in Table 13 and 14.

Freshly-laid eggs were having the shape of a coriander seed (Plates XII, XIV). They were brownish and broader towards the middle region. Cocoons recorded a mean length of 4.04 ± 0.115 mm and maximum width of 2.4 ± 0.09mm. The newly-emerged larvae were light pinkish (length 1.45 ± 0.05 cm and width 0.537 ± 0.017 mm).

In six weeks time the worms attained reproductive (clitellate) stage and had a mean length of 7.125 ± 0.096 cm and a mean width of 2.975 ± 0.137 mm (Table 14). Cocoon required 29 ± 1.101 days for hatching. The hatching rate was only 56.25 ± 1.19 per cent in the laboratory condition. The mean number of juveniles per cocoon was 2.875 ± 0.35 (Table 15).

The mean period required for the earthworm to attain reproductive stage was 43.38 ± 0.558 days. The dorsal side of the juveniles turned darker during the

Plate XI. Compost prepared from banana waste

Plate XII. Cocoons of *Eudrilus eugeniae*

Plate XIII. Cocoons of *Perionyx sansibaricus*

Plate XIV. Cocoons of *Perionyx sansibaricus* (a) and *Eudrilus eugeniae* (b)

Plate XV. Adults of *Eudrilus eugeniae* (a) and *Perionyx sansibaricus* (b)

Plate XVI. Life cycle of *Eudrilus eugeniae*

(a) Cocoon (b) Juvenile (c) Adult


a
b

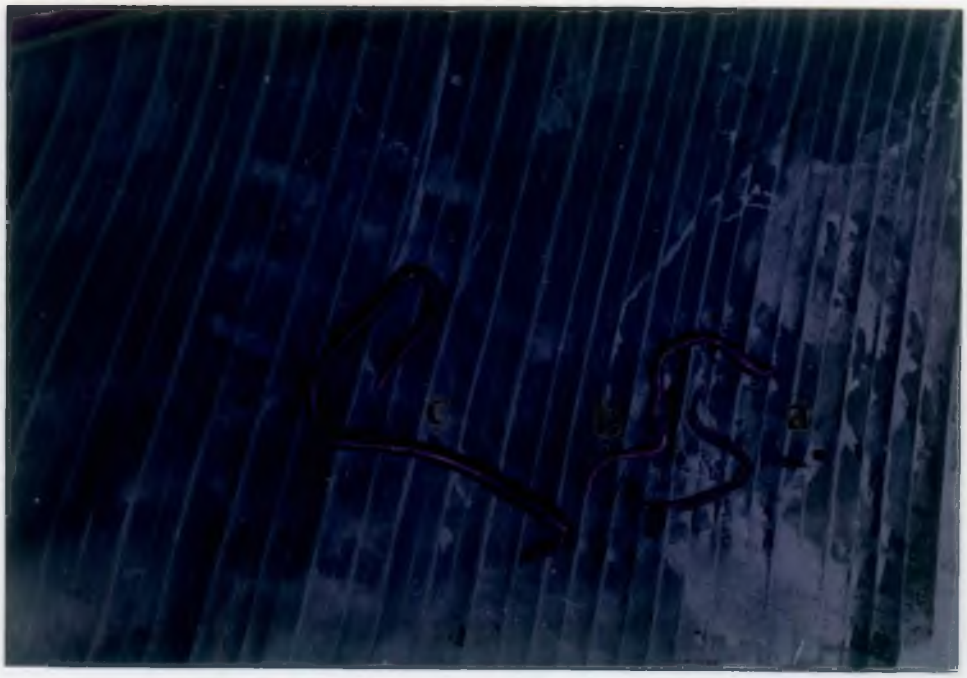

c
b
a

Table 13. Biometrics of *Eudrilus eugeniae* and *Perionyx sansibaricus*

Character	Length (cm)		Width (mm)	
	E. eugeniae	*P. sansibaricus*	*E. eugeniae*	*P. sansibaricus*
Cocoon	0.4 040 ± 0.115	0.3 93 ± 0.091	2.40 ± 0.090*	1.46 ± 0.090
Newly emerged	1.450 ± 0.050	1.300 ± 0.039	0.537 ± 0.017*	0.425 ± 0.023
One week old juvenile	2.280 ± 0.067*	1.940 ± 0.012	0.993 ± 0.046*	0.738 ± 0.035
Two week old juvenile	3.480 ± 0.065*	2.740 ± 0.096	1.560 ± 0.073*	1.080 ± 0.033
Three week old juvenile	4.350 ± 0.063*	3.290 ± 0.057	2.140 ± 0.053*	1.640 ± 0.035
Four week old juvenile	5.075 ± 0.067 *	4.010 ± 0.051	2.360 ± 0.083*	1.810 ± 0.037
Five week old juvenile	6.037 ±0.111*	4.550 ± 0.068	2.580 ± 0.082*	1.940 ± 0.032
Six week old adult	7.125 ± 0.096*	5.040 ± 0.046	2.975 ± 0.137*	2.040 ± 0.040
Eight week old adult	10.790 ± 0.338*	6.875 ± 0.1319	3.200 ± 0.008*	2.150 ± 0.018

* Significantly higher based on "t test"

Table 14. Biology of *Eudrilus eugeniae* and *Perionyx sansibaricus*

Character	*Eudrilus eugeniae*	*Perionyx sansibaricus*
Hatching percentage	56.250 ± 3.125	64.060± 3.440
Hatching period (days)	29.000 ± 1.101 *	16.000 ± 0.433
No. of juveniles/cocoon	2.875 ± 0.35 *	1.250 ± 0.153
Juvenile to adult period (days)	43.370 ± 0.560 *	38.250 ± 0.701
Pre-oviposition period (days)	6.250 ± 0.233	5.750 ± 0.210

* Significantly higher based on "t test"

Table 15. Cocoon production by *Eudrilus eugeniae* and *Perionyx sansibaricus*

Period	No. of cocoons produced by *Eudrilus eugeniae*	No. of cocoons produced by *Perionyx sansibaricus*
1st	1.25 ± 0.15	2.38 ± 0.35 *
2nd week	3.50 ± 0.30	6.75 ± 0.99 *
3rd week	3.63 ± 0.35	3.13 ± 0.54
4th week	4.13 ± 0.33	4.50 ± 0.61
5th week	3.25 ± 0.23	5.25 ± 0.84 *
6th week	3.50 ± 0.35	4.63 ± 0.66
7th week	2.75 ± 0.29	4.13 ± 0.60
8th week	3.25 ± 0.15	4.87 ± 1.23
9th week	2.50 ± 0.35	4.63 ± 0.39 *
10th week	2.75 ± 0.34	4.75 ± 0.66 *
11th week	2.38 ± 0.23	6.38 ± 0.66 *
12th week	2.63 ± 0.29	5.25 ± 0.66 *
13h week	3.13 ± 0.28	6.38 ± 0.68 *

* Significantly higher based on "t test"

Plate XVII. Life cycle of *Perionyx sansibaricus*

(a) Cocoon (b) Juvenile (c) Adult

Plate XVIII. Effect of *in situ* vermiculture on the growth of bhindi


a
b
c

course of development and displayed bio-luminiscence. The ventral side remained flat and lighter in colour. After attaining the clitellate stage the worms required 6.25 ± 0.233 days to start laying cocoons. The details of cocoons laid during the first three months of the reproductive period is presented in Table 15.

4.3.4. Biology and biometrics of *P. sansibaricus*

The observations on the biology and biometrics of *P. sansibaricus* (Plates XV and XVII) are presented in Table 13 and 14.

Freshly-laid eggs were elongate, slender, broader towards the middle and tapering towards both ends, with a mean length of 3.93 ± 0.091mm and a maximum width of 1.46 ± 0.09 mm (Plate XIII and XIV). Eggs were laid on the surface of the moist undecomposed organic matter, often in parallel lines. The time required for the cocoon to hatch was 16 ± 0.43 days. The hatching rate under laboratory condition was 64.00 ± 3.44 per cent (Table 15). The newly emerged juveniles were slender and pinkish with a mean length of 1.3 ± 0.039 cm and a mean width of 0.425 ± 0.023mm.

The biometrics of *P. sansibaricus* is presented in Table 13. By the sixth week the worm attained a mean length of 5.04 ± 0.046 cm and a width of 2.04 ± 0.04 mm. The mean time required for juveniles to become adult was 38.25 ± 0.70

days. The clitellum develops during this stage. The clitellar region is slightly yellowish, compared to the other body parts, which are pinkish red. The ventral side of the body is flat and lighter in colour. After clitellar formation, the worms required a mean period of 5.75 ± 0.23 days for the laying of cocoons. The details of the cocoon laid during the first three months are presened in Table 15.

4.4. Effect of vermicompost on the yield of bittergourd and cowpea

The results of the field experiment to study the effect of vermicompost on the yield of bittergourd and cowpea are presented in Table 16.

Vermicompost, along with full inorganic fertilizer, increased the yield of bittergourd and cowpea by 21.1 per cent and 19.0 per cent, respectively (Fig. 4). In cowpea, application of vermicompost and inorganic fertilizer was equally effective (yield 3415 g per pit) as the recommended manurial schedule (yield 4155 g per pit). However, in bittergourd the yield was significantly reduced when vermicompost alone was applied without inorganic fertilizers (2322 g per pit), compared to control (3222 g per pit). The nitrogen requirement when completely met through vermicompost application in bittergourd and cowpea, without using inorganic fertiliser, the effect was equal to that of the recommended manurial schedule. The treatments "vermicompost along with half inorganic fertilizers" and "vermicompost along with three fourth inorganic fertilizers" were

Table 16. Effect of vermicompost on the yield of bittergourd and cowpea

Treatment		Yield per plot (4 m^2)	
		Bittergourd (g)	Cowpea (g)
T1	(POP) recommendations	3222	4155
T2	Vermicompost substituting FYM	2322	3415
T3	Vermicompost substituting FYM + Half inorganic fertilisers as per POP	2842	3701
T4	Vermicompost substituting FYM + Three fourth inorganic fertilisers as per POP	3254	4080
T5	Vermicompost substituting FYM + Nitrogen requirement as per POP through vermicompost	2965	3569
T6	Vermicompost substituting FYM + Full inorganic fertilisers as per POP	4023	4944
CD (0.05)		702.66	740.07

The data represent the mean values of five replications

Table 17. Effect of vermicompost on the fruit fly incidence in bittergourd

Treatment	1st week	2nd week	3rd week	4th week	5th week	6th week	7th week
T1	21.62 (13.58)	13.51 (5.46)	25.56 (18.63)	32.39 (28.71)	32.98 (29.65)	48.50 (44.13)	55.74 (48.27)
T2	7.05 (1.51)	13.71 (5.62)	14.47 (6.25)	24.03 (16.59)	22.61 (14.79)	17.88 (9.44)	13.04 (5.09)
T3	17.85 (9.40)	15.74 (7.37)	16.71 (8.27)	7.98 (1.93)	20.86 (12.69)	0 (0)	29.98 (25.01)
T4	20.48 (12.26)	9.65 (2.47)	9.43 (2.69)	10.05 (3.05)	28.04 (22.11)	18.33 (10.43)	42.51 (40.67)
T5	11.85 (4.22)	16.62 (8.19)	16.15 (7.73)	10.18 (3.09)	13.75 (5.63)	0 (0)	10.61 (3.39)
T6	14.09 (5.93)	15.38 (7.04)	16.21 (7.79)	9.89 (2.95)	24.20 (16.58)	48.16 (43.92)	41.75 (40.24)
CD 0.05	NS	NS	NS	NS	NS	24.39	25.19

The data represent the mean values of five replications.
The values in parentheses are transformed values (angular transformation)
Treatments are as in Table 16

Table 18. Effect of vermicompost on the incidence of epilachna beetle in bittergourd

Treatement	1st week	2nd week	3rd week	4th week	5th week	6th week
T1	0.173 (1.082)	0.314 (1.146)	0.560 (1.230)	0 (1.000)	0.314 (1.146)	0.314 (1.146)
T2	0.769 (1.330)	0 (1.000)	0 (1.000)	0 (1.000)	0 (1.000)	0 (1.000)
T3	0.314 (1.146)	0 (1.000)	0.314 (1.146)	0 (1.000)	0 (1.000)	0.358 (1.660)
T4	0.314 (1.146)	0.511 (1.229)	0 (1.000)	0.511 (1.229)	0.314 (1.146)	0.314 (1.146)
T5	1.043 (1.429)	0 (1.000)	0 (1.000)	0 (1.000)	0 (1.000)	0 (1.000)
T6	0.671 (1.290)	0.314 (1.146)	0.440 (1.200)	0.359 (1.660)	0.440 (1.200)	0.314 (1.146)
CD 0.05	NS	NS	NS	NS	NS	NS

The data represent the mean values of five replications.
The values in parentheses are transformed values ($\sqrt{x}+1$ transformation)
Treatments are as in Table 16

Table 19. Effect of vermicompost on the incidence of aphids in cowpea

Treatment	No. of aphids/ 5 cm length of shoot in 1st week of flowering	No. of aphids/ 5 cm length of shoot in 2nd week of flowering
T1	29.27 (5.50)	7.35 (2.88)
T2	19.77 (4.55)	0.56 (1.25)
T3	8.81 (3.13)	3.63 (2.15)
T4	12.68 (2.41)	5.62 (2.57)
T5	0 (1.00)	1.54 (1.37)
T6	10.88 (3.45)	5.77 (2.66)
CD 0.05	NS	NS

The data represent the mean values of five replications. The values in parentheses are transformed values ($\sqrt{x}+1$ transformation). Treatments are as in Table 16.

Table 20. Effect of vermicompost on the incidence of epilachna beetle in cowpea

Treatment	Number of beetles per five leaves				
	1st week	2nd week	3rd week	4th week	5th week
T1	4.14 (2.27)	0 (1.00)	0.64 (1.28)	0.39 (1.18)	0.87 (1.37)
T2	1.50 (1.25)	0 (1.00)	0 (1.00)	0 (1.00)	0 (1.00)
T3	5.27 (2.50)	0.99 (1.41)	0.56 (1.25)	1.44 (1.56)	0 (1.00)
T4	2.65 (1.91)	0 (1.00)	0.56 (1.25)	0.71 (1.31)	0.99 (1.41)
T5	0.57 (1.25)	0.22 (1.10)	0 (1.00)	0.22 (1.10)	0.46 (1.21)
T6	3.97 (2.23)	0 (1.00)	0.39 (1.18)	0.56 (1.25)	0.56 (1.25)
CD 0.05	NS	NS	NS	NS	NS

The data represent the mean values of five replications.The values in parentheses are transformed values ($\sqrt{x}+1$ transformation). Treatments are as in Table 16.

Table 21. Effect of vermicompost on the incidence mosaic in cowpea

Treatment	Mosaic infested plants per plot in first week of flowering	Mosaic infested plants per plot in second week of flowering
T1	0.50 (1.22)	1.00 (1.41)
T2	0.01 (1.00)	0 (1.00)
T3	0.75 (1.34)	1.75 (1.66)
T4	1.00 (1.41)	1.00 (1.41)
T5	0 (1.00)	0.50 (1.22)
T6	0 (1.00)	0.50 (1.22)
CD 0.05	NS	NS

The data represent the mean values of five replications. The values in parentheses are transformed values ($\sqrt{x}+1$ transformation).Treatments are as in Table 16.

Fig. 4. Effect of vermicompost on the yield of bittergourd and cowpea

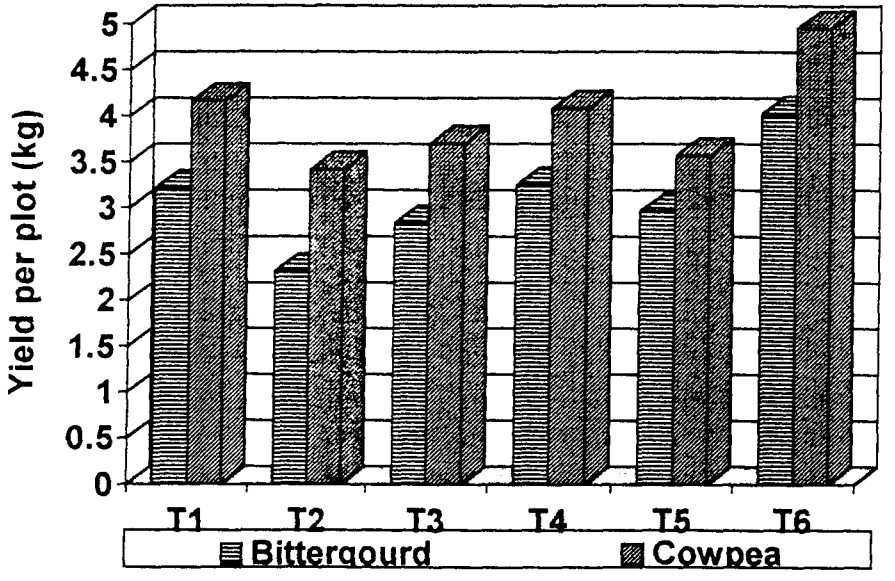
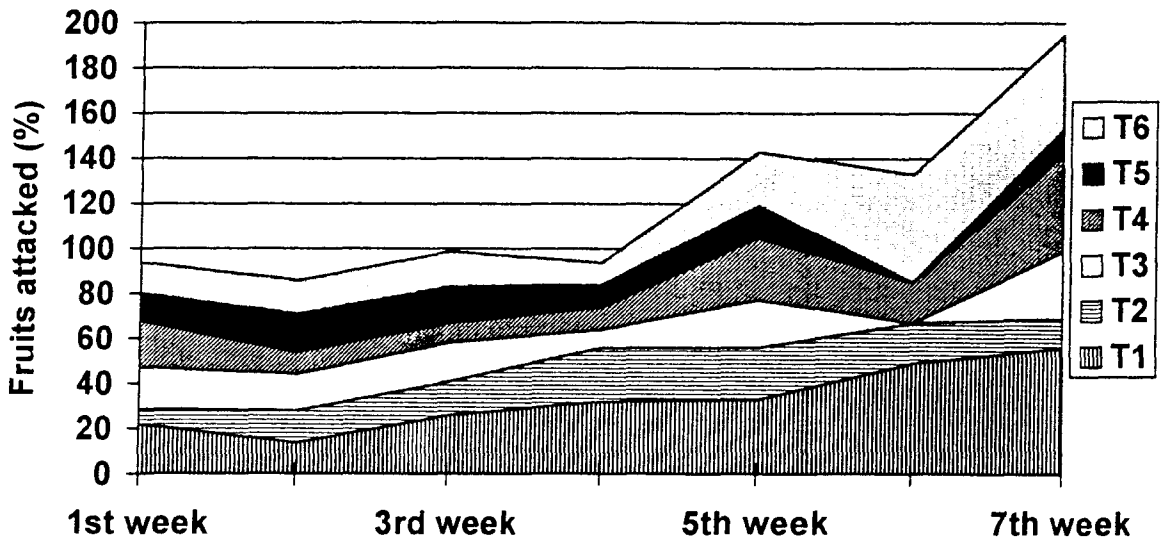


Fig. 5. Effect vermicompost on the fruit fly incidence in bittergourd



equally effective as the package of practices recommendations, in bittergourd as well as cowpea (Fig. 4).

There was decrease in the incidence of fruit fly attack in the vermicompost treated plots. However, the reduction in the pest attack was not significant, except at two intervals (Table 17; Fig. 5). The incidence of epilachna beetle attack in bittergourd plants belonging to different treatments (Table 18) was observed only in a few instances.

In the cowpea crop the pests observed were epilachna beetle, pod borer, aphid and serpentine leaf miner. Mosaic disease was also observed. The pest and disease incidence was observed only in very few instances. No significant difference among treatments was observed (Tables 19, 20 and 21).

4.5. Effect of vermicompost as a component of potting mixture

Results of the pot culture experiment to study the effect of vermicompost as a potting mixture on yield as well as pest and disease incidence in bhindi are presented in Table 22.

There was significant increase in the yield of bhindi when vermicompost was used as a potting mixture. This increase was observed with respect to the

Table 22. Effect of vermicompost on the yield and pest incidence in bhindi (Pot culture experiment)

Treatment	Yield per plant (g)	Height of plant (cm)	No.of leaves per plant	No.of aphids on upper leaf	No.of aphids on middle leaf	No.of aphids on lower leaf	No.of jassids per leaf	No. of rolled leaves per plant
T1	196.67	35.0	7.3	16.13 (4.14)	16.67 (4.20)	2.33 (1.93)	2.00 (1.73)	1.00 (1.41)
T2	243.33	50.0	9.0	1.49 (1.36)	1.67 (1.63)	0 (1.00)	0.66 (1.29)	1.00 (1.41)
T3	231.66	44.0	7.7	1.20 (1.48)	1.67 (1.63)	0 (1.00)	0 (1.00)	1.00 (1.41)
T4	245.00	36.3	7.3	0 (1.00)	0 (1.00)	0 (1.00)	0.33 (1.15)	0 (1.00)
T5	220.00	34.7	7.3	3.13 (2.03)	3.67 (2.16)	0 (1.00)	0 (1.00)	0 (1.00)
T6	211.67	29.7	8.0	11.41 (3.52)	15.00 (4.00)	2.33 (1.82)	0 (1.00)	0.66 (1.29)
T7	195.10	34.3	5.7	5.81 (2.61)	7.33 (2.89)	0 (1.00)	0 (1.00)	0 (1.00)
T8	215.00	34.3	7.3	0 (1.00)	0 (1.00)	0 (1.00)	1.00 (1.41)	0 (1.00)
T9	231.66	44.0	7.0	10.33 (3.36)	13.33 (3.78)	0 (1.00)	0 (1.00)	0 (1.00)
T10	208.37	29.7	7.3	3.00 (2.00)	5.00 (2.45)	0.67 (1.29)	0 (1.00)	2.00 (1.73)
CD 0.05	24.19	NS	NS	NS	NS	NS	NS	NS

T1	Control (POP)	T6	Vermicompost containing glyricidia leaves
T2	Vermicompost from banana waste alone	T7	Vermicompost containing eupatorium leaves
T3	Vermicompost containing neem cake	T8	Vermicompost containing thevetia leaves
T4	Vermicompost containing neem leaves	T9	Vermicompost containing clerodendron leaves
T5	Vermicompost containing mahua cake	T10	Vermicompost containing calotropis leaves

The data represent the mean values of three replications.
The values in parentheses are transformed values ($\sqrt{x+1}$ transformation)

treatments T2 (vermicompost prepared from banana leaves), T3 (vermicompost prepared from banana leaves and neem cake), T4 (vermicompost prepared from banana leaves and neem leaves) and T9 (vermicompost prepared from banana leaves and eupatorium leaves). The treatments T2, T3, T4 and T9 recorded 243.33 g, 231.66 g, 245.00 g and 231.66 g fruits per plant, respectively. The other treatments were on par with the control (196.67 g per plant). However, no significant difference in biometric characters was observed. There was an increasing trend in the height and number of leaves in treatments involving vermicompost as a potting mixture. The maximum plant height (50 cm) was observed in T2. The treatments T3 and T9 recorded a mean plant height of 44 cm.

A decreasing trend in pest and disease incidence was observed in vermicompost-treated plots. However, the decrease was not statistically significant. The decrease was more pronounced in the case of aphids. With respect to jassids and leaf roller no definite trend was observed.

4.6. Effect of *in situ* vermiculture in bhindi

The results of the experiments to assess the effect of *in situ* vermiculture in bhindi are presented in Table 23.

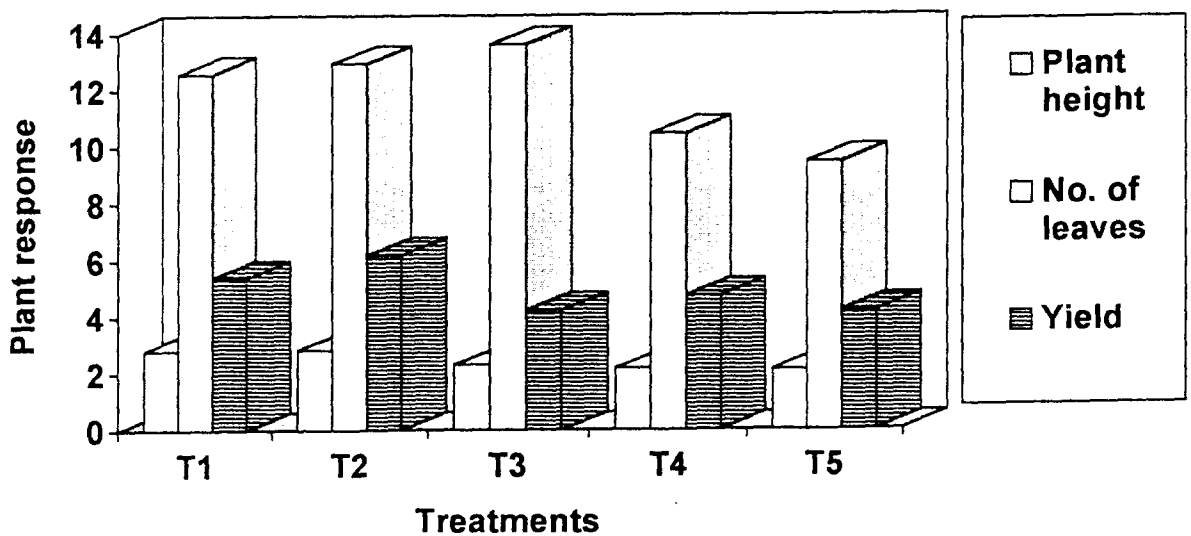
Table 23. Effect of *in situ* vermiculture in bhindi

Treat-ment	Height (cm) 1 month	Height (cm) 2 month	Height (cm) 4month	No. of Branches 1 month	No. of Branches 2 month	No. of Branches 3 month	No. of leaves 1 month	No. of leaves 2 month	No. of leaves 4 month	Yield per plot (g)
T1	58.56	133.44	279.82	1.06	1.40	1.88	6.32	11.69	12.56	5393
T2	51.93	139.75	283.06	1.03	1.69	2.19	5.56	12.04	12.94	6193
T3	50.63	104.33	230.63	1.03	1.81	1.81	7.18	10.44	13.59	4220
T4	46.63	108.00	217.44	0.69	1.56	1.75	5.34	10.34	10.44	4723
T5	46.92	88.50	211.94	0.59	1.19	1.63	6.00	8.88	9.44	4200
CD (0.05)	9.86	29.47	56.90	-	-	-	-	-	-	891.8

T1 POP
T2 Vermicompost substituting FYM + Full inorganic fertilisers as per POP
T3 *In situ* vermiculture (150 worms per plot)
T4 *In situ* vermiculture (250 worms per plot)
T5 Vermicompost substituting FYM + Nitrogen requirement as per POP through vermicompost

The data represent the mean values of four replications

Fig. 6. Effect of *in situ* vermiculture on the growth and yield of bhindi



There was no significant variation among the five treatments in plant biometric characters, except height one month after sowing. The treatments involving Package of Practices Recommendations recorded maximum height, compared to the other treatments. The treatment involving vermicompost with full inorganic fertilizers was on par with the POP. These treatments recorded a mean height of 58.56 cm and 51.93 cm, respectively. Among the biometrice characters only the plant height showed significant increase, both two months after sowing and at the end of the experiment. Two months after sowing the treatment consisting of vermicompost along with full inorganic fertilizer recorded the maximum plant height (139.75 cm). The lowest plant height was recorded by T5 (N_2 application through vermicompost). At the end of the experiment the vermicompost along with full inorganic fertilisers recorded the maximum plant height (283.06 cm). The effect of the Package of Practices Recommendations and *in situ* vermiculture on plant height were equal. Vermicompost along with full inorganic fertilisers increased the yield by 15 per cent. The effect of *in situ* vermiculture (250 worms / plot) was on par with that of the Package of Practices recommendations (Fig. 6; Plate XVIII).

4.7. Effect of biopesticides on the growth and multiplication of *E. eugeniae*

The result of the study on the effect of biopesticides on growth and multiplication of *E. eugeniae* is presented in Table 24.

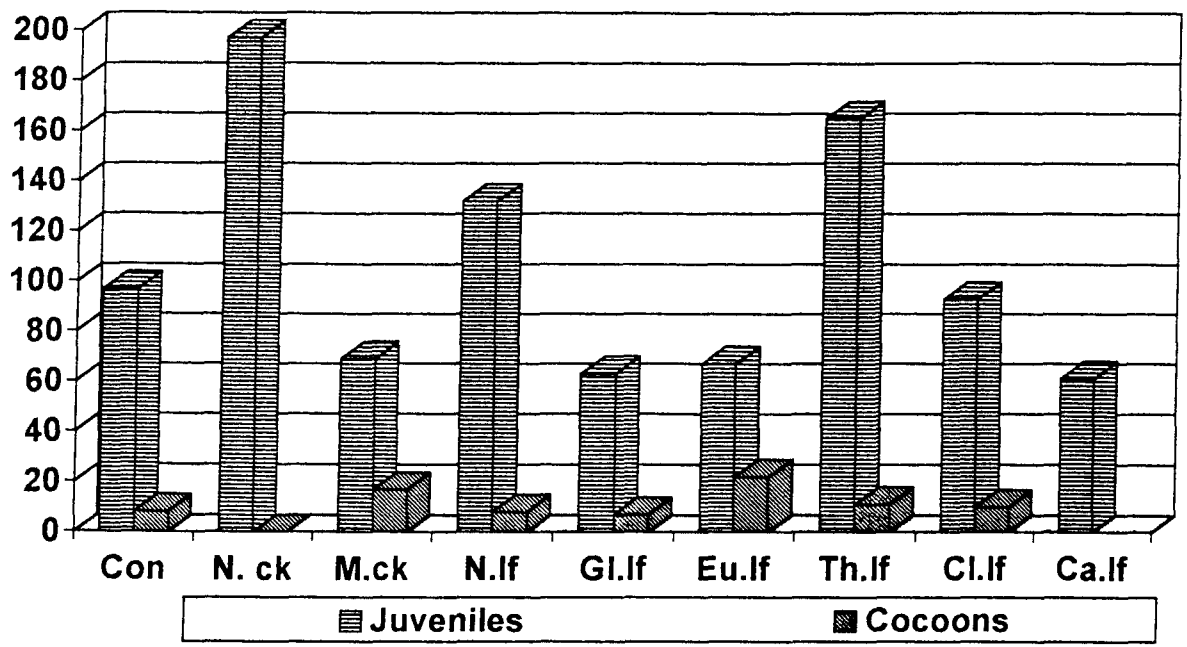
Neem cake was the most beneficial treatment for supporting growth and multiplication of *E. eugeniae.* Leaves of neem and thevetia were also found effective . Neem cake increased the juvenile worm production by 102 per cent. It was found to be superior to all other treatments. In treatments with neem and thevetia, the mean juvenile worm counts (Fig. 7) were 132.0 and 165.0, respectively; whereas in the control the juvenile worm count was only 97.33. In the other treatments (leaves of glyricidia, eupatorium, clerodendron and calotropis) the counts of juvenile worm were less than that in the control (banana leaf-cowdung mixture 1:1 w/w). However, this did not affect the cocoon production. The cocoon production was the highest (22.0) for treatments with thevetia leaves, followed by neem leaves (17.0). The number of adults (12.0) was significantly lower in mahua cake treatment. Among the other treatments, there was not much variation in adult worm count. The lowest number of adults and cocoons was recorded in mahua cake treatment.

Table 24. Effect of biopesticides on earthworm *Eudrilus eugeniae*

Treatment	Population count of earthworm after one month		
	Adults*	Juveniles**	Cocoons**
Control (banana leaves + cow dung mixture)	20.00 (4.58)	97.33 (9.91)	8.00 (2.99)
Neem cake	20.33 (4.62)	197.33 (14.08)	8.33 (3.04)
Mahua cake	11.72 (3.57)	68.60 (8.31)	0 (1.00)
Neem leaves	20.33 (4.62)	132.00 (11.41)	17.00 (4.18)
Glyricidia leaves	20.57 (4.62)	63.33 (7.97)	8.33 (3.05)
Eupatorium leaves	20.99 (4.69)	67.00 (8.21)	7.33 (2.86)
Thevetia leaves	20.33 (4.62)	165.00 (12.88)	22.00 (4.78)
Clerodendron leaves	20.33 (4.62)	92.66 (9.59)	10.66 (3.29)
Calotropis leaves	20.29 (4.62)	61.33 (7.89)	10.33 (2.31)
CD (0.05)	0.464	1.781	0.825

The data represent the mean values of four replications
The values in parentheses are transformed values
* $\sqrt{x}$ transformation ** $\sqrt{x+1}$ transformation

Fig. 7. Effect of biopesticides on *E. eugeniae*



4.8. Effect of biopesticides on the growth and multiplication of *P. sansibaricus*

The effect of biopesticides on the growth and multiplication of *P. sansibaricus* is presented in Table 25.

Neem cake was effective in supporting growth and multiplication of the indigenous species *P. sansibaricus*. It recorded 52 per cent increase in juvenile worm production (Fig. 8), compared to control (banana leaves - cowdung mixture 1:1 w/w). Treatments consisting of the leaves of neem, clerodendron and glyricidia recorded increase in juvenile worm production, compared to control.

Leaves of neem, clerodendron and glyricidia recorded juvenile worm counts of 93.33, 90.33 and 79.67, respectively which were, however, on par with the juvenile worm count of control (76.00). In treatments involving thevetia and eupatorium leaves the juvenile worm counts were numerically less than that of the control. However, statistically they were also on par with the control. Calotropis leaves and mahua cake caused significant reduction in adult, juvenile and cocoon production.

In the exotic species *E. eugeniae* as well as the indigenous species *P. sansibaricus*, neem cake was found beneficial for supporting growth and

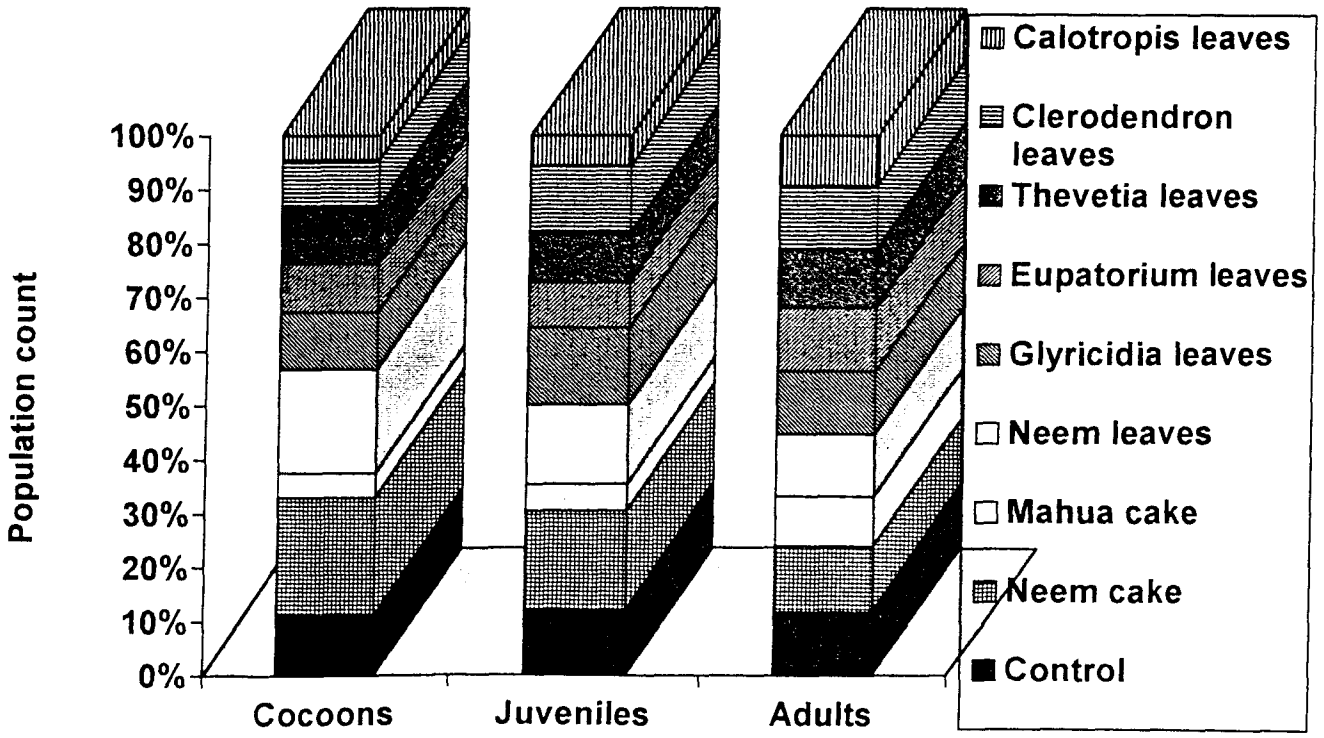
Table 25. Effect of biopesticides on earthworm *Perionyx sansibaricus*

Treatment	Population count of earthworm after one month		
	Adults	Juveniles	Cocoons
Control	20.00 (4.47)	76.00 (8.66)	10.67 (3.23)
Neem cake	20.67 (4.55)	116.00 (10.75)	21.33 (4.59)
Mahua cake	15.67 (3.95)	31.00 (5.45)	4.33 (2.03)
Neem leaves	19.67 (4.43)	93.33 (9.57)	18.67 (4.29)
Glyricidia leaves	20.00 (4.47)	90.33 (9.48)	10.33 (3.20)
Eupatorium leaves	20.00 (4.47)	52.33 (7.22)	8.67 (2.93)
Thevetia leaves	18.33 (4.27)	57.00 (7.39)	10.00 (3.12)
Clerodendron leaves	20.00 (4.47)	79.67 (8.82)	8.67 (2.93)
Calotropis leaves	16.00 (3.99)	35.33 (5.87)	4.33 (2.03)
CD (0.05)	0.381	2.220	0.840

The data represent the mean values of four replications

The values in parentheses are transformed values ($\sqrt{x+1}$ transformation)

Fig. 8. Effect of biopesticides on *Perionyx sansibaricus*



multiplication. In *E. eugeniae* neem leaves and thevetia leaves were effective in supporting multiplication. With respect to indigenous species, these treatments were not much effective. Calotropis leaves and mahua cake were not at all suitable for the growth and multiplication of *P. sansibaricus*.

4.9. Effect of insecticides on the earthworm *E. eugeniae*

The results of the experiments to assess the effect of the insecticides carbofuran, phorate and quinalphos at the rates of 0.5, 1, and 1.5 kg ai/ha on *E. eugeniae* when introduced at different periods after the application of chemicals are presented in Table 26.

4.9.1. Effect of chemicals

Carbofuran 1.5 kg ai/ha recorded the lowest count of earthworms surviving (7.37). This count was significantly low, compared to all other treatments. The mortality was 63.15 per cent. The treatments phorate 1.5 kg ai/ha and phorate 1.0 kg ai/ha recorded lower counts of earthworms surviving (7.87 and 8.22, respectively). Quinalphos 0.5 kg ai/ha was the least toxic with 7.4 per cent mortality.

4.9.2. Effect of methods

Methodology 2 (chemicals applied only in the soil in the pot, not mixing with the organic wastes put above the soils) was superior for the survival of the worms. The mean worm count of 12.68, compared to methodology 1 (10.55).

4.9.3. Effect of periods

The earthworms died when introduced on the same day of application of chemicals at all the concentrations. There was a drastic increase in the count of earthworms surviving (2.26 to 19.94) from the 3rd day to the 28th day after the application of chemicals. The highest mean survival (19.94) was recorded on the 28th day and the lowest (2.26) on the 3rd day.

4.9.4. Effect of insecticide-method interaction

The highest count of earthworms surviving (18.79) was recorded by I_7M_2 (quinalphos 0.5 kg ai/ha) followed by I_7M_1(quinalphos 0.5 kg ai/ha). The lowest count (5.26) was recorded by I_3M_1 (carbofuran 1.5 kg ai/ha). The methodology M_2 was superior, with respect to the survival of earthworms.

Table 26. Effect of insecticides, their methods of application and intervals on the survival of earthworm *Eudrilus eugeniae*

Treatment			Survival of earthworms per pot
I 1	Carbofuran	0.5 kg ai/ha	10.76 (3.43)
I 2	Carbofuran	1.0 kg ai/ha	10.10 (3.32)
I 3	Carbofuran	1.5 kg ai/ha	7.37 (2.89)
I 4	Phorate	0.5 kg ai/ha	10.08 (3.33)
I 5	Phorate	1.0 kg ai/ha	8.22 (3.04)
I 6	Phorate	1.5 kg ai/ha	7.87 (2.98)
I 7	Quinalphos	0.5 kg ai/ha	18.52 (4.42)
I 8	Quinalphos	1.0 kg ai/ha	17.79 (4.33)
I 9	Quinalphos	1.5 kg ai/ha	16.64 (4.20)
CD (0.05)			0.06
P1	3rdday		2.26 (1.81)
P2	7th day		8.81 (3.13)
P3	14th day		15.25 (4.03)
P4	21st day		16.6 (4.19)
P5	28th day		19.94 (4.58)
CD (0.05)			0.04
M1	Method 1		10.55 (3.40)
M2	Method 2		12.68 (3.70)
CD (0.05)			0.03

Continued.....

Table 26. Effect of the interaction of insecticides with the methods of application and the intervals on the survival of earthworm *Eudrilus eugeniae*

Treatment	Survival of the earthworms per pot				
I1M1	9.93 (3.31)				
I1M2	11.62 (3.52)				
I2M1	9.02 (3.17)				
I2M2	11.01 (3.47)				
I3M1	5.26 (2.50)				
I3M2	9.78 (3.28)				
I4M1	9.32 (3.21)				
I4M2	10.87 (3.45)				
I5M1	6.96 (2.82)				
I5M2	9.58 (3.25)				
I6M1	6.45 (2.73)				
I6M2	9.41 (3.23)				
I7M1	18.24 (4.39)				
I7M2	18.79 (4.45)				
I8M1	17.41 (4.29)				
I8M2	18.16 (4.38)				
I9M1	16.35 (4.17)				
I9M2	16.93 (4.23)				
CD (0.05)	0.18				
	P1	**P2**	**P3**	**P4**	**P5**
I1M1	0.00 (1.00)	6.98 (2.82)	14.33 (3.92)	16.99 (4.24)	19.66 (4.55)
I1M2	0.00 (1.00)	11.31 (3.51)	16.33 (4.16)	19.33 (4.51)	20.00 (4.58)
I2M1	0.00 (1.00)	5.61 (2.57)	11.64(3.55)	15.99 (4.12)	20.00 (4.58)
I2M2	0.00 (1.00)	9.18 (3.19)	17.99 (4.36)	16.64 (4.20)	20.00 (4.58)
I3M1	0.00 (1.00)	0.00 (1.00)	3.97 (2.23)	12.99 (3.74)	19.66 (4.55)
I3M2	0.00 (1.00)	10.61(3.41)	11.64 (3.55)	13.99 (3.87)	20.00 (4.58)
I4M1	0.00 (1.00)	4.32 (2.31)	12.99 (3.74)	18.66 (4.43)	20.00 (4.58)
I4M2	0.00 (1.00)	8.64 (3.11)	14.66 (3.96)	20.00 (4.58)	20.00 (4.58)
I5M1	0.00 (1.00)	0.00 (1.00)	13.33 (3.79)	12.99 (3.74)	20.00 (4.58)
I5M2	0.00 (1.00)	7.66 (2.94)	12.66 (3.70)	15.31 (4.04)	20.00 (4.58)
I6M1	0.00 (1.00)	0.00 (1.00)	9.98 (3.31)	13.33 (3.79)	19.66 (4.55)
I6M2	0.00 (1.00)	7.98 (3.00)	11.33 (3.51)	15.31 (4.04)	20.00 (4.58)
I7M1	11.99 (3.60)	20.00(4.58)	20.00(4.58)	20.00(4.58)	20.00 (4.58)
I7M2	14.33 (3.92)	20.00(4.58)	20.00(4.58)	20.00(4.58)	20.00 (4.58)
I8M1	8.98 (3.10)	19.60 (4.55)	20.00(4.58)	20.00(4.58)	20.00 (4.58)
I8M2	11.66 (3.56)	20.00(4.58)	20.00(4.58)	20.00(4.58)	20.00 (4.58)
I9M1	7.98 (3.00)	15.66 (4.08)	20.00(4.58)	20.00(4.58)	20.00 (4.58)
I9M2	9.63 (3.26)	16.33 (4.16)	20.00 (4.58)	20.00 (4.58)	20.00 (4.58)
CD (0.05)	0.13				
	P1	**P2**	**P3**	**P4**	**P5**
I 1	0.00 (1.00)	9.03 (3.17)	15.31 (4.04)	18.14 (4.38)	19.83 (4.56)
I 2	0.00 (1.00)	7.29 (2.88)	14.65 (3.96)	16.32 (4.16)	20.00 (4.58)
I 3	0.00 (1.00)	3.86 (2.20)	7.36 (2.89)	13.48 (3.81)	19.83 (4.56)
I 4	0.00 (1.00)	6.32 (2.71)	13.81 (3.85)	19.33 (4.51)	20.00 (4.58)
I 5	0.00 (1.00)	2.89 (1.97)	12.99 (3.74)	14.13 (3.89)	20.00 (4.58)
I 6	0.00 (1.00)	2.99 (2.00)	10.65 (3.41)	14.30 (3.91)	19.83 (4.56)
I 7	13.13 (3.76)	20.00 (4.58)	20.00 (4.58)	20.00 (4.58)	20.00 (4.58)
I 8	10.28 (3.36)	19.83 (4.56)	20.00 (4.58)	20.00 (4.58)	20.00 (4.58)
I 9	8.79 (3.13)	16.00 (4.12)	20.00 (4.58)	20.00 (4.58)	20.00 (4.58)
CD (0.05)	0.13				

Table 27. Effect of insecticides on earthworms

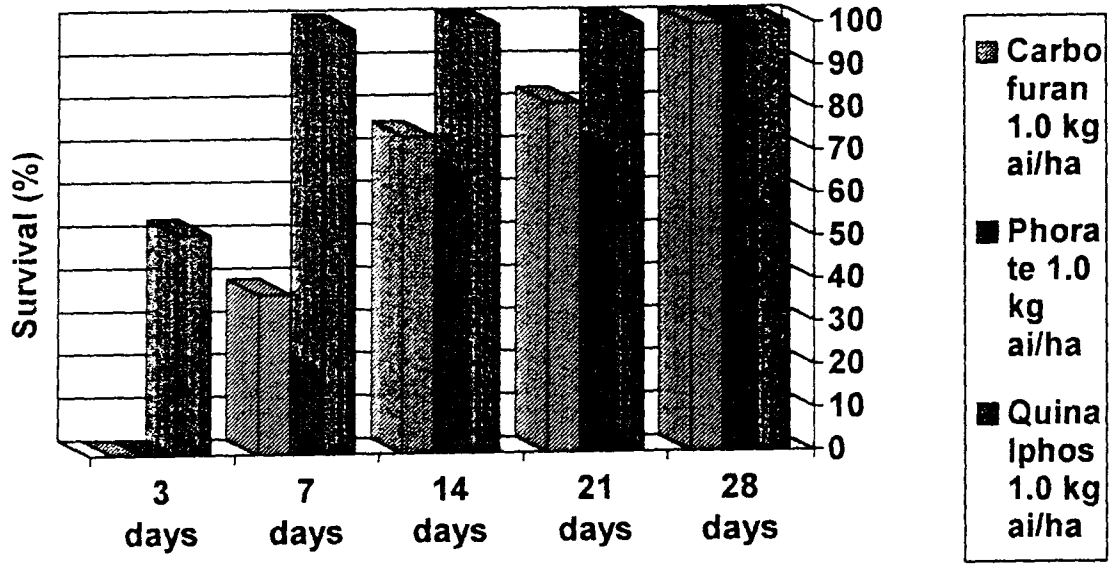
Days after chemical application	Mean survival of the earthworms in the media (%) (Mean of Methodology 1 & 2)								
	Carbofuran (kg ai/ha)			Phorate (kg ai/ha)			Quinalphos (kg ai/ha)		
	0.5	1.0	1.5	0.5	1.0	1.5	0.5	1.0	1.5
3	0	0	0	0	0	0	65.80	51.60	44.16
7	56.67	37.50	26.25	32.40	19.15	19.95	100.00	99.00	80.00
14	76.65	74.08	39.03	69.13	64.98	53.28	100.00	100.00	100.00
21	90.80	81.58	67.45	96.65	70.75	71.60	100.00	100.00	100.00
28	99.15	100.00	99.15	100.00	100.00	99.15	100.00	100.00	100.00

The data represent the mean values of three replications.

Table 28. Regression model of the effect of insecticides on earthworms

Treatment	Regression model (linear)	F	R^2	Time for 100 % survival (days)
Carbofuran 0.5 kg ai/ha	y = 1.7879 + 0.7337 x 1	131.169	0.824	24.82
Carbofuran 1.0 kg ai/ha	y = 0.943 + 0.7367 x 1	131.350	0.824	25.86
Carbofuran 1.5 kg ai/ha	y = -1.5451 + 0.7428 x 1	123.431	0.815	29.01
Phorate 0.5 kg ai/ha	y = 0.1306 + 0.8084 x 1	234.256	0.893	24.57
Phorate 1.0 kg ai/ha	y = -0.4955 + 0.8103 x 1	152.940	0.845	25.29
Phorate 1.5 kg ai/ha	y = -1.5649 + 0.7761 x 1	316.976	0.919	27.78
Quinalphos 0.5 kg/ha	y = 15.8300 + 0.1918 x 1	17.770	0.388	21.72
Quinalphos 1.0 kg/ha	y = 14.0264 + 0.2744 x 1	19.205	0.407	21.77
Quinalphos 1.5 kg/ha	y = 11.3156 + 0.3871 x 1	49.630	0.639	22.45

Fig. 9. Effect of insecticides on the survival of *Eudrilus eugeniae*



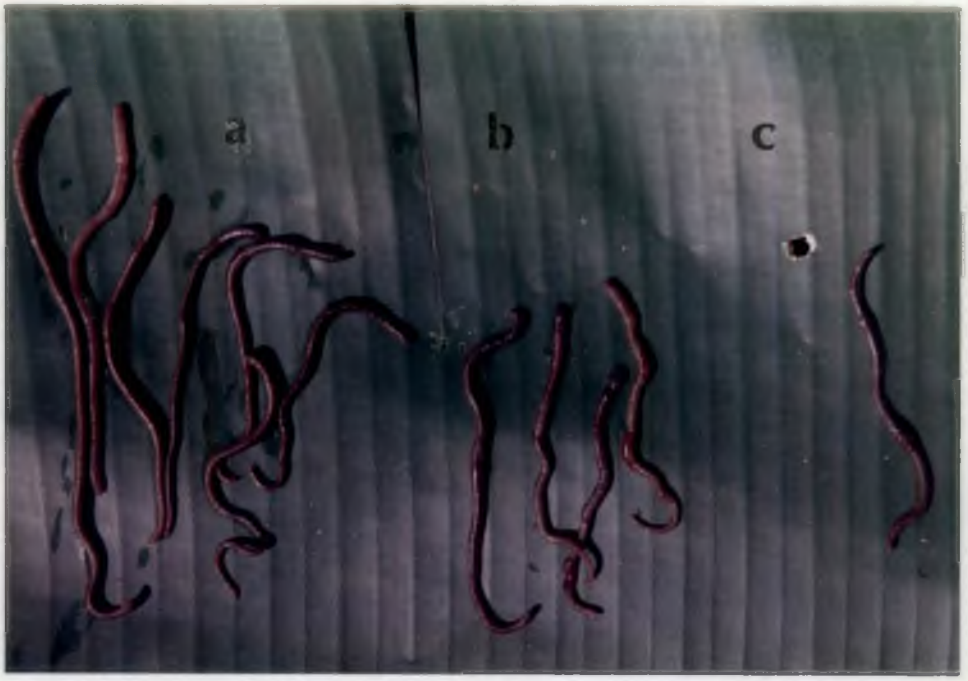
4.9.5. Effect of insecticide-period interaction

Mortality of earthworms was total in all the concentrations of carbofuran and phorate on the 3rd day (Plate XIX). However, quinalphos was less toxic. Quinalphos 0.5, 1.0, and 1.5 kg ai/ha caused 34.35, 48.6 and 56.05 per cent mortality, respectively. The highest survival (20) at P2 (7th day) was recorded by quinalphos (0.5 kg ai/ha) and the lowest by phorate 1.0 kg ai/ha(2.89). On the 14th day carbofuran 1.5 kg ai/ha recorded the lowest count of earthworms surviving (7.36) with a mortality of 63.2 per cent. On the 21st day, however, carbofuran 1.5 kg ai/ha recorded the lowest count of 13.48 (mortality 32.6 per cent).

4.9.6. Effect of insecticide x method x period interaction

Among the treatment combinations, quinalphos was the least toxic and there was total survival of earthworms after an interval of seven days (quinalphos 0.5 kg ai/ha [M_1 x M_2] and quinalphos 1.0 kg ai/ha [M_2]). However, quinalphos 1.5 kg (M1 and M2) caused 21.30 and 18.35 per cent mortality, respectively. But from the 14th day onwards there was cent per cent survival in all concentrations of the chemical. However, carbofuran and phorate were toxic to the earthworm even at this period. Carbofuran 1.5 kg ai/ha (M_1) recorded the lowest survival (3.97) with 80.15 per cent mortality. Phorate 1.5 kg ai/ha (M_1) recorded a

Plate XIX. Lethal effect of carbofuran 0.5 (a), 1.0 (b) and 1.5 (c) kg ai/ha on the adult worms of *Eudrilus eugeniae*, introduced three days after application


a
b
c

survival of 9.98 with 50.1 per cent mortality. Carbofuran 1.0 and 1.5 kg ai/ha (M_2), phorate 1.5 kg ai/ha (M_2) and phorate 0.5 kg ai/ha (M_1) recorded a survival of 11.64, 11.33, 12.99 and mortality rates of 41.80, 43.35 and 35.05 per cent, respectively.

After an interval of 21 days, phorate 0.5 kg ai/ha (M2) recorded cent per cent survival. Carbofuran 0.5 kg ai/ha (M2) was on par. Phorate 0.5 kg ai/ha (M1) recorded a count of 18.6 surviving earthworms (6.7 per cent mortality). However, carbofuran and phorate at the rate of 1.0 and 1.5 kg ai/ha were toxic to earthworm. Carbofuran 1.5 kg ai/ha (M_1) caused a mortality of 35.05 per cent. The other treatments of carbofuran and phorate caused mortality percentages ranging from 3.5 to 33.35. In all the cases the survival of worms was more when methodology 2 (M2) was followed. Mean survival (M_1 and M_2) of earthworms in the insecticide treated media (Table 27; Fig. 9) is worked out and presented. A regression model for predicting the time for total survival was also developed (Table 28).

4.10. Detection of insecticides residues in the medium

The residue levels of carbofuran, phorate and quinalphos in the medium, seven, fourteen, twenty one and twenty eight days after the application are presented in Table 29.

4.10.1. Effect of insecticides

The mean residue level was maximum (0.81 ppm) for carbofuran 1.5 kg ai/ha. The residue level for carbofuran 1.0 kg ai/ha (0.65 ppm) was significantly lower. The next residue levels were recorded by phorate 1.5 kg ai/ha (0.56 ppm) and quinalphos 1.5 kg ai/ha (0.61 ppm). The lowest residue (0.21 ppm) level was observed for quinalphos 0.5 kg ai/ha (Table 30).

4.10.2. Effect of periods

The residue levels tended to decline as the period of composting advanced. After the 7th day there was a drastic decline in the residues. The residue levels of the 7th and the 14th day were 0.88ppm and 0.44 ppm, respectively. The residue levels on the 21st and 28th day (Table 30) were on par (0.32 and 0.22 ppm, respectively).

4.10.3. Effect of insecticide residue-period interaction

The highest residue level on the 7th day was recorded by carbofuran 1.5 kg ai/ha (1.42 ppm) and phorate 1.5 kg ai/ha (1.31 ppm). These treatments were on par. On the 14th day also carbofuran 1.5 kg ai/ha recorded the highest residue

Table 29. Mean residue values (ppm) of insecticides carbofuran, phorate and quinalphos in the composting medium at various intervals after application

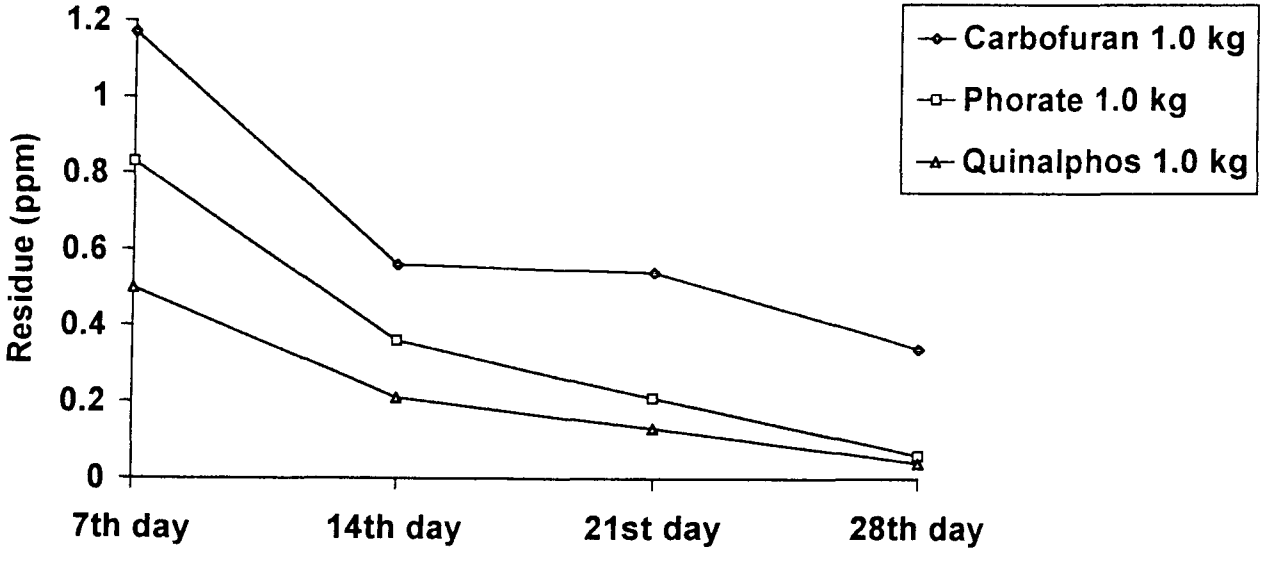
Insecticide (kg ai per hectare)	Residue on 7th day (ppm)	Residue on 14th day (ppm)	Residue on 21st daym (ppm)	Residue on 28th day (ppm)
Carbofuran 0.5	0.98 ± 0.12	0.45 ± 0.06	0.35 ± 0.03	0.32 ± 0.05
Carbofuran 1.0	1.17 ± 0.04	0.56 ± 0.08	0.54 ± 0.04	0.34 ± 0.02
Carbofuran 1.5	1.42 ± 0.15	0.86 ± 0.04	0.52 ± 0.06	0.45 ± 0.03
Phorate 0.5	0.25 ± 0.11	0.19 ± 0.03	0.15 ± 0.05	0.08 ± 0.01
Phorate 1.0	0.83 ± 0.12	0.36 ± 0.07	0.21 ± 0.09	0.06 ± 0.03
Phorate 1.5	1.31 ± 0.49	0.33 ± 0.09	0.31 ± 0.08	0.29 ± 0.05
Quinalphos 0.5	0.58 ± 0.09	0.17 ± 0.05	0.07 ± 0.05	0.02 ± 0.01
Quinalphos 1.0	0.50 ± 0.08	0.21 ± 0.08	0.13 ± 0.04	0.04 ± 0.02
Quinalphos 1.5	0.89 ± 0.08	0.83 ± 0.05	0.58 ± 0.25	0.14 ± 0.06

Table 30. Insecticide residue x Period interaction

Insecticide	Insecticide residue (ppm)				
	7th day (P1)	14th day (P2)	21st day (P3)	28th day (P4)	Marginal mean
Carbofuran 0.5 kg ai/ha (I1)	0.98	0.45	0.35	0.32	0.52
Carbofuran 1.0 kg ai/ha (I2)	1.17	0.56	0.54	0.34	0.65
Carbofuran 1.5 kg ai/ha (I3)	1.42	0.86	0.52	0.45	0.81
Phorate 0.5 kg ai/ha (I4)	0.25	0.19	0.15	0.08	0.17
Phorate 1.0 kg ai/ha (I5)	0.83	0.36	0.21	0.06	0.36
Phorate 1.5 kg ai/ha (I6)	1.31	0.33	0.31	0.29	0.56
Quinalphos 0.5 kg/ha (I7)	0.58	0.17	0.07	0.02	0.21
Quinalphos 1.0 kg/ha (I8)	0.50	0.21	0.13	0.04	0.22
Quinalphos 1.5 kg/ha (I9)	0.89	0.83	0.58	0.14	0.61
Marginal mean	0.88	0.44	0.32	0.22	-

CD (0.05) Insecticide (I) = 0.15
CD (0.05) Period (P) = 0.10
CD (0.05) Insecticide x Period (IxP) = 0.30
The data represent the mean values of three replications.

Fig. 10.Insecticide residue in the culture media of earthworms



level (0.86 ppm) which was on par with carbofuran 1.0 kg ai/ha (0.56 ppm). Residue levels recorded by the other treatments were significantly lower. On the 21st day higher residue levels were observed for quinalphos 1.5 kg ai/ha (0.58 ppm) and carbofuran 1.0 kg (0.54 ppm) and 1.5 kg ai/ha (0.52 ppm). The lowest level was reported for quinalphos 0.5 kg (0.07 ppm). On the 28th day, the highest residue level was observed for carbofuran 1.5 kg ai/ha (0.45 ppm). Carbofuran 0.5 kg and 1.0 kg ai/ha recorded mean residue levels of 0.32 and 0.34 ppm, respectively and these treatments were on par (Table 29 and 30; Fig. 10).

4.11. Microbial studies

4.11.1. Estimation of CO_2 evolution and microbial count during the period of composting

The results of experiments to estimate CO_2 evolution and microbial count in the composting process are presented in Tables 31 to 34.

4.11.1. 1. Effect of nature of composting on CO_2 evolution

The treatments involving earthworms for composting evolved significantly high volume of CO_2 during the period of composting, compared to the control treatment without worms (229.05 mg). The CO_2 evolved by the treatments

involving *E. eugeniae* (248.46 mg) and *P. sansibaricus* (251.58 mg) were on par (Table 31).

4.11.1.2. Effect of periods on CO_2 evolution

Maximum CO_2 evolution was observed on the 21st day (446.52 mg). This was significantly superior to the CO_2 evolution estimated at various other intervals. The next superior period with regard to CO_2 evolution was the 28th day (412.43 mg) and 14th day (406.14 mg) which were on par. Carbon dioxide evolution was the lowest on the 70th day (62.15 mg) followed by the 63rd day (69.69 mg). There was an increase in the CO_2 evolution up to the 21st day of composting. From the 21st day onwards, a declining trend in CO_2 evolution was observed. However, the decrease was more drastic after the 35th day. The decline was from 383.00 mg to 132.46 mg in a short span of seven days. After that the decrease was only gradual up to the 70th day (Table 31; Fig. 11).

4.11.1.3. Effect of nature of composting-period interaction

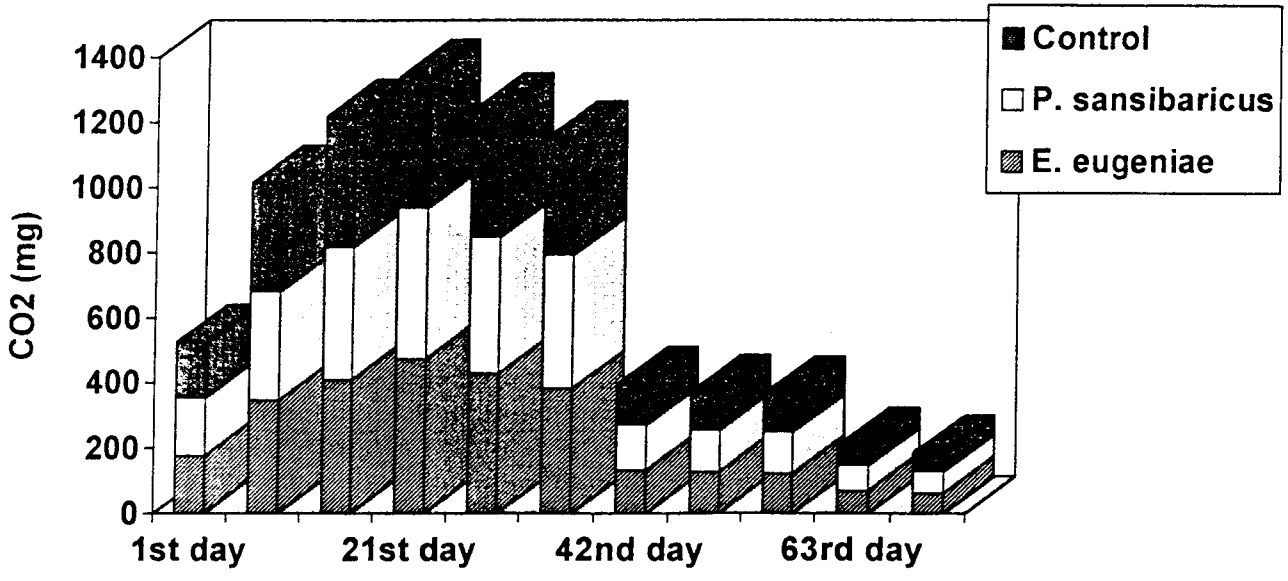
A sharp reduction in the CO_2 evolution was observed on the 35th day in the treatment in which *E. eugeniae* was used, and the 42nd day in the treatment in which *P. sansibaricus* was used. The increase in CO_2 evolution was significant, compared to control from 7th day onwards in *E. eugeniae* and 14th day onwards

Table 31. Effect of earthworm species, composting periods and their interaction on the evolution of carbon dioxide

Treatment		Carbondioxide evolution per pot per day (mg)
S1	Treatment *Eudrilus eugeniae*	248.46
S2	Treatment with *Perionyx sansibaricus*	251.58
S3	Treatment with without worms	229.05
CD (0.05)		4.406
P1	1st day	175.40
P2	7th day	338.67
P3	14th day	406.14
P4	21st day	446.52
P5	28th day	412.43
P6	35th day	383.00
P7	42nd day	132.46
P8	49th day	124.08
P9	56th day	122.32
P10	63rd day	69.69
P11	70th day	62.15
CD (0.05)		6.370
S1P1		176.29
S1P2		346.48
S1P3		409.92
S1P4		473.58
S1P5		429.29
S1P6		383.38
S1P7		131.78
S1P8		126.21
S1P9		122.91
S1P10		70.24
S1P11		62.92
S2P1		179.66
S2P2		337.04
S2P3		409.13
S2P4		465.81
S2P5		420.35
S2P6		412.18
S2P7		140.43
S2P8		130.24
S2P9		127.89
S2P10		77.59
S2P11		67.10
S3P1		170.24
S3P2		332.49
S3P3		399.37
S3P4		400.17
S3P5		387.64
S3P6		354.93
S3P7		125.18
S3P8		115.79
S3P9		116.16
S3P10		61.23
S3P11		56.43
CD (0.05)		11.04

The data represent the mean values of three replications

Fig. 11. Carbondioxide evolution from the vermicomposting media



in *P. sansibaricus*. This significant increase in CO_2 evolution was observed up to the 35th day in *E. eugeniae* and up to the 70th day in *P. sansibaricus* (Table 31).

4.11.2. Estimation of microbial population during the period of composting

4.11.2. 1. Bacteria

The treatments involving *P. sansibaricus* and *E. eugeniae* had a significantly higher bacterial count, compared to those without worms (Table 32).

Bacterial counts showed a negative trend as the period of composting advanced. Bacterial count on the first day was the highest in all cases. The bacterial count on the 14th and the 20th day were on par. The counts on the 42nd, 56th and 70th day were on par.

For *E. eugeniae* the bacterial counts on 14th (66.18×10^6) and 28th (72.91×10^6) day were on par. For *P. sansibaricus* also the bacterial count on 14th (75.32×10^6), 28th (65.60×10^6) and 42nd (52.05×10^6) were on par. In the treatment without worms, there was a decline in the count from the beginning to the end of the experiment.

Table 32. Effect of earthworm species, composting periods and their interactions on the population of bacteria $10^{6}g^{-1}$ in the composting medium

Treatment	P1 1st day	P2 14th day	P3 28th day	P4 42nd day	P5 56th day	P6 70th day	Marginal mean
E. eugeniae S1	317.92 (17.83)	66.18 (8.13)	72.91 (8.54)	47.6 (6.9)	26.59 (5.16)	29.09 (5.39)	75.00 (8.66)
P.sansibaricus S2	361.11 (19.0)	75.32 (8.68)	65.6 (8.10)	52.05 (7.21)	38.39 (6.20)	28.26 (5.32)	82.62 (9.09)
Control S3	281.52 (16.78)	46.66 (6.83)	42.90 (6.55)	35.53 (5.96)	22.91 (4.79)	17.96 (4.24)	56.55 (7.52)
Marginal mean	319.34 (17.84)	62.09 (7.88)	59.75 (7.73)	44.76 (6.69)	28.94 (5.38)	24.80 (4.98)	-

CD S = 0.581 CD P = 0.813 CD S x P = 1.41

The data represent the mean values of three replications.

The values in parentheses are transformed values

Table33. Effect of earthworm species, composting periods and their interactions on the population of fungi $10^{4}g^{-1}$ in the composting medium

Treatment	P1 1st day	P2 14th day	P3 28th day	P4 42nd day	P5 56th day	P6 70th day	Marginal mean
E. eugeniae S1	13.62 (3.69)	46.68 (6.83)	46.24 (6.80)	25.92 (5.09)	33.18 (5.76)	25.29 (5.03)	30.58 (5.53)
P.sansibaricus S2	21.361 (4.62)	57.82 (7.60)	33.94 (5.83)	25.81 (5.08)	53.96 (7.35)	38.38 (6.19)	37.33 (6.11)
Control S3	16.45 (4.06)	25.81 (5.08)	20.28 (4.50)	28.28 (5.32)	26.32 (5.13)	18.89 (4.35)	22.47 (4.74)
Marginal mean	16.97 (4.12)	42.38 (6.51)	32.60 (5.71)	26.63 (5.16)	36.97 (6.08)	26.94 (5.19)	-

CD S = 0.391 CD P = 0.464 CD S x P = 0.804

The data represent the mean values of three replications.

The values in parentheses are transformed values

4.11.2.2. Fungi

The treatments T2 (*P. sansibaricus*) and T1 (*E. eugeniae*) were superior to the control with respect to the count of fungi (Fig. 12).

The highest fungal count (42.38 $x10^4$) was recorded on the 14th day after the initiation of the experiment and the lowest ($16.97x10^4$) on the first day.

The highest fungal count ($46.24x10^4$) for *E. eugeniae* was recorded on the 28th day and for the other two treatments on the 14th day. Towards compost maturity, the fungal counts were more or less steady in E. *eugeniae*. However, a slight increase in the count was noticed on the 56th day. No definite trend could be detected in the count of fungal colonies due to the treatment without worms (Table 33).

4.11.2.3. Actinomycetes

The treatment involving *P. sansibaricus* recorded the highest count ($39.06x10^4$) of actinomycetes which was superior to other treatments. The other treatments were on par (Table 34; Fig. 13).

Fig. 12. Effect of earthworm species on the population of fungi in the composting media

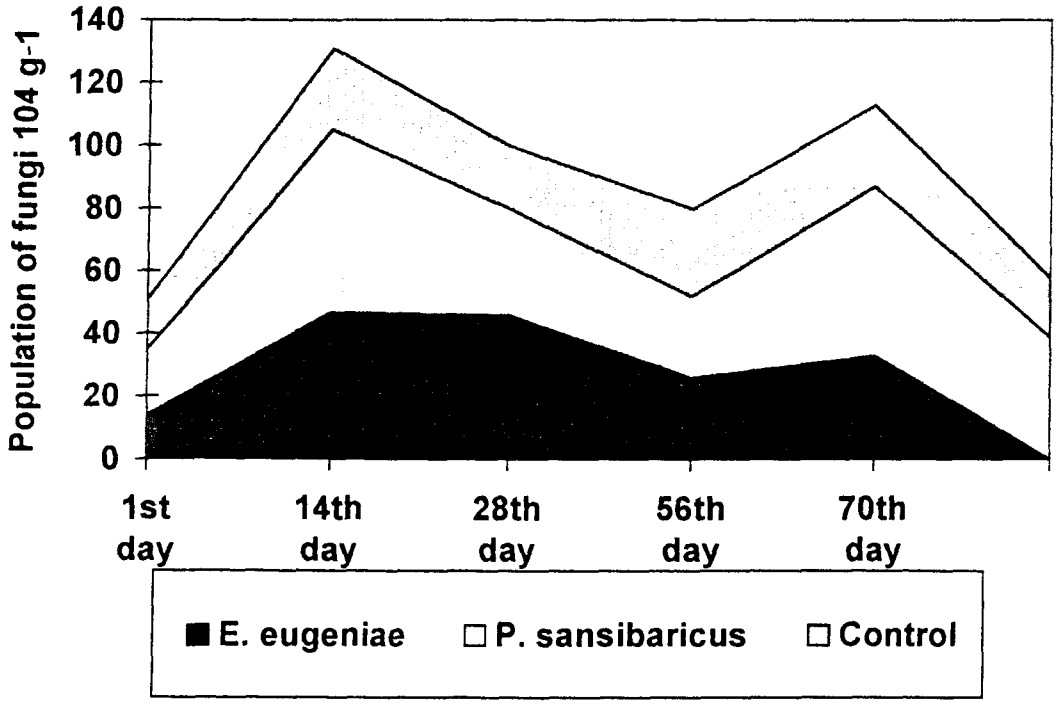


Table 34. Effect of earthworm species, composting periods and their interactions on the population of actinomycetes $10^{4}g^{-1}$ in the composting medium

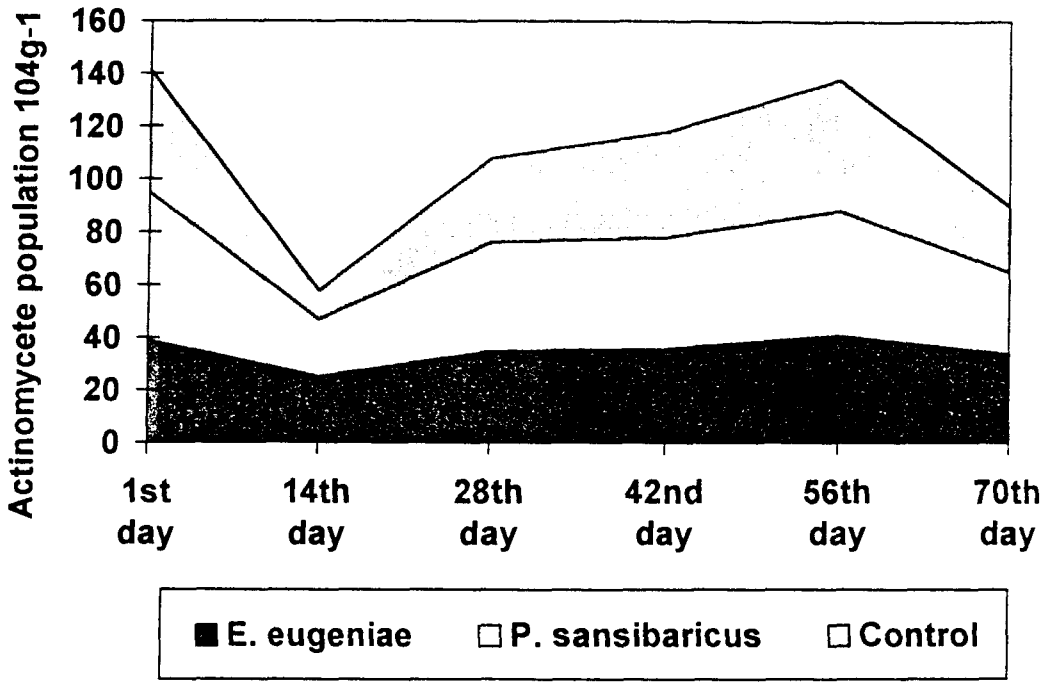
Treatment	P1 1st day	P2 14th day	P3 28th day	P4 42nd day	P5 56th day	P6 70th day	Marginal mean
E. eugeniae S1	39.32 (6.27)	24.75 (4.97)	34.64 (5.89)	35.83 (5.99	40.71 (6.38)	33.61 (5.80)	34.57 (5.88)
P.sansibaricus S2	55.97 (7.48)	22.29 (4.72)	41.27 (6.42)	41.97 (6.48)	46.65 (6.83)	31.24 (5.59)	39.06 (6.25)
Control S3	46.36 (6.81)	11.31 (3.36)	31.77 (5.64)	40.00 (6.32)	49.51 (7.04)	25.29 (5.03)	32.49 (5.70)
Marginal mean	46.92 (6.85)	18.92 (4.35)	35.76 (5.98)	39.19 (6.26)	45.56 (6.75)	28.92 (5.47)	-

CD S = 0.474 CD P = 0.513 CD S x P = 0.888

The data represent the mean values of three replications.

The values in parentheses are transformed values

Fig. 13.Effect of earthworm species on the population of actinomycetes in the composting media



There was no definite trend with respect to actinomycetes count and the time for composting. The highest mean count ($46.92x10^4$) was recorded on the first day, followed by the 56th day ($45.56x10^4$). These two values were on par.

The highest count of actinomycetes for treatment involving *E. eugeniae* was recorded on the 56th day ($39.32x10^4$). The other two treatments also recorded the peak population. In general, the first and 56th day recorded high actinomycetes population in all the three treatments.

DISCUSSION

DISCUSSION

Increased crop productivity necessitated the use of chemical fertilisers and synthetic pesticides. This in turn caused serious damage to environment and human health. Continuous application of inorganic chemical fertilisers disturbs soil structure, soil aeration, pH and even soil biology. Increased levels of nitrate in water can transfer nitrate to human body which may be converted to secondary and tertiary amines. These nitrosamines are likely to cause fatal diseases such as cancer (Shivashankar, 1996). The residues of pesticides contaminate both surface water and ground water. They can enter the life chain through aquatic organisms, resulting in biomagnification. These hazardous chemicals also may contaminate the lithosphere. All these factors make farming unsustainable and environment hostile to mankind.

The concept of a healthy agro-ecosystem is essential for sustainable agriculture which should involve successful management of resources for agriculture to satisfy the changing human needs, while maintaining or enhancing the quality of environment and conserving natural resources. The terms `Sustainable agriculture' and `organic farming' have caught the imagination of farmers and consumers who are aware of health hazards and are trying to do away with harmful chemicals and pesticides.

Large quantities of bio-wastes are accumulated in urban areas causing environmental pollution and health hazards. Safe disposal of these wastes is very important for abating environmental pollution. Composting by vermitechnology is a cost-effective method for reducing environmental pollution and at the same time converting the foul smelling biowastes to nutrient rich organic fertiliser.

Vermicomposting and enriched organic manures provide a powerful package of eco-friendly inputs. The presence of vermicompost enhances the uptake of macro and micro nutrients by plants, harbours rich amount of microbes, and degrades and mobilises the nutrients to available form. Exudates of earthworms support the microorganisms which secrete plant growth hormones. These organisms are also found to fix atmospheric nitrogen into available nitrogen for the plants. Similarly, on passage through earthworm gut the waste materials are degraded to release phosphorus in the form available to the plants. Vermicompost also enhances the soil structure and improves the water holding capacity and porosity to facilitate the root respiration and growth (Lee, 1985).

The present study was conducted to evaluate the feasibility of vermiculture in the farming condition of Kerala. The study covered different aspects of vermicomposting in the State. It included collection and identification of earthworms, study of their composting efficiency and breeding potential of the identified earthworm species, bionomics of earthworm species under humid

tropical conditions of Kerala, effect of the application of vermicompost on pests, diseases and yield of bittergourd and cowpea, the effect of biopesticides and synthetic chemical insecticides on earthworms and quantification of soil microflora during the period of composting.

The survey on earthworm was conducted in five soil types of southern Kerala during May-June 1995. It revealed that the earthworm populations ranged from a mean 9.29 to 40.2/m^2. Of the five soil types, forest soil was comparatively richer in earthworm population to the other soil types (Table 1 and 2). Eight species belonging to three families were identified. The species identified were *Megascolex cochinensis, M. konkanensis, M. trilobatus, M. trivandranus, Pheretima heterochaeta* (Megascolecidae), *Pontoscolex corethrurus* (Glossoscolecidae) and *Drawida* (Moniligastridae). Aiyer (1926) reported that oligochaeta of Travancore belonged to four families *viz.* Moniligastridae, Megascolecidae, Eudrilidae and Lumbricidae.

Reports indicate that species belonging to ten families are found to be distributed in India and the Deccan plateau holds about 82 per cent of the endemic fauna (Julka and Paliwal, 1986).

The forest soil with high waterholding capacity (44.52 per cent), organic carbon content (4.05 per cent) and slightly acidic pH (4.8) recorded the highest

population count. Species diversity was also very high in the forest soil. Moncompu soil even with high organic carbon content recorded less population count. Acidic soil pH (4.37) may be the reason for low level of earthworm population. In laterite soil due to relatively low organic carbon content (0.82) and low water holding capacity (32.35 per cent), compared to forest soil, the population level was low. Sandy soil even with the low water holding capacity and high coarse sand composition the population count was superior to other soil types, except forest soil. The reason may be the better status in the organic carbon content (1.15 per cent).

The results revealed that the earthworm populations were generally low in cultivated lands, compared to forest soil. Many workers have reported that Lumbricid populations are generally lower in cultivated lands than in permanent grass lands in many countries like Germany (Graff, 1953) and United States of America (Hopp, 1946). Mechanical damage, due to tillage implements has often assumed to be the major cause of mortality and worm population decline. The loss of surface litter and general decline in soil organic matter content due to continuous cultivation may be the other possible reasons. Environmental factors and soil conditions determine the density and distribution of earthworms (Bano and Kale, 1991; Kale and Krishnamoorthy, 1981 b). Injudicious use of fertilisers, granular insecticides, fungicides and herbicides in the soil may be another reason for the low population level. Fertilisers are found to have dual effect on

earthworm population. The undesirable effect may be either due to corrosive effect of chemicals on the tissues of earthworm or due to change in soil reaction, unfavourable for survival.

Results of the pot culture studies to determine composting efficiency of various earthworm species showed that *E. eugeniae* was relatively more efficient for composting in terms of duration for composting and biomass production. Potentiality of *E. eugeniae* for composting has been proved (Kale and Bano, 1986; Padmaja *et al.*, 1994). When same number of worms were used for composting the indigenous species *P. sansibaricus* was also found good. However, the time required was more than that for *E. eugeniae.* The potentiality of *Perionyx* sp for vermicomposting has been already reported. Shanthi *et al.* (1993) reported that *P. excavatus* was the appropriate species for vegetable waste composting. Maximum survival of *P. sansibaricus* was noticed in slaughter house waste followed by vegetable market waste. Singh and Rai (1996) found that *P. sansibaricus* was good for vermicomposting kitchen waste mixed with cowdung.

The results of the study on the field evaluation of two earthworm species revealed that when equal quantity (weight) of worms were put, the time for vermi-composting was equal. This indicated that *P. sansibaricus* was an efficient decomposer as *E. eugeniae*. Owing to its significantly smaller size, more number of *P. sansibaricus* was required to become as efficient as *E. eugeniae*. The

multiplication rate of *E. eugeniae* and *P. sansibaricus* was also comparable. However, the robust nature of *E. eugeniae* might be the reason for the high biomass per kilo gram compost.

The other seven earthworm species *viz. Megascolex cochinensis, M. konkanensis, M. trivandranus M. trilobatus, Pontoscolex corethrurus, Megascolex* and *Pheretima heterochaeta* were not efficient for composting. None of them perform well in the banana leaf-cowdung mixture (Table 4). These species might belong to those worms of least importance in the composting process. In the tropical and subtropical soils, majority of earthworms which feed on soil mixed with humus are not efficient for composting.

Environmental factors affect duration for composting as well as the multiplication rate of the earthworms. Many species of earthworm are known to be reproductively active throughout the year. However, seasonal variations are known to affect productivity (Evans and Guild, 1947). The present data revealed that during summer months reproductive rate was comparatively less both in the exotic and indigenous species. This was mere pronounced in the case of *P. sansibaricus*. With respect to *E. eugeniae* there was positive correlation between juvenile count and rainfall. However, count of juveniles and cocoons expressed negative correlation with maximum temperature. (Table 7). With respect to *P. sansibaricus* adult and juvenile count expressed positive correlation with rainfall

and humidity. However, there was negative correlation between adult, juvenile and cocoon counts and maximum temperature. Cocoon count showed positive correlation with rainfall. The period required for composting as well as decomposed / undecomposed ratio also showed that summer months had a negative influence. Reinecke *et al.* (1992) found that in the southern sub region of Africa the winter temperature seemed to be a limiting factor for both *E. eugeniae* and *P. excavatus* used for outdoor vermiculture. Viljoem and Reinecke (1992) reported that *E. eugeniae* was sensitive to low temperature and could thrive well only upto 30°C. The optimum temperature range for growth and fecundity was found to be 22 to 25°C. Similarly several workers have related cocoon productivity to ecological type, available nutrients and environmental factors (Graff, 1981; Kale *et al.*, 1982; Senapati and Dash, 1982; Lavelle, 1988).

Space was found to be a limiting factor in the growth and multiplication of earthworms. The result presented in Table 12-17 shows that density pressure of worms greatly influenced biomass production. There was drastic decline in the biomass from 219.33 days onwards with respect to the first container (Table 9). In the case of the second container which was larger than the first one, multiplication rate of the earthworms was more and the decline in the population started at a later stage (Table 10). In the field condition population increase was far superior (16.34 times), compared to the first two containers (Table 11); whereas in the first and second situations the increases observed were 6.89 (at an

interval of 217 days) and 12.73 times (at an interval of 264 days), respectively. According to Kale and Bano (1988) 1000 cm^2 area could hold a maximum of 200 reproducing adults at a time. The earthworm bed had to be renewed in every six months. The young ones emerged had to be removed into new culture beds.

Morphometry studies revealed that the size of the cocoon and number of hatchings / cocoon of *E. eugeniae* were more than those of *P. sansibaricus*. The percentage hatchability under laboratory condition was however, lower than that of *P. sansibaricus*. The time required for hatching and time required for the development of juvenile to adult were significantly lower in *P. sansibaricus,* compared to those in *Eudrilus eugeniae*. The cocoon laying / week was also more in the case of *P. sansibaricus*. The high fecundity of *P. sansibaricus* compensated for the low rate of juvenile production / cocoon (Table 14 & 15). The larger size and robust nature of *E. eugeniae* was evident in the study. Bano and Kale (1988) reported that *E. eugeniae* has an endogenous rhythm on reproduction. The maximum number that can be laid under ideal condition was about 100 cocoons by a pair of worms in three to six months and generally three juveniles come out of each cocoon. The artificial conditions in the laboratory might be the reason for the low hatching percentages for both species in the present study.

In the present study the multiplication rate of *P. sansibaricus* was higher to *E. eugeniae* due to the lesser time requirement in hatching and development of

juvenile to adult. Raut *et al.* (1996) observed that the increase in count of *P. sansibaricus* was 5.1 to 9.6 times at 90 days stage and 11.2 to 19.2 times at 180 days stage. Better perforamance of *P. sansibaricus* was also reported by Singh and Rao (1996).

The benefit of using vermicompost in improving soil fertility has been advocated by several workers (Richards, 1955; Dash and Patra, 1979; Lee, 1985). In the present study the requirement for chemical fertilisers in cowpea var. 'Malika' and bittergourd var. 'Preethi' was reduced where the recommended dose of farm yard manure was substituted by equal quantity of vermicompost. Interestingly, vermicompost with full dose of inorganic fertilisers increased the yield of bittergourd and cowpea by 21 per cent and 19 per cent respectively as compared to the Packages of Practices Recommendations. Several reasons may be attributed for the positive influence of vermicompost on the nutritional requirement of bittergourd and cowpea. The positive effect of vermicompost may be due to its beneficial influence on the physical, chemical and biological properties of the soil. Nitrogen excretion is an essential contribution of earthworm to soil fertility (Satchell, 1967; Edwards and Lofty, 1972; Christensen, 1987). Earthworms have been reported to contain more soil exchangeable cation (Lal and Akinene, 1983). Earthworms were observed to produce plant growth stimulating substances (Nielson, 1964). Moreover, plant growth promoting hormones like gibberellins, cytokinins and auxins are released due to metabolic activity of

microbes harboured in the casts (Tomati *et al.*, 1983). Levels of nitrogen and potassium in vermicompost are significantly higher than those of FYM and cattle dung (Bano and Suseeladevi, 1996).

In cowpea, application of vermicompost instead of farm yard manure without inorganic fertiliser was equally effective for increasing the yield (21 per cent) as the recommended manurial schedule. Similar yield increase in vegetables and other crops was reported in cabbage and leek (Saciragic and Dzelilovic, 1986); coriander (Vadiraj *et al.*, 1990), tomato (Pushpa and Prabhakumari, 1997); rice (Kale and Bano; 1986, Vasanthi and Kumaraswamy, 1996); guinea grass (George and Pillai, 1996); cotton (Jambhekar, 1996), water melon (Ismail *et al.*, 1991), chillies (Ismail *et al.*, 1993) and mulberry (Dorigal and Gauda, 1996). Kale and Bano, 1986 as well as Sarawad *et al.*, 1996 observed that by using wormcast as a fertiliser in field it was possible to reduce the use of chemical fertilisers. Kale *et al.* (1992) observed that vermicompost application enhanced the activity of beneficial microbes like nitrogen fixers and mycorrhizal fungi and hence played a significant role in nitrogen fixation and phosphate mobilisation, leading to higher uptake of nutrients by plants. The enhanced activity of nitrogen fixers may be the reason for the treatment effect by vermicompost application in the present study. There are also reports that vermicompost can enhance root colonisation of vesicular arbuscular micorrhizal fungi (Kale *et al.*, 1987).

In the present study no significant difference in pest and disease incidence was observed among treatments, except in the case of fruit fly, at two intervals, in bittergourd. Many scientists have observed low levels of pest and disease occurrence in crops due to vermicompost application (Szczeh *et al.*, 1993). The positive effect of vermicompost application in soil may become more evident in subsequent crops. That may be the possible reason for the lack of significant difference in pest and disease incidence.

The positive effect of vermicompost as a component of potting mixture was also evident in the pot culture experiment. Significant increase in yield was observed with respect to treatments involving, vermicompost prepared from banana leaves alone, banana leaves: neem cake mixture (6:1 w/w), banana leaves: neem leaves mixture (6:1 w/w) and banana leaves: clerodendron leaves mixture (6:1 w/w). All other treatments were on par with control with respect to yield. The nutrient contents of compost may vary slightly based on the nature of biowastes and species of earthworm used for composting. The better nutrient content of the above treatments can be the reason for increased yield and also increased trend in biometric characters of plants in these treatments. Ushakumari *et al.* (1996)reported that vermicompost was a biofertiliser containing 1.5 to 2.0 per cent N, 0.5 per cent P_2O_5 and 1.8 to 2.0 per cent K_2O. Apart from major nutrients, compost might also contain a number of micro nutrients, beneficial microorganisms, antibiotics and phyto-stimulatory hormones. The high content of

nitrogen in the neem cake (3.5 per cent) may be responsible for the better performance of the treatment involving the vermicompost prepared from it. Similarly, the high content of potash in the vermicompost prepared from banana leaves may be responsible for the better performance of the treatment. The early availability of nutrients from vermicompost, compared to the cowdung might be another reason for the increased yield in all the vermicompost treated plots. Similar studies have been undertaken by previous workers. Vermicompost slurry significantly increased rooting in mulberry (Gunathilagaraj and Ravignanam, 1996 a). Krishnakumar *et al.* (1994) reported that the use of vermicompost in potting medium helped better growth and development of seedling in cardamom nursery.

In situ vermiculture has been found effective in enhancing the growth and yield of crops (Edwards and Bater, 1992; Singh and Rai, 1996). The present study also revealed that *in situ* vermiculture was beneficial. It was equally effective as the Package of Practices Recommendations with respect to plant height and yield (Table 23) in bhindi. The positive effective of *in situ* vermiculture may be due to various reasons. The presence of worms in soil can improve aeration and water infiltration. The earthworms can increase the availability of essential nutrients. They can produce plant growth substances in the alimentary canal and excrete it along with their casts (Nielson, 1964). The earthworms were reported to excrete

nitrogen to the surrounding which could enhance soil fertility (Satchell, 1967; Edwards and Lofty, 1972).

The highest yield (15 per cent more yield as compared to that in the Package of Practices Recommendations) in bhindi in the present study was recorded by the treatment involving vermicompost + full dose of inorganic fertilisers. *In situ* vermiculture @ 250 worms/plot was as effective as the Package of Practices Recommendations. However, it produced lower plant growth than the treatment involving vermicompost + full dose of inorganic fertilisers. No inorganic fertilisers were applied in treatments involving *in situ* vermiculture and banana wastes containing equal quantity of N as per POP was used. The slow release of nutrients may be the reason for the lesser yield. Yield increase and other positive effects of *in situ* vermiculture were experienced in various crops like barley (Atlavinyte, 1974), grape vine (Barve, 1993; Phule, 1993), and mulberry (Kolhar and Patel, 1996; Ravignanam and Gunathilagaraj, 1996 b). In mulberry the number of leaves, leaf area, leaf weight, total chlorophyll content, nitrogen, potassium and iron were stimulated in the treatment which received recommended doses of N, P and K fertilisers and earthworm + cowdung mulch. Barve (1993) reported that in grape vine garden when grown on vermiculture, the soil was alkaline in reaction. Yield increase was reported in bhindi (69.4 per cent), compared to POP where *in situ* vermiculture @ 50 Nos. of *E. eugeniae*/m^2

was applied along with basal dose of inorganic fertiliser (Ushakumary *et al.*, 1996).

In the present study *P. sansibaricus* was used for *in situ* vermiculture and was found encouraging. The positive effect of *P. excavatus* on the growth of *Amaranthus dubius* was reported by Alfred and Gunathilagaraj (1996). Better results would have been obtained if inorganic fertilisers were also used as basal dose.

In the present study on the effect of biopesticides on earthworms it was observed that most of the biopesticides used were not harmful to the earthworms. Instead many of them had promoted their growth and multiplication(Table 24 and 25). Leaves of neem and thevetia were found very effective in supporting the growth and multiplication of *E. eugeniae*. Neem cake increased the juvenile worm production of *E. eugeniae* and *P. sansibaricus* by 102 and 52 per cent respectively. With respect to *P. sansibaricus* thevetia leaves were not as encouraging as in the case of *E. eugeniae*. In both the cases calotropis leaves and mahua cake caused significant reduction in juvenile and cocoon production. Similar results have been reported by Kale *et al.* (1986). They observed that 0.4 to 1.6 per cent neem cake in the medium had a positive effect on worm biomass production. There are earlier reports that when neem leaves and seed kernels were incorporated into potting soil containing earthworm (*Eisenia foetida*) the number of young worm

produced increased by 25 per cent. Similarly, in a field trial the average weight of worms were the highest in neem treated plots (NRC, 1991). According to Pars and Krishnan (1989), the presence of flowers of *Thevetia peruviana* in the rearing environment of *Erias vitella* increased its rate of larval development, number of adult emerging and reproductive potential. Madhukeshwara *et al.* (1996) found that the growth and fecundity of earthworm and the rate of compost production showed variation with respect to the substrate used in the feed. They reported maximum biomass production where spent leaves of tea were used.

The effect of synthetic pesticides was also studied in the present instance. The results presented in Table 26 revealed that organophosphates and carbamates are toxic to earthworms. There was a drastic increase in the count of earthworm surviving (2.20 to 19.94) from 3rd day to 28th day after the application of chemicals. Even after the 14th day carbofuran 1.5 kg ai/ha recorded the lowest count of earthworm surviving (7.30) with a mortality percentage of 63.2 per cent. On the 21st day, phorate 1.5 kg could kill 46.75 per cent earthworms. According to Sileo and Gilman (1975) organophosphates could increase acid and alkaline phosphatase activity of earthworms. This could be indicated by cell damage, protein deficiency and disruption of cellular activity. This was proved by Bharathi and Subbarao (1986) with 0.34, 4.87 and 022 ppm of phosphamidon, monocrotophos and dichlorvos. In the present study cell damage, oozing out of blood and blackening of tissues were observed in treatments involving both

carbofuran and phorate. The relative low level toxicity of quinalphos was reported by Visalakshi *et al.* (1988). They reported a decline of 89.4, 84.2 and 75.6 per cent in the carbofuran, phorate and quinalphos treated plots respectively and recovery of worms were observed from third weeks onwards.

Gupta and Sundararaman (1988) found that α amylase activity in the earthworms was reduced by carbaryl 2-8 mg/kg. Carbofuran on topical application induced muscle necrosis in *Lumbricus terrestris* and became swollen, rigid and immobile (Sileo and Gilman, 1975). There are many reports that organophosphates and carbamates are toxic to several non-target organisms (Davis 1968; Rajukkannu *et al.*, 1977; Agnihotrudu and Mithyantha 1978; Beevi, 1987). The acute toxicity of phorate was reported by many workers (Edwards *et al.*, 1967; Way and Scopes, 1968). Way and Scopes (1968) found that phorate 250 ppm killed almost all earthworms in sandy loam of pH 6.1. The toxicity of the pesticide to earthworms @ 1.0 kg ai/ha in paddy field also was proved. They found that phorate @ 2.0 kg ai/ha caused reduction of earthworm population up to 55 per cent four months after the treatment and 25 per cent one year after the treatment. Among the treatments treated quinalphos was found least toxic and there was complete survival in all concentrations of the chemicals over seven days after the application of chemicals.

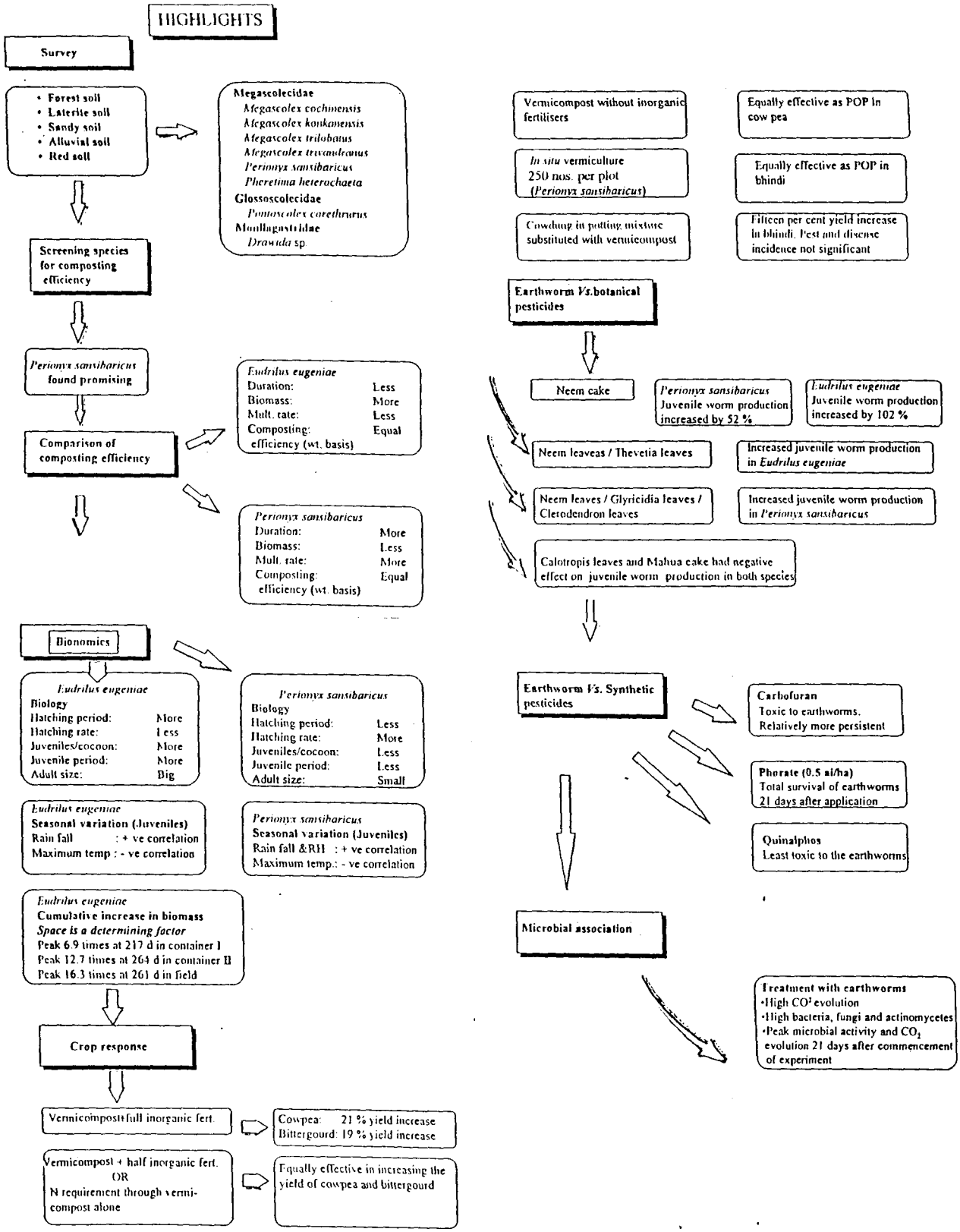
The data on the residue level in the culture medium of earthworms revealed that in all the treatments degradation of chemical was more during the initial period. In the later period the residue level gradually lowered. There are reports that toxicity of chemicals on different earthworm may vary (Kale and Krishnamoorthy, 1979; Stenersen, 1979). Carbofuran and phorate were more toxic to earthworm *E. eugeniae* compared to quinalphos with the same residue level. The systemic nature of carbofuran and phorate may be the reason for the high mortality rate compared to quinalphos, which is contact in action and was not toxic to *E. eugeniae* at the same residue levels. Carbofuran was found relatively more persistent in the medium. However, phorate with low residue level was equally toxic. Rajukkannu (1977) reported that carbofuran persisted in soil for more than 30 days after application. Garg and Agnihotri (1984) found that the half life period of carbofuran in laterite soil was 69 days. In the present study carbofuran and phorate were found highly toxic to earthworm *E. eugeniae.*

The treatments involving earthworms for composting evolved significantly high CO_2 during the period of composting, compared to the control treatment without worms (Table 31). In these treatments microbial counts were also significantly high. The increased CO_2 evolution could particularly be due to increased microbial activity. High metabolic rate and microbial load in worm-worked soil were already proved by many workers (Harinikumar *et al.*, 1991). The enhanced CO_2 evolution can as well be attributed to increased fungal activity.

Respiration of earthworms can also lead to CO_2 production. The preponderance of fungi Imperfecta on decomposing leaf litter has been reported by several workers (Shukla *et al.*, 1978; Macauley, 1979).

Bacterial count showed a declining trend in population from the beginning. Here primed banana cowdung mixture (1:1 w/w) was used for the study. This may be a reason for the initial rapid increase in number of bacteria. Such increase in the number of bacteria and fungi on decomposing litter was already reported by several workers (Gray *et al.*, 1974; Jensen, 1974; Rai and Srivastava, 1982).

There was a hike in the actinomycetes population towards the end of the composting period. The role of actinomycetes in the decomposition is limited. The bacteria act as secondary decomposers and the fungi are recognised as chief colonisers (Hudson, 1968; Hayes, 1979). The counts of actinomycetes are known to become prominent on decomposing organic matter only where the nutrient becomes limiting and the presence of more effective competitors like bacteria and fungi diminishes (Alexander, 1977).


HIGHLIGHTS
Survey
• Forest soil
• Laterite soil
• Sandy soil
• Alluvial soil
• Red soil
Megascolecidae
Megascolex cochinensis
Megascolex konkanensis
Megascolex trilobatus
Megascolex travancicanus
Perionyx sansibaricus
Pheretima heterochaeta
Glossoscolecidae
Pontoscolex corethrurus
Moniligastridae
Drawida sp.
Screening species for composting efficiency
Perionyx sansibaricus found promising
Comparison of composting efficiency
Eudrilus eugeniae
Duration: Less
Biomass: More
Mult. rate: Less
Composting efficiency (wt. basis): Equal
Perionyx sansibaricus
Duration: More
Biomass: Less
Mult. rate: More
Composting efficiency (wt. basis): Equal
Bionomics
Eudrilus eugeniae
Biology
Hatching period: More
Hatching rate: Less
Juveniles/cocoon: More
Juvenile period: More
Adult size: Big
Perionyx sansibaricus
Biology
Hatching period: Less
Hatching rate: More
Juveniles/cocoon: Less
Juvenile period: Less
Adult size: Small
Eudrilus eugeniae
Seasonal variation (Juveniles)
Rain fall : + ve correlation
Maximum temp : - ve correlation
Perionyx sansibaricus
Seasonal variation (Juveniles)
Rain fall &RH : + ve correlation
Maximum temp.: - ve correlation
Eudrilus eugeniae
Cumulative increase in biomass
Space is a determining factor
Peak 6.9 times at 217 d in container I
Peak 12.7 times at 264 d in container II
Peak 16.3 times at 261 d in field
Crop response
Vermicompost+full inorganic fert.
Cowpea: 21 % yield increase
Bittergourd: 19 % yield increase
Vermicompost + half inorganic fert.
OR
N requirement through vermi-compost alone
Equally effective in increasing the yield of cowpea and bittergourd
Vermicompost without inorganic fertilisers
Equally effective as POP in cow pea
In situ vermiculture
250 nos. per plot
(Perionyx sansibaricus)
Equally effective as POP in bhindi
Cowdung in potting mixture substituted with vermicompost
Fifteen per cent yield increase in bhindi. Pest and disease incidence not significant
Earthworm Vs.botanical pesticides
Neem cake
Perionyx sansibaricus
Juvenile worm production increased by 52 %
Eudrilus eugeniae
Juvenile worm production increased by 102 %
Neem leaveas / Thevetia leaves
Increased juvenile worm production in Eudrilus eugeniae
Neem leaves / Glyricidia leaves / Clerodendron leaves
Increased juvenile worm production in Perionyx sansibaricus
Calotropis leaves and Mahua cake had negative effect on juvenile worm production in both species
Earthworm Vs. Synthetic pesticides
Carbofuran
Toxic to earthworms. Relatively more persistent
Phorate (0.5 ai/ha)
Total survival of earthworms 21 days after application
Quinalphos
Least toxic to the earthworms
Microbial association
Treatment with earthworms
•High CO2 evolution
•High bacteria, fungi and actinomycetes
•Peak microbial activity and CO2 evolution 21 days after commencement of experiment

SUMMARY

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A study was conducted on various aspects of vermiculture. It included collection and identification of earthworms, assessment of the composting efficiency and breeding potential of the identified earthworm species, bionomics of earthworm species under the tropical conditions of Kerala, effect of applying vermicompost on pests, disease incidence and yield of vegetables *viz.* bittergourd and cowpea, effect of biopesticides on indigenous species (*Perionyx sansibaricus*) and exotic species *Eudrilus eugeniae* and quantification of microflora during the period of vermicomposting.

Eight species of earthworm belonging to three families were identified from five soil types of southern Kerala. The identified species were *Megascolex cochinensis* and *M. konkanensis*, *M. trilobatus*, *P. sansibaricus* and *Pheretima heterochaeta* (Megascolecidae), *Pontoscolex corethrurus* (Glossoscolecidae) and *Drawida sp.* (Moniligastridae). *M. cochinensis* and *P. corethrurus* were found to be ubiquitous. *P. sansibaricus* was confined only to forest soil and red soil. Forest soil with high water holding capacity, organic carbon content and slightly acidic pH recorded the highest population count. Species diversity was also very high in forest soil.

E. eugeniae was relatively more efficient for composting in terms of duration of composting and biomass production. However, multiplication rate of *P. sansibaricus* was more than that of *E. eugeniae*. The other identified species did not come up well in the medium consisting of banana leaves and cowdung. In the field evaluation of composting efficiency, where the same weight of worms were used, the time taken for composting was found equal. However, the weight of worms per kg compost was significantly higher for *E. eugeniae* than for *P. sansibaricus*.

In a study on the seasonal variation in earthworm population, the indigenous species *P. sansibaricus* recorded the lowest adult count in the experiments set in February. The counts of adult worms in experiments set in April, May, June, July, September and October were superior to that of the other months. The counts of the juveniles was high in experiments set in September, June and July and the lowest count was obtained in the experiments set in January. The observations from November to March was significantly lower. The cocoon counts were high in experiments set in June, July and September. The count was the lowest in November. For the exotic species *E. eugeniae* adult count was the highest in experiments set in October. Observation in May was on par. The other treatments recorded lesser worm counts. July, followed by June and August recorded higher juvenile counts. The other months of the year recorded significantly lesser worm counts. The highest cocoon count was obtained in the

In *E. eugeniae* the highest decomposition rate was observed in the experiment set in May. The observations in June, July, August and September were on par. Experiments set in the other months recorded significantly lower rates of decomposition. The lowest decomposition rate was observed in January.

Density pressure influenced biomass production of earthworms. Space was found a limiting factor in the growth and multiplication of earthworms. Both in pot culture study and field study where the same space was used for maintaining worms, the decline of earthworm started after attaining the peak. In the second container which was larger than the first, the multiplication rate of the worm was more and decline of population started at a later stage. The container I and II recorded 6.89 times increase in a period of 217 days, 12.73 times in a period of 264 days, respectively. In field condition the population increase (16.34 times in 261 days) was far superior, compared to the first two containers.

The cocoon of *E. eugeniae* resembled coriander seed. Cocoons required a period of 29 ± 1.1 days for hatching. The hatching rate was 56.25 ± 1.19 per cent. The mean number of juveniles hatched / cocoon was 2.875 ± 0.35. The period required to attain reproductive stage was 43.37 ± 0.56 days.

The cocoon of *P. sansibaricus* was elongate and slender. The time required for the cocoon to hatch was 16 ± 0.43 days. The hatching rate was 64.06 ± 3.44

per cent. The time required for juveniles to become adult was 38.25 ± 0.70 days. The number of cocoons laid per week was also significantly superior to that of *E. eugeniae*.

Vermicompost, along with full inorganic fertilizers increased the yield by 21.4 per cent and 19.0 per cent in bittergourd and cowpea, respectively. In cowpea, the application of vermicompost without inorganic fertilisers was equally effective as that of the recommended manurial schedule. Vermicompost with half or three fourth inorganic fertiliser was equally good as that of Package of Practices Recommmendation both in bittergourd and cowpea. In all the cases there was decrease in the incidence of fruit fly attack. However, the reduction in pest attack was not significant, except at two cases. In cowpea also there was no significant difference in pest and disease incidence with the control.

There was significant increase in yield when vermicompost was used as a potting mixture. Significant increase in yield was noticed with respect to treatments T2 (vermicompost prepared from banana leaves), T3 (vermicompost containing neem cake) and T4 (vermicompost containing neem leaves). However, no significant difference in the biometric characters of plants and pest and disease incidence were noticed.

Vermicompost along with full inorganic fertiliser increased the yield of bhindi by 15 per cent. The effect of *in situ* vermiculture (250 numbers of *P. sansibaricus*/per plot) was on par with that of Package of Practices Recommendation. There was no significant variation in the biometric characters, except plant height. This parameter showed significant increase two months after sowing and at the end of the experiment. In both the cases, treatments involving vermicompost + full inorganic fertilizer recorded the highest plant height. At the end of the experiment, Package of Practices Recommendation and *in situ* vermiculture were equally effective.

Neem cake was found beneficial for supporting growth and multiplication of E. *eugeniae*. Neem cake recorded 102 per cent increase in juvenile worm production. Neem leaves and thevetia leaves were found equally effective. Mahua cake was not found supportive for growth and multiplication of earthworms.

Neem cake was effective in supporting growth and multiplication of *P. sansibaricus*. Neem cake recorded 52 per cent increase in juvenile worm production, compared to that in the control. In treatment consisting of neem leaves, clerodendron leaves and glyricidia leaves the juvenile worm production was on par with that of neem cake. In treatments involving thevetia leaves and eupatorium leaves, the juvenile worm count was less than that of the control.

Calotropis leaves and mahua cake caused significant reduction in adult, juvenile and cocoon production.

In a pot culture experiment to test the toxicity of insecticides on earthworm, the methodology II was superior with respect to survivability of the worms. Among the different treatments (carbofuran, phorate and quinalphos), quinalphos 0.5 kg and 1.0 kg ai/ha was the least toxic to earthworms. There was total survival after an interval of seven days. However, quinalphos 1.5 kg ai / ha caused 21.30 and 18.35 per cent mortality in methodology I and II, respectively. But from the 14th day onwards there was cent per cent survival in all concentrations of the chemicals. However, carbofuran and phorate were toxic to earthworms even at this stage. Carbofuran 1.5 kg ai/ha recorded the lowest survival with 80.15 per cent mortality. However, after an interval of 21 days phorate 0.5 kg ai/ha (methodology II) recorded total survival. Carbofuran 0.5 kg ai/ha in methodology II was on par. Carbofuran and phorate 1.0 and 1.5 kg ai/ha were toxic to earthworms at this interval. Carbofuran 1.5 kg ai/ha in methodology I caused a mortality of 35.0 per cent. In all the cases the survival of the worms was more when methodology II was followed.

The residue levels declined as the period of composting advanced. Among the different observations, the highest residue level (1.42 ppm) was recorded by carbofuran 1.5 kg ai/ha, followed by phorate 1.5 kg ai/ha (1.31 ppm) on the 7th

day. On the 14th day also carbofuran 1.5 kg ai/ha recorded the highest residue level which was on par with carbofuran 1.0 kg ai/ha. The residue levels of the other treatments were significantly lower. On the 21st day higher residue levels were observed for carbofuran 1.0 and 1.5 kg ai/ha and quinalphos 1.5 kg ai/ha. The lowest residue level was found for quinalphos 0.5 kg ai/ha. On the 28th day high residue levels were observed for carbofuran 1.5 kg ai/ha and phorate 1.5 kg ai/ha. Carbofuran 0.5 kg and 1 kg ai/ha recorded mean residue levels of 0.32 and 0.34 ppm, respectively and the values were on par.

The treatments involving earthworms for composting evolved significantly higher CO_2 during the period of composting, compared to the control treatment without worms. The values of carbondioxide evolution recorded by the treatments involving *E. eugeniae* and *P. sansibaricus* were on par. Maximum carbondioxide evolution was observed on the 21st day which was significantly superior to the CO_2 evolution estimated at various other intervals. The next superior intervals with regard to CO_2 evolution were the 28th day and the 14th day. There was a hike in the carbon dioxide evolution upto the 21st day. From the 21st day onwards downward trend in carbon dioxide evolution was observed.

However, this decrease was more drastic after the 35th day. The decline was from 383.00 to 132.46 mg in a short span of seven days. Carbon dioxide evolution was the lowest on the 70th day.

The treatments involving *P. sansibaricus* and *E. eugeniae* had a significantly higher bacterial count, compared to the treatment without worms. Bacterial count showed a decreasing trend as the period of composting advanced. The bacterial count on the first day was the highest in all cases and it was significantly higher than the counts at the other intervals. With respect to fungi also the treatments involving the two worms were superior to the control. The highest fungal count was detected on 28th day for *E. eugeniae*. In the other two cases the highest fungal count was observed on the 14th day. Towards compost maturity, the fungal counts were more or less steady, in *E. eugeniae*. However, a slight increase in the count was observed on the 56th day.

There was no definite trend with respect to actinomycetescount during the period of composting. The highest count of actinomycetes was recorded in the treatment involving *E. eugeniae* on the 1st and 56th day. The other two treatments also recorded the peak population at the same interval.

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* Originals not seen

APPENDICES

Appendix I

Weather parameters during 1994-95

Month	Maximum temperature (^{0}C)	Minimum temperature(^{0}C)	Humidity (%)	Rainfall (mm)
May	30.8	26.4	87.4	23.8
June	29.7	23.8	87.8	23.4
July	29.2	23.4	82.6	39.3
August	29.3	23.4	85.0	34.1
September	29.7	23.0	82.5	30.5
October	28.5	22.5	80.2	20.2
November	29.5	23.6	77.8	4.1
December	30.5	23.8	88.4	- -
January	31.8	22.6	72.7	1.2
February	32.1	22.5	74.7	- -
March	31.5	24.6	77.8	4.5
April	29.5	23.4	80.2	5.1
May	30.8	23.5	79.5	-

Appendix II

Composition of microbial culture media

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a. Composition of compost extract agar medium

Glucose	:	1.0 g
K_2HPO_4	:	0.5 g
Agar agar	:	15 g
Compost extract	:	100 ml
Tap water	:	900 ml

b. Composition of Martins rose bengal streptomycin agar medium

Dextrose	:	100 g
Peptone	:	5.0 g
K_2HPO_4	:	1.0 g
$MgSO_4.7\ H_2O$	:	0.5 g
Rose Bengal	:	One part in 30,000 parts media
Agar agar	:	20 g
Streptomycin	:	30 g
Distilled water	:	1000 ml

c. Composition of Kenknight Munaier's medium

Dextrose	:	1.00 g
K_2HPO_4	:	0.10 g
$Na\ NO_3$	:	0.10 g
KCl	:	0.10 g
$MgSO_4.7\ H_2O$	:	0.10 g
Agar agar	:	15.00 g
Distilled water	:	1000 ml

COMPOSTING EFFICIENCY OF INDIGENOUS AND INTRODUCED EARTHWORMS

BY

JIJI, T.

ABSTRACT OF A THESIS
SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENT FOR THE DEGREE
DOCTOR OF PHILOSOPHY
FACULTY OF AGRICULTURE
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VELLAYANI, THIRUVANANTHAPURAM

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ABSTRACT

Eight species of earthworm belonging to three families were identified from five different soil types of southern Kerala. The identified species were *Megascolex cochinensis, M. konkanensis, M. trivandranus, M. trilobatus, Perionyx. sansibaricus, Pheretima heterochaeta* (Megascolecidae), *Pontoscolex corethrurus* (Glossoscolecidae) and *Drawida sp.* (Moniligastridae). *M. cochinenses* and *P. corethrurus* were ubiquitous. *P. sansibaricus* was confined to forest soil and red soil. Forest soil with high water holding capacity, organic carbon content and acidic pH had the highest total count of worms and the highest species diversity.

The exotic species *Eudrilus eugeniae* was more efficient for composting in terms of duration for composting and biomass production. However, the multiplication rate of the indigenous *P. sansibaricus* was more than that of *E. eugeniae*.

In field conditions, when the same weight of worms was used, the time taken for composting was found equal for *E. eugeniae* and *P. sansibaricus*. However, the biomass recovery of earthworm was more in *E. eugeniae*.

Both species performed well in the rainy season, compared to hot summer months. The breeding potential, time required for composting and decomposition

rate were significantly superior from June to September. There was positive correlation between juvenile count and rainfall and negative correlation with maximum temperature with respect to *E. eugeniae*. In *P. sansibaricus* adult and juvenile counts expressed positive correlation with rainfall and humidity and negative correlation with maximum temperature.

Space was found to be a determining factor in the growth and multiplication of earthworms.

The cocoons of *E. eugeniae* required 29 ± 1.10 days for hatching. The hatching rate was only 56.25 ± 1.19 per cent in laboratory condition. The mean number of juveniles hatched/cocoon was 2.88 ± 0.35. The period required to attain reproductive stage was 43.38 + 0.56 days. Cocoons of *P. sansibaricus* was elongate and slender. The time required for hatching of cocoon was 16 ± 0.43 days. The hatching rate was 64.06 ± 3.44 per cent in laboratory conditions. The juveniles required 38.25 ± 0.70 days to become adults. The number of cocoon laid/week was also significantly superior, as compared to *E. eugeniae*.

Vermicompost along with full inorganic fertiliser increased the yield by 21.4 per cent and 19.0 per cent in bittergourd and cowpea, respectively. In cowpea, application of vermicompost without inorganic fertilizer was equally effective as that of the recommended manurial schedule.

There was significant yield increase when vermicompost was used as a potting mixture in bhindi. However, no significant difference in the biometric characters of plants was observed.

Vermicompost along with full inorganic fertiliser increased the yield of bhindi by 15 per cent. The effect of *in situ* vermiculture (250 worms of *P. sansibaricus*/plot) was on par with that of Package of Practices Recommendations.

Neemcake was found beneficial for supporting growth and multiplication of *E. eugeniae*. Neem cake recorded 102 per cent increase in juvenile worm production. Neem leaves and thevetia leaves were equally effective. Mahua cake was not supportive for growth and multiplication. Neem cake was effective in supporting growth and multiplication of *P. sansibaricus*. Neem cake recorded 52 per cent increase in juvenile worm production. Leaves of neem, clerodendron and glyricidia were equally effective in supporting juvenile worm production as that of the control. Calotropis leaves and mahua cake caused significant reduction in adult, juvenile and cocoon production.

In a pot culture study, among the treatments, carbofuran, phorate and quinalphos , quinalphos (0.5 kg and 1.0 kg ai/ha) was found the least toxic to earthworm and there was total survival after an interval of seven days.

The treatments involving earthworms for composting evolved significantly higher CO_2 during the period of composting, compared to the control treatment of banana : cowdung mixture without worms. The CO_2 evolved by the treatments involving *E. eugeniae* and *P. sansibaricus* were on par. Maximum CO_2 evolution was observed on the 21st day which was significantly superior to the CO_2 evolution estimated at various other intervals. From the 21st day onwards a decline in the CO_2 evolution was recorded.

The treatment involving earthworm had a significantly higher bacterial, fungal and actinomycetes counts, as against the treatment without worms. The highest fungal count for *E. eugeniae* was found on the 28th day. Towards compost maturity the fungal counts were more or less steady; however, a slight increase in the count was observed on the 56th day. There was no definite trend with respect to actinomycetes count during the period of composting.