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BIOTIC ENRICHMENT OF ORGANIC WASTES FROM AYURVEDIC PREPARATIONS

By

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Biotic Enrichment of Organic Wastes from Ayurvedic Preparations"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other university or society.

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Certified that the thesis entitled **"Biotic Enrichment of Organic Wastes from Ayurvedic Preparations"** is a record of research work done independently by **Ms. Preetha. D,** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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We, the undersigned members of the Advisory Committee of **Ms. Preetha, D.** a candidate for the degree of **Master of Science in Agriculture** with major in **Soil Science and Agricultural Chemistry** agree that the thesis entitled **"Biotic Enrichment of Organic Wastes from Ayurvedic Preparations"** may be submitted by Ms. Preetha, D. in partial fulfilment of the requirement for the degree.

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My Beloved Parents

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Introduction

1. INTRODUCTION

Agriculture, the primary activity on the planet earth and in every society, has an extremely critical role to play in sustaining life. In view of maintaining soil health, there is an increasing awareness about alternative agricultural systems known as biological, ecological, organic, regenerative, natural, biodynamic or low input agriculture. In addition to integrated use of minerals and organics, renewable waste is accepted as the most appropriate strategy for sustaining crop yields, minimizing soil depletion and value added disposal of what are traditionally labelled as 'wastes'.

The concept of waste recycling is centuries old. Only the urgency, the scale and the complexities of recycling have gone up many fold. In addition, more efficient and versatile recycling processes and technologies have become available, which if applied on the required scale can bring recyclable wastes into the main stream of farm input management strategies. Recycling of materials is an important aspect in solving garbage problem. The total garbage generated per day in Kerala state is about 2400 tonnes approximately (The Hindu, 2003). Disposal of this garbage is a very serious problem these days and needs much attention. We not only have to save and utilize waste but also recycle them in an effective and economic manner with minimum leakage and losses. Among the various waste management methods, composting is more eco-friendly and important method of recycling from the agricultural point of view. Composting offers several advantages as a waste disposal method including increased availability of plant nutrients, destruction of pathogens, elimination of unfavourable odours and easy handling.

Vermiculture biotechnology is an aspect of biotechnology involving the use of earth worms as versatile natural bioreactors for effective recycling of non-toxic organic wastes to the soil. Earthworms along with soil microorganisms play a major role in degrading organic waste materials and thus maintain the nutrient flux in the system. This mutually supportive association of "soil, biomass and microbes" their interaction and interdependence is a self reliant auto dynamic effluent free system which works on a recycling principle. Recycling is also essential to maintain a pollution free environment.

There are several instances of successful utilisation of agro-industrial wastes like coirpith, press mud, lime sludge etc. in agriculture. One such agroindustrial waste generated in huge quantity that requires effective disposal is medicinal waste produced by Oushadhi, an ayurvedic medicine manufacturing company, located at Kuttanalloor, Thrissur District, which produces bio-degradable wastes of more than 400 ayurvedic formulations (Anon, 1999). Through the different processes, about one tonne wastes are being originated per day for want of scientific and effective disposal techniques. By applying suitable bioagents and biodegradation techniques, the organic waste materials can be converted to nutrient rich compost. Again, the addition of suitable organic enriching materials like cowdung, quail manure etc will not only provide a suitable micro-environment for the various biotic agents but also enhance the quality of the resulting manure. There is a good demand for quality vermicompost not only for the use of raising crops but also for the use in aqua culture industry. With these factors in view, the present study was taken up with the following objectives.

1. *To standardize the substrate controlled microenvironment for the biotic* decomposition of organic wastes from Ayurvedic preparations

2. To identify the promising bioagents including earth worms for the enrichment of organic wastes

3. To evaluate the soil and crop response to the resulting compost material

Review of Literature

2. REVIEW OF LITERATURE

2.1 IMPORTANCE OF RECYCLING OF ORGANIC WASTES

Recycling of organic resources for the replenishment of plant nutrients is a necessary practice, since the chemical fertilizers alone do not provide all the nutrients in the balanced quantities needed by plants. Management of nutrients is an important aspect for maintaining soil productivity and maximizing yield (Goswami and Rattan, 1992; Mishra and Kapoor, 1992).

Thampan (1993) recommended on-farm recycling of organic wastes and the application of bulky organic manures such as FYM and compost as the most popular agronomic measure to sustain soil health. According to Ramaswamy (1996) biocycling of organic wastes help to improve the soil properties like bulk density, infiltration, hydraulic conductivity, water holding capacity, pH etc. It also improves the soil health and helps to improve the clay humus complex, nutrient status, buffering capacity, CEC and yield of crops. Thus under conditions of intensive farming where the nutrient turnover in the soil-crop system is quite large, the integrated nutrient management involving the judicious use of nutrient enriched compost in conjunction with chemical fertilizers is the most appropriate farming practice for achieving sustainability in crop yields of a high order, without any drastic deterioration in soil health and productivity (Aruna *et al.*, 1996).

Further, the preparation of organic manures by recycling of animal wastes (Thampan, 1993) rural and urban wastes (Paulraj and Sreeramulu, 1994), industrial wastes (Gopinathan, 1996) etc. provide valuable manure for maintaining the soil health besides helping in the safe and hygienic disposal of solid wastes.

According to Hamza (1989), uncontrolled discharge and open dumping of agro-industrial wastes contributed to appreciable environmental deterioration, which was manifested as (a) serious hazards to public health, (b) pollution of air and water bodies, (c) increased eutrophication due to excessive discharge of nutrients, (d) depletion of dissolved oxygen in surface water, (e) offensive odours due to anaerobic decomposition of organic residues, (f) unsightly conditions in waste storage and land disposal sites.

Disposal of the different types of wastes produced by agricultural, industrial and human activities is of great concern in the modern world. Problems caused to modern society by solid wastes became more severe, over the last few years, because of increasing amounts of waste and decreasing availability of land fill space (Alter, 1991; Finstein, 1992).

2.2 SOURCES OF ORGANIC WASTES

The total annual waste biomass of India is about 2500 million tonnes, which includes municipal solid wastes, agricultural residues, cattle manure, poultry manure and agroindustrial wastes (Tandon, 1995). According to Thimmiah and Bhatnagar (1999), India generated 345 million tonnes of solid waste annually of which approximately 25 million tonnes were municipal solid wastes and 320 million tonnes were agricultural residues.

Biswas (1991) reported that there was a potential for supplying 3.44, 1.31 and 2.21 mt. of N, P_2O_5 and K_2O respectively from the annual production of cattle and buffalo wastes. The nutrients present in them could be recycled either by composting, mulching or direct incorporation into the soil. According to Gaur (1992), the major sources of organic wastes available in India are farmyard manure, rural and urban compost, sewage-sludge, agro industrial byproducts and industrial wastewater. Nutrient potential of these sources come to 6.08 mt N, 5.1 mt. P_2O_5 and 7.86 mt K_2O, respectively. He also reported that the potential of cereal straw residues from rice, wheat, sorghum, pearl millet and bajra were 1.13, 1.41 and 3.54 mt. of N, P_2O_5 and K_2O, respectively. Jain (1993) emphasized on the importance of agricultural residues and these could supplement the chemical fertilizer needs of the next crop.

Bhardwaj (1995) reported on the possibility of gathering 750 million tonnes of cattle dung, 250 million tonnes of buffalo manure and hundreds of million tonnes of rural and urban compost. He also opined that the organic wastes available in India were estimated to supply 7.1, 3.0 and 7.6 mt of N, P_2O_5 and K_2O, respectively. The crop residues alone supplied 1.13, 1.41 and 3.54 mt of N, P_2O_5 and K_2O respectively. Some of the proliferous weeds like *Eicchornia crassipes* and *Salvinia molesta* could be utilized for bioconversion as organic manures (Sandhyarani and Ramaswamy, 1996).

Among the different agro-industries, sugar industry, is the biggest one producing 274 million tonnes of press mud annually (Rai *et al.*, 1980). The vast quantities of cellulosic wastes generated during the processing of rice, sugarcane, cotton, timber and other crops could be applied safely to crop land (Silva and Breitenbeck, 1997).

Coirpith, a highly lignocellulosic material obtained as a byproduct of coconut coir industry can be effectively used as an organic manure by composting or such bioconversions. According to Arumughan and Damodharan (1993), there are about 84,000 retting and coir extracting units in Kerala producing white fibre and about 650 brown coir units located in Tamil Nadu, Karnataka and Andhra Pradesh.

Vast amounts of nutrient rich industrial wastes were available as a result of growing urbanization and industrialization (Arya *et al.*, 1981). The rapidly increasing amounts of municipal wastes could serve as an alternate source of organic amendment that can be used safely and beneficially to increase productivity (Bhardwaj and Gaur, 1985). The use of municipal solid waste composts in agriculture was a practical alternative to other disposal methods (Hampton *et al.*, 1994). According to Thomas (2001) the KCPL (Kerala Chemicals and Proteins Ltd.) effluent sludge, a bone based industrial waste could serve as an efficient organic source, both under aerobic and water logged conditions.

2.3 COMPOSTING

Composting is the microbiological conversion of biodegradable organic wastes to a stable humus by indigenous flora, including bacteria, fungi and actinomycetes, which are widely distributed in nature (Gaur and Sadasivam, 1993). Composting has become an attractive option for solid waste management with the capacity of reducing the volume and weight by approximately 50 per cent and resulting in a stable product that could be beneficial to agriculture (He *et al.*, 1992).

According to Gill (1993) the wastes could be processed by conversion processes and the final product should be non pollutant and safely used in economic or agricultural activity. Gaur and Geethasingh (1995) reported that due to the effect of high temperature and antibiotics produced during bioconversion, the end product was free of pathogens. Humus and CO_2 were produced and essential nutrients such as nitrate, sulphate and phosphates were released during the process of composting.

Selective co-composting of waste materials with sewage-sludge, night soil, etc provided a readily compostable mixture and higher quality product (Wilson, 1989). Under Indian farming conditions, co-composting of manure slurries with plant residues was a more viable and profitable proposition (Gaur and Sadasivam, 1993).

Dung slurry and biogas spent slurry were found to be good additives for improving the rate of decomposition of crop waste composts (Gaur and Mathur , 1990). Budhar *et al.* (1991) emphasized the superiority of poultry manure as an organic source. Composting of wide C:N ratio materials such as bark waste, rice straw, sawdust etc. with low C:N ratio material such as poultry manure, resulted in a more favourable ratio for composting and compost produced had higher nutrient content (Echeandia and Menoyo, 1991). Organic wastes poor in nitrogen was enriched by incorporating fishmeal, non edible oil cakes, poultry manure or 1 per cent N as urea (Jaggi, 1991). The volatilization loss of ammoniacal nitrogen from poultry manure can be minimised by composting it with substrates having wide ratio. Rice straw mixed with 10 per cent poultry waste yielded a more friable and nitrogen rich compost. The output was more by 15 per cent, compared to compost made from poultry manure alone (Sims and Wolf, 1994). Moorthy *et al.* (1996) also proved the beneficial effect of cowdung for the enrichment of coirdust.

2.3.1 Factors Influencing Composting and Compost Maturity

The various factors like C:N ratio, pH, temperature, moisture, presence of micro organisms, aeration, particle size etc. have their influence on the process of composting and compost maturity, as well.

2.3.1.1 C:N ratio

According to Krishnamurthy (1978), the satisfactory initial C:N ratio for composting was from 30 to 35. If the C:N ratio exceeds this, it takes a longer time for composting. Chanyasak *et al.* (1982) recommended the use of C:N rates as index of maturity. Shen-Qi-Rong *et al.* (1997) reported that C:N ratio decreased during composting. A C:N ratio of 10 to 12 is usually considered to be an indicator of stable and decomposed organic matter (Jimenez and Garcia, 1992). Sameer and Sushama (2003) also reported the reduction of C:N ratio of raw coir pith from 169.23 to 44.64, by composting.

2.3.1.2 pH

Ganapini *et al.* (1979) suggested the use of pH value as an indicator of compost maturity. According to Wilson (1989) most well stabilised composts had a pH between 6.5 and 7.5. Adjusting the pH, downward to near neutral, reduced the volatalisation of ammonia and other odorous compounds. Zacchariah (1994) opined that vermicomposts showed a pH ranging from neutral to alkaline. pH of vermicompost was recorded as 7.34, while that of ordinary compost was 6.33. Maximum pH during composting was observed at the thermophilic stage (Thomas, 2001).

2.3.1.3 Temperature

Physical parameters like temperature, odour and colour had also been proposed to be characteristics of compost maturity (Sugahara *et al.*, 1979; Guisquiani *et al.*, 1989). Several workers have demonstrated that fermentations operating at thermophilic temperatures, resulted in more rapid degradation of organic matter (Hashimoto *et al.*, 1981; Kimchie *et al.*, 1988). Eghball *et al.* (1997) reported that during composting of cattle feed lot manure, the temperature reached 65°C within 24 hours at all depths within the compost pile. After 65 days, the temperature decreased to 40°C. The temperature was near ambient after 110 days. According to Nair (1997) peak value of temperature, 66.3°C and pH 7.4 was attained during the thermophilic stage of composting A temperature rise in the first two weeks of composting was recorded by Thomas (2001).

2.3.1.4 Moisture and Aeration

According to Krishnamurthy (1978), moisture content of the composting material has an important role in satisfactory decomposition. At very low moisture, bacterial decomposition was arrested and nitrogen escaped as ammonia and other volatile forms of nitrogen. At a very high moisture level, anaerobic conditions set in and brought down the speed of decomposition. High initial moisture content in compost hindered aeration and induced undesirable anaerobic conditions during composting which was identified with low temperature below 35°C and occurrence of foul odours (Haug, 1980). Kurihara (1984) stated that if the moisture content of compost exceeded 60%, it should be stockpiled and matured for one to two months to accelerate decomposition of absorbents.

Numerous studies showed that at adequate aeration, the temperature in the compost pile increased to greater than 60°C. This accelerated the decomposition process and resulted in complete destruction of pathogens, parasites and weed seeds (Bishop and Godfrey, 1983; Parr *et al.*, 1994).

2.3.1.5 Microbial Presence

De Bertoldi *et al.* (1982) found that during initial stages of composting ammonia producing and proteolytic bacteria increased considerably reaching numbers greater than 10^6 cells/g dry weight. As compost matured their population decreased while the population of nitrogen fixers increased again. Wittling *et al.* (1995) proposed microbial criteria as indicator of compost maturity. Studies conducted by Nair (1997) has revealed maximum microbial population of bacteria (358.7×10^5), actinomycetes (163.3×10^5) and fungi (62×10^4) in the thermophilic stage.

Vermicompost produced by *Eudrilus eugeniae* had a higher population of bacteria (5.7×10^7), fungi (22.7×10^4) and actinomycetes (17.7×10^6), when compared to that of ordinary compost (Nair *et al.*, 1997). Dilution plate method followed to calculate the amounts of microorganisms present in vermi compost revealed that it contains 67×10^6 bacteria, 8.3×10^5 actinomycetes and 1.3×10^5 fungi/g of vermi compost (Meera, 1998).

2.3.1.6 Particle Size

Kalaiselvy and Ramaswamy (1996), in their review on compost maturity stated that mature compost should have a tea brown colour, no noxious smell and good stability which could no longer produce high temperatures. Maximum diameter of the compost material should not exceed 10 mm, with 5 mm as optimum. Thomas (2001) opined that organic meals produced by composting of spent slurry were odourless and in innocuous form, light brown to black in colour. Consistency of the material seemed to be in a bead like attractive form, easy to handle.

2.3.2 Maturity of Compost

According to Zucconi *et al.* (1981) immature composts applied to crops could result in plant phytotoxicity from intermediate organic compounds. Chefetz *et al.* (1996) also reported that, in immature composts, low molecular weight organic acids induced phytotoxicity, in addition to competition for oxygen and nutrients due to high rates of organic matter decomposition.

2.3.3 Need for Compost Enrichment

The conventional method of composting takes a long time to produce good compost. So inoculation with cellulose decomposers and addition of nitrogen phosphate and potassium salts hastened the production of sawdust compost (Wilde, 1958). Gaur *et al.* (1982) reported the use of mesophilic cellulolytic fungi in the preparation of plant residue compost, which reduced the period of composting as well as improved the quality of compost. Inoculation with *Azotobacter chroococcum* and phosphate solubilising micro-organisms improved the manurial value of compost (Gaur *et al.*, 1975). Introduction of earthworms for composting is beneficial because earthworm casts were rich in nutrients (N,P,K,Ca and Mg) and also in bacterial and actinomycete population which were many times more than that in original soil (Gaur, 1982). The earthworms in the compost heaps had been found to mix the materials, aerate the heap and hasten decomposition.

2.3.3.1 Enrichment with Microbes

Rasal (1988) showed that enrichment of compost by the use of micro-organisms improved the quality of the compost, but did not increase the nutrient content as obtained by the use of inorganic fertilizers. Microbial inoculation of organic wastes was done for selective degradation, phosphate solubilisation and nitrogen fixation. These inoculants found to promote the composting process are the fungi such as Aspergillus, Trichurus, Trichoderma, Phanerochaete etc. (Radhakrishna, 2001). The decomposition process of paddy straw was enhanced by inoculation with *Trichoderma viride* (Misra *et al.*, 2002). Sameer and Sushama (2003) reported that the addition of *Aspergillus awamorii* hastened the P release from the coirpith.

According to Bopaiah (1991) five spawn bottles of *Pleurotus sajor-caju* fungus and 5 kg urea were needed for decomposing 1 tonne of coirpith. Coirpith composted by *Pleurotus* sp. and treated with urea and rockphosphate helped to increase the nutrient availability (Jothimani, 1993). Acrobic fungi such as *Pleurotus* sp. and *Schizophyllus communae* had been successfully used for pretreatment in biopulping, as these fungi were capable of degradation of lignin and cellulose (Kirk *et al.*, 1994). Savithri and Khan (1994) reported *Pleurotus* sp., *Trichoderma* sp. and *Aspergillus* sp. as potent degraders of coirpith.

2.3.3.2 Enrichment with Earthworms

Earthworms gained importance because of their detritivorous habit and were being exploited commercially in waste management and biodegradation technology (Hartenstein and Rothwell, 1973). Hartenstein and Bisesi (1989) reported that epigeic earthworm species seemed to be well fitted for the management of organic waste material, because of their surface activity and ability to colonise organic matter quickly. According to Bhawalkar and Bhawalkar (1993), earthworms feed on any organic waste, consume 2-5 times their body weight and excrete the mucus coated undigested matter as wormcasts. The nutrients in wormcast are readily soluble in water for the uptake of plants.

Kale and Bano (1988) and Edwards and Barter (1992) found *Eudrilus eugeniae* as a good species for organic waste management under tropical conditions. Zacchariah (1994) reported the superiority of *Eudrilus eugeniae* to other local earthworms in the conversion of vegetable garbage to compost. According to Jiji (1997) the vermicompost produced with *Eudrilus eugeniae* was significantly superior over control with respect to the count of fungi and bacteria.

The earthworm, *Eisenia foetida* was a common inhabitant of compost heaps and areas rich in organic debris. This earthworm was thought to feed on the micro-organisms present in such environments (Miles, 1963; Neuhauser *et al.*, 1980; Flack and Hartenstein, 1984). Haimi and Huhta (1990) reported that on using *Eisenia foetida*, the composting time was reduced very much and homogeneous mass of castings was obtained in a period of one month, when sufficient potential biomass was provided. Hand *et al.* (1988) reported that *Eisenia foetida* increased the nitrite N content of cowdung, the substrate used for vermicomposting.

2.3.4 Role of FYM in Soil and Crop Relations

Organic manures especially FYM contained a very large population of bacteria, actinomycetes and fungi and stimulated those already present in the soil. The application of organics helped micro-organisms to produce polysaccharides which build up better soil structure. Nitrogen fixation and phosphorus solubilisation were also increased due to improved microbiological activity in organic amended soils. The beneficial effects of humus on soil characteristics ultimately resulted in increased crop yields (Balasubramaniam *et al.*, 1972).

2.3.4.1 Release of Nutrients from Soil

The role of FYM application in increasing the organic carbon level has been reported by many workers (Biswas *et al.*, 1969; Bijaysingh *et al.*, 1983). Application of FYM increased the availability of both native and applied micronutrient cations. These ions formed stable complexes with organic ligands which decrease their susceptibility to adsorption and fixation (Swarup, 1984). Bhajansingh *et al.* (1985) have reported that FYM application increased available P status of soil. According to Srivastava (1985)

FYM addition increased the N and K status in the soil. Rabindra and Honnegowda (1986) opined that FYM had greater buffering capacity and helps to maintain soil pH.

2.3.4.2 Nutrient Uptake by Plants

Raju *et al.* (1991) observed FYM to be more effective in increasing N uptake in chickpea. They reported that FYM application enhanced P uptake in potato and maize. Organic manures applied in conjunction with optimal dose of NPK fertilizers resulted in highest K uptake by crops (Singh and Tomar, 1991). Minhas and Sood (1994) opined that FYM application was beneficial in enhancing all the three major nutrients in potato and maize.

2.3.4.3 Crop Growth and Yield Parameters

Bohec (1990) noted that the maximum yield was obtained in celery, lettuce and leek, when grown on land with annual application of FYM, composted urban waste or composted sewage-sludge, when compared to control without added organic matter. Patel and Patel (1991) found that FYM had no effect on any growth parameters in redgram. In hyacinth bean, the highest seed yield was obtained with the incorporation of FYM, along with chemical fertilizers (Noor *et al.*, 1992). In Soyabean, FYM application along with NPK fertilizer increased plant height and number of branches per plant (Singh *et al.*, 1993).

2.3.4.4 Quality of the Produce

Bhawalkar and Bhawalkar (1993) reported better keeping quality for tomato due to application of FYM. Organic manures like FYM, compost, oilcakes, green leaf, poultry manure etc. improved the quality of vegetables in crops like tomato, onion, gourd, chillies etc. Increase of ascorbic acid content in tomato, pyruvic acid in onion and minerals in gourds were the impact of application of organic manures to vegetable crops.

2.3.5 Manurial Value of Vermicompost

Application of organic manure in the form of vermicompost in soil, recorded the highest value for all the available nutrients (Rajalekshmi, 1996). Availability of N, P_2O_5,

K_2O, Ca and Mg was highest when 25 t of vermicompost along with full dose of inorganic fertilizers was used in tomato (Pushpa, 1996).

2.3.5.1 Available N

Haimi and Huhta (1990) reported that the earthworms increased the proportion of mineral N available for plants at any given time, although N was clearly immobilised in the initial stage. Vermicompost when analysed for different fractions of N, showed that mineral N constituted 20.2 per cent of total N, easily hydrolysable 20 per cent, noneasily hydrolysable 32.4 per cent and non-hydrolysable 32.2 per cent (Kalembasa *et al.*, 1993). Parkin and Berry (1994) found that earthworms were actively involved in the cycling of C and N in soil and earthworm casts are enriched in mineral N. According to Bano and Devi (1996), the N content in vermicompost ranged from 1.4 to 2.17 per cent. Reddy and Mahesh (1995) reported an increased availability of N in soil by the application of vermicompost compared to FYM. Increased availability of N in earthworm casts compared to noningested soil had been reported by several workers (Srinivasarao *et al.*, 1996).

2.3.5.2 Available P

Higher concentration of available P in wormcasts compared with surrounding soil had been reported by Mansell *et al.* (1981), Tiwari *et al.* (1988) and Srinivasarao *et al.* (1996). In a field experiment with sorghum, it was observed that the content of available P increased, in soil with vermicompost application (Sarawad *et al.*, 1996). According to Bijulal (1997) the release of different forms of P viz., Bray extractable P, Fe-P and Al-P from rockphosphate was highest in the presence of vermicompost compared to other organic manures. Soil analysis for available P_2O_5 revealed a significant increase in treatment receiving enriched vermicompost (Sailajakumari, 1999).

2.3.5.3 Available K

Increased concentration of available and exchangeable K content in casts were reported by Lal and Vleeschauwer (1982) and Tiwari *et al.* (1989). Romero and Chamooro (1993) and Srinivasarao *et al.* (1996) have also reported increased availability of K by earthworm activity. Compared to non-ingested soil, different forms of K increased in earthworms casts. Due to selective feeding of earth worms and biological grinding, organically rich substances will be produced. The influence of these material on finer soil particles finally resulted in the increase of the different forms of K.

2.3.5.4 Secondary and Micronutrients Availability

Romero and Chamooro (1993) examined an increased concentration of exchangeable Ca and Mg in the wormcast than in the surrounding soil.

Stephens *et al.* (1994) observed a significant increase in the foliar concentration of elements like Mn, Cu and Fe on introduction of an earthworm species. Vasanthi and Kumaraswamy (1996) reported the highest concentration of micronutrients in the treatment that received vermicompost along with NPK fertilizers compared to NPK alone.

2.3.6 Nature of Vermicompost as a Growth Promoter

Sagaya and Gunathilagaraj (1996) obtained a more germination per centage of amaranthus seeds raised in beds incorporated with earthworms. Curry and Boyle (1987) obtained enhanced plant growth in the presence of earthworms which was attributed to an increased supply of readily available plant nutrients. Kale *et al.* (1987) found that wormcast when used as a manure in place of FYM, significantly influenced vegetative and flowering characters. Shuxin *et al.* (1991) reported 20-25 per cent increase in height and 50 per cent increase in weight of soyabean plants when vermicompost was applied. Higher number of leaves per plant were observed in treatments receiving 100 per cent vermicompost by Govindan *et al.* (1995) in Bhindi and Janaki and Hari (1997) in paddy. Reddy *et al.* (1998) reported superiority in the growth parameters like plant height in gardenpea and cowpea respectively, when applied with vermicompost. Shoot length, fresh and dry weight of plants etc. were higher in treatments in which vermicompost and NPK was applied in chilli (Yadav and Vijayakumari, 2003).

2.3.7 Influence of Vermicompost on Nutrient Uptake by Plants

2.3.7.1 Nitrogen

Kale *et al.* (1992) found significantly higher levels of N uptake by rice plants treated with vermicompost. Application of earthworms increased foliar N concentration of clover by 5-20 per cent (Doube *et al.*, 1994). Stephens *et al.* (1994) found that presence of earthworms caused a significant increase in foliar concentration of N in wheat. Shuxin *et al.* (1991) observed 30-50 per cent increase in N uptake by soyabean due to vermicompost application. Reddy and Mahesh (1995) reported that vermicompost application increased organic carbon and nitrogen uptake in greengram compared to FYM. Sagaya and Gunathilagaraj (1996) noticed more N content in amaranthus plants grown with earthworm application. Pushpa (1996) and Rajalekshmi (1996) reported increased uptake of nutrients and higher yields in tomato and chilli respectively on application of vermicompost.

2.3.7.2 Phosphorus

Kale *et al.* (1992) and Stephens *et al.* (1994) showed significant increase in P uptake by rice plants and wheat plants, respectively, treated with vermicompost. Reddy and Mahesh (1995) reported that vermicompost application increased the P uptake in greengram compared to FYM. Sagaya and Gunathilagaraj (1996) noticed more P content in amaranthus plants grown with earthworm application. Use of vermicompost coated seeds produced the maximum uptake of P at maximum flowering stage and at harvest (Meera, 1998). Plant uptake of major and micro-nutrient were maximum for the highest concentration of vermiwash applied through foliage along with full inorganic fertilizers (Ranijasmine, 1999).

2.3.7.3 Potassium

Zacchariah (1994) reported increased uptake of nutrients by chilli, when treated with *Eudrilus Eugeniae* compost. Sagaya and Gunathilagaraj (1996) noticed more K content in amaranthus plants grown with earthworm cast application. Pushpa (1996) reported increased uptake of K and higher yields in tomato with vermicompost application. According to Sureshkumar (1998) on leaf, vine and tuber analysis of sweet potato, the potassium content was maximum in the treatment receiving full dose of inorganic fertilizer as well as organic fertilizers as vermicompost.

2.3.7.4 Uptake of Secondary and Micronutrients

In Frenchbean, uptake of S was more in soils, which received vermicompost compared to ammonium sulphate and control at harvest. Residual activity of S was higher in vermi compost treated soil at flowering and at harvest (Shivananda *et al.*, 1996). Stephens *et al.* (1994) found that, there was a significant increase in foliar concentration of elements like Mn, Cu and Fe on introduction of earthworm species. Vasanthi and Kumaraswamy (1996) observed highest content of micro-nutrients in the treatment that received vermicompost along with NPK fertilizers compared to NPK alone.

2.3.8 Vermicompost and Crop Yield

Application of worms worked compost resulted in higher yield of paddy crop to the tune of 95 per cent increase in grain and 128 per cent increase in straw and root production (Senapathi *et al.*, 1985). Ushakumari *et al.* (1996) found that Package of Practices with cattle manure as the organic source, vermicompost as organic source along with half the recommended dose of inorganic fertlizers and vermicompost as the sole source of nutrients recorded almost the same yield in Bhindi.

Maximum yield of bhindi due to 100 per cent vermicompost application was documented by Govindan *et al.* (1995). Yadav and Vijayakumari (2003) reported that vermicompost application in chilli brought about significant changes in the maximum number of fruits per plant, fruit weight per plant, single fruit weight, fruit length and fruit diameter. Yield attributes like number of pods per plant, number of seeds per pod, hundred seed weight and total grain yield of cowpea were significantly increased by the application of enriched vermicompost (Sailajakumari, 1998).

2.3.9. Value Addition by Vermicompost

Protein, carbohydrate and crude fibre per centage as well as lycopene content of tomatoes showed a significant increase with vermicompost application (Puspha, 1996).

Ranijasmine (1999) has reported that vermiwash application to tomato produced fruits with more shelf life.

2.3.10 Vermicompost as a Soil Conditioner

Vijayalakshmi (1993) reported that soil aggregation, porocity, soil transmission, conductivity and dispersive power of wormcast fertilized soil was improved as compared with no wormcast amended soil as reflected in the pot experiment of paddy growth. Sarawad *et al.* (1996) indicated that physical properties of vertisol improved with vermicompost as compared to fertilizer application. According to Rajalekshmi (1996), the presence of earthworms in the organic wastes, retained more soil moisture in the field at maximum flowering stage of chilli crop. Bulk density, porocity, water holding capacity and infilteration rate of soil significantly improved with the application of organic manures (Malewar *et al.*, 2000).

Materials and Methods

3. MATERIALS AND METHODS

The investigations on 'Biotic enrichment of organic wastes from Ayurvedic preparations', were conducted at College of Horticulture, Vellanikkara during October, 2002 to August 2003. The study consisted of two parts as mentioned below:

1. Enrichment techniques of the Oushadhi ayurvedic wastes
2. Soil-crop response studies

3.1 ENRICHMENT TECHNIQUES OF ORGANIC WASTES FROM AYURVEDIC PREPARATIONS

3.1.1 Study Material

Materials used for this part of the study was the biowastes obtained from Oushadhi, the Pharmaceutical Corporation (India Medicines), a Government of Kerala undertaking. The manufacturing unit of the company is located at Kuttanalloor, in Thrissur Corporation, Kerala. About one tonne waste is generated per day and the material is having a pleasant smell with number of alkaloids and lipids.

3.1.1.1 Physico-chemical Properties and Biochemical Composition of the Oushadhi Wastes

The physico-chemical and biochemical properties of the substrate was analysed by standard reference methods (Table 3.1, Table 3.2 and Table 3.3).

Table 3.1 Physical properties of the Oushadhi ayurvedic wastes

Property	*Method*	*Reference*
Colour	Physical appearance	Jackson, 1958
Odour	Physical appearance	
Consistency	Using sieves of size 0.5 mm, 1 mm, 2 mm and 4.75 mm	
Moisture content	Gravimetric	

Table 3.2 Chemical properties of Oushadhi ayurvedic wastes

Property	*Method*	*Reference*
pH	1:2.5 suspension	Jackson, 1958
Carbon	Ashing	
N	Microkjeldahl digestion and distillation	
P	Diacid extract – spectro photometry	
K	Diacid extract – flame photometry	

Table 3.3 Biochemical composition of Oushadhi ayurvedic wastes

Property	*Method*	*Reference*
Crude protein	Microkjeldahl digestion and distillation for N and then multiplication by the factor 2.5	Thimmaiah, 1989
Crude lipid	Extraction with ether using soxhlets apparatus and estimation by gravimetry	Thimmaiah, 1989
Crude fibre	Acid-alkali treatment for extraction and estimation by gravimetry	Thimmaiah, 1989
Cellulose	Extraction using acetic-nitric acid mixture and estimation by spectrophotometry	Updegroff, 1969
Lignin	Extraction by 64 per cent H_2SO_4 and estimation by gravimetry	Thimmaiah, 1989

3.1.2 Treatments and Design

3.1.2.1 Type of Substrates

Oushadhi substrate was partitioned into 3 types based on the size (Plate 1, 2 & 3).

i) 4 mm sieved composite samples (O_1)

ii) 2 mm sieved composite samples(O_2)

iii) Unsieved composite samples as obtained from the factory(O_3)

The required cowdung for the enrichment studies was procured from the University Livestock Farm, Mannuthy, where animals were fed with feeds of uniform composition. Another enrichment material in the present study was quail manure collected from the University Poultry Unit, Mannuthy.

3.1.2.2 Levels of Enrichers

i. Cowdung 5 per cent (C_1)

ii. Cowdung 10 per cent (C_2)

iii. Cowdung 15 per cent (C_3)

iv. Quail manure 5 per cent (Q_1)

v. Quail manure 10 per cent (Q_2)

vi. Quail manure 15 per cent (Q_3)

vii. Mixture of cowdung and quail manure 5 per cent (M_1)

viii. Mixture of cowdung and quail manure10 per cent (M_2)

ix. Mixture of cowdung and quail manure 15 per cent (M_3)

3.1.2.3 Biotic Agents

i) *Pleurotus platypus* (P)

ii) Schizophyllus Communae (S)

iii) *Eudrilus eugeniae* (E)

iv) *Eisenia foetida* (I)

v) Native macro and micro organisms as flourishing in open heap control(N)

Plate 1. 4 mm sieved oushadhi substrate used in the present investigation

Plate 2. 2 mm sieved oushadhi substrate used in the present investigation

Plate 3. Unsieved oushadhi substrate used in the

Plate 4. Earthworm – *Eudrilus eugeniae* used in the present investigation

Plate 5. Earthworm – *Eisenia foetida* used in the present investigation

Accordingly, 135 treatment combinations 3 x 9 x 5 were tested and the treatment notations used are given in Appendix 1.

The design used was CRD (Completely Randomized Design) with 135 treatments and three replications.

3.1.3 Enrichment Techniques

Enrichment of Oushadhi substrates as per the above treatments were tried in accordance with the established principle of aerobic composting. The nutrient composition of enrichers are given in Appendix 2.

The biodegradable waste material obtained as such from the factory was sorted by passing through 4 mm and 2 mm sieves to use as substrates. Cowdung, quail manure as well as the mixture of both were added at the rate of 5, 10 and 15 per cent of the substrate.

The selected fungal inoculi namely *Pleurotus platypus* and *Schizophyllus communae* were inoculated @ 25 g of spawn per 5 kg of substrate at the first day of composting.

The earthworms, *Eudrilus eugeniae* and *Eisenia foetida* were introduced @ 25 numbers per 5 kg of substrate after 20 days of precomposting (Plate 4 & 5).

The substrates were mixed as per the different treatment combinations prior to the introduction into 40 cm diameter tanks designed for vermicomposting (Zacchariah, 1994). The moisture content was maintained at 60-70per cent throughout the experimental period by sprinkling required quantity of water. The tanks were protected from sunlight and the contents were thoroughly mixed at alternate days, till the decomposition was completed (Plate 7).

3.1.4 Observations

The variations in temperature were noted using the multichannel temperature recorder at 7.15 am daily during the entire period of composting (Thomas, 2001). The atmospheric temperature was also noted down which is provided in Appendix 3. The pH

Plate 6. The selected enriched compost

Plate 7. The field laboratory for compost enrichment technique

was recorded at fortnightly intervals during the entire period of composting. Qualitative observations on colour, odour, consistency and appearance of the compost were done periodically to judge the maturity of the compost. Number of days required for the completion of the composting process was also recorded. Major nutrients of N, P, K and C content were analysed as per the methods given in table 3.2. for each set of compost material at the initial stage after enrichment and at final stages. C:N ratio of each set of material was also worked out at initial and final stages of composting. Besides, cellulose, lignin, crude fibre, crude lipid and crude protein contents were also found out following the approved procedures provided in table 3.3. for the three types of substrates.

Microbial count at three different stages of composting for thirty selected treatments was indirectly assessed by determining the dehydrogenase enzyme activity. For determination of dehydrogenase activity, the samples were mixed with phosphate buffer containing 1 per cent triphenyl tetrazolium chloride (TTC) and incubated for 15 hours at room temperature. Then it was mixed with 90 per cent carbon tetrachloride and centrifuged at 3000 rpm for 10 minutes. The concentration of triphenyl formazon (TPF) produced by the reduction of TTC was estimated by measuring the intensity of the reddish colour at 530 nm in a spectrophotometer. With reference to the calibration graph prepared from TPF standards, the activity of dehydrogenase was expressed as µg of TPF formed g^{-1} soil h^{-1} (Domsch *et al.*, 1979).

Earthworm counts were taken twice at one month interval in all the 54 treatments in which earthworms were introduced. Regarding the earthworm count, the number of adult earthworms in the five kg substrate of each treatment were recorded. Cocoons and juvenile worms were not included in the earthworm count (Zacchariah, 1994)..

3.1.5 Selection of the Best Compost Material

By monitoring the colour, odour and consistency and thermodynamics at various stages of composting of 135 treatment combinations, the rapidity and maturity of composting of each treatment was arrived at. Based on these factors, the best treatment combination, T_{125} (O_3M_1I) was selected for detailed study and production of compost in concrete tanks of 1 m diameter.

The selected compost (Plate 6) was also analysed for cellulose, lignin, crude fibre, crude protein and crude fat content as explained in table 3.3. As detailed in table 3.1 and table 3.2, the various parameters were examined for the selected enriched compost also.. Common invertebrates (macro-organisms) encountered during mesophilic, thermophilic and maturity stages of composting were observed and recorded down. For collection of invertebrates, grab samples of the compost material were taken from various locations, and then spread on light coloured trays. The organisms were sorted out by using plastic spoons and painting brushes. Flash light and magnifying lenses were used to enhance the observation (Olynciw, 2000).

3.2 SOIL-CROP RESPONSE STUDIES

3.2.1 Site, Soil and Climate

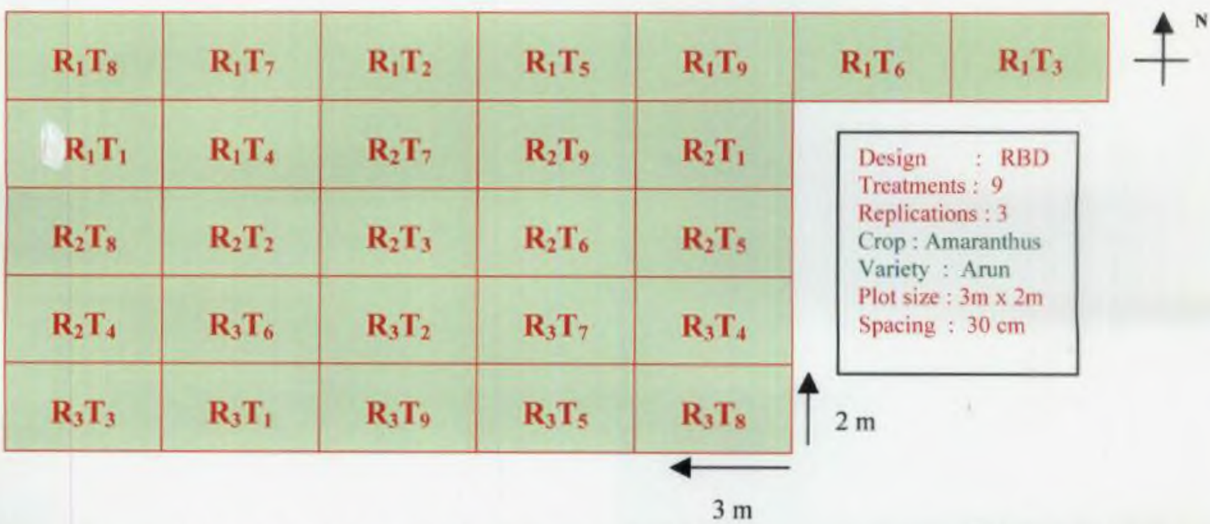
The field experiment was laid out near the vegetable seed farm of Department of Olericulture, College of Horticulture, Vellanikkara (Plate 8). The soil used for the study was of laterite type of order oxisol, belonging to Vellanikkara series. During the period of study from March to May 2003, the temperature varied from a mean maximum of 34.6°C to a mean minimum of 25°C. The total number of rainy days during the period were six.

3.2.2 Crop, Layout, Treatments and Design

A gross area of 162 m^2 was selected for field study with the crop amaranthus (*Amaranthus tricolor* L.) and the land was thoroughly ploughed and shallow trenches of width 40 cm were taken 30 cm apart, in which 20 days old seedlings were transplanted. The layout of the field and the treatment details are provided in figure 1.

3.2.3 Nutrient Management of the Crop

The entire quantity of compost and FYM were given as basal as per the treatments. The fertilizers such as urea, rockphosphate and muriate of potash were used as the inorganic sources for N, P and K. Nutrient contents of the organic and inorganic sources used for field studies are provided in Appendix 2. The entire quantity of P and



T_1 - Absolute control without any manures and fertilizers
T_2 - 5 t ha^{-1} FYM
T_3 - 5 t ha^{-1} FYM + 50:50:50 kg NPK ha^{-1}.
T_4 - 5 t ha^{-1} SEC
T_5 - 5 t ha^{-1} SEC + 50:50:50 kg NPK ha^{-1}.
T_6 - 5 t ha^{-1} SEC + 25:25:25 kg NPK ha^{-1}.
T_7 - 2.5 t ha^{-1} SEC
T_8 - 2.5 t ha^{-1} SEC + 50:50:50 kg NPK ha^{-1}.
T_9 - 2.5 t ha^{-1} SEC + 25:25:25 kg NPK ha^{-1}.
SEC - Selected Enriched Compost FYM – Farm Yard Manure

R_1 - Replication 1
R_2 - Replication 2
R_3 - Replication 3

Fig.1. Layout plan of the field experiment

half of N and K were given as basal. The remaining half of N and K were applied after first harvest.

3.2.4 Observations

3.2.4.1 Growth and Yield Parameters

Biometric observations such as height of the plant and number of leaves per plant were noted at two stages of growth ie., 15 days after planting and 30 days after planting. Yield per plot was recorded for the first harvest ,15 days after planting and second harvest, 30 days after planting.

3.2.4.2 Crop Uptake of NPK at Harvest

N, P and K content of the plant were analysed by following the standard procedure as described in table 3.2.

3.2.4.3 Physico-chemical Properties of the Pre and Post Treated Soil

pH, organic carbon, CEC of the soil and available N, P and K were determined following the standard procedure as described in table 3.4.

Table 3.4 Methods used for soil analysis

Sl. No.	*Soil Analysis*	*Method*	*Reference*
1	pH	1 : 2.5 soil water suspension	Jackson, 1958
2	Organic carbon	Walkley and Black titration	Walkley and Black, 1934
3	Available N	Alkaline permanganate distillation	Subbaiah and Asija, 1956
4	Available P	Bray 1 extractant – ascorbic acid reductant – spectrophotometry	Bray and Kurtz, 1945
5	Available K	Neutral normal ammonium acetate – Flame photometry	Jackson, 1958

3.3 STATISTICAL ANALYSIS

Data generated were compiled, tabulated and analysed by applying the analysis of variance technique (Panse and Sukhatme, 1985). Wherever 'F' tests were significant, appropriate critical differences were calculated to test the level of significance among treatment means and treatment means were ranked accordingly. Treatment means in a column with the same superscript do not differ significantly.

Results

4. RESULTS

4.1 ENRICHMENT TECHNIQUES OF OUSHADHI WASTES

4.1.1 Basic Properties of Oushadhi Ayurvedic Wastes

Being a new material, the physico-chemical properties as well as the chemical composition of oushadhi wastes were studied in composite samples. The details are provided in Table 4.1 and 4.2.

4.1.1.1 Physio-chemical Properties and Biochemical Constituents of the wastes

The Oushadhi ayurvedic waste is light to deep brown in colour with a pleasant smell due to the presence of alkaloids and lipids. It seemed to be of fibrous nature, and was oily too. The waste material was neutral in reaction. The moisture content was around 50 per cent , with the unsieved samples recording the highest value of 52 per cent . Consistency of the three substrates varied, but in all the three, the particle size distribution was such that the final particles, ie., < 0.5 mm size dominated with values 32 per cent, 38.2 per cent and 28.4 per cent for 4 mm, 2 mm and unsieved substrates respectively. In unsieved substrates the particles greater than 4.75 mm size was recorded in higher proportion (27.63 per cent).

The chemical analysis revealed that the oushadhi ayurvedic waste is a neutral (pH of 6.62 to 6.72) material with high amounts of carbon ranging from 77.3 per cent (O_3) to 78.8 per cent (O_2). The contents of N, P and K were more in 2 mm sieved samples compared to 4 mm and unsieved, registering values of 2.3 per cent , 0.35 per cent and 0.88 per cent respectively. The C:N ratio of the material was 31.81, 30.78 and 30.66 for unseived, 4 mm and 2 mm sieved samples respectively. Regarding the crude protein content, it was maximum in 2 mm sieved substrates with a value of 14.38 per cent while it was minimum in unsieved samples with a value of 12.68 per cent . Crude fibre values ranged from 33.4 per cent to 30.8 per cent with the highest value for unsieved and the lowest value for 2 mm sieved. With respect to crude lipid, the unsieved substrates registered the maximum crude lipid content of 6.3 per cent and the minimum crude lipid of 5.8 per cent was recorded in 2 mm sieved substrates. The maximum cellulose and

Table 4.1. Physico-chemical properties of Oushadhi Ayurvedic wastes

Property	Values		
	4 mm sieved (O_1)	2 mm sieved (O_2)	Unsieved (O_3)
Percentage distribution of particles			
< 0.5 mm	32.0	38.2	28.40
0.5 to 1 mm	28.0	33.1	13.13
1 to 2 mm	24.3	29.0	12.60
2 to 4.75 mm	15.7	-	18.20
> 4.75 mm	-	-	27.63
Moisture content (%)	50.3	49.7	52.00
Odour	Pleasant aromatic	Pleasant aromatic	Pleasant aromatic
Colour	Deep brown	Deep brown	Light to deep brown
pH	6.68	6.62	6.72
C:N ratio	30.78	30.66	31.81

Table 4.2. Chemical composition and biochemical constituents of the Oushadhi ayurvedic wastes

Property	Values (%)		
	4 mm sieved (O_1)	2 mm sieved (O_2)	Unsieved (O_3)
Carbon	78.20	78.80	77.30
Nitrogen	2.17	2.30	2.03
Phosphorus	0.35	0.35	0.33
Potassium	0.87	0.88	0.85
Crude protein	13.56	14.38	12.68
Crude fibre	31.20	30.80	33.40
Crude lipid	6.15	5.80	6.30
Cellulose	34.20	33.70	35.70
Lignin	33.40	31.20	37.90

lignin contents of 35.7 per cent and 37.9 per cent respectively were noted in unsieved substrates while the corresponding minimum values were noted in 2 mm sieved substrates.

4.1.2 Temperature

The variations in temperature as influenced by the different kinds of substrates, substrate enrichers and biotic agents were pooled at 10 days interval for a period of 60 days and are given in Table 4.3. Temperature variations at 10 days interval for a total of 60 days as influenced by substrate-substrate enricher interaction and substrate enricher-biotic agent interaction are provided in Table 4.4 and Table 4.5, respectively.

In general, irrespective of the treatment differences the temperature was found to be high during the 10^{th} day and low during 60^{th} day of composting. On consideration of the influence of substrates on the temperature variations at 10 days interval for a period of 60 days, it can be seen that 2 mm sieved substrates (O_2)recorded the highest temperature during all the days, while the unsieved substrates (O_3), recorded the lowest values of temperature at all days for which temperature was noted (Table 4.3). The maximum temperature of 39.40°C was observed at 10^{th} day in O_2 and the minimum temperature of 36.20°C was noted at 10^{th} day in O_3. Significant differences in temperature were noticed between the treatments at all intervals.

With reference to the effect of various substrate enrichers, irrespective of the enrichment techniques, the temperature raised from the day of composting to the 10^{th} day and then gradually decreased to stable values by 60^{th} day. Generally, the maximum value of temperature was recorded in quail manure enriched treatments (Q) especially during the initial and middle stages of composting. Of the maximum temperatures recorded at 10^{th} day, the highest maximum temperature was noted as 38.40°C in Q_2.

Generally, the lowest temperatures recorded during the various intervals were in cowdung-quail manure mixture (M). However the lowest minimum temperature value was 27.00°C, recorded at 60^{th} day in M_3 and M_1. Another important observation was that during the middle stages, ie. 30^{th} and 40^{th} days of composting, no significant temperature variations were recorded between the different substrate enrichers.

Table 4.3. Influence of substrates, substrate enrichers and biotic agents on the temperature at 10 days intervals of composting

Treatments	Temperature (°C)						
	0th day	10th day	20th day	30th day	40th day	50th day	60th day
Substrates							
O_1	28.6[b]	38.8[b]	33.8[b]	30.8[b]	29.6[b]	28.7[b]	27.2[b]
O_2	30.0[a]	39.4[a]	34.0[a]	31.3[a]	30.5[a]	29.3[a]	27.3[a]
O_3	26.9[c]	36.2[c]	33.0[c]	30.2[c]	29.3[c]	28.2[c]	27.0[c]
Substrate enrichers							
C_1	28.4[b]	38.2[ab]	34.1[a]	30.7[cd]	29.9[b]	28.9[a]	27.3[a]
C_2	28.2[b]	38.0[ab]	34.0[b]	30.7[d]	29.8[c]	28.6[d]	27.3[a]
C_3	28.3[b]	38.2[ab]	33.7[cd]	30.7[d]	29.8[c]	28.7[cd]	27.1[dc]
Q_1	28.5[ab]	38.2[ab]	33.6[cd]	31.0[a]	29.9[b]	28.7[bc]	27.2[b]
Q_2	28.6[ab]	38.4[a]	33.6[cd]	30.9[b]	29.8[c]	28.7[c]	27.1[bcd]
Q_3	29.0[a]	38.3[a]	33.7[c]	30.6[c]	29.6[d]	28.7[b]	27.1[cde]
M_1	28.5[ab]	37.5[b]	33.3[e]	30.7[d]	29.8[c]	28.6[cd]	27.0[e]
M_2	28.6[ab]	38.2[ab]	33.0[f]	30.7[c]	30.0[a]	28.5[e]	27.1[bc]
M_3	28.3[b]	38.1[ab]	31.5[d]	30.7[d]	29.8[c]	28.8[a]	27.0[e]
Biotic agents							
N	28.5[a]	37.9[b]	33.6[b]	30.8[b]	29.9[a]	28.7[c]	27.1[b]
S	28.1[b]	37.9[b]	33.5[bc]	30.9[a]	29.8[a]	28.7[c]	27.2[a]
P	28.5[a]	37.8[b]	33.5[c]	30.9[ab]	29.8[b]	28.8[a]	27.2[b]
E	28.7[a]	38.3[b]	33.9[a]	30.7[c]	29.8[bc]	28.7[b]	27.1[c]
I	28.7[a]	38.9[a]	33.6[b]	30.5[d]	29.7[c]	28.7[bc]	27.1[b]

Table 4.4. Influence of substrate-substrate enricher interaction on temperature at 10 days intervals of composting

Treatments	Temperature (°C)						
	0th day	10th day	20th day	30th day	40th day	50th day	60th day
O_1C_1	28.3^{fg}	38.4^{cde}	34.1^{bc}	30.8f^{g}	29.8^{f}	28.8^{f}	27.5^{ab}
O_1C_2	28.4^{efg}	38.2^{de}	33.9^{cd}	30.8^{gh}	29.6^{g}	28.6^{hi}	27.3^{de}
O_1C_3	28.2^{fg}	38.5^{bcde}	34.1^{cd}	30.8^{fg}	29.6^{g}	28.6^{gh}	27.3^{de}
O_1Q_1	29.0^{def}	39.1^{abcd}	33.5^{e}	31.3^{d}	30.0^{def}	28.6^{hi}	27.1^{f}
O_1Q_2	28.9^{def}	39.2^{abcd}	33.4^{e}	30.6^{ij}	29.2^{ij}	28.4^{j}	26.9^{hi}
O_1Q_3	28.9^{def}	39.1^{abcd}	33.9^{cd}	31.1^{e}	29.6^{g}	28.7^{fg}	27.1^{fg}
O_1M_1	28.7^{def}	38.6^{abcd}	33.4^{e}	30.7^{hij}	29.6^{g}	28.7^{gh}	27.1^{fg}
O_1M_2	29.1^{de}	39.1^{abcd}	33.4^{e}	30.7^{hi}	30.0^{de}	29.0^{d}	27.0^{ghi}
O_1M_3	27.7^{gh}	39.3^{abcd}	34.5^{a}	30.6^{jk}	29.3^{h}	28.6^{gh}	27.1^{f}
O_2C_1	29.3^{cd}	38.9^{abcd}	34.4^{ab}	30.9^{f}	30.0^{d}	29.1^{d}	27.5^{ab}
O_2C_2	29.2^{cde}	29.5^{abcd}	33.9^{cd}	31.3^{d}	30.2^{c}	28.8^{f}	27.4^{cd}
O_2C_3	30.0^{abc}	39.9^{ab}	34.0^{cd}	31.5^{bc}	30.4^{b}	29.4^{c}	27.1^{fg}
O_2Q_1	30.0^{bc}	39.4^{abcd}	34.5^{a}	31.6^{ab}	30.4^{b}	29.3^{c}	27.4^{bc}
O_2Q_2	30.0^{bc}	39.9^{a}	34.0^{cd}	31.5^{e}	30.8^{a}	29.6^{b}	27.6^{a}
O_2Q_3	30.6^{ab}	39.6^{abc}	33.9^{cd}	31.1^{e}	30.4^{a}	29.7^{ab}	27.1^{fg}
O_2M_1	30.4^{ab}	38.2^{dc}	34.0^{cd}	31.0^{e}	30.2^{c}	29.1^{d}	27.1^{fg}
O_2M_2	29.5^{cd}	39.6^{abc}	33.8^{cd}	31.4^{d}	30.8^{a}	28.9^{e}	27.5^{abc}
O_2M_3	30.8^{a}	39.6^{abcd}	34.0^{cd}	31.7^{a}	30.8^{a}	29.7^{a}	27.1^{f}
O_3C_1	27.7^{gh}	37.3^{ef}	33.9^{cd}	30.5^{k}	29.9^{ef}	28.8^{ef}	26.9^{hi}
O_3C_2	26.9^{ij}	36.2^{fg}	34.1^{cd}	30.0^{m}	29.6^{ej}	28.5^{ij}	27.2^{e}
O_3C_3	26.6^{j}	36.3^{fg}	32.9^{f}	29.8^{no}	29.3^{hi}	28.0^{n}	26.8^{i}
O_3Q_1	26.6^{j}	36.2^{fg}	32.9^{f}	30.1^{m}	29.2^{ij}	28.2^{k}	27.1^{fg}
O_3Q_2	26.9^{ij}	36.2^{fg}	33.5^{e}	30.5^{jk}	29.3^{hi}	28.0^{mn}	26.9^{hi}
O_3Q_3	27.4^{hi}	36.3^{fg}	33.5^{e}	29.7^{o}	28.8^{k}	27.9^{o}	27.1^{fg}
O_3M_1	26.6^{j}	35.8^{g}	32.4^{g}	30.5^{k}	29.6^{g}	28.1^{lm}	27.0^{fgh}
O_3M_2	27.3^{hij}	35.9^{g}	21.9^{h}	30.3^{d}	29.2^{j}	27.7^{p}	27.0^{fgh}
O_3M_3	26.6^{j}	35.6^{g}	32.2^{gh}	29.9^{n}	29.2^{ij}	28.2^{kl}	26.9^{hi}

Table 4.5. Influence of substrate enrichers - biotic agent interaction on temperature at 10 days interval of composting

Treatments	Temperature (°C)						
	0th day	10th day	20th day	30th day	40th day	50th day	60th day
C_1N	28.1	38.2	34.6	30.6	30.2	28.8	27.2
C_1S	28.1	38.0	34.1	31.2	30.2	29.3	27.5
C_1P	28.0	36.9	33.7	30.5	29.8	28.9	27.1
C_1E	28.7	38.9	34.5	30.9	29.6	28.7	27.2
C_1I	28.6	38.8	33.6	30.5	29.8	28.7	27.5
C_2N	27.2	37.3	33.8	30.5	29.8	28.5	27.0
C_2S	28.2	37.5	33.9	31.1	29.8	28.6	27.3
C_2P	28.6	37.9	33.7	30.7	29.7	28.7	27.5
C_2E	28.7	38.3	34.5	30.7	29.9	28.6	27.2
C_2I	28.3	38.9	33.9	30.5	29.7	28.7	27.5
C_3N	28.4	38.1	33.9	30.6	29.7	28.6	27.2
C_3S	27.8	37.8	33.6	31.0	30.1	29.1	27.3
C_3P	28.5	38.2	33.4	31.3	29.5	28.4	26.4
C_3E	28.5	38.5	33.9	30.4	29.6	28.5	26.9
C_3I	28.1	38.5	33.4	30.2	29.9	28.7	27.5
Q_1N	28.2	37.9	33.7	30.9	29.5	28.3	27.1
Q_1S	28.4	37.9	33.7	30.7	29.8	28.6	27.5
Q_1P	28.7	37.6	33.3	31.6	30.1	29.0	27.3
Q_1E	28.8	38.6	33.3	31.0	29.9	28.7	26.8
Q_1I	28.5	39.1	34.2	30.8	30.0	28.9	27.2
Q_2N	28.7	38.2	33.2	30.8	29.9	29.0	27.3
Q_2S	28.9	38.2	33.7	31.1	29.6	28.4	27.1
Q_2P	28.5	37.9	33.2	31.1	29.7	28.5	27.1

Table 4.5. contd........

Treatments	Temperature (°C)						
	0^{th} day	10^{th} day	20^{th} day	30^{th} day	40^{th} day	50^{th} day	60^{th} day
Q_2E	27.9	38.7	34.0	30.7	29.9	29.0	27.3
Q_2I	28.7	39.2	33.9	30.7	29.8	28.6	26.7
Q_3N	29.0	37.9	34.0	31.0	29.8	28.6	26.9
Q_3S	28.8	38.1	33.4	30.6	29.6	28.7	27.0
Q_3P	28.6	38.1	33.7	30.6	29.6	28.9	27.3
Q_3E	29.2	38.8	34.3	30.8	29.6	28.8	27.3
Q_3I	29.2	38.9	33.4	30.3	29.3	28.6	26.9
M_1N	29.2	37.7	32.9	31.0	29.6	28.7	27.2
M_1S	27.9	37.6	33.1	31.0	29.8	28.3	26.9
M_1P	27.6	37.9	33.1	30.7	30.3	29.1	27.2
M_1E	28.9	35.3	33.5	30.4	29.7	28.7	27.0
M_1I	29.2	39.0	33.7	30.4	29.5	28.4	26.8
M_2N	28.3	38.0	33.0	30.9	30.1	28.6	27.5
M_2S	28.4	37.7	32.6	30.7	29.9	28.4	27.2
M_2P	29.0	37.5	33.1	30.5	29.7	28.6	26.7
M_2E	28.4	38.7	33.2	30.7	30.1	28.5	27.1
M_2I	29.1	39.1	33.2	31.1	30.0	28.6	27.2
M_3N	28.9	38.0	33.4	31.2	30.3	28.8	26.7
M_3S	26.5	37.9	33.6	30.6	29.7	28.5	27.3
M_3P	28.7	37.8	33.8	30.9	29.7	28.9	27.8
M_3E	28.8	38.5	33.5	30.6	29.6	29.0.	26.6
M_3I	28.9	38.5	33.3	30.3	29.5	29.0	26.8
CD (0.05)	0.9178	1.451	0.3435	0.1377	0.1408	0.1345	0.1497

With reference to the influence of biotic agents on the temperature variations during composting, all of them recorded the maximum values at 10^{th} day, in the descending order of I (38.90°C), E (38.30°), N&S (37.90°C) and P (37.80°C). Barring *Eisenia foetida* introduced treatments, all the others were on par. The lowest values of temperature were noted at 60^{th} day by all the biotic agents in the order S&P (27.20°C) and N, E & I (27.10°C).

On consideration of the substrate-substrate enricher interaction (Table 4.4), it was seen that irrespective of the treatment differences the highest temperature was noted during the 10^{th} day and the least temperature during the 60^{th} day indicating compost maturity. The significant observation was that during most of the periods the quail manure enriched 2 mm sieved substrate (O_2Q) showed the maximum temperature, while the cowdung quail manure mixture enriched unsieved substrates (O_3M) registered the minimum temperature. Among the treatment combinations, the maximum temperature value at the 10^{th} day, was observed in O_2Q_2 with a value of 39.90°C while the minimum temperature was observed in O_3M_3 with a value of 35.60°C.

With respect to the interactive influence of substrate enrichers and biotic agents (Table 4.5), the temperature seemed to increase from the 0^{th} day, reaching a peak value at 10^{th} day and then decreasing, and finally reaching a stabilised value. At 10^{th} day, the maximum temperature of 39.20°C was observed in Q_2I, while the lowest value of 35.30°C was observed in M_1E. During 30^{th} and 40^{th} day, the lowest temperature was recorded in *Eisenia foetida* introduced treatments, ie., in C_3I and Q_3I respectively.

4.1.3 pH

The changes in pH at fortnightly intervals as influenced by the different kinds of substrates, substrate enrichers and biotic agents are given in Table 4.6. The two factor interactions of substrate – substrate enrichers and substrate enricher – biotic agents are provided in Table 4.7 and Table 4.8 respectively.

In general, irrespective of the treatments the pH at first increased during the first and second fortnights then decreased and later stabilised at final stages of composting. Considering the influence of substrates on the values of pH (Table 4.6), it was seen that

Table 4.6. Influence of substrates, substrate enrichers and biotic agents on pH at fortnightly intervals of composting

Treatments	pH				
	0^{th} day	15^{th} day	30^{th} day	45^{th} day	60^{th} day
Substrates					
O_1	6.87^{a}	7.94^{a}	7.97^{a}	7.09^{b}	6.31^{c}
O_2	6.80^{c}	7.94^{ab}	7.95^{b}	7.10^{b}	6.40^{b}
O_3	6.84^{b}	7.92^{b}	7.93^{c}	7.12^{a}	6.49^{a}
Substrate enrichers					
C_1	6.86^{ab}	7.93^{abcd}	7.93^{a}	7.13^{ab}	6.40^{bcd}
C_2	6.80^{e}	7.93^{abcd}	7.96^{a}	7.12^{bc}	6.37^{cd}
C_3	6.79^{e}	7.90^{d}	7.95^{a}	7.09^{cd}	6.39^{bc}
Q_1	6.83^{cd}	7.96^{a}	7.94^{a}	7.09^{cd}	6.36^{d}
Q_2	6.84^{bc}	7.95^{abc}	7.95^{a}	7.08^{cd}	6.41^{b}
Q_3	6.81^{ac}	7.94^{abc}	7.96^{a}	7.07^{d}	6.37^{d}
M_1	6.88^{a}	7.92^{cd}	7.96^{a}	7.13^{a}	6.40^{b}
M_2	6.87^{ab}	7.96^{ab}	7.94^{a}	7.13^{ab}	6.52^{a}
M_3	6.84^{bc}	7.92^{bcd}	7.97^{a}	7.10^{c}	6.40^{b}
Biotic agents					
N	6.79^{c}	7.89^{b}	7.92^{b}	7.08^{b}	6.35^{c}
S	6.80^{c}	7.91^{b}	7.96^{a}	7.07^{b}	6.37^{b}
P	6.79^{c}	7.91^{b}	7.95^{a}	7.08^{b}	6.38^{b}
E	6.87^{b}	7.97^{a}	7.95^{a}	7.14^{a}	6.45^{a}
I	6.92^{a}	7.99^{a}	7.98^{a}	7.13^{a}	6.45^{a}

Table 4.7. Influence of substrate-substrate enrichers interaction on pH at different fortnightly intervals of composting

Treatments	pH				
	0^{th} day	15^{th} day	30^{th} day	45^{th} day	60^{th} day
O_1C_1	6.92^{ab}	7.94^{abcd}	7.92^{bcd}	7.18^{ab}	6.40^{fgh}
O_1C_2	6.82^{fgh}	7.92^{cde}	7.97^{abcd}	7.14^{bcd}	6.40^{fgh}
O_1C_3	6.69^{l}	7.84^{f}	7.95^{bcd}	7.06^{fg}	6.35^{ijk}
O_1Q_1	6.91^{ab}	7.96^{abcd}	7.97^{abcd}	7.09^{def}	6.36^{hijk}
O_1Q_2	6.91^{abc}	7.99^{abc}	7.99^{ab}	7.09^{efg}	6.34^{jkl}
O_1Q_3	6.89^{bcd}	7.97^{abcd}	8.02^{a}	7.04^{g}	6.23^{o}
O_1M_1	6.87^{cdef}	7.90^{def}	7.99^{abcd}	7.07^{efg}	6.28^{n}
O_1M_2	6.91^{abc}	8.00^{a}	7.97^{abcd}	7.08^{efg}	6.22^{o}
O_1M_3	6.87^{cdef}	7.98^{abc}	7.99^{ab}	7.07^{efg}	6.24^{o}
O_2C_1	6.88^{bcde}	7.94^{abcd}	7.96^{abcd}	7.10^{def}	6.33^{klm}
O_2C_2	6.86^{defg}	7.94^{abcd}	7.95^{bcd}	7.06^{fg}	6.30^{mn}
O_2C_3	6.78^{hij}	7.93^{bcd}	7.95^{bcd}	7.07^{efg}	6.30^{lmn}
O_2Q_1	6.74^{jk}	7.99^{ab}	7.95^{bcd}	7.07^{efg}	6.39^{fghi}
O_2Q_2	6.77^{j}	7.99^{abc}	7.97^{abcd}	7.08^{efg}	6.40^{fgh}
O_2Q_3	6.77^{jk}	7.94^{abcd}	7.96^{abcd}	7.05^{g}	6.40^{fgh}
O_2M_1	6.82^{ghi}	7.93^{bcde}	7.94^{bcd}	7.19^{a}	6.38^{ghij}
O_2M_2	6.84^{efg}	7.92^{bcde}	7.94^{bcd}	7.17^{ab}	6.63^{b}
O_2M_3	6.77^{j}	7.84^{f}	7.95^{bcd}	7.08^{efg}	6.48^{de}
O_3C_1	6.78^{hij}	7.90^{def}	7.92^{cd}	7.10^{def}	6.43^{f}
O_3C_2	6.73^{kl}	7.92^{cde}	7.97^{abcd}	7.11^{cde}	6.42^{g}
O_3C_3	6.89^{bcd}	7.93^{abcd}	7.95^{bcd}	7.15^{abc}	6.52^{cd}
O_3Q_1	6.83^{fg}	7.92^{bcde}	7.91^{d}	7.09^{efg}	6.33^{klm}
O_3Q_2	6.85^{defg}	7.86^{ef}	7.91^{d}	7.08^{efg}	6.49^{de}
O_3Q_3	6.78^{ij}	7.92^{cde}	7.91^{d}	7.11^{cde}	6.47^{e}
O_3M_1	6.95^{a}	7.93^{abcd}	7.95^{abcd}	7.14^{bcd}	6.54^{c}
O_3M_2	6.85^{defg}	7.95^{abcd}	7.91^{cd}	7.14^{bcd}	6.72^{a}
O_3M_3	6.89^{bcd}	7.93^{abcd}	7.96^{abcd}	7.14^{bcd}	6.48^{de}

Table 4.8. Influence of substrate enrichers-biotic agents interaction on pH at fortnightly intervals of composting

Treatments	pH				
	0^{th} day	15^{th} day	30^{th} day	45^{th} day	60^{th} day
C_1N	6.84	7.90	7.82	7.07	6.38
C_1S	6.83	7.87	7.97	7.11	6.43
C_1P	6.84	7.92	7.96	7.11	6.34
C_1E	6.86	7.95	7.94	7.16	6.42
C_1I	6.94	7.99	7.98	7.18	6.34
C_2N	6.70	7.92	7.95	7.13	6.30
C_2S	6.79	7.85	7.96	7.06	6.38
C_2P	6.74	7.88	7.92	7.11	6.33
C_2E	6.84	7.96	7.99	7.13	6.37
C_2I	6.94	8.01	7.99	7.08	6.49
C_3N	6.80	7.82	7.92	7.06	6.39
C_3S	6.75	7.81	7.92	7.03	6.33
C_3P	6.71	7.90	7.94	7.06	6.35
C_3E	6.85	7.98	7.99	7.14	6.49
C_3I	6.82	7.99	7.95	7.18	6.40
Q_1N	6.81	7.96	7.95	7.05	6.34
Q_1S	6.76	8.00	7.96	7.08	6.36
Q_1P	6.75	7.93	7.96	7.09	6.38
Q_1E	6.88	7.97	7.92	7.11	6.35
Q_1I	6.95	7.95	7.93	7.10	6.38
Q_2N	6.79	7.96	7.95	7.08	6.39
Q_2S	6.77	7.85	7.90	7.03	6.36
Q_2P	6.83	7.96	7.99	7.10	6.37

Table 4.8. contd....

Treatments	pH				
	0^{th} day	15^{th} day	30^{th} day	45^{th} day	60^{th} day
Q_2E	6.89	7.95	7.94	7.13	6.43
Q_2I	6.94	8.01	8.00	7.08	6.50
Q_3N	6.70	7.93	7.96	7.01	6.31
Q_3S	6.77	7.96	7.96	7.05	6.36
Q_3P	6.83	7.87	7.96	7.05	6.40
Q_3E	6.84	7.97	7.92	7.10	6.39
Q_3I	6.91	7.99	8.01	7.12	6.38
M_1N	6.84	7.84	7.93	7.08	6.27
M_1S	6.86	7.96	8.03	7.11	6.35
M_1P	6.83	7.84	7.91	7.04	6.35
M_1E	6.92	7.95	7.93	7.20	6.52
M_1I	6.93	8.00	7.99	7.24	6.50
M_2N	6.82	7.91	7.92	7.13	6.48
M_2S	6.87	7.93	7.93	7.12	6.48
M_2P	6.82	7.96	7.94	7.08	6.55
M_2E	6.91	8.01	7.97	7.17	6.59
M_2I	6.90	7.99	7.93	7.14	6.52
M_3N	6.85	7.78	7.89	7.12	6.34
M_3S	6.83	7.93	7.98	7.04	6.32
M_3P	6.74	7.93	8.00	7.12	6.34
M_3E	6.87	7.98	7.99	7.11	6.51
M_3I	6.93	7.98	7.99	7.09	6.49
CD (0.05)	0.05083	0.07765	0.07189	0.05083	0.0508

during the first and second fortnights, the highest values of pH were in 4 mm sieved substrates, while at later stages of composting ie., at 45th and 60th days, higher values of 7.12 and 6.49 respectively were in unsieved substrates. The pH values ranged from 7.97 to 6.31 at first and fourth fortnight respectively.

In the case of influence of various substrate enrichers on the pH, the same trend of registering the peak values of pH at second fortnight and the lowest values at 4th fortnight was seen. With respect to various enrichers, the highest pH was observed during the 30th day, and the values were on par for all of them. The lowest pH for all the enrichers were observed during the 60th day with values ranging from a maximum of 6.52 to a minimum of 6.36.

Regarding the influence of biotic agents, the maximum pH was observed during the second fortnight with values ranging from 7.98 to 7.92. However, during all stages, the earthworm introduced treatments registered a higher pH compared to others.

On perusal of substrate-substrate enricher interaction (Table 4.7) on the pH values, it was seen that during Oth and 15th day, the lowest pH was noted in O_1C_3 with values 6.69 and 7.84 respectively. At 30th day, maximum pH of 8.02 was recorded in O_1Q_3 while the lowest value of 7.91 was recorded in quail manure enriched unsieved substrates (O_3Q_1, O_3Q_2, O_3Q_3 and O_3M_2). During 45th day pH values showed a decrease with a maximum of 7.19 in O_2M_1 and a minimum of 7.04 in O_1Q_3. By 60th day, the pH values decreased to a minimum of 6.22 in O_1M_2 and a maximum of 6.72 in O_3M_2.

On consideration of the interactive influence of substrate enrichers and biotic agents (Table 4.8), it was seen at 0th, 15th and 45th days, maximum pH was noted in Q_1I, C_2I and M_1I respectively. Here also, a definite trend with maximum pH values at second fortnight with the highest value of 8.03 in M_1S and the lowest value of 7.82 in C_1N were observed. Later on, the pH values stabilised around 6.59 to 6.27 in M_2E and M_1N respectively by the 60th day of composting.

4.1.4 Dehydrogenase Activity

The effect of the substrates, substrate enrichers and biotic agents on the dehydrogenase activity at the three stages of composting viz., mesophilic, thermophilic and maturity stages are provided in Table 4.9. Effect of substrate and substrate enricher interaction as well as substrate enricher and biotic agents interaction at three stages of composting are given in Table 4.10 and Table 4.11 respectively.

In general, maximum dehydrogenase activity was observed, during the thermophilic stage. It decreased towards the maturity phase. However the lowest dehydrogenase activity was observed during mesophilic stage of composting.

With respect to the substrates (Table 4.9) , the 2 mm sieved substrates recorded the highest dehydrogenase activity compared to the unsieved substrates at all the stages.

On considering the effect due to substrate enrichers during the mesophilic stage as well as the maturity stage, 10 per cent quail manure enriched treatments (Q_2) showed the highest dehydrogenase activity of 913.7 $\mu g\ g^{-1}$ soil h^{-1}. In both the above mentioned stages, the lowest values were recorded in 10 per cent cowdung enriched treatments (C_2). However, during the thermophilic stage, the highest dehydrogenase activity was 3108 $\mu g\ g^{-1}$ soil h^{-1} and the lowest value was 2778 $\mu g\ g^{-1}$ soil h^{-1} recorded in Q_2 and M_2 respectively.

In the case of influence of biotic agents on the dehydrogenase activity, there was no significant variations. During the mesophilic and the thermophilic stages, the maximum dehydrogenase activity was measured in *Pleurotus platypus* introduced treatments. During the maturity stage, the highest value of 2112 $\mu g\ g^{-1}$ soil h^{-1} was recorded in *Eisenia foetida* introduced treatments.

Considering the substrate-substrate enricher interaction, in all the three stages of composting, mesophilic, thermophilic and maturity (O_2Q_2) recorded the highest dehydrogenase activity with values 998.7, 3161 and 2218 $\mu g\ g^{-1}$ soil h^{-1} respectively (Table 4.10). At mesophilic and maturity stages the unsieved substrate enriched with 10 per cent cowdung (O_3C_2) recorded the lowest values of 703.1 and 1739 $\mu g\ g^{-1}$ soil h^{-1}

Table 4.9. Influence of substrates, substrate enrichers and biotic agents on the dehydrogenase activity (μg TPF g^{-1} soil h^{-1}) at three different stages of composting

Treatments		Mesophilic	Thermophilic	Maturity
Substrates	O_2	968.2[a]	3119.3[a]	2123.3[a]
	O_3	780.8[b]	2808.6[b]	1900.4[b]
Substrate enrichers	C_2	822.5[c]	3006.0[b]	1883.0[c]
	Q_2	913.7[a]	3108.0[a]	2132.0[a]
	M_2	887.6[b]	2778.0[c]	2019.0[b]
Biotic agents	N	897.7[b]	2784.0[d]	1808.0[e]
	S	862.5[c]	2906.0[c]	1975.0[d]
	P	939.2[a]	3113.0[a]	2067.0[c]
	E	810.6[d]	3013.0[b]	2096.0[b]
	I	862.9[c]	3004.0[b]	2112.0[a]

Table 4.10. Influence of substrate - substrate enrichers interactions on the dehydrogenase activity (μg TPF g^{-1} soil h^{-1}) at three different stages of composting

Treatments	Mesophilic	Thermophilic	Maturity
O_2C_2	941.8[c]	3120.0[ab]	2028.0[d]
O_2Q_2	998.7[a]	3161.0[a]	2218.0[a]
O_2M_2	964.3[b]	3077.0[b]	2124.0[b]
O_3C_2	703.1[f]	2893.0[c]	1739.0[f]
O_3Q_2	828.7[d]	3054.0[b]	2046.0[c]
O_3M_2	810.8[e]	2479.0[d]	1915.0[e]

Table 4.11. Influence of substrate enricher-biotic agents interaction on the dehydrogenase activity (μg TPF g^{-1} soil h^{-1}) at three different stages of composting

Treatments	Mesophilic	Thermophilic	Maturity
C_2N	807.2^{j}	2762.0^{f}	1632.0^{j}
C_2S	825.0^{i}	3114.0^{b}	1885.0^{g}
C_2P	954.5^{d}	3062.0^{bcd}	1930.0^{f}
C_2E	770.2^{l}	3054.0^{bcd}	1937.0^{f}
C_2I	755.4^{m}	3040.0^{bcd}	2033.0^{c}
Q_2N	1027.0^{a}	3134.0^{b}	2026.0^{cd}
Q_2S	872.1^{f}	3054.0^{bcd}	2181.0^{b}
Q_2P	895.8^{e}	3309.0^{a}	2280.0^{a}
Q_2E	787.0^{k}	3108.0^{bc}	2168.0^{b}
Q_2I	986.5^{b}	2932.0^{de}	2086.0^{de}
M_2N	858.7^{g}	2454.0^{g}	1766.0^{i}
M_2S	890.5^{e}	2550.0^{g}	1860.0^{h}
M_2P	967.3^{c}	2968.0^{cde}	1992.0^{e}
M_2E	874.7^{f}	2877.0^{ef}	2183.0^{b}
M_2I	846.7^{h}	3040.0^{bcd}	2297.0^{a}

respectively. During thermophilic stage, the lowest dehydrogenase activity was recorded in O_3M_2.

On consideration of substrate enricher-biotic agent interaction during the mesophilic stage, the maximum dehydrogenase activity of 1027 µg g^{-1} soil h^{-1} was observed in Q_2N and the minimum value of 755.4 µg g^{-1} soil h^{-1} was in C_2I. During the thermophilic and maturity stages, the maximum dehydrogenase activity was recorded in (Q_2P) with values 3309 and 2280 µg g^{-1} soil h^{-1} respectively (Table 4.11). At maturity stage, M_2I (2297 µg g^{-1} soil h^{-1}) was on par with Q_2P..

4.1.5 Earthworm Count

The count for the two types of earthworms, ie., *Eudrilus eugeniae* and *Eisenia foetida* were noted at two intervals, one month and two months after introduction of earthworms as influenced by various substrates, substrate enrichers and biotic agents are provided in Table 4.12. The earthworm count of the two types of earthworms one month and 2 months after introduction of the earthworms as influenced by the interactive effect of substrate –substrate enrichers are provided in Table 4.13.

With respect to the influence of substrates, the maximum earthworm count (*Eudrilus eugeniae*) at the two periods were noted in 4 mm sieved substrates while the lowest earthworm count was noted in unsieved substrates.

Regarding the influence of substrate enrichers, (Q_2) registered the maximum count of 127.3 after one month. However, during the second month, the 15 per cent quail manure enrichment (Q_3) and 10 per cent cowdung enrichment (C_2), gave maximum counts of 436.4 and 438 which were on par.

On consideration of interactive influence of substrate – substrate enricher (Table 4.13), maximum count was observed in O_1M_1 during 1^{st} month with a value of 146.7 and in O_1C_2 during 2^{nd} month with a value of 571.

With respect to the count of *Eisenia foetida*, maximum count of 171.1 during first month and a maximum count of 529.1 during 2^{nd} month were observed in 4 mm

Table 4.12. Influence of various substrates and substrate enrichers on the earthworm counts at monthly intervals after inoculation

Treatments	*Eudrilus eugeniae* count		*Eisenia foetida* count	
	After 1 month	After 2 months	After 1 month	After 2 months
Substrates				
O_1	136.8[a]	532.8[a]	171.1[a]	529.1[a]
O_2	119.3[b]	455.7[b]	141.4[b]	495.9[b]
O_3	107.5[c]	289.0[c]	130.7[c]	322.0[c]
Substrate enrichers				
C_1	119.8[cd]	421.8[e]	141.0[bc]	457.4[b]
C_2	123.4[b]	438.0[a]	141.4[bc]	455.7[b]
C_3	118.1[d]	426.0[cd]	142.9[bc]	438.0[d]
Q_1	115.3[e]	428.7[b]	150.7[ab]	432.9[d]
Q_2	127.3[a]	408.3[f]	159.1[a]	447.3[c]
Q_3	124.6[b]	436.4[a]	161.7[a]	467.0[a]
M_1	120.4[c]	421.1[e]	158.7[a]	445.8[c]
M_2	120.9[c]	427.2[bc]	134.4[c]	447.9[c]
M_3	121.1[c]	425.2[d]	139.9[bc]	448.9[c]

Table 4.13. Influence of substrates-substrate enricher interaction on the earthworm counts at monthly intervals after inoculation

Treatments	*Eudrilus eugeniae* count		*Eisenia foetida* count	
	After 1 month	After 2 months	After 1 month	After 2 months
O_1C_1	136.7^{d}	543.7^{d}	180.3^{a}	573.0^{a}
O_1C_2	142.3^{bc}	571.0^{a}	165.7^{abcd}	531.0^{c}
O_1C_3	131.7^{ef}	551.3^{c}	166.7^{abcd}	473.3^{g}
O_1Q_1	121.0^{hi}	526.7^{e}	182.7^{a}	505.3^{def}
O_1Q_2	136.0^{d}	495.0^{h}	181.7^{a}	514.7^{d}
O_1Q_3	144.0^{ab}	564.0^{b}	169.3^{abc}	558.0^{b}
O_1M_1	146.7^{a}	520.7^{f}	165.7^{abcd}	562.3^{b}
O_1M_2	140.3^{c}	521.3^{f}	172.3^{ab}	531.0^{c}
O_1M_3	132.7^{e}	501.7^{g}	156.0^{bcde}	513.0^{d}
O_2C_1	122.3^{gh}	465.0^{j}	131.3^{fghij}	474.0^{g}
O_2C_2	118.3^{ijk}	471.7^{i}	131.3^{fghij}	481.3^{g}
O_2C_3	113.0^{lm}	442.7^{l}	140.3^{efghi}	503.3^{def}
O_2Q_1	124.3^{g}	457.7^{k}	150.3^{cdef}	498.3^{ef}
O_2Q_2	129.0^{f}	436.7^{m}	146.7_{defg}	512.0^{d}
O_2Q_3	110.3^{mn}	470.7^{i}	169.7^{abc}	510.7^{d}
O_2M_1	115.7^{kl}	431.0^{n}	170.3^{abc}	479.7^{g}
O_2M_2	120.0^{hij}	455.0^{k}	111.0^{j}	494.7^{f}
O_2M_3	121.0^{hi}	471.3^{i}	122.0^{hij}	508.7^{de}
O_3C_1	100.3^{op}	256.7^{v}	111.3^{j}	325.3^{jk}
O_3C_2	109.7^{n}	271.3^{u}	127.3^{ghij}	354.7^{h}
O_3C_3	109.7^{n}	284.0^{s}	121.7^{hij}	337.3^{i}
O_3Q_1	100.7^{op}	301.7^{q}	119.0^{ij}	295.0^{l}
O_3Q_2	117.0^{jk}	293.3^{r}	149.0^{cdef}	315.3^{k}
O_3Q_3	119.3^{hij}	274.7^{t}	146.0^{defg}	332.3^{ij}
O_3M_1	99.0^{p}	311.7^{o}	140.0^{efghi}	295.3^{l}
O_3M_2	102.3^{o}	305.3^{p}	120.0^{ij}	318.0^{k}
O_3M_3	109.7^{n}	302.7^{pq}	141.7^{efgh}	325.0^{jk}

sieved substrates, while the corresponding lower counts were noted in unsieved substrates (Table 4.12). This trend was seen in the case of *Eudrilus eugeniae* also.

Considering the influence of substrate enrichers on the count of *Eisenia foetida*, the maximum counts of 161.7 and 467 after 1 month and 2 months respectively were noted in 15 per cent quail manure enriched treatments (Q_3). Regarding the influence of substrate-substrate enricher interaction (Table 4.13), there was no trend in variations of earthworm population. After one month, O_1Q_1 recorded the maximum count, which were on par with O_1Q_2 and O_1C_1. But after 2 months, O_1C_1 recorded the maximum count of 573.

4.1.6 Nutrient Contents of Nitrogen, Phosphorus and Potassium at Initial Stages of Composting

Mean values of nitrogen, phosphorus and potassium contents in the waste material after the addition of the organic enrichers and biotic agents, as influenced by the different substrates, substrate enrichers and biotic agents are provided in Table 4.14.

The mean values of nitrogen, phosphorus and potassium as influenced by the two factor interaction of substrate–substrate enricher and substrate enricher–biotic agents are provided in Table 4.15 and Table 4.16 respectively.

4.1.6.1 Nitrogen

Nitrogen content during the initial stages of composting was recorded more in 4mm sieved substrates with a value of 2.67 per cent , while the unsieved substrates recorded the lowest value of 2.34 per cent (Table 4.14).

In the case of substrate enrichers, the maximum mean value of 2.64 per cent N was recorded by Q_3 while the minimum mean value of 2.27 per cent was recorded by M_3.

Regarding the influence of introduction of biotic agents, the maximum mean value of N content (2.54%) was noted where only native macro and microorganisms

Table 4.14. Influence of substrates, substrate enrichers and biotic agents on the contents of N, P & K at the initial stages of composting

Treatments	Nitrogen (%)	Phosphorus (%)	Potassium (%)
Substrates			
O_1	2.67^{a}	0.290^{c}	0.846^{b}
O_2	2.45^{b}	0.337^{a}	0.876^{a}
O_3	2.34^{c}	0.335^{b}	0.846^{b}
Substrate enrichers			
C_1	2.37^{d}	0.285^{g}	0.856^{bc}
C_2	2.52^{c}	0.272^{h}	0.870^{ab}
C_3	2.62^{a}	0.289^{f}	0.856^{bc}
Q_1	2.56^{b}	0.303^{e}	0.850^{bc}
Q_2	2.51^{c}	0.319^{d}	0.842^{bc}
Q_3	2.64^{a}	0.386^{a}	0.873^{ab}
M_1	2.51^{c}	0.354^{b}	0.834^{c}
M_2	2.37^{d}	0.340^{c}	0.824^{c}
M_3	2.27^{e}	0.340^{c}	0.900^{a}
Biotic agents			
N	2.54^{a}	0.318^{c}	0.824^{c}
S	2.47^{b}	0.321^{b}	0.831^{c}
P	2.47^{b}	0.310^{d}	0.829^{c}
E	2.43^{c}	0.327^{a}	0.885^{b}
I	2.53^{a}	0.327^{a}	0.911^{a}

Table 4.15. Influence of substrate - substrate enricher interactions on the nutrient contents of N, P and K at initial stage of composting

Treatments	Nitrogen (%)	Phosphorus (%)	Potassium (%)
O_1C_1	2.51[ef]	0.182[u]	0.816
O_1C_2	2.51[ef]	0.259[t]	0.888
O_1C_3	2.27[c]	0.279[l]	0.861
O_1Q_1	3.00[a]	0.308[l]	0.847
O_1Q_2	2.71[c]	0.306[l]	0.805
O_1Q_3	2.91[b]	0.361[g]	0.808
O_1M_1	2.68[c]	0.294[o]	0.804
O_1M_2	2.51[ef]	0.325[k]	0.819
O_1M_3	2.53[c]	0.298[n]	0.965
O_2C_1	2.30[i]	0.285[q]	0.977
O_2C_2	2.54[e]	0.286[q]	0.873
O_2C_3	2.59[d]	0.296[no]	0.903
O_2Q_1	2.44[g]	0.299[n]	0.844
O_2Q_2	2.54[e]	0.307[l]	0.884
O_2Q_3	2.59[d]	0.427[a]	0.876
O_2M_1	2.49[f]	0.404[b]	0.859
O_2M_2	2.41[g]	0.366[de]	0.799
O_2M_3	2.15[k]	0.365[ef]	0.869
O_3C_1	2.31[i]	0.388[c]	0.775
O_3C_2	2.51[ef]	0.271[s]	0.849
O_3C_3	2.54	0.291[p]	0.802
O_3Q_1	2.29	0.302[m]	0.859
O_3Q_2	2.28	0.344[i]	0.836
O_3Q_3	2.41	0.369[d]	0.935
O_3M_1	2.35	0.364[f]	0.838
O_3M_2	2.20	0.330[j]	0.853
O_3M_3	2.14	0.355[h]	0.864

Table 4.16. Influence of substrate enrichers-biotic agents interaction on the nutrient contents of N, P and K at initial stage of composting

Treatments	Nitrogen (%)	Phosphorus (%)	Potassium (%)
C_1N	2.48	0.260	0.836
C_1S	2.13	0.271	0.782
C_1P	2.26	0.284	0.806
C_1E	2.36	0.294	0.894
C_1I	2.64	0.316	0.961
C_2N	2.54	0.278	0.853
C_2S	2.65	0.300	0.844
C_2P	2.51	0.224	0.796
C_2E	2.27	0.274	0.922
C_2I	2.62	0.282	0.936
C_3N	2.75	0.289	0.904
C_3S	2.68	0.292	0.839
C_3P	2.68	0.307	0.814
C_3E	2.42	0.287	0.886
C_3I	2.56	0.268	0.834
Q_1N	2.63	0.270	0.848
Q_1S	2.59	0.307	0.792
Q_1P	2.56	0.294	0.842
Q_1E	2.55	0.293	0.928
Q_1I	2.48	0.348	0.841
Q_2N	2.60	0.300	0.821
Q_2S	2.32	0.304	0.831
Q_2P	2.53	0.302	0.823
Q_2E	2.47	0.348	0.817
Q_2I	2.64	0.340	0.916

Table 4.16 contd.....

Treatments	Nitrogen (%)	Phosphorus (%)	Potassium (%)
Q_3N	2.62	0.404	0.789
Q_3S	2.70	0.401	0.859
Q_3P	2.65	0.379	0.851
Q_3E	2.59	0.358	0.894
Q_3I	2.63	0.385	0.971
M_1N	2.49	0.403	0.732
M_1S	2.52	0.357	0.791
M_1P	2.51	0.310	0.871
M_1E	2.63	0.350	0.878
M_1I	2.39	0.350	0.896
M_2N	2.41	0.324	0.673
M_2S	2.39	0.346	0.871
M_2P	2.29	0.341	0.777
M_2E	2.34	0.359	0.854
M_2I	2.43	0.332	0.944
M_3N	2.33	0.332	0.958
M_3S	2.25	0.310	0.868
M_3P	2.23	0.349	0.880
M_3E	2.21	0.381	0.890
M_3I	2.36	0.325	0.902
CD (0.05)	0.05083	0.002935	0.06563

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flourished (N). The least value of 2.43 per cent was noted for *Eudrilus eugeniae* (E) introduced treatments.

On consideration of the interactive influence of the substrate-substrate enricher (Table 4.15), the maximum per centage of Nitrogen (3%) was noted for O_1Q_1. The lowest value for Nitrogen was noted with O_3M_3 (2.14 per cent).

The influence of substrate enricher-biotic agent interaction (Table 4.16) on the nitrogen content was such that, a maximum value of 2.75 per cent was noted for C_3N while the minimum value of 2.13 per cent was found in 5 per cent cowdung enriched treatments in which *Schizophyllus communae* were introduced (C_1S).

4.1.6.2 Phosphorus

Phosphorus content was recorded maximum in 2 mm sieved substrate with a value of 0.337 per cent and minimum in 4 mm sieved substrate with a value of 0.290 per cent (Table 4.14).

The Q_3 treatment recorded the maximum value of 0.386 per cent for P, while the minimum value of 0.272 per cent was recorded in 10 per cent cowdung enriched treatments (C_2).

Considering the influence of biotic agents, treatments with *Eisenia foetida* and *Eudrilus eugeniae* were introduced, gave the maximum value of 0.327 per cent for P, while the minimum value of 0.318 per cent was recorded in *Pleurotus platypus* introduced treatments.

The interactive effect of the treatment combination, substrate-substrate enricher (Table 4.15) gave the highest value of P in O_2Q_3 with a value of 0.427 per cent . The lowest value noted was 0.182 per cent in O_1C_1.

With the substrate–biotic agent interaction effect (Table 4.16), the highest Phosphorus content was 0.404 per cent , noted in Q_3N. The lowest value was 0.224 per cent noted in C_2P.

4.1.6.3 Potassium

Potassium contents at initial stages of composting was noted maximum for 2 mm sieved substrates with a value of 0.876 per cent (Table 4.14).

Among the different types of substrate enrichers, maximum mean value of Potassium was 0.900 per cent noted in M_3. The lowest value of 0.824 per cent was noted in M_2 which was on par with M_1.

With respect to the influence of biotic agents on the K content, the maximum value of 0.911 per cent was noted for *Eisenia foetida* (I) introduced treatments while the lowest value of 0.824 per cent was noted in treatments where no external biotic agents were introduced (N).

On consideration of the interactive influence of substrate-substrate enrichers on K content (Table 4.15), the maximum value of 0.977 per cent was noted in 2 mm sieved substrates, enriched with 5 per cent cowdung (O_2C_1). The lowest value of 0.775 per cent was noted in unsieved substrates enriched with 5 per cent cowdung (O_3C_1).

The substrate enrichers-biotic agent interactions on the K content (Table 4.16) revealed that, a maximum value of 0.971 per cent K was noted in Q_3I, while the lowest value of 0.673 per cent was in M_2N.

4.1.7 Nutrient Contents of Carbon, Nitrogen, Phosphorus and Potassium at Final Stages of Composting

Mean values of the contents of N, P and K at final stages of composting for different substrates, substrate enrichers and the different biotic agents are provided in Table 4.17. The two factor combinations showing the interaction effect of these different factors are provided in Table 4.18 and Table 4.19.

4.1.7.1 Nitrogen

Nitrogen per centage at final stage of composting was maximum for 2 mm sieved and unsieved substrates (O_2 & O_3), with a value of 3.34 per cent , while the minimum value of 3.26 per cent was noted for 4 mm sieved substrates (O_1) (Table 4.17).

Table 4.17. Influence of substrates, substrate enrichers and biotic agents on the contents of N, P & K at the final stages of composting

Treatments	Nitrogen (%)	Phosphorus (%)	Potassium (%)
Substrates			
O_1	3.26[b]	0.639[c]	0.709[b]
O_2	3.34[a]	0.720[b]	0.753[a]
O_3	3.34[a]	0.766[a]	0.716[b]
Substrate enrichers			
C_1	3.32[b]	0.662[g]	0.682[b]
C_2	3.30[bc]	0.643[h]	0.726[abc]
C_3	3.26[c]	0.621[i]	0.715[bc]
Q_1	3.29[bc]	0.680[f]	0.749[a]
Q_2	3.39[a]	0.741[d]	0.716[abc]
Q_3	3.40[a]	0.768[b]	0.747[ab]
M_1	3.22[d]	0.724[e]	0.743[abc]
M_2	3.31[b]	0.770[a]	0.710[cd]
M_3	3.30[bc]	0.764[c]	0.747[ab]
Biotic agents			
N	3.29[c]	0.681[e]	0.701[c]
S	3.27[d]	0.687[d]	0.699[c]
P	3.29[c]	0.700[c]	0.704[c]
E	3.33[b]	0.727[b]	0.744[b]
I	3.37[a]	0.746[a]	0.782[a]

Table 4.18. Influence of substrate - substrate enrichers interactions on the nutrient contents of N, P and K at final stage of composting

Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)
O_1C_1	3.28^{ghij}	0.557^{a}	0.645
O_1C_2	3.35^{efg}	0.530^{v}	0.758
O_1C_3	3.30^{fghi}	0.477^{w}	0.710
O_1Q_1	3.32^{efgh}	0.591^{t}	0.726
O_1Q_2	3.38^{cde}	0.708^{n}	0.673
O_1Q_3	3.31^{fghi}	0.767^{f}	0.707
O_1M_1	3.10^{m}	0.629^{l}	0.683
O_1M_2	3.09^{m}	0.749^{h}	0.692
O_1M_3	3.23^{jk}	0.746^{i}	0.781
O_2C_1	3.41^{bcd}	0.696^{p}	0.786
O_2C_2	3.21^{kl}	0.640^{r}	0.697
O_2C_3	3.16^{l}	0.651^{q}	0.770
O_2Q_1	3.30^{fghi}	0.703^{o}	0.818
O_2Q_2	3.43^{bc}	0.730^{i}	0.787
O_2Q_3	3.44^{b}	0.747^{hi}	0.743
O_2M_1	3.24^{ijk}	0.726^{m}	0.758
O_2M_2	3.51^{a}	0.784^{d}	0.695
O_2M_3	3.32^{efgh}	0.799^{b}	0.727
O_3C_1	3.28^{hij}	0.734^{k}	0.615
O_3C_2	3.33^{efgh}	0.760^{g}	0.723
O_3C_3	3.34^{efgh}	0.736^{j}	0.664
O_3Q_1	3.25^{ijk}	0.747^{hi}	0.702
O_3Q_2	3.35^{def}	0.786^{d}	0.689
O_3Q_3	3.46^{ab}	0.789^{c}	0.790
O_3M_1	3.32^{efgh}	0.818^{a}	0.787
O_3M_2	3.34^{efgh}	0.774^{e}	0.745
O_3M_3	3.34^{efgh}	0.746^{i}	0.732

Table 4.19. Influence of substrate enrichers - biotic agent interactions on the nutrient contents of N, P and K at final stage of composting

Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)
C_1N	3.36	0.641	0.693
C_1S	3.19	0.636	0.617
C_1P	3.22	0.668	0.680
C_1E	3.37	0.672	0.677
C_1I	3.47	0.694	0.744
C_2N	3.27	0.612	0.637
C_2S	3.34	0.600	0.736
C_2P	3.25	0.631	0.699
C_2E	3.32	0.675	0.810
C_2I	3.31	0.698	0.748
C_3N	3.31	0.595	0.781
C_3S	3.27	0.610	0.726
C_3P	3.26	0.604	0.644
C_3E	3.27	0.639	0.699
C_3I	3.20	0.659	0.723
Q_1N	3.28	0.611	0.748
Q_1S	3.27	0.645	0.680
Q_1P	3.18	0.696	0.744
Q_1E	3.32	0.694	0.798
Q_1I	339	0.756	0.773
Q_2N	3.30	0.719	0.696
Q_2S	3.22	0.743	0.701
Q_2P	3.25	0.758	0.707
Q_2E	3.60	0.722	0.679
Q_2I	3.57	0.763	0.799
Q_3N	3.35	0.721	0.696

Table 4.19 contd.....

Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)
Q_3S	3.29	0.701	0.709
Q_3P	3.81	0.787	0.743
Q_3E	3.27	0.826	0.786
Q_3I	3.29	0.803	0.801
M_1N	3.18	0.690	0.633
M_1S	3.24	0.701	0.702
M_1P	3.17	0.733	0.748
M_1E	3.19	0.759	0.797
M_1I	3.33	0.740	0.833
M_2N	3.19	0.780	0.648
M_2S	3.33	0.791	0.709
M_2P	3.24	0.724	0.644
M_2E	3.41	0.758	0.726
M_2I	3.37	0.792	0.826
M_3N	3.38	0.758	0.776
M_3S	3.24	0.756	0.712
M_3P	3.25	0.698	0.723
M_3E	3.24	0.800	0.730
M_3I	3.38	0.805	0.793
CD (0.05)	0.07189	0.002935	0.0029

Regarding the influence of the different substrate enrichers, the highest N per cent was noticed in 15 per cent quail manure enriched treatments (Q_3), while the lowest N per cent was noticed in 5 per cent mixture of cowdung-quail manure enriched treatments (M_1) with values 3.40 per cent and 3.22 per cent respectively.

With respect to the influence of various biotic agents, the maximum N per cent was 3.37 in *Eisenia foetida* introduced treatments (I) while the minimum N per cent was 3.27 in *Schizophyllus communae* (S) introduced treatments.

On considering, the interactive influence of the substrates-substrate enrichers (Table 4.18), the highest N per cent was noticed in O_2M_2 while the lowest N per cent was noticed in O_1M_2. The values were 3.51 per cent and 3.09 per cent respectively.

Regarding the interaction of substrate enrichers-biotic agents (Table 4.19), maximum value for N was 3.81 per cent , noted in 15 per cent quail manure enriched substrate in which *Pleurotus platypus* (Q_3P)were introduced while the minimum value was 3.17 per cent noted in 5 per cent mixture of cowdung-quail manure treatments in which *Pleurotus platypus* were introduced (M_1P).

4.1.7.2 Phosphorus

In general, at the final stage of composting, the P content was maximum in unsieved substrate (O_3), while it was minimum in 4 mm sieved substrates (O_1), with values 0.766 per cent and 0.639 per cent respectively (Table 4.17).

Regarding the various substrate enrichments the maximum value of 0.770 per cent of P was noted in M_2, while the minimum value of 0.621 per cent of P was noted for 15 per cent cowdung. enriched substrates.

With respect to the influence of biotic agents on the P content of compost, the maximum value of 0.746 per cent was noted in *Eisenia foetida* (I) introduced treatments, while the lowest value of 0.681 per cent was noted in N.

On considering the interactive influence of substrates and substrate enrichers (Table 4.18), the maximum P content of 0.818 per cent was noted for O_3M_1 and the minimum 0.447 per cent was noted for O_1C_3.

The interaction between substrate enrichers-biotic agents (Table 4.19) influenced the P content of the final compost, such that the highest value of 0.826 per cent was noted for Q_3E and the lowest value noted was 0.595 per cent in C_3N.

4.1.7.3 Potassium

In general, the potassium content ranged from 0.753 per cent in 2 mm sieved substrates (O_2) to 0.709 per cent in 4 mm sieved substrates at final stages of composting (Table 4.17). With respect to the influence of substrate enrichers, on the final K content of the compost, the maximum value of 0.749 per cent was noted in 5 per cent quail manure enriched substrates (Q_1), while the lowest value of 0.682 per cent was noted in 5 per cent cowdung enriched substrates (C_1).

With respect to the influence of the biotic agents, on the final K content of the compost, the maximum value of 0.782 per cent was noted in *Eisenia foetida* introduced substrates while the minimum value of 0.699 per cent was noted in *Schizophyllus communae* introduced treatments.

On consideration of the interactive influence of substrates-substrate enrichers (Table 4.18), the highest value of 0.818 per cent was noticed in O_2Q_1 while the lowest value of 0.615 per cent was noted in O_3C_1.

Regarding the interactive influence of substrate enricher-biotic agents (Table 4.19) on the K content of compost, the maximum value of 0.833 per cent was noted for 5 per cent mixture of cowdung-quail manure enriched treatment in which *Eisenia foetida* were introduced (M_1I) while the lowest value of 0.617 per cent was noted in 5 per cent cowdung enriched treatments in which *Schizophyllus communae* were introduced (C_1S).

4.1.8 C:N Ratio and Compost Maturity Period

C:N ratios at the initial and final stages of the composting as well as compost maturity period as influenced by the different substrates, substrate enrichers and biotic agents are provided in Table 4.20. Interactive influence of substrate-substrate enrichers and substrate enricher-biotic agents on the C:N ratios (initial and final) as well as the compost maturity period are provided in Table 4.21 and Table 4.22 respectively.

4.1.8.1 Initial C:N Ratio

During the initial stages of composting, the mean value of C:N ratio was maximum in 2 mm sieved substrates (O_2) and minimum in 4 mm sieved substrates (O_1) each recording a value of 33.7 and 32.1, respectively. In the case of substrate enrichment, the highest value of C:N ratio, ie. 36.3 was observed in M_3 and lowest value of 30.8 was observed in Q_2. With respect to the influence of biotic agents, the maximum mean value of C:N ratio (34.0) was noted for *Eudrilus eugeniae* enriched treatments (E). The minimum C:N ratio 31.9 was observed in treatment combination where no external biotic agents (N) were introduced.

Considering the interactive influence of substrate-substrate enrichers (Table 4.21), the highest C:N ratio of 40 was noted for O_2M_3. The lowest value of 28.5 was noted in (O_3Q_2). The influence of the interaction effect of the different substrates enrichments and the biotic agents (Table 4.22) were such that the C:N ratio was noted maximum in M_3E with a value of 39.1. The lowest value of 29.0 was observed in Q_2P.

4.1.8.2 Final C:N Ratio

C:N ratio at the end of composting was lowest in 4 mm sieved substrates (O_1), while highest in unsieved substrates (O_3) with values 11.1 per cent and 11.4 per cent respectively (Table 4.20). With respect to the various substrate enrichers, the highest C:N ratio value of 12 was noted in 5 per cent mixture of cowdung-quail manure enriched (M_1) while the lowest value 10.6 was noted in 10 per cent cowdung enriched treatments (C_2). Regarding the influence of the various biotic agents on the final C:N ratio of the compost, the highest value of 11.6 was noted in treatments where no external biotic

Table 4.20. Influence of substrates, substrate enrichers and biotic agents on initial C:N ratio, final C:N ratio and compost maturity period

Treatments	Initial C:N ratio	Final C:N ratio	Compost Maturity Period (days)
Substrates			
O_1	32.1[c]	11.1[c]	53.2[a]
O_2	33.7[a]	11.2[b]	52.4[c]
O_3	32.7[b]	11.4[a]	53.0[b]
Substrate enrichers			
C_1	34.5[b]	11.1[c]	55.5[a]
C_2	32.6[c]	10.6[f]	55.0[b]
C_3	31.7[d]	11.4[b]	54.3[c]
Q_1	31.7[d]	10.9[d]	54.2[c]
Q_2	30.8[e]	10.8[e]	52.6[d]
Q_3	31.3[d]	11.2[c]	52.2[e]
M_1	32.4[c]	12.0[a]	51.1[f]
M_2	34.4[b]	11.5[b]	50.8[g]
M_3	36.3[a]	11.5[b]	50.2[h]
Biotic agents			
N	31.9[c]	11.6[a]	54.0[a]
S	32.9[b]	11.3[c]	53.2[c]
P	32.9[b]	11.4[e]	53.7[b]
E	34.0[a]	11.1[d]	52.0[d]
I	32.6[b]	10.9[e]	51.6[e]

Table 4.21. Influence of substrate - substrate enrichers interaction on the initial C:N ratio, final C:N ratio and compost maturity period

Treatments	Initial C:N ratio	Final C:N ratio	Compost maturity period (days)
O_1C_1	31.3[ijk]	11.1[i]	55.9[a]
O_1C_2	34.7[cd]	10.7[j]	55.2[b]
O_1C_3	31.6[hijk]	11.2[hi]	54.2[d]
O_1Q_1	29.3[mn]	10.3[k]	54.8[bc]
O_1Q_2	31.1[jk]	9.9[l]	52.7[g]
O_1Q_3	30.0[lm]	11.3[gh]	52.6[g]
O_1M_1	33.0[fg]	11.8[b]	52.1[h]
O_1M_2	34.1[de]	12.1[a]	51.0[jk]
O_1M_3	34.1[de]	11.6[def]	50.7[kl]
O_2C_1	36.5[b]	11.5[efg]	54.7[c]
O_2C_2	32.5[gh]	11.0[i]	54.2[d]
O_2C_3	32.1[ghij]	11.3[gh]	53.8[de]
O_2Q_1	32.0[ghij]	10.8[j]	53.9[de]
O_2Q_2	32.9[fg]	10.8[j]	51.4[ij]
O_2Q_3	31.3[ijk]	10.9[j]	50.7[kl]
O_2M_1	32.2[ghi]	12.2[a]	51.5[i]
O_2M_2	33.7[ef]	10.6[j]	51.0[jk]
O_2M_3	40.0[a]	11.4[fgh]	50.3[l]
O_3C_1	35.6[c]	10.8[j]	55.9[a]
O_3C_2	30.7[kl]	10.2[k]	55.7[a]
O_3C_3	31.3[ijk]	11.8[bcd]	55.0[bc]
O_3Q_1	33.9[de]	11.8[bcd]	53.7[e]
O_3Q_2	28.5[n]	11.6[cdef]	53.8[de]
O_3Q_3	32.7[g]	11.5[efg]	53.1[f]
O_3M_1	32.0[ghij]	12.0[a]	49.7[m]
O_3M_2	35.4[c]	11.8[bc]	50.4[l]
O_3M_3	34.8[cd]	11.6[cde]	49.7[m]

Table 4.22. Influence of substrate enrichers – biotic agents interaction on the initial C:N ratio, final C:N ratio and compost maturity period

Treatments	Initial C:N ratio	Final C:N ratio	Compost maturity period (days)
C_1N	33.0	11.1	56.3
C_1S	37.3	11.2	55.7
C_1P	36.5	11.7	57.1
C_1E	34.1	10.9	54.0
C_1I	31.5	10.6	54.3
C_2N	32.3	11.2	55.7
C_2S	30.8	11.3	55.2
C_2P	30.8	11.2	55.8
C_2E	38.2	9.9	54.2
C_2I	31.1	9.5	54.3
C_3N	30.3	11.3	54.9
C_3S	31.8	11.8	54.8
C_3P	31.0	11.3	55.2
C_3E	32.9	11.0	53.3
C_3I	32.3	11.7	53.4
Q_1N	32.3	11.3	54.7
Q_1S	31.0	10.4	54.6
Q_1P	30.7	11.6	55.2
Q_1E	31.7	10.9	53.1
Q_1I	33.0	10.5	53.2
Q_2N	29.8	11.4	53.7

Table 4.22 contd.....

Treatments	Initial C:N ratio	Final C:N ratio	Compost maturity period (days)
Q_2S	32.3	10.9	52.9
Q_2P	29.0	10.7	53.3
Q_2E	31.9	10.5	52.2
Q_2I	31.1	10.5	51.0
Q_3N	31.0	11.7	53.6
Q_3S	30.6	11.7	52.6
Q_3P	31.3	10.6	52.2
Q_3E	32.8	11.3	51.7
Q_3I	31.0	10.7	50.8
M_1N	32.3	11.3	52.6
M_1S	31.9	12.1	51.1
M_1P	32.6	12.2	52.4
M_1E	30.4	12.4	49.8
M_1I	34.8	12.1	49.7
M_2N	34.1	13.6	52.7
M_2S	33.9	11.6	51.2
M_2P	36.2	11.4	51.2
M_2E	34.8	10.4	50.0
M_2I	32.8	10.5	48.9
M_3N	31.8	11.2	51.8
M_3S	36.5	10.8	51.0
M_3P	38.1	11.9	50.4
M_3E	39.1	12.2	49.2
M_3I	35.9	11.6	48.8
CD (0.05)	1.134	0.2402	0.5242

agents were introduced (N) while the lowest value of 10.9 was noted in *Eisenia foetida* introduced treatments (I).

On consideration of the interactive influence of substrates-substrate enrichers (Table 4.21), it was seen that the maximum value of 12.2 was observed in O_2M_1, which was on par with O_1M_2 (12.1) and O_3M_1 (12) while the minimum value of 9.9 was observed in O_1Q_2. When substrate enricher-biotic agents interaction was considered (Table 4.22), the maximum C:N ratio was 13.6 observed in M_2N while the minimum value of 9.5 was observed in 10 per cent cowdung enriched treatments in which *Eisenia foetida* (C_2I) were introduced.

4.1.8.3 Compost Maturity Period

In general, the 2 mm sieved substrates (O_2) attained compost maturity in 52.4 days, compared to unsieved (53 days) and 4 mm sieved substrates (53.2 days) (Table 4.20).

Regarding the influence of substrate enrichers, the compost maturity period was observed as the lowest in M_3 with a mean value around 50.2 days. The treatments C_1 took the longest period of 55.5 days to attain compost maturity.

With respect to the influence of biotic agents on compost maturity, it was seen that *Eisenia foetida* introduced treatments (I) recorded the lowest number of days ie. a mean value of 51.6 days to attain compost maturity, while the treatments in which no external biotic agents were introduced (N) took the longest period, ie., 54.0 days to attain compost maturity. Regarding the influence of interaction between substrate-substrate enrichers (Table 4.21) on the compost maturity period, the lowest time for attaining maturity, ie., 49.7 days was observed in O_3M_1 and O_3M_3. The longest period ie. 55.9 days was noted in O_1C_1 and O_3C_1 which was on par with O_3C_2 (55.7 days). On consideration of the influence of substrate enricher-biotic agent interaction (Table 4.22), the longest compost maturity time was noted in 5 per cent cowdung enriched treatments inoculated with *Pleurotus platypus* (C_1P), while the lowest compost maturity period was noted in M_3I (48.8 days).

4.1.9 Studies on Selected Enriched Compost

Physico-chemical properties and chemical composition of the selected enriched compost are provided in Table 4.23 and Table 4.24.

As revealed from Table 4.23, the moisture content of the selected compost material was around 29.8 per cent and the compost was finely pulverized, compared to the original unsieved waste material as detailed in section in 4.1.1. The particle size distribution was such that the fine particles, < 0.5 mm were in the range of 37.2 per cent closely followed by particles in the range of 0.5 mm – 1 mm recording about 29.04 per cent . The bigger sized particles, ie., > 4.75 mm were only 3.52 per cent of the total weight, showing the extent of degradation that has occurred in the original substrate material. On chemical analysis of the selected enriched composts pH value was around 6.82. The C:N ratio was decreased to 11.4, which is an index of the maturity of the compost.

4.1.9.1 Consistency of the Selected Enriched Compost

Table 4.23 Physico-chemical properties of the selected enriched compost

Properties	Values
Per centage distribution of particles	
< 0.5 mm	37.20
0.5 to 1 mm	29.04
1 to 2 mm	23.90
2 to 4.75 mm	6.45
> 4.75 mm	3.52
Moisture content (per cent)	29.80
Odour	Odourless
Colour	Deep black
pH	6.82
C:N ratio	11.40

4.1.9.2 Chemical Composition and Biochemical Constituents of the Selected Enriched Compost

Table 4.24 Chemical composition and biochemical constituents of the selected enriched compost

Characters	Values (%)
Crude protein	22.60
Crude fibre	13.90
Crude lipid	0.70
Cellulose	28.20
Lignin	18.80
Carbon	40.70
Nitrogen	3.62
Phosphorus	0.85
Potassium	0.89
C:N ratio	11.40

Carbon content was around 40.70 per cent . The N, P and K contents of the enriched compost was appreciably high with values 3.62, 0.85 and 0.89 per cent respectively. Crude protein content was 22.6 per cent , while the crude fibre and crude lipid recorded were 13.9 and 0.7 per cent respectively. Cellulose content of the selected enriched compost was around 28.2 per cent and the lignin content was around 18.8 per cent.

4.1.9.3 Macroorganisms Encountered During Composting

The wide range of invertebrates encountered during various stages of composting, ie., at mesophilic, thermophilic and maturity stages are grouped and provided in Table 4.25.

Table 4.25 Macroorganisms encountered at different stages of composting

Invertebrate organisms		
Mesophilic	Thermophilic	Maturity
Pillbugs	Millipedes	Millipedes
Dipteran flies	Centipedes	Centipedes
White worms	Mites	Predatory mites
	Fomicid ants	Earwigs
	Carabid beetles	Spring tails
	Nematodes	Ground beetles
		Fomicid ants
		Spiders
		Nematodes

During the early stages of composting process, dipteran flies and pillbugs were found in large numbers. On approaching the thermophilic stages, some type of mites and nematodes were seen in large numbers along with centipedes and millipedes. During the maturity stage, apart from the nematodes and ground beetles, a number of predatory mites and earwigs were also observed. Spiders, ants, millipedes and centipedes formed the other inhabitants of the compost pile.

4.2 SOIL-CROP RESPONSE STUDIES

It was an exploratory trial to determine the suitability of the best selected compost on the major growth and yield parameters of the test crop, amaranthus. The data on growth and yield parameters are provided in Table 4.26 and Table 4.27 respectively.

4.2.1 Growth and Yield Parameters

4.2.1.1 Plant Height

Plant height increased progressively with advancing age of the crop irrespective of the treatments. At 15 DAP, the height varied from 19.6 cm in T_1 to 39.1 cm in T_5. At 30 DAP, the variation was from 33.27 cm in T_1 to 52.07 cm in T_5. It was seen that at both 15 DAP and 30 DAP, the treatment T_5, receiving 5 t ha^{-1} of compost and full dose of NPK recorded the maximum height while T_1 the absolute control maintained the lowest plant height.

4.2.1.2 Number of Leaves

Number of leaves at 15 DAP and 30 DAP (Table 4.26) showed the same trend as that of plant height. The number of leaves varied from 11.33 in T_1 to 25.67 in T_5 at 15 DAP. During 30 DAP, the number of leaves ranged from 14.67 in T_1 to 31.0 in T_5. The treatments, T_3, T_4 and T_9 were on par with each other recording 23.33, 23.0 and 22.33 leaves respectively.

4.2.1.3 Dry Matter Production

Dry matter accumulation was seen to increase during the second harvest, compared to the first harvest (Table 4.27). There was significant difference in dry matter production between the various treatments in both first and second harvests.

In the first harvest, the maximum dry weight $plant^{-1}$ was observed in T_5, the treatment receiving 5 t ha^{-1} of compost and full dose of NPK. The value recorded was

Table 4.26. Effect of different treatments on plant height and number of leaves at 15 DAP and 30 DAP of the crop amaranthus

Treatments	15 DAP		30 DAP	
	Plant height (cm)	Number of leaves	Plant height (cm)	Number of leaves
T_1	19.6^{h}	11.33^{b}	33.27^{i}	14.67^{e}
T_2	23.2^{g}	14.00^{e}	38.00^{h}	18.67^{d}
T_3	33.1^{c}	16.3^{cd}	47.27^{b}	23.33^{c}
T_4	31.27^{d}	18.33^{c}	43.23^{c}	23.00^{c}
T_5	39.1^{a}	25.67^{a}	52.07^{a}	31.00^{a}
T_6	34^{b}	23.67^{ab}	46.17^{c}	27.67^{b}
T_7	27.17^{b}	15.00^{dc}	38.93^{g}	19.67^{d}
T_8	33.2^{c}	23.00^{b}	45.04^{d}	28.67^{b}
T_9	29.13^{e}	18.33^{c}	41.13^{f}	22.33^{c}

DAP – Days after planting

Table 4.27. Effect of different treatments on dry weight plant^{-1} and yield plot^{-1} during first and second harvest of the crop amaranthus

Treatments	First harvest		Second harvest	
	Dry wt plant^{-1} (g)	Yield plot^{-1} (g)	Dry wt plant^{-1} (g)	Yield plot^{-1} (g)
T_1	0.975^{i}	190.8^{i}	1.057^{i}	210.1^{h}
T_2	1.770^{h}	350.7^{h}	2.010^{h}	400.3^{g}
T_3	3.863^{e}	762.5^{e}	4.063^{e}	798.1^{e}
T_4	2.667^{f}	525.1^{f}	2.66^{f}	542.2^{f}
T_5	9.617^{a}	1881^{a}	9.837^{a}	1921^{a}
T_6	6.913^{c}	1350^{c}	8.143^{c}	1590^{c}
T_7	2.317^{g}	450.3^{g}	2.085^{g}	400.8^{g}
T_8	9.160^{b}	1791^{b}	9.183^{b}	1795^{b}
T_9	5.230^{d}	1020^{d}	5.293^{d}	1035^{d}

9.617g. In the second harvest also, the same trend followed with T_5 recording the maximum dry weight of 9.837g and T_1 recording the least dry weight of 1.057g. Immediately following T_5 are the treatments T_8 and T_6 which recorded a dry matter accumulation of 9.183 and 8.143 g respectively during the second harvest.

4.2.1.4 Yield

Data on the yield of amaranthus recorded during first and second harvests are provided in Table 4.27.

In the first harvest the lowest yield of 190.8g was recorded in the treatment T_1 (absolute control). The maximum yield of 1881g plot^{-1} was recorded in the treatment T_5 receiving 5 t ha^{-1} of compost and full dose of NPK. The second highest yield was recorded in Treatment T_8 receiving 2.5 t ha^{-1} of compost and full dose of NPK followed by T_6 receiving 5 t ha^{-1} of compost and half dose of NPK.

Treatment (T_4) receiving 5 t ha^{-1} of compost alone (525.1 g) was significantly superior than T_2 receiving 5 t ha^{-1} of FYM alone (350.7 g).

In the second harvest, the yield ranged from 210.1g plot^{-1} in T_1 to 1921g plot^{-1} in T_5. The treatment T_4 receiving 5 t ha^{-1} of compost gave significantly superior yield of 542.2 g plot^{-1} than treatment T_2 receiving 5 t ha^{-1} as FYM, which recorded a yield of 400.3g plant^{-1}.

However the yields of T_2 and T_7 were on par with each other recording yields of 400.3 and 400.8 g plant^{-1} respectively. In both the harvests, T_5 receiving 5 t ha^{-1} of compost and full dose of NPK recorded the highest yield followed by T_8 receiving 2.5 t ha^{-1} of compost and full dose of NPK. Increasing the levels of the enriched compost brought about significant yield increase in both the harvests.

4.2.2 Nutrient Uptake

The uptake of major nutrients N, P and K was studied during the first and second harvests, the details of which are presented in Table 4.28.

Table 4.28. Effect of treatments on major nutrient uptake (mg plot^{-1}) during first and second harvest of the crop amaranthus

Treatments	First harvest			Second harvest		
	N	P	K	N	P	K
T_1	343.5^{i}	35.83^{i}	472.4^{i}	389.6^{i}	40.25^{i}	508.6^{i}
T_2	796.3^{h}	81.84^{h}	897.9^{h}	929.6^{h}	86.77^{h}	1060^{h}
T_3	2152^{e}	234.5^{e}	2229^{e}	2345^{e}	228.4^{e}	2416^{e}
T_4	1756^{f}	152.8^{f}	1475^{f}	1682^{f}	150.9^{f}	1450^{f}
T_5	6855^{a}	733.5^{a}	6902^{a}	7183^{a}	696.2^{a}	6937^{a}
T_6	4699^{c}	462.3^{c}	4698^{c}	5698^{c}	506.7^{c}	5657^{b}
T_7	1408^{g}	116.6^{g}	1242^{g}	1238^{g}	98.25^{g}	1087^{g}
T_8	6023^{b}	602.3^{b}	5221^{b}	6219^{b}	576^{b}	1060^{c}
T_9	3373^{d}	305.9^{d}	2824^{d}	3267^{d}	306.8^{d}	508.6^{d}

4.2.2.1 Nitrogen Uptake

During the first harvest, the maximum N uptake was recorded in T_5 with a value of 6855 mg $plot^{-1}$. It was followed by T_8 with an uptake of 6023 mg $plot^{-1}$. There was significant variation in nitrogen uptake between the various treatments.

During the second harvest, nitrogen uptake ranged from 389.6 mg $plot^{-1}$ in T_1, the absolute control to 7183 mg $plot^{-1}$ in T_5. Immediately following T_5, the next higher N uptake was with T_8 which recorded a value of 6219 mg $plot^{-1}$. The nitrogen uptake was seen to increase in the second harvest in almost all the treatments barring T_4, T_7 and T_9.

4.2.2.2 Phosphorus Uptake

There was significant difference in the phosphorus uptake between the various treatments. In the first harvest, treatment T_5 recorded the maximum phosphorus uptake of 733.5 mg $plot^{-1}$, followed by T_8 with a value of 602.3 mg $plot^{-1}$. The lowest phosphorus uptake was recorded in T_1 (35.83 mg $plot^{-1}$). In the second harvest, the phosphorus uptake $plot^{-1}$ was seen to decrease in almost all the treatments except T_1, T_2, T_6 and T_9. The maximum phosphorus uptake of 696.2 mg $plot^{-1}$ was recorded in treatment T_5 receiving 5 t ha^{-1} of compost and full dose of NPK. The absolute control, T_1 recorded the least phosphorus uptake of 40.25 mg $plot^{-1}$.

4.2.2.3 Potassium Uptake

Potassium uptake seemed to differ significantly between treatments both in first harvest and second harvest. In the first harvest, the potassium uptake ranged from 472.4 in T_1 to 6902 mg $plot^{-1}$ in treatment T_5. The treatment T_8 recorded the second highest potassium uptake of 5221 mg $plot^{-1}$.

Potassium uptake recorded during second harvest was high compared to the first harvest ranging from 508.6 mg $plot^{-1}$ in T_1 to 6937 mg $plot^{-1}$ in T_5.

4.2.3 Studies on Soil Characteristics

4.2.3.1 Soil Characteristics of the Experimental Site

Before the initiation of the treatments, soil samples were collected and analysed for pH, cation exchange capacity, organic carbon, available nitrogen, available phosphorus and available potassium. The data are provided in Table 4.29.

Table 4.29 Soil characteristics of the experimental site

Sl. No.	Particulars	Value
1	pH	5.94
2	Organic carbon (per cent)	1.18
3	Available N (kg ha^{-1})	277.70
4	Available P (kg ha^{-1})	14.44
5	Available K (kg ha^{-1})	86.58
6	CEC (cmol(+)kg^{-1} soil)	3.11

4.2.3.2 Soil Characteristics After Harvest of the Crop

The pH, cation exchange capacity, organic carbon, available N, P and K of the post-harvest soil are presented in Table 4.30.

4.2.3.2.1 pH

The pH ranged from 6.45 in T_4 to 5.79 in T_8. On comparison with the initial pH status of 5.94, it can be seen that the pH of the post harvest soil seemed to increase in all the treatments except T_8 and T_9. T_2 with 5 t ha^{-1} of FYM, T_3 with 5 t ha^{-1} of FYM and full

Table 4.30. Effect of treatments on pH, CEC, Organic Carbon and available major nutrient contents of post-harvest soil

Treatments	pH	CEC (cmol(+)kg^{-1})	Organic Carbon (%)	Available Nitrogen (kg ha^{-1})	Available Phosphorus (kg ha^{-1})	Available Potassium (kg ha^{-1})
T_1	5.95^{d}	3.09^{i}	1.10^{i}	275.1^{i}	14.60^{i}	88.0^{i}
T_2	6.08^{c}	3.51^{f}	1.30^{h}	300.7^{h}	16.2^{g}	99.4^{g}
T_3	6.08^{c}	4.41^{d}	1.57^{e}	360.9^{b}	19.5^{f}	106.6^{d}
T_4	6.45^{a}	6.90^{a}	1.75^{c}	327.8^{f}	23.5^{d}	119.4^{a}
T_5	6.16^{c}	5.05^{c}	1.82^{a}	390.2^{a}	27.0^{a}	108.3^{b}
T_6	6.31^{b}	4.25^{e}	1.76^{b}	340.3^{d}	25.4^{b}	102.7^{e}
T_7	6.29^{b}	5.40^{b}	1.42^{g}	319.8^{g}	17.8^{g}	98.5^{h}
T_8	5.79^{e}	3.24^{h}	1.67^{d}	349.2^{c}	25.0^{c}	107.4^{c}
T_9	5.89^{d}	3.36^{g}	1.45^{f}	337.1^{e}	20.0^{e}	100.3^{h}

dose of NPK and T_5 with 5 t ha^{-1} of compost and full dose of NPK recorded a pH of 6.1, 6.1 and 6.2 respectively which were, on par with each other.

4.2.3.2.2. Cation Exchange Capacity

Compared to the initial CEC of the soil, the CEC of the post harvest soil of all the treatments were much higher. It ranged from 3.09 cmol(+) kg^{-1} soil in T_1 absolute control to 6.9 cmol(+) kg^{-1} in T_4, the treatment receiving 5 t ha^{-1} of compost alone. The second highest CEC was recorded in T_7, the treatment receiving 2.5 t ha^{-1} of compost alone.

4.2.3.2.3 Organic Carbon

The organic carbon content of the post harvest soil ranged from 1.1 in T_1 to 1.82 per cent in T_5, the treatment receiving 5 t ha^{-1} compost and full dose of NPK. There was significant difference in the per centage of soil organic carbon in the various treatments. The organic carbon content of the treatment receiving 5 t ha^{-1} of compost (T_4) was far superior than the treatment T_2, receiving 5 t ha^{-1} of FYM and treatment T_3 receiving 5 t ha^{-1} FYM and full dose of NPK.

4.2.3.2.4 Available Nitrogen

The available nitrogen status showed a considerable increase after the harvest of the crop in all the treatments. It ranged from 275.1 kg ha^{-1} in T_1, absolute control to 390.2 in T_5 receiving 5 t ha^{-1} of compost and full dose of NPK. Next to T_5, the treatment T_3, receiving 5 t ha^{-1} of FYM and full dose of NPK recorded the highest available nitrogen with a value of 360.9 kg ha^{-1}.

4.2.3.2.5 Available Phosphorus

The soil available Phosphorus in the post harvest soil varied significantly between treatments with values ranging from 14.6 in T_1 to 27 kg ha^{-1} in T_5. However, for all the treatments, the available phosphorus status of the post harvest soil showed a considerable increase compared to the initial status of available phosphorus in the soil.

4.2.3.2.6 Available Potassium

In comparison to the initial, potassium status of 87.1 kg ha^{-1}, the available potassium increased considerably in all the treatments. The highest available potassium was recorded in treatment T_4 receiving 5 t ha^{-1} of compost alone. It was followed by T_5 the treatment receiving 5 t ha^{-1} of compost and full dose of NPK and T_8 the treatment receiving 2.5 t ha^{-1} of compost and full dose of NPK with values 108.3 and 107.4 kg ha^{-1} respectively.

Discussion

5. DISCUSSION

The results of the various experiments on the basic properties of the substrate (Oushadhi ayurvedic wastes), the influence of various biotic agents on the enrichment of the same and finally on the response of a sensitive crop to the addition of the best enriched compost material from the substrate were studied and presented in Chapter 4. They are discussed in this chapter.

5.1 ENRICHMENT TECHNIQUES OF OUSHADHI WASTES

The results of the basic properties of oushadhi wastes and the influence of various enrichment techniques on the temperature and pH variations at different stages of composting provided under section 4.1.2 and 4.1.3 in Tables 4.3 to Table 4.8 are discussed below.

5.1.1 Basic Properties of Oushadhi Wastes

The studies on the particle distribution of Oushadhi ayurvedic wastes revealed that most of the fractions are lesser than 4.75 mm and so sieving a cumbersome process is not much necessary. Moreover, the material possess a moisture content of 52 per cent which will be a contributory factor in the easiness of bio-composting. Though the reduced particle size is a good parameter of compostability, the moisture level of finer particles (4 mm and 2 mm) are comparatively low to the unsieved substrates. As reported by earlier workers (Gaur and Sadasivam, 1993) substrate with 50 per cent inherent moisture and with dominance of finer fractions, can assume congenial substrate controlled environment for rapid composting. The oushadhi waste which is available in ideal consistency and 52 per cent moisture content (Table 4.1) therefore be considered as a good substance without added effort for sieving and separation.

Regarding the chemical properties of the material, the waste in general is more carbonaceous in nature with appreciable N, P and K contents and the C:N ratio of around 30 falls between the wide and narrow range (Tisdale *et al.*, 1995). Perusal of the Table 4.2 also revealed that oushadhi wastes are proteinacious with good fibre and lipid content. The biodegradability is also better as the contents of cellulose and lignin are almost at the equal level (Gaur, 1999). These basic physico-chemical properties of the substrate qualifies it as an ideal material for composting.

5.1.2 Temperature

The results of the various enrichment techniques on the temperature variations at different stages of composting provided under section 4.1.2. and in Table 4.3. revealed that the temperature in general increased to a peak value of 39.4°C in O_2 on the 10^{th} day of composting and later decreased to a stabilised value of around 27.3°C in O_2. Irrespective of the treatments, the whole fluctuations in temperature tend to specify 3 stages in composting – mesophilic with a mean value around 28.5°C, thermophilic with a mean value around 38.1°C and the maturity stage around 27.1°C. Supportive findings were reported by Gaur and Sadasivam (1993), Klamer and Baath (1998) and Thomas (2001). In all composting processes, thermophilic stage is of great importance. The elevated temperatures of 40-50°C found during the mesophilic stage are essential for rapid degradation of lignocellulose, as the thermophilic microfungi and actinomycetes involved in this process thrive at that high temperature (Tuomela *et al.*, 2000). So there exists an intrinsic relationship between temperature and the time of composting. Maturity of compost always coincides with the temperature stabilisation period.

Particle size seemed to have a major effect on the rate of decomposition which was evident from the high temperature with finer particles of 2 mm sieved substrates at various stages of composting compared to 4 mm and unsieved substrates (Fig.2). In the case of unsieved substrate, the temperature never raised to very high values, though it also got composted satisfactorily without much variation in the period of maturity. The hike in temperature for the finer substrate is understandable in the back drop of microbial proliferation enhanced by the greater surface area of the substrate (Gaur and Sadasivam, 1993). However, the particle constitution as discussed under section 5.1.1. provides satisfactory explanation for the comparable compatibility and period of maturity of the unsieved substrate.

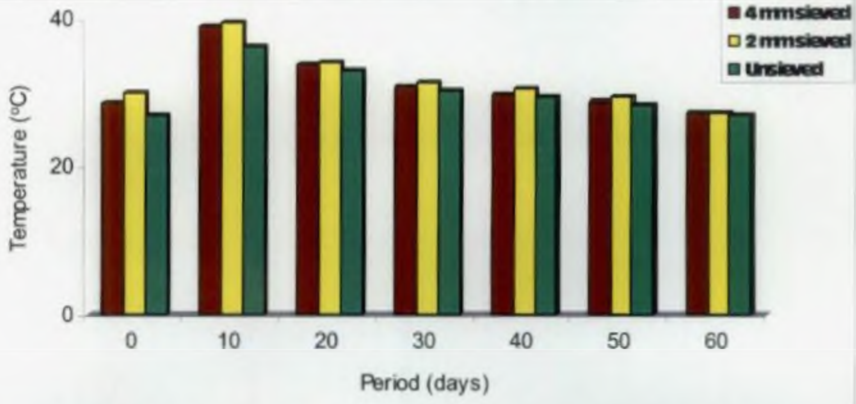

Fig.2 Temperature variations at different intervals of composting in 4 mm, 2 mm and unsieved substrates

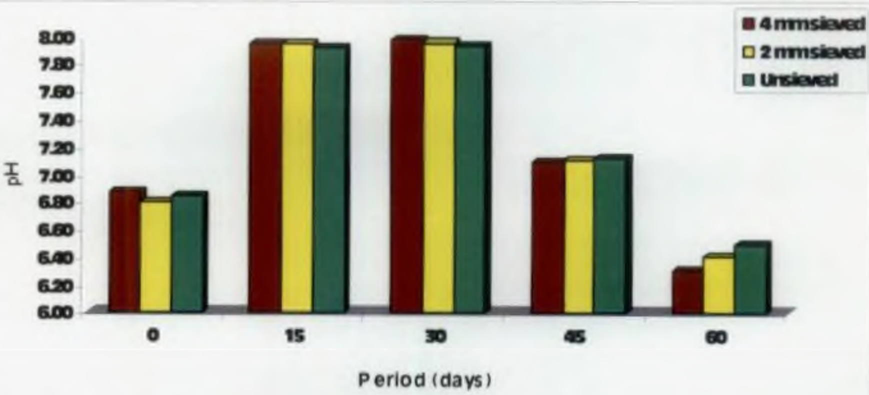

Fig.3 Variation in pH at different intervals of composting in 4 mm, 2 mm and unsieved substrates

At almost all the stages of composting, quail manure enriched treatments registered a higher value compared to cowdung enriched treatments with the highest mean value of 38.4°C at the thermophilic stage, ie., at 10th day of composting. The possible explanation is that quail manure is a much concentrated heat manure compared to cowdung as observed by Yawalkar and Agarwal (1962).

The heat producing capability of an enricher in composting media is a function of its C:N ratio than any other single characteristic. Quail manure with the lowest C:N value among the target substrates and enrichers liberates energy at a faster rate for the multiplication of microbes and promote to assume the critical bacterial load for fast accomplishment of the thermophilic stage. The enricher thus also act as a booster doze of bacterial inoculum favoured by its low C:N value and resultant faster degradation of substrate. The observed hike in temperature at all stages, levels and interaction can be attributed to this quality of the enrichers, proportionately.

5.1.3 pH

The results of various enrichment techniques on the pH variations at different stages of composting provided under section 4.1.2. and Table 4.8 are discussed below. Eventhough no distinct coincidence between temperature and pH hikes are seen, a definite trend is there in the pH variations at the three stages of composting. In general the pH of the Oushadhi wastes raised from a near neutral value of 6.9 (O_1) at 0th day to about 8.0 (O_1) at 30th day and then decreased and stabilised to a value of 6.3 (O_1) at the end of composting (Fig.3), irrespective of the treatment. According to Wilson (1989), most well stabilised composts had a pH between 6.5 and 7.5. In contrast to the temperature variations, there was no clear cut indication on the pH fluctuations for the various substrates and substrate enrichers. This may be due to the inherently neutral range of the substrate material. Most materials decomposing aerobically will come within a pH range that is conducive for microbiological growth thus eliminating the need for pH control (Gaur and Sadasivam, 1993).

With respect to the influence of biotic agents, at all stages of composting, the earthworm introduced treatments gave maximum pH (Fig.4). The initial pH of the

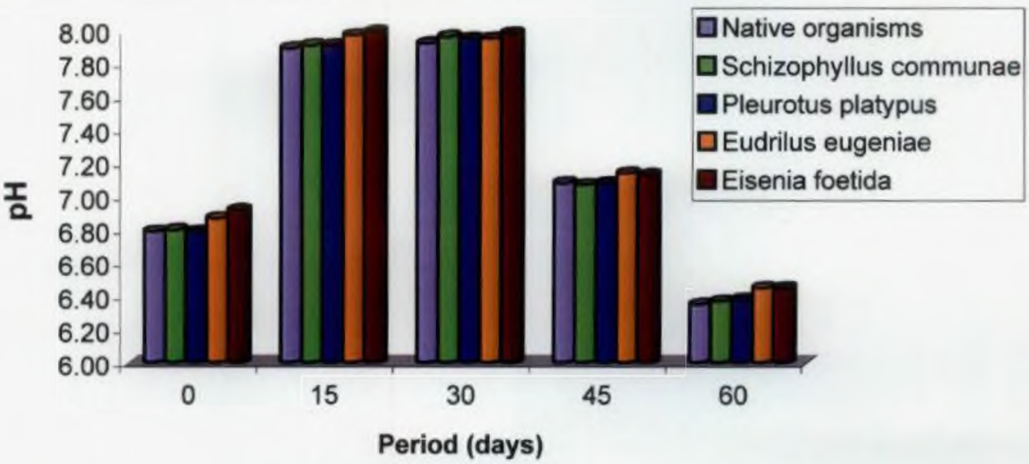

Fig.4 Influence of the different biotic agents on pH variations during composting

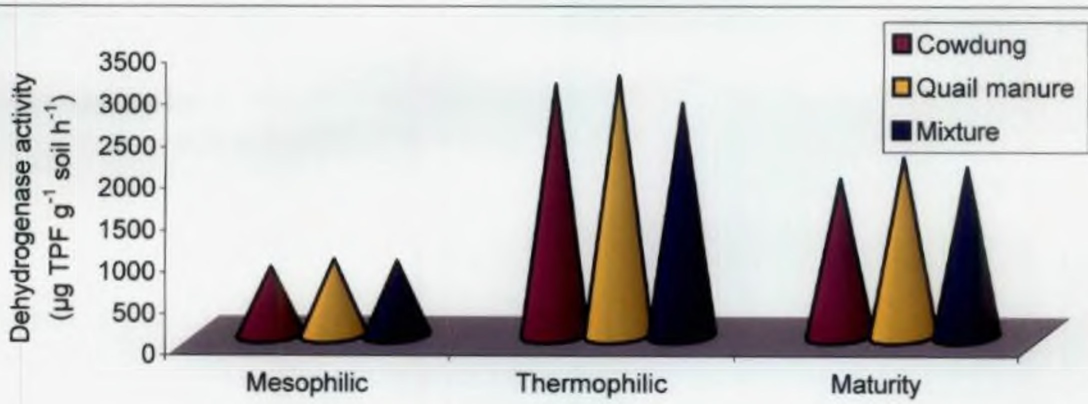

Fig.5 Effects of different substrate enrichers on the dehydrogenase activity at various stages of composting

substrate which was near neutral also seemed to be conducive for growth and proliferation of earthworms. The possible factors acting on the increased pH of worm castes are the NH_4 + excretion and addition from calciferous glands (Lee, 1985). So, vermicomposts generally showed a pH of neutral to alkaline which is considered most comfortable for composting (Gaur, 1999).

5.1.4 Dehydrogenase Activity

The results of the dehydrogenase activity of the compost material at different stages as influenced by various substrates, substrate enrichers, biotic agents and their interactive combinations are provided under section 4.1.4. and presented in Table 4.9, Table 4.10 and Table 4.11. The pertinent points are discussed below.

The lower values of microbial activities as indicated by the lower values of dehydrogenase activity during the mesophilic stages, increased to a maximum value at thermophilic stage and then again decreased towards the maturity phase. But, irrespective of the treatments, the dehydrogenase activity was more in the maturity stages compared to the initial mesophilic stages. With respect to the substrates, the 2 mm sieved substrates (O_2) recorded the maximum dehydrogenase activity value at all stages of composting, compared to the unsieved substrates (O_3). This was due to the much cohesive nature of the substrate encouraging more microbial activity, despite its sieved or unsieved nature.

In the case of substrate enrichers, quail manure enriched treatments (Q_2), recorded the maximum dehydrogenase value at all the stages of composting. The high temperature recorded in quail manure enriched substrates (Q_2) as observed under section 4.1.2 and described under section 5.1.2. might have resulted in proliferation of thermophilic microorganisms. As composting is a biological process, the conditions for the microbes to get themselves flourished are based on the nature of substrates and the environment. In all the biological decomposition processes, the substrate itself is treated as an environment factor because it is extrinsic to the microbial population and as such exercises influence on the extent and rate of microbial activity (Thomas, 2001). Here, the 2 mm sieved substrate is in the most congenial form for microbial activity as discussed in section 5.1.2. This material therefore, when charged with additives such as quail manure, which is rich in nitrogen favoured the flourishing of microbes and the dehydrogenase activity to around 998.7, 3161 and 2218 µg g^{-1} soil h^{-1} (Table 4.10) during mesophilic, thermophilic and maturity periods respectively (Fig.5). Temperature hike has also favoured the growth and proliferation of microbes at the thermophilic stage of decomposition. This peculiarity can only be attributed to the nature of the substrate, as it is established that capacity of the microbes to assimilate a given substrate depends on its ability to synthesize the enzyme involved in the breaking down of complex compounds into intermediate simpler metabolites for synthesizing new microbial cellular materials (Gaur and Sadasivam, 1993).

5.1.5 Earthworm Count

For an emphasised study on the influence of introduced biotic agents, earthworm count was taken at two stages, one month and two months after introduction of earthworms. In general, the sieved substrates (O_1 and O_2), to which the two types of earthworms viz., *Eisenia foetida* and *Eudrilus eugeniae* were introduced gave more earthworm count compared to unsieved substrate (O_3) (Table 4.1.2). The unsieved substrates recorded high water retention while the 2 mm sieved substrates recorded a lower value. Hence, the 4 mm sieved substrates which recorded optimum moisture content and fine pattern of particles ranked first for the two types of earthworm population.

Among the substrates enrichment substrates, the quail manure enriched treatments influenced the counts of both the earthworm types significantly.

Among the two types, *Eisenia foetida* thrives best due to more cocoon production and much tolerance to temperature fluctuations. These observations were supported by the findings of increased hatching success of 73 per cent in *Eisenia foetida* compared to 50 per cent in *Eudrilus eugeniae* (Slejska, 1996). Moreover, the mean number of hatchlings per cocoon was also more in *Eisenia foetida*. The observations of Reinecke *et al.* (1992) who found wider tolerance of *Eisenia foetida* to temperature fluctuations compared to *Eudrilus eugeniae* together with the substrate controlled environmental factors as described in section 5.1.2. and 5.1.3. hold good here to explain the observed trends in earthworm activity vis-a-vis the treatment differences..

5.1.6 N, P and K Contents of Oushadhi Wastes and the Selected Enriched Compost

With respect to the Table 4.14 to Table 4.20 of initial and final nutrient contents of compost material as influenced by substrates, substrate enrichers, biotic agents and their interaction, the pertinent points are discussed as follows.

Regarding the variation in the initial nutrient concentration of the different materials, there is only a vague indication as the sampling was done immediately after the substrate enrichment. But, the data provides a clear indication that at the final stage of composting, there is notable increase in the nutrient contents of N and P irrespective of the treatments and treatment combinations. In general, initial N content ranged from 2.34 to 2.67 per cent in unsieved and 4 mm sieved substrates respectively (Table 4.14). The range of initial P content was from 0.290 to 0.337 per cent for 4 mm sieved and 2 mm sieved substrates respectively, while the values of initial K was in the range 0.846 to 0.876 per cent in unsieved (O_3) and sieved substrates (O_1 and O_2). With respect to the effect of substrates, both final contents of nitrogen and phosphorus were high in unsieved substrates as compared to 4 mm and 2 mm sieved substrates (Table 4.17). This is due to screening and discarding of fibrous and bulky material in the sieving process and thereby reducing the dilution effect of the nutrients per unit mass of the substrates. However, it is interesting to note that the K content of the 2 mm sieved substrates is higher than that of unsieved and 4 mm sieved at the final stage of composting. This may be due to the effect of particle size in changing the K concentration, besides the inherent low K content of the original oushadhi waste. Observations of Gaur *et al.* (1971) that the chemical composition of compost varies depending on the sources from which it is prepared can tender satisfactory explanation to this observation. Moreover, nitrogen mineralising as well as phosphorus solubilising organisms present during composting may increase the availability of those elements but due to the peculiar nature of the element potassium different micro-organisms have no role in increasing its availability. It is well known that K is not bound to any organic compound in the plant and organic matter decomposition is

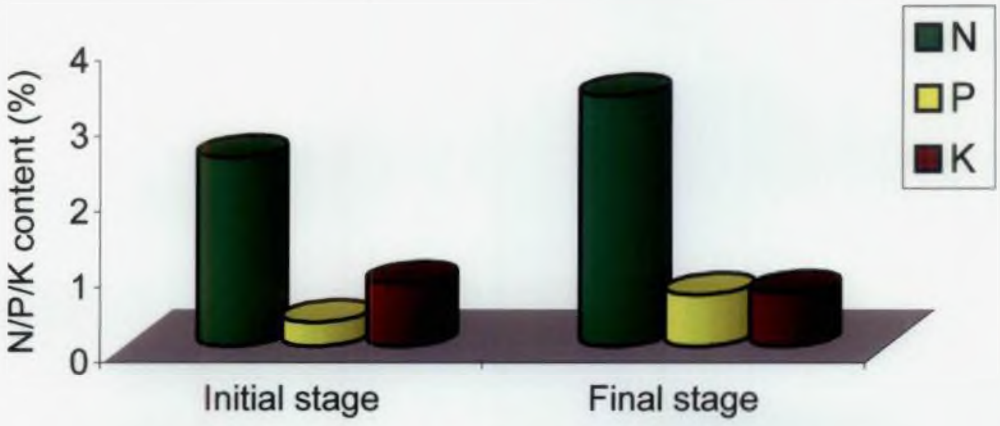

Fig.6 N P K contents at initial and final stages of composting, as influenced by *Eisenia foetida*

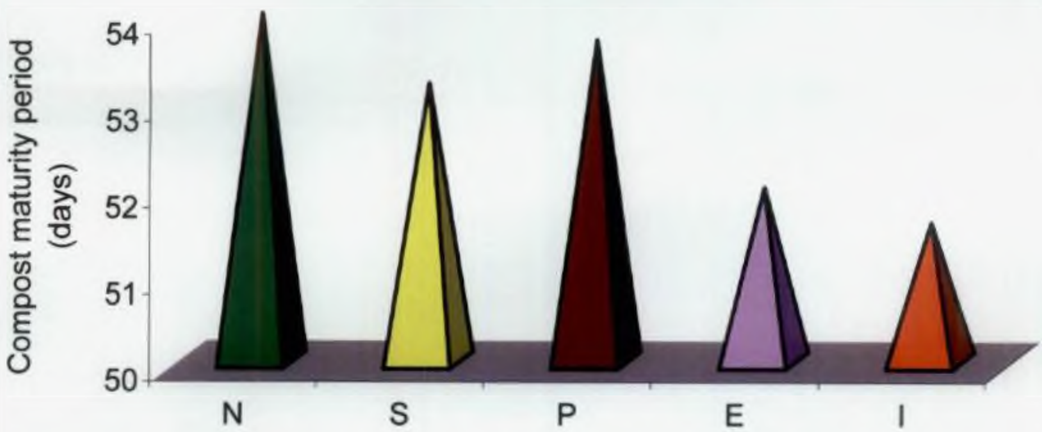

Fig.7 Influence of the different biotic agents on compost maturity period

not an index of potassium availability (Mengel and Kirkby, 1987). Also substrate itself have certain inhibitory factors which will retard the K availability during composting which needs further clarification.

With respect to the effect of enrichers maximum values of N and K content were noted in quail manure enriched treatments (Q), whereas the final P content was maximum in cowdung quail manure mixture (M) enriched treatments (Table 4.17). Higher content of nitrogen in quail manure (Appendix 2), togehter with the enhanced C:N assimilation as discussed under section 5.1.2. might have resulted in increased N content of the compost material.

There was a tremendous influence for the different biotic agents on the nutrient concentration of the final compost material. As compared to other treatments, the treatments inoculated with *Eisenia foetida* recorded the highest concentration of N, P and K with mean values of 3.37, 0.746 and 0.782 per cent respectively (Table 4.17). This is very clearly depicted in the figure 6. Sultan (1997) has reported the presence of readily available plant nutrients, growth enhancing substances, and number of beneficial micro-organisms like N fixing, P solubilising and cellulose decomposing organisms in vermi compost. The increased levels of N, P and K in earth worm casts have been reported earlier as well (Bano *et al.*, 1987 and Bano and Devi, 1996).

With respect to the influence of substrate-substrate enricher interactions, the supremacy of O_2M_2 in the case of final N content, O_3M_1 in the case of final P content and O_2Q_1 in the case of final K content may be substantiated in light of points discussed above.

5.1.7 C:N Ratio and Maturity Period of the Compost

C:N ratio is a major maturity parameter that determines the worth of compost as a manure. It clearly reflects the organic matter decomposition and stabilisation during composting. As composting proceeds, the microflora use the substrate with carbon as the energy source and the carbonaceous materials are converted to microbial biomass, CO_2, water and humus. Nitrogen is used for cell building. It is the major nutrient required by microorganisms in the assimilation of carbon compounds from the organic wastes. The decomposition involves the reduction of relative proportion of elements to a point where available carbon has been totally consumed and bacterial activity ceases. Monitoring the C:N ratio values (Table 4.20) as influenced by various substrates, it can be seen that at initial stages, for 4 mm sieved, 2 mm sieved and unsieved substrates, the values of C:N ratio were 32.1, 33.7 and 32.8 which got reduced in the final stages to 11.1, 11.2 and 11.4 respectively. On pooling the mean values for the three substrates, it can be observed that the initial C:N ratio which was around 32.9 decreased to a stabilised values of around 11.2 at the end of composting. According to Jimenez and Garcia (1992) C:N ratios ranging from 10 to 12 can be considered as an indicator of stable and decomposed organic matter. With respect to the influence of different substrates on the C:N ratio, it was seen that the lowest C:N ratio of 11.1 was observed in 4 mm sieved substrate with comparable values for other substrates as well, indicating the overall acceptability of the oushadhi waste as a good material for composting.

With regard to the substrate enricher influence on final C:N ratio, it was seen that the lowest value was observed in cowdung enriched treatments (C_2). Cowdung acts as a good substrate for proliferation of microorganisms thus facilitating enhanced carbon mineralization and thus C:N ratio values get decreased (Press *et al.*, 1996; Chawla, 1984).

Regarding the influence of biotic agents (Table 4.20) on the final C:N ratio the lowest value was observed in treatments where *Eisenia foetida* (I) were introduced which was closely followed by *Eudrilus eugeniae* (E) introduced treatments. Among the two types of fungal inoculum tried, *Schizophyllus communae* was considered as the most efficient organic matter degrader. Reduced time taken for composting was in line with reduced C:N ratio. On consideration of the effect of various biotic agents, it was seen that final C:N ratio was maximum for treatments in which no fungus or earthworms were introduced (N). Time taken for composting was also more in that case (Fig.7).

On perusal of the treatment combinations, it was seen that unsieved substrates enriched with cowdung-quail manure mixture (O_3M) showed the lowest maturity period

Unsieved Oushadhi wastes

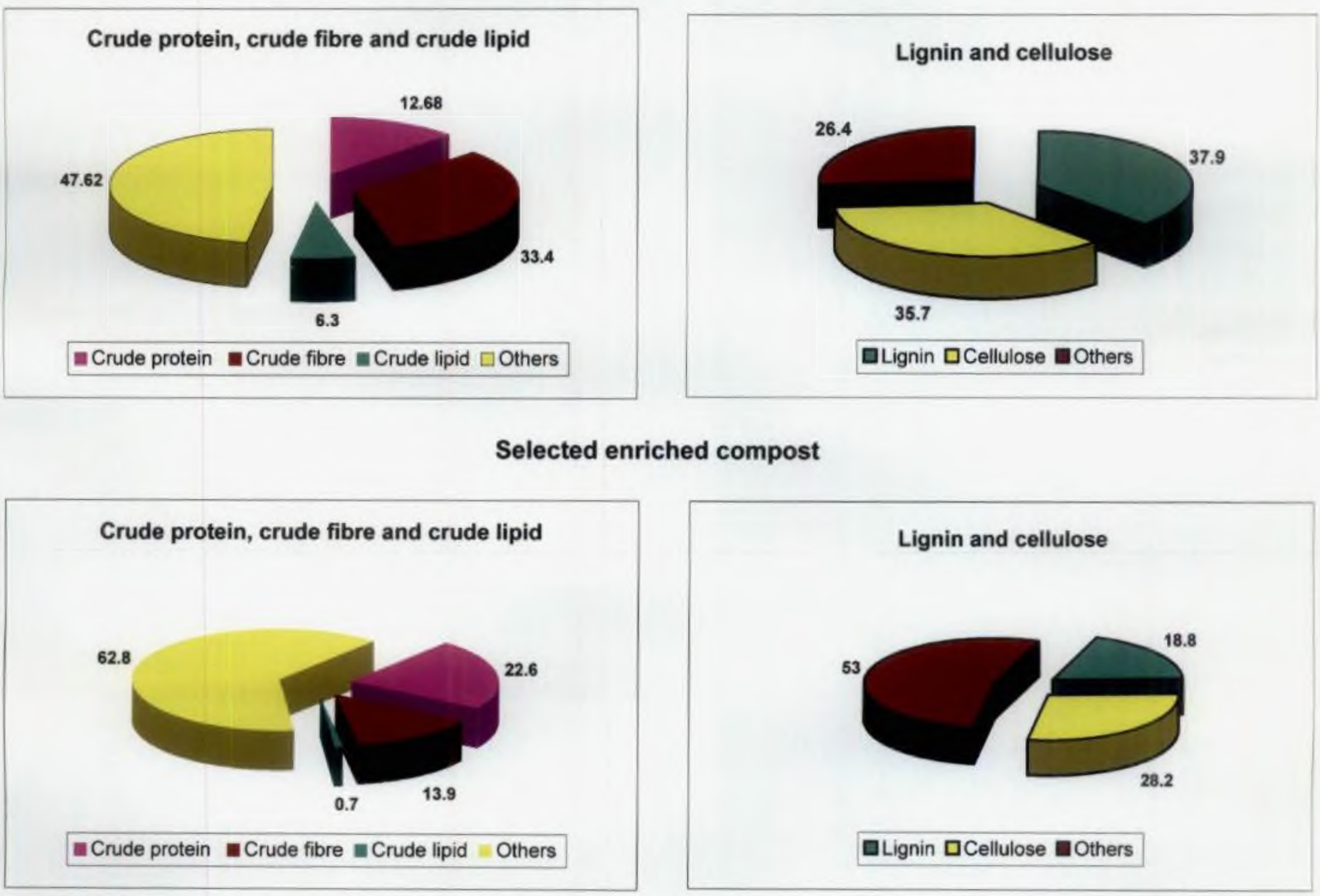

Fig.8 Biochemical compostion of unsieved Oushadhi wastes and selected enriched compost - a comparisc

of 49.7 days (Table 4.21). With reference to substrate enricher and biotic agent interaction (Table 4.22), it was seen that M_3I showed the lowest compost maturity period of 48.8 days. Clear evidence regarding the role of earthworms in the organic matter degradation and decomposition and lowering of C:N ratio was noticed. While passing the organic residues through the gut, the earthworms not only reduce the volume of the composting material by comminution but also favour the growth and multiplication of microorganisms especially N fixers and P solubilisers (Indira *et al.*, 1996). This favourably influence the C:N ratio which in turn is reflected in the compost maturity period as seen above.

5.1.8 Studies on the Selected Enriched Compost

The selected enriched compost (unsieved substrates enriched with 5 per cent mixture of cowdung and quail manure inoculated with *Eisenia foetida)* maintained a stable C:N ratio of 11.4 which gives an indication of the maturity attained by the same. Moreover, the compost was odourless. This is because, most well stabilised composts had a pH range near neutral which reduced the volatilisation of ammonia and other odorous compounds (Wilson, 1989). Moreover, the earthworm gut acts as a tubular bioreactor with a built in oxygen plant which can separate aerial oxygen by chemical absorption into blood haemoglobin thus producing an aerobic condition and hence a deodorizing effect of the resultant vermicompost. Regarding the nutrient content, the N, P and K contents of the selected enriched compost were 3.62, 0.85 and 0.89 per cent respectively which was appreciably higher than ordinary composts which had values of 1.08, 0.46 and 0.95 per cent of N, P and K respectively (Zacchariah, A.S., 1994).

Regarding the biochemical composition (Fig.8), the crude protein content increased to 22.6 per cent from the value of 12.6 in the original unsieved waste material as detailed in section 4.1.9. The crude protein increased due to the proteinacious nature of earthworm casts. The protein content and amino acid content of protein meals made from *Eisenia foetida* and *Eudrilus eugeniae* were very high (Lee, 1985). The crude lipid and crude fibre contents were reduced to 0.7 and 13.9 per cent respectively. Ravankar *et al.* (1998) have observed maximum degradation of crude fat and crude fibre in *Eisenia foetida* introduced treatments. Lignin and cellulose contents also showed a reduction from the original unsieved waste material. This may be because of the increased activity of lignocellulolytic degrading organisms present in the earthworm gut. Also, the microbial population capable of degrading bacterial cell walls were present in large amounts in the compost heaps at various stages of composting. Similar findings of high rate of lignolysis in vermicompost and decreased C:N ratio reflecting the changes in carbon fractions as well as higher proportions of nitrogen were reported by Vinceslas *et al.* (1997).

With respect to the macroorganisms encountered at various stages of composting (Table 4.24), it was seen that millipedes and centipedes which were more in thermophilic and maturity stages favoured the composting processes. Tian *et al.* (1995) have found that combined application of millipedes and earthworms resulted in greater plant residue breakdown than when earthworms were introduced alone. The predatory mites and predatory earwigs were found in larger number during the later stages, ie., at maturity stage. Similar observation were also made by Idinger and Kromp (1997), which are in agreement with the observations of the present study vide table 4.24.

5.2 Soil-Crop response studies

5.2.1 Growth and yield parameters

From the results of the present investigation as detailed in 4.2.1, it can be seen that the application of manures and fertilizers always imparted significant effect on the vegetative growth of amaranthus. The vegetative growth involves the formation of new leaves and elongation of the stem. The influence of vermicompost was highly evident in all the growth characters studied. Plant height and number of leaves were found to be maximum with the treatment that received the highest dose of vermicompost and full dose of NPK fertilizers (T_5) (Table 4.26). The same treatment exerted much superiority over the treatment which received almost the same dose of FYM and fertilizers (T_3). This clearly indicates the influence of vermicompost on improved plant metabolism leading to higher utilisation of plant nutrients and hence improved vegetative growth. The vegetative growth of vermicompost treated plants is enhanced by the release of plant growth promoting compounds by the earthworms into their casts (Nielson, 1965) which can increase the polymerisation of aromatic compounds thereby accelerating the humification and growth characteristics (Neuhauser and Hartenstein, 1976; Neuhauser *et al.*, 1978). In contrast to FYM, the presence of higher amounts of nitrogen fixing bacteria (Indira *et al.*, 1996) in the vermicompost may lead to an increased N content of the soil by biological N fixation which is taken up by the crop and used for improved vegetative growth. The increased plant height arising out of rapid meristematic activity due to positive influence of vermicompost application has been reported by Shuxin *et al.* (1991)

The yield of a crop may be considered in biological as well as agricultural terms. Biological yield refers to the total dry matter production of the crop whereas the economic yield takes into account the production of only the harvestable portion for which the crop is grown. For crops like amaranthus, the amount of plant materials produced above ground ie. the stems and leaves accounts for the economic yield. As the harvestable produce is the end result of effective sinking of photosynthetic assimilates (Bidwell, 1974; Devlin and Witham, 1986), yield is influenced by vegetative as well as yield attributing characters. The dependence of vegetative growth stage on yield lies on the fact that during vegetative growth, green plant tissues are formed which provide photosynthates for the entire plant growth. As meristematic tissues have a very active protein metabolism, photosynthates transported to these sites are predominantly used for the synthesis of nucleic acids and proteins. So, nitrogen nutrition plays a major role in this aspect, which is clearly indicated by the increased yield in treatments receiving higher amounts of nitrogen (Fig.9). So, the treatment T_5, receiving the highest dose of vermicompost and full dose of NPK fertilizers, which recorded the maximum value for vegetative growth characters naturally gave maximum values for yield also.

The results of the study also emphasises the need for balanced fertilizer application because almost similar yield as that of full dose of vermicompost and full dose NPK fertilized treatments (T_5) were obtained in treatments receiving half dose of vermicompost and full dose of NPK (T_8). This is because after a critical limit, any

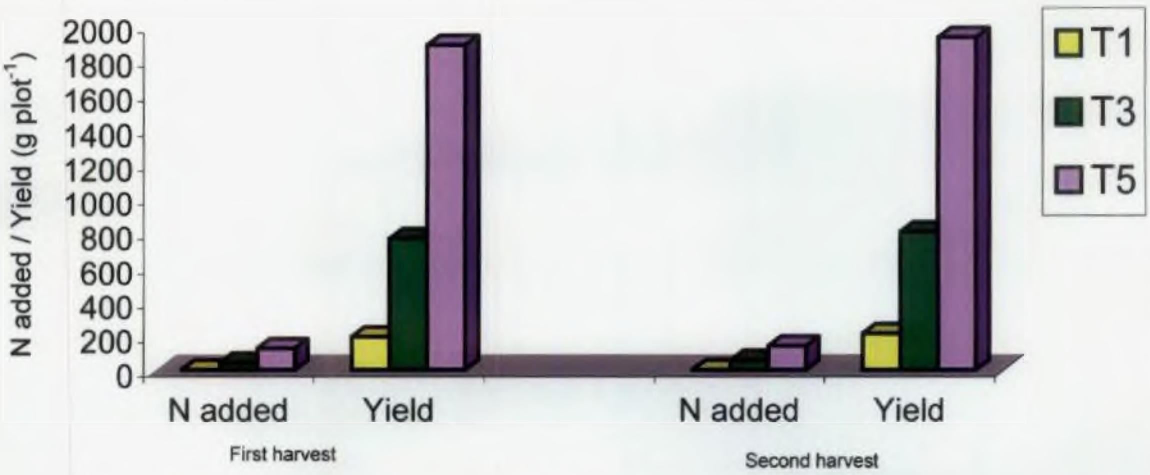

Fig.9 Nitrogen added Vs. yield for T_1, T_3 and T_5 at two stages of harvest

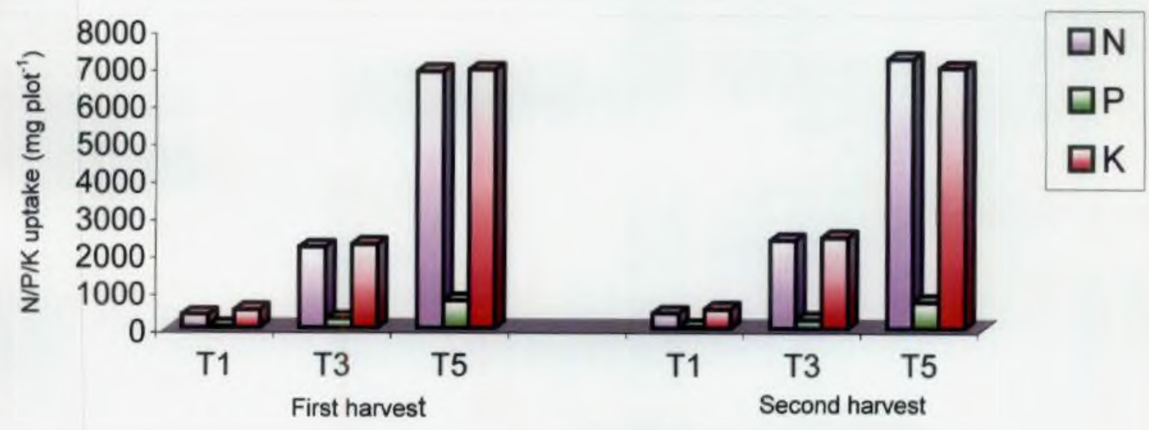

Fig.10 Uptake of N, P and K in T_1, T_3 and T_5 at two stages of harvest

addition of fertilizer becomes waste and tend to inflate the cultivation expenditure and associated environmental consequences (Tisdale *et al.*, 1995). Doubling the dose of NPK fertilizers did not produce corresponding yield doubling in the present study. This can be attributed to the fact that the economic produce need not always increase linearly with addition of nutrients especially beyond a critical limit and there is an observed insensitiveness in yield with increased NPK application (Savithri *et al.*, 1991; Lavanya and Manickam, 1993).

Another significant inference arrived at from the results in the present investigation is that complete substitution of inorganic fertilizers with the organic fertilizers like vermicompost is not advisable. This point needs clarification. The per centage nutrient content of organic manure like vermicompost in comparison with equal quantity of an inorganic fertilizer is very less and so very large quantities of vermi compost is needed to maintain the nutrient balance which is not a feasible proposition. Moreover, the nutrients in inorganic fertilizers are in water soluble form which are readily available to plant roots while the nutrients supplied through organic manures would become available for the crop, only slowly (Kumaraswamy, 2002). The relatively slow release of nitrogen by organic fertilizers in comparison with inorganic nitrogen fertilizers may be due to the effect of certain environmental factors, concerned with the release of nitrogen. The conversion of amino nitrogen and the heterocyclic nitrogen of organic substances via., reduction to ammoniacal nitrogen and subsequent oxidation to nitrate nitrogen is accomplished by a number of soil microbes whose metabolic activities are highly dependent on soil conditions. The increased number of nitrogen fixers and phosphorus solubilising organisms in the vermicompost compared to FYM as well as the improved physical environment created by worms results in higher availability of N and P thus contributing to higher yields (More, 1994). Thus, on comparison of FYM and vermicompost, the easy availability of nutrients from vermicompost may be the reason for increased yields in T_4 treatment with 5 t ha^{-1} of compost compared to T_2, the treatment with 5 t ha^{-1} of FYM. However, sustained productivity and profitability of short duration crops under organic farming needs to be explored in expanded investigations.

5.2.2 Nutrient uptake

Nutrient uptake by different crops is a fairly good guide for the response of crop to fertilizers. The amount of nutrients taken up by a plant is a function of the available nutrients in the soil. The crop yield can also be considered as a function of the nutrient extracted from the soil under well defined conditions. Thus, increased nutrient uptake (Fig.10) can be related to increased dry matter productions. The treatment T_5 which recorded the maximum dry matter production also recorded maximum uptake of all the nutrients (Table 4.28). Higher rate of metabolic activity with rapid cell division brought about by vermicompost application have resulted in higher uptake of nutrients and this might have resulted in increased utilization of nitrogen (James *et al.*, 1967). Higher levels of N, P and K nutrition favouring the plant content of those nutrients was previously reported Haris (1989). Vegetables are generally heavily manured with organic manures. A balanced use of NPK fertilizers are also needed to obtain good yields of these crops. In the case of vegetables crops like amaranthus, the responses to Nitrogen are more couspicuous. However Phosphorus and Potassium are also essential for the production of good quality vegetables.

5.2.3 Studies on Soil Characteristics

The objective of manuring is to improve the nutritional status of the soil by increasing the pool of nutrients present in them so as to raise the yield from a lower to higher level. Ideally the nutrient added should supplement the nutrients already present in the soil so as to supply to the plants just the correct amount of available nutrients so that the fertility balance as a whole should be such as to produce good crop.

The pH of the soil was seen to be increasing considerably in the case of post harvest soil for almost all the treatments and the highest pH of 6.5 was observed in T_4, the treatment in which 5 t ha^{-1} compost alone was applied. The worm casts are very much close to neutral pH range than the surrounding soil and the possible factors that act on pH may be NH_4^+ excretion and addition from calciferous glands (Mulongoy and Bedoret, 1989). Conversion of organic N to NH_3 and further to NH_4^+ temporarily reduces the pool of H^+ in the soil. Earthworm significantly raised the pH of humus and the effect of earthworms on the soil pH was probably due to an increase in the concentration of ammoniacal nitrogen (Haimi and Huhta, 1990).

This enhanced soil pH is favourable for N fixation, since at low pH, nitrogen fixation will be inhibited by high H^+ ion concentration as well as the presence of high Fe or Al ions in laterites (Mohan *et al.*, 1987). Phosphorus solubilising bacteria, nitrogen fixing organisms and entamophagous fungi were observed in the range of 10^5 to 10^6, which are seen to induce many biochemical transformation leading to better availability of nutrients in the soil. Process of aminisation, ammonification and oxidative deamination brought about by microbially mediated enzyme systems are active in vermicompost leading to better availability of soluble nutrients in soils treated with vermicompost. The higher available phosphorus in treatment T_5, receiving 5 t ha^{-1} of vermicompost and full dose of NPK may be because of the comfortable C:N ratio of 10-12 of the selected vermicompost which helps in the easy release of inorganic phosphate from insoluble rockphosphate. Also, the high microbial activity and enhanced mineralisation of soil phosphorus coupled with high phosphatase and phytase activity have resulted in high soil available phosphorus (Alexander, 1978).

The increased available potassium in the post harvest soil may be due to the faster degradation of the organic matter leading to better mineralisation pattern consequent to high microbial activity resulting in release of more basic cations like K^+ (Ammal and Muthiah, 1994). Similar findings of high potassium build up in soil solutions of vermicompost treated soil, due to high microbial and enzyme activity in the vermicompost have been reported by Basker *et al.* (1994).

The response of a particular crop to a given fertilizer, either organic or inorganic, cannot be foretold because when placed in contact with the soil and crop, the reaction may occur both chemically and biologically, affecting its efficiency. In the present field study, an attempt has been made to highlight the various soil and plant factors affecting the response of the crop to various levels of vermicompost and inorganic fertilizer application and to suggest the soil and crop management to increase the efficiency of the same based on field studies.

Summary and Conclusion

6. SUMMARY AND CONCLUSION

Study on the "Biotic Enrichment of Organic Wastes from Ayurvedic Preparations", was conducted at College of Horticulture, Vellanikkara during the period 2001-2003. The experiments included: (i) an incubation study, to standardise the best substrate controlled micro-environment and to identify the promising biotic agent in the composting of ayurvedic wastes obtained from the Oushadhi Pharmaceutical Corporation and (ii) a field study near Vegetable Farm, Department of Olericulture with the crop amaranthus, to evaluate the effectiveness of the best selected enriched compost on crop and soil.

In order to standardise the substrate controlled micro environment, the Oushadhi wastes, a light brown coloured neutral material with a moisture content of 52% and high values of crude protein (12.68%), crude lipid (6.3%), crude fibre (33.4%), Cellulose (35.7%) and liginin (37.9%) was sieved through 4 mm and 2 mm sized sieves for obtaining the prescribed substrates. Unsieved substrate material was used as a control. Substrates were mixed with organic enrichers like cowdung, quail manure in different proportions, and then inoculated with two species of fungi, two types of earthworms and the composting was carried out till the material attained maturity. Observations on temperature (daily), pH (fortnightly), dehydrogenase activity and macro organisms count (at mesophilic, thermophilic and maturity stages) and earthworm count (monthly) were recorded.

The nutrient contents of N, P, K and compost maturity were assessed and the best selected enriched compost was taken for field studies with Amaranthus. Observations on growth and yield attributes, nutrient uptake and soil nutrient status were taken during the field study. The salient findings are summarised below:

1. Enrichment techniques

- During the composting process the temperature raised to a high value of 39.4°C after 10 days, then decreased and finally stabilised to 27°C in 2 mm sieved substrates, thus defining three distinct stages of composting – mesophilic, thermophilic and maturity. Other group of substrates also showed the similar trend.

- At all stages of composting, 2 mm sieved substrates registered higher values of temperature compared to unsieved substrates. The 2 mm sieved substrates registered the highest values of 39.4^{0}C while the unsieved substrates registered the lowest value of 36.2°C at 10th day of composting.

- With respect to enrichers, the maximum temperature hikes were observed in quail manure enriched treatments. For example, after 10 days Q_2 (38.4°C) and Q_3 (38.3°C) recorded the maximum temperatures compared to other enrichers.

- The pH value of all type of substrates showed a definite trend with a rise in value and then a decrease and stabilization at the end of composting. For instance a rise in value to 7.97 at second fortnight and then a decrease to a value of 7.09 and subsequent stabilization to 6.31 at the end of composting was observed in 4 mm sieved substrates.

- Regarding the influence of biotic agents on pH compared to others, *Eudrilus eugeniae* and *Eisenia foetida* introduced treatments gave higher values of 7.95 and 7.98 respectively (at second fortnight).

- The dehydrogenase activity in µg TPF g^{-1} soil h^{-1} showed a definite pattern of variations with an increase from a low initial value to very high values at thermophilic stage and then, a subsequent decrease by the end of composting. However, at compost maturity period the activity was always higher than that at initial mesophilic stage, indicating clearly the proliferation of micro-organisms in matured compost.

- *Eisenia foetida* showed higher multiplication rates in Oushadhi ayurvedic wastes, compared to *Eudrilus eugeniae,* with 7.3 times multiplication (one month after inoculation) and 23 times multiplication (two months after inoculation), while the corresponding values for *Eudrilus eugeniae* were 5.8 times and 22.8 times.

- Regarding the effect of substrate enrichners on the nutrient contents of compost, the maximum values of N (3.40%) and K (0.749%) were noted in quail manure enriched treatments, while the maximum P content (0.770%) were noted in cowdung-quail manure mixture enriched treatments.

- Reduction in K content of the compost material in comparison with the original waste was a significant observation in all the treatment combinations.

- C:N ratio of the Oushadhi Waste material showed a reduction from values of 32.1 (4 mm sieved), 33.7 (2 mm sieved) and 32.7 (unsieved) to corresponding values of 11.1, 11.2 and 11.4 at the final stage of composting.

- Regarding the compost maturity period, the lower values 51.1, 50.8 and 50.2 days were observed in 5, 10 and 15 per cent cowdung-quail manure mixture enriched treatments, compared to other substrate enrichners.

- The selected enriched compost was deep black in colour and was odourless, with a neutral pH of 6.8 and moisture content of 29.8 per cent

- The selected enriched compost had a nutrient content of N (3.62%), P (0.85%) and K (0.89%).

- Cellulose and lignin components of the selected compost were 28.8 and 18.8 per cent which was a reduction from the original values of 35.7 and 37.9 per cent in unsieved Oushadhi wastes, pointing out the possibility of ligno-cellulolytic breakdown during composting.

- Macro-organisms like millipedes and centipedes, favouring the biocomposting process were found in large numbers during mesophilic and maturity stages. The predatory mites and earwigs were observed in large numbers, during the maturity stages.

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2. Soil-Crop Response Studies

- The maximum yield of 1881 g $plot^{-1}$ (first harvest) and 1921 g $plot^{-1}$ (second harvest) were noted in treatment T_5, where full dose of NPK along with 5 t ha^{-1} of selected enriched vermicompost were applied.

- The dry matter production was higher in treatment T_5 (9.617 g $plant^{-1}$) during first harvest as well as second harvest (9.837 g $plant^{-1}$). However, in all the treatments, there was always an increased drymatter production during the second harvest, compared to the first harvest.

- During first harvest, N uptake was maximum in T_5 (6855 mg $plot^{-1}$) and minimum in T_1 (343.5 mg $plot^{-1}$). During second harvest also, the same trend was seen with T_5 recording a value of 7183 mg $plot^{-1}$ and T_1 recording a value of 389.6 mg $plot^{-1}$.

- P uptake during first and second harvests were recorded maximum in treatment T_5, with values 733.5 and 696.2 mg $plot^{-1}$ respectively. However, a decrease in P uptake was noticed during the second harvest.

- Treatment T_5 recorded the maximum uptake of K during the first harvest (6902 mg $plot^{-1}$) and the second harvest (6937 mg $plot^{-1}$).

- The pH, CEC and organic carbon content of the post-harvest soil showed a hike from the initial values, irrespective of the treatments. The treatment T_4, receiving 5 t ha^{-1} of selected enriched compost, recorded the maximum CEC value of 6.9. The highest content of organic carbon (1.82%) was recorded in T_5.

- Available N, P and K in the post harvest soil showed much higher increased values compared to the initial status representing the build up of nutrients in the soil. The maximum values of available N (390.2 kg ha^{-1}) and available P (27 kg ha^{-1}) were recorded in T_5 while the maximum content of available K was noted in T_4 (119.4 kg ha^{-1}).

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** Original not seen*

Appendices

Appendix 1 Treatment notations of the 135 treatment combinations

Treatment	*Treatment notation*	*Treatment*	*Treatment notation*
T_1	O_1C_1N	T_{35}	O_1M_1I
T_2	O_1C_1S	T_{36}	O_1M_2N
T_3	O_1C_1P	T_{37}	O_1M_2N
T_4	O_1C_1E	T_{38}	O_1M_2P
T_5	O_1C_1I	T_{39}	O_1M_2E
T_6	O_1C_2N	T_{40}	O_1M_2I
T_7	O_1C_2S	T_{41}	O_1M_3N
T_8	O_1C_2P	T_{42}	O_1M_3S
T_9	O_1C_2E	T_{43}	O_1M_3P
T_{10}	O_1C_2I	T_{44}	O_1M_3E
T_{11}	O_1C_3N	T_{45}	O_1M_3I
T_{12}	O_1C_3S	T_{46}	O_2C_1N
T_{13}	O_1C_3P	T_{47}	O_2C_1S
T_{14}	O_1C_3E	T_{48}	O_2C_1S
T_{15}	O_1C_3I	T_{49}	O_2C_1E
T_{16}	O_1Q_1N	T_{50}	O_2C_1I
T_{17}	O_1Q_1S	T_{51}	O_2C_2N
T_{18}	O_1Q_1P	T_{52}	O_2C_2S
T_{19}	O_1Q_1E	T_{53}	O_2C_2P
T_{20}	O_1Q_1I	T_{54}	O_2C_2E
T_{21}	O_1Q_2N	T_{55}	O_2C_2I
T_{22}	O_1Q_2S	T_{56}	O_2C_3N
T_{23}	O_1Q_2P	T_{57}	O_2C_3S
T_{24}	O_1Q_2E	T_{58}	O_2C_3P
T_{25}	O_1Q_2I	T_{59}	O_2C_3E
T_{26}	O_1Q_3N	T_{60}	O_2C_3I
T_{27}	O_1Q_3S	T_{61}	O_2Q_1N
T_{28}	O_1Q_3P	T_{62}	O_2Q_1S
T_{29}	O_1Q_3E	T_{63}	O_2Q_1P
T_{30}	O_1Q_3I	T_{64}	O_2Q_1E
T_{31}	O_1M_1N	T_{65}	O_2Q_1I
T_{32}	O_1M_1S	T_{66}	O_2Q_2N
T_{33}	O_1M_1P	T_{67}	O_2Q_2S
T_{34}	O_1M_1E	T_{68}	O_2Q_2P

Appendix 1 contd.....

Treatment	*Treatment notation*	*Treatment*	*Treatment notation*
T_{69}	O_2Q_2E	T_{103}	O_3C_3P
T_{70}	O_2Q_2I	T_{104}	O_3C_3E
T_{71}	O_2Q_3N	T_{105}	O_3C_3I
T_{72}	O_2Q_3S	T_{106}	O_3Q_1N
T_{73}	O_2Q_3P	T_{107}	O_3Q_1S
T_{74}	O_2Q_3E	T_{108}	O_3Q_1S
T_{75}	O_2Q_3I	T_{109}	O_3Q_1E
T_{76}	O_2M_1N	T_{110}	O_3Q_1I
T_{77}	O_2M_1S	T_{111}	O_3Q_2N
T_{78}	O_2M_1P	T_{112}	O_3Q_2S
T_{79}	O_2M_1E	T_{113}	O_3Q_2P
T_{80}	O_2M_1I	T_{114}	O_3Q_2E
T_{81}	O_2M_2N	T_{115}	O_3Q_2I
T_{82}	O_2M_2S	T_{116}	O_3Q_3N
T_{83}	O_2M_2P	T_{117}	O_3Q_3S
T_{84}	O_2M_2E	T_{118}	O_3Q_3P
T_{85}	O_2M_2I	T_{119}	O_3Q_3E
T_{86}	O_2M_3N	T_{120}	O_3Q_3I
T_{87}	O_2M_3S	T_{121}	O_3M_1N
T_{88}	O_2M_3P	T_{122}	O_3M_1S
T_{89}	O_2M_3E	T_{123}	O_3M_1P
T_{90}	O_2M_3I	T_{124}	O_3M_1E
T_{91}	O_3C_1N	T_{125}	O_3M_1I
T_{92}	O_3C_1S	T_{126}	O_3M_2N
T_{93}	O_3C_1P	T_{127}	O_3M_2S
T_{94}	O_3C_1E	T_{128}	O_3M_2P
T_{95}	O_3C_1I	T_{129}	O_3M_2E
T_{96}	O_3C_2N	T_{130}	O_3M_2I
T_{97}	O_3C_2S	T_{131}	O_3M_3N
T_{98}	O_3C_2P	T_{132}	O_3M_3S
T_{99}	O_3C_2E	T_{133}	O_3M_3P
T_{100}	O_3C_2I	T_{134}	O_3M_3E
T_{101}	O_3C_3N	T_{135}	O_3M_3I
T_{102}	O_3C_3S		

Appendix 2 Nutrient composition of the organics and inorganics used in the experiment

Items	Nutrient composition (%)		
	N	P	K
1. Cowdung	0.80	0.50	0.60
2. Quail manure	1.50	1.40	0.75
3. Urea	46.00	-	-
4. Rockphosphate	-	20.04	0.21
5. Muriate of Potash	-	-	60.00
6. Selected enriched compost	3.62	0.85	0.89

Appendix 3 Atmospheric temperature values at 10 days interval for a period of two months of composting

Days after composting	Temperature (°C)
0	27.02
10	27.11
20	26.98
30	27.25
40	27.03
50	26.92
60	27.10

BIOTIC ENRICHMENT OF ORGANIC WASTES FROM AYURVEDIC PREPARATIONS

By

PREETHA D.

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the requirement for the degree of

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Kerala Agricultural University

Department of Soil Science and Agricultural Chemistry

COLLEGE OF HORTICULTURE

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ABSTRACT

The study on the 'Biotic Enrichment of Organic Wastes from Ayurvedic Preparations' was conducted at College of Horticulture, Vellanikkara, during the period 2001-2003 using ayurvedic wastes from Oushadhi, the Pharmaceutical Corporation (Indian Medicines), a Government of Kerala undertaking. The investigations were undertaken to standardise the substrate controlled micro-environment as well as to identify the promising bioagents for the composting of Oushadhi wastes and to determine the effect of the best selected enriched compost on soil and plant.

The standardisation of the best substrate and enrichment techniques were based on the principle of aerobic composting. The collected wastes were grouped into three different size categories such as unsieved, 4 mm sieved and 2 mm sieved. The enrichers used were cowdung, quail manure and their 1:1 mixtures, each at 5, 10 and 15 percent levels respectively. As the introduced biotic agents, two types of earthworms (*Eudrilus eugeniae* and *Eisenia foetida*) and two fungal inoculi (*Schizophyllus communae* and *Pleurotus platypus*) were tried. They were compared with native macrofauna and microflora so as to monitor their respective role in the composting process.

Analysis of the alkaloid rich Oushadhi wastes with aromatic odour revealed that it contains the nutrients N, P and K as 2.03, 0.33 and 0.85 percent respectively. Biochemical composition of the same, included crude protein (12.67%), crude fibre (33.4%), crude lipid (6.3%), cellulose (35.7%) and lignin (37.9%).

The temperature within the treatments of compost was recorded daily and the fluctuations of pH were noted at fortnightly intervals. Based on these parameters, three distinct stages of composting as mesophilic (upto 10 days), thermophilic (10-30 days) and maturity (30-60 days) were identified. Dehydrogenase activity was maximum (3119.3 μg TPF g^{-1} soil h^{-1}) at thermophilic stage, followed by maturity and mesophilic stages. After the thermophilic stage, the earthworms were introduced and the counts with

respect to *Eudrilus eugeniae* were more than that of *Eisenia foetida* at the two stages of sampling.

Based on the C:N ratio (11.4) and the least time take n (48 days) for maturity the best treatment was selected, which registered manurial contents of N (3.62%), P (0.85%) and K (0.89%). In the same material, the biochemical constituents of crude fibre (13.9%), crude lipid (0.7%), crude protein (12.68%), lignin (28.2%) and cellulose (18.8%) were determined. The best means of composting involves the use of the unsieved substrate which must be enriched with 5 per cent mixture of cowdung and quail manure (1:1 ratio) and later vermicomposted with *Eisenia foetida*.

So as to evaluate the effect of the selected enriched compost, the much responsive crop amaranthus was field tested for a period of two months. The selected enriched compost was tested at two rates (5 t ha^{-1} and 2.5 t ha^{-1}), with and without full and half levels of recommended package of NPK fertilizers, along with FYM and absolute control. Recording of growth and yield parameters, nutrient uptake studies and determination of nutrient removal were undertaken during the period of study, April-May 2003. The results indicated that with higher doses (5 t ha^{-1}) of the selected enriched compost along with 50:50:50 NPK gave the maximum yield followed by the treatment in which 2.5 t ha^{-1} of selected enriched compost along with 50:50:50 NPK was applied.