EFFICIENCY OF VERMICONVERSION AND DECOMPOSITION OF FARM RESIDUES ON SOIL HEALTH, YIELD AND QUALITY OF BANANA (*Musa spp.*)

by

MAYADEVI, M. R.

(2012 – 21 - 126)

THESIS

Submitted in partial fulfilment of the
Requirement for the degree of

DOCTOR OF PHILOSOPHY IN AGRICULTURE

Faculty of Agriculture
Kerala Agricultural University

Department of Soil Science and Agricultural Chemistry

COLLEGE OF HORTICULTURE

KERALA AGRICULTURAL UNIVERSITY

THRISSUR 680656

KERALA, INDIA

2016

DECLARATION

I, hereby declare that this thesis entitled **"EFFICIENCY OF VERMICONVERSION AND DECOMPOSITION OF FARM RESIDUES ON SOIL HEALTH, YIELD AND QUALITY OF BANANA (*Musa spp.*)"** is a bona-fide 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, associateship, fellowship or other similar title, of any other University or Society.

Vellanikkara
22.07.2016

Mayadevi, M.R
(2012-21-126)

CERTIFICATE

Certified that this thesis, entitled **"Efficiency of vermiconversion and decomposition of farm residues on soil health, yield and quality of banana (*Musa spp.*)"** is a record of research work done independently by **Ms. MAYADEVI, M. R.** 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.

Vellanikkara
22.7.'16

Dr. P. K. Sushama
(Major Advisor, Advisory Committee)
Professor (Retd.) (Soil Science
and Agricultural Chemistry)
Kerala Agricultural University,
Vellanikkara

CERTIFICATE

We, the undersigned members of the Advisory Committee of **Ms. Mayadevi, M.R., (2012-21-126)**, a candidate for the degree of **Doctor of Philosophy in Agriculture** with major in **Soil Science and Agricultural Chemistry**, agree that the thesis entitled **"Efficiency of vermiconversion and decomposition of farm residues on soil health, yield and quality of banana (*Musa* spp.)"** may be submitted by **Ms. Mayadevi, M. R.** in partial fulfilment of the requirements for the degree.

22/7/16
Dr. P. K. Sushama
(Chairperson, Advisory Committee)
Professor (Retd.)
Department of Soil Science and
Agricultural Chemistry
College of Horticulture, Vellanikkara

22.07.16
Dr. Jayasree Sankar, S.
(Member, Advisory Committee)
Professor and Head
Department of Soil Science and
Agricultural Chemistry
College of Horticulture, Vellanikkara

22.7.16
Dr. Mercy George
(Member, Advisory Committee)
Associate Director of Research
Kerala Agricultural University
Vellanikkara

22/7/16
Dr. K. Nandini
(Member, Advisory Committee)
Professor and Head
Department of Plant Physiology
College of Horticulture, Vellanikkara

Dr. S. Krishnan 22/7/2016
(Member, Advisory Committee)
Professor and Head
Department of Agricultural Statistics
College of Horticulture
Vellanikkara

22/7/2016
External Examiner
Dr. C.T. Subbarayappa
professor, Dept. of SS&AC
UAS, GKVK,
Bengaluru-560065

Acknowledgement

I wish to place on record my heartfelt thanks to the beacon light, the moving spirit, the great source of stimulating, intellectual inspiration, ***Dr. P. K. Sushama,*** *Professor (Retd.), Department of Soil Science & Agricultural Chemistry, for reposing full confidence in my ability to work and write on a subject, for her unceasing, and steadfast encouragement, patient counseling and guidance. Ever since, she has supported me not only by providing a research guideship over almost four years, but also ethically and emotionally moulding me through the rough roads to finish this thesis. I wish to gratefully thank her for her motherly care and constant inspiration, without which this thesis would not have seen the light of the day.*

I express my whole hearted gratitude to ***Dr. Rema Menon.****, Professor (Retd.), Banana Research Station, Maraikkal, Kannara and my advisory committee member for her expert advice and valuable suggestions throughout the conduct of field experimentation and research.*

My sincere and heartfelt thanks to ***Dr. Jayasree Sankar, S****, Professor and Head, Department of Soil Science and Agricultural Chemistry, Member of my Advisory Committee for her affection, constant encouragement and patience to listen to me and console me to overcome the riddles.*

I am deeply indebted to ***Dr. K. Nandini****, Professor and Head, Department of Plant Physiology, and member of my Advisory Committee for the extreme care, timely guidance and constructive criticisms throughout the conduct of my course work and research.*

I remember with great sense of gratitude and indebtedness to ***Dr. Mercy George****, Associate Director of Research, Kerala Agricultural University, Vellanikkara and member of my Advisory Committee, who offered her frequent field visits, critical suggestions during the course work and research programme.*

My sincere heartfelt gratitude is due to ***Dr. S. Krishnan,*** *Professor and Head, Department of Agricultural Statistics and member of my Advisory Committee for his expert advice and timely help in doing the statistical analysis and interpretation of data.*

No word can truly express my deep sense of respect, gratitude and indebtedness to ***Dr. P. Sureshkumar, Dr. Betty Bastin, Sri. S Visweswaran,, Dr. K.***

M. Durgadevi, Dr. Beena, V. I., Smt. Bhindu, P. S., Smt. Rajalekshmi, my beloved teachers *in the Department of Soil Science and Agricultural Chemistry who supported me with critical insights, encouragement and consoled me during my hardships. I deeply pay honour and respect* ***Dr. P. S. John****, Professor (Retd.) for his inspiring talks and joyous ambience.*

On a personal note, I am fortunate in having ***Dr. A. C. Aipe, Dr. K. Anita Cherian, Dr. Manju*** *and* ***Dr. Gavas*** *Banana Research Station, Kannara, with me during the entire period of field experimentation. A word of thanks to* ***Dr. Nirmala Devi****, Professor, Department of Olericulture,* ***Dr. Diji Bastin****, Professor, Department of Plant Breeding and Genetics and* ***Dr. Sreeja*** *for their esteemed advice and timely help throughout the doctoral programme.*

I owe my deep indebtedness to ***Dr. Thomas P. Thomas, Dr. M. P. Sujatha, Dr. Suma, Dr. Jayaraj, Ms. Kripa, P. K.,*** *and* ***Ms. Ninu Jose (KFRI, Peechi)*** *for their support and assistance during the course of my research.*

I am extremely grateful to ***Dr. Sindhu S., Dr. Divya Vijayan, Dr. Aryalekshmi, V., Dr. Geetha, P., Dr. Savitha Antony, Dr. Syama S. Menon****, for their never-ending earnest friendship and valuable suggestions. I owe my sincere thanks to* ***Mr. Rajendra Babu and Mr. Sunny of Banana Research Station*** *for their kind co-operation and providing all facilities in time to carry out the field experiments. Sincere thanks are due to* ***Smt. Bindu Regi, Saradha Chechi, Malathy Chechi, Baby Chechi, Prasad, Vijithra Chechi, Sreenath and Saritha, Sreela, Sheena*** *for the timely help during the conduct of my research and lab analysis.*

Special thanks to my juniors ***Ms. Vysakhi, Irene, Rincy, Anuja, Aswathi, Aneesa, Beena, Sridhar, Adithya, Amrutha, Mr. Ramana*** *and* ***Mr. Arun*** *for their help, care, affection and joyous company. I place deep love and special thanks to* ***Devi chechi and Suma chechi*** *who were helping hands and honest advisors at my sixes and sevens. I owe much and is forever deeply indebted to my* ***achan, amma,*** *and* ***Soumya*** *for their support and blessings. There are no words to express my gratitude to my* ***mother –in – law*** *for her sacrifice, love and support encouragement and blessings. My heartfelt regards to* ***Sandhya*** *and* ***Appus*** *for their love, care and concern. I feel blessed and graced to have my husband,* ***Sandeep*** *and daughter* ***Sreeya*** *for their support, sacrifice and affection.*

***Senior Research Fellowship** of **Kerala Agricultural University** is greatly acknowledged. My deep gratitude is due to **College Library** and **Central Library** for being a valuable cradle of information.*

(Mayadevi, M. R)

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

Introduction

1. INTRODUCTION

India, primarily an agrarian economy has vast majority of its land in farming with wide range of crops cultivated in its different agro-ecological regions. With a burgeoning population to feed and crop intensification, it is, but natural, that a huge volume of crop residues are produced both on-farm and off-farm. It is estimated that approximately 500-550 Mt of crop residues accounting to about 61 percent of the total organic wastes, are produced annually in the country (Manna *et al.,* 2012). These crop residues are put to multitude of uses like animal feed, soil mulching, bio-manure, thatching for rural homes and fuel for domestic and industrial use. Nevertheless, in recent years a large portion of these residues is burnt or left unattended on-farm primarily due to shortage of human labour, high cost of removing the crop residues by conventional methods and use of combines for harvesting of crop.

Bananas and plantains occupy the fourth most important universal food commodity which generates about 220 t of crop waste ha^{-1}. It ranks second next to mango, among the fruit crops cultivated in the world. Total world production of banana is107 mt. In India, it is cultivated in an area of 8.3 lakh ha (11.1% of total fruit area) with a production of 30 mt. Banana contributes 33.4 percent to the total fruit production in India with a productivity of 37mt ha^{-1}. In Kerala, banana is a major fruit crop raised on plantation scale. The total area under banana in Kerala is 34460 ha. Current production of banana is 528210 mt and productivity is 15 mt ha^{-1} (NHB, 2014). *Nendran* is popular cultivar in the state due to its market and commercial inclinations. It occupies 50 percent share of total banana export from Kerala. Owing to the huge biomass generation in the form of fibrous pseudostem, leaves, bunch peduncle and rhizomes after the harvest of bunches, banana residue offers great scope for recycling and use in the subsequent crop. At present, these biomass particularly pseudostem is absolutely treated as waste in most of the states of India and farmers incur about ₹8000 to ₹10000 ha^{-1} for disposing pseudostem. Moreover disposal of pseudostem in regular ways like dumping on field bunds and burning, depositing in natural drains *etc.* causes severe environmental hazards.

Waste recycling is neither a modern concept nor a stunning momentary craze. It is only that the urgency, intensity and complications of reprocessing of wastes has gone up many folds and is continuing. Crop residues are an important source of organic matter which is easily available at low or no cost. In our country, the low productivity of soils is attributed to scanty organic matter reserve of the soil particularly in areas where fertilizer is being used in escalating extent year after year without adequate enhancement of organic matter. Crop waste recycling and subsequent incorporation to soil as organic manures can bring up the much needed organic and mineral matter in the soil. As the available natural resources like land, soil and water are over exploited and shrinking day by day, these resources are to be effectively utilized without affecting the natural equilibrium. Effective utilization of these wastes will also help in reducing the over emphasis on mineral fertilizers. More competent and adaptable crop waste processing technologies should emerge which, if applied, on appropriate quantities, can uplift the recyclable wastes into the mainstream of farm input management strategies.

It is well established that life sustaining programmes should focus on nutrient fortification of soil by incorporation of crop derived organic matter. As such, new avenues to maintain soil health by recycling of crop wastes are setting trends. Proper management of these residues is very essential as these wastes contain different types of plant nutrients and can be converted into useful substances by recycling process in agriculture. Rapid depletion of nutrients from soil by the over use of high analysis fertilizers and intensive nutrient mining have ruined native soil health and quality. A healthy soil is the one which has adequate quantities of organic matter 'the store house' of nutrients and beneficial micro and macro organisms like earthworms. Healthy soils are the basis of healthy ecosystem and it is a paradox that the general health and wellbeing of soil is deteriorating day by day especially due to the non-application or non-availability of organic manures.

Application of organic amendments to the soil system will significantly increase humic fractions, the most active components of soil organic matter in soil, and have multiple effects that can greatly benefit plant growth and soil quality. The escalating costs of chemical fertilizers and its undesirable effects on soil properties have led to inclusion of organic manures in cultivation of crops. Incorporation of crop residues into soil or converting them into composts is an easy way of waste disposal and managing the organic matter requirement of soils. Composting has got several positive influences on physical, chemical and biological properties of soil. For example, the crop residues act as a reservoir for plant nutrients, increase cation exchange capacity, prevent leaching of nutrients, increase microbial biomass, provide congenial environment for biological N_2 fixation and enhance activities of enzymes such as dehydrogenase and phosphatases. Increased microbial biomass can enhance nutrient availability in soil as well as act as sink and source of plant nutrients. Converting substantial amounts of crop residues into *in-situ* composts will not only help to sustain soil health but also provide a low cost viable option to manage farm wastes: Besides this, the role of crop residues on carbon sequestration in soils would be an added advantage in relation to global climate change mitigation strategies. Establishment and maintenance of soil health is inextricably linked to the achievement of effective and efficient nutrient management in different cropping systems. Proficient nutrient management with minimal ecosystem injury is thus possible only with the recycling and reuse of potential organic resources like livestock and human wastes, crop wastes, tree wastes and aquatic weeds, urban and rural wastes, agro-industries by-products, tank silt and marine wastes.

In India, among the waste utilization strategies, composting and (or) vermicomposting are proven "waste to wealth" technologies. Composting is essentially a microbial alteration of mixed organic substrates, under controlled conditions into hygienic, humus rich, relatively bio-stable product which can be used to improve soil physical conditions and nourish crop plants. Vermicomposting on the other hand, is mesophilic oxidative conversion of organic matter to mucus coated granular worm casts through the combined action of microorganisms and earthworms. Earthworms ingest large quantities of soil and organic remains and grind them in its gizzard. When the plant material passes through gizzard it mixes with intestinal fluid, enzymes and microbes, segregates into fragments which in turn increases contact area for microbial colonization. Out of the total ingested material, more than 90 percent is excreted as mucus coated granular worm casts. Activity of beneficial microorganisms in worm castings is 10 to 20 times higher than that of in the soil. The crawling movement of earthworms create channels which add to the aeration of compost pile. Hence vermicomposting is faster than thermophilic composting. Worm castings contain up to 5 times the plant available nutrients found in furrow slice soil. Vermicompost contains on an average 1.5 - 2.0 percent N, 1.8 - 2.2 percent P and 1.0 - 1.5 percent K. In our country, the major problem of low productivity of soils is attributed to low organic matter content of the soil particularly in areas where fertilizer is being used in increasing quantity year after year without adequate supplement of organic matter (IARI, 2012).

At present *ex-situ* methods of crop waste vermiconversion is adopted in most agricultural systems. In states like Kerala, where wages and labour charges are high, this adds to the cost of production. Hence exploring methods to effectively utilize farm wastes at the site itself will cut down the waste management costs drastically and improve soil health at the planting sites. Besides this, the planting sites get enriched with useful physicochemical and biological components added during the decomposition by worms.

Most of the work on earthworms in India is confined to vermicomposting using exotic earthworm species and very little information is available on the indigenous fauna of worms with respect to their utility in vermicomposting or in improving soil health. Exploring the effect of these *in-situ* developed vermicomposts (using both exotic and native earthworms) *vis–a–vis* crop and soil health will help to further the cause of such methodologies in organic banana cultivation.

Farming community urgently need a sustainable substitute which is both cost-effective and productive without harnessing soil health and ecological balance. The modern concept of organic farming relies on ecological farming which focuses on production of pollution free food and environment.

Vermicomposting and its avenues can certainly suggest the best answer for ecologically sustainable agriculture. Hence it may be concluded that the most important beneficiary from organic farming and allied activities is our ecosystem. Thus, the present project proposes to evaluate the efficacy of exotic and native worms in converting the farm residues to useful compost and the benefits, both to soil and crop, added thereupon.

The project is formulated with the following objectives.

1. To compare the efficiency of native and exotic earthworms in vermiconversion of farm residues
2. To assess the effects of different modes of vermicomposting on soil health, yield and quality of banana and
3. To study the *in-situ* decomposition of banana crop residues

Review of Literature

2. REVIEW OF LITERATURE

The present investigation entitled "Efficiency of vermiconversion and decomposition of farm residues on soil health, yield and quality of banana (*Musa spp.*) was undertaken at College of Horticulture, Vellanikkara and Banana Research Station, Kannara during 2013-2015 in order to meet the objectives as detailed in chapter 1. Literature on the importance of farm residue recycling, exploitation of native earthworm species for compost preparation and decomposition dynamics of the organically grown banana residues are discussed in this chapter along with importance of organic farming in soil health management.

2.1. Farm residues

Farm residues, the leftover portion of crops after the harvest of produce are agro-wastes produced from farming activities. The various agro-wastes include animal manures, bedding, plant stalks, hulls, leaves, and vegetable matter. In farming situation, these wastes are often useless and will be discarded. The accumulation of agro-wastes may create alarming health, safety, environmental, and aesthetic concern which represent a problem with its safe disposal. Farm residues contain insoluble chemical constituents such as cellulose and lignin and soluble constituents like sugar, amino acids, and organic acids. Other constituents are fats, oil waxes, resins, pigments, protein, and minerals. The decaying part of plants is the primary source of organic matter in soil. Therefore, farm residues are the cheapest source that can be used by farmers to improve the fertility of soil. Every year, human, livestock and crops produce approximately 38 billion tons of organic waste worldwide. In India, it had been reported that from 1.2 billion people, about 1113.6 mt of wastes are being generated annually and the rate of per capita waste generation is boosting at a rate of 1.0 to 1.33 percent per year (Bhat *et al.,* 2015). Out of the estimated total annual production of 679 mt (61% of the total crop production) of crop residues, 369 mt of animal dung, one third of crop residues and half of animal dung were being recycled for use in agriculture in India (Manna *et al.*, 2012). It is reported that about 90-93 mt of crop residues were burnt in Indian farms (IARI, 2012) to clear the field for the subsequent crop. Being easy and cheap, burning of crop residues in the field practised everywhere. This practices augmented air pollution, increased soil erosion and caused respiratory problems and increased fog incidences even in the cities (Singh and Nain, 2014). Recent reports pointed out that surplus crop residues to the tune 141 mt and fruit and vegetable wastes of about 1.81 mt were being generated in India. The highest contributor of crop wastes is cereals (58%) followed by fibre crops (23%). Horticultural and plantation sector also contribute farm residues to the tune of 263.4 mt out of which 134 mt is available for recycling. According to IARI (2012) in Kerala, out of the total 9.74 mt of crop waste, 5.07 mt waste was available for recycling. These are left abandoned in heaps as garbage which emit foul smell and turn out to be potential breeding grounds for insects, rodents and pathogens and thus pollute air, soil and aquatic environments. The pathogens were transmuted and much dreadful diseases like dengue fever, malaria and plague are spreading day by day. This situation is going to be worsened in the ensuing years, with accelerated urbanization and scarcity of land areas. Moreover the increased usage of pesticides, high analysis fertilizers and plant protection chemicals add to the irreversible degradation of the air, water and soil. Hence in order to bring back the ecosystem health and sustainability, the generated wastes are to be recycled. The multi functionalities and significances of farm residues are discussed hereunder.

2.1.1. As a nutrient rich organic manure

Farm residues have unique physical and chemical properties. They retain certain proportion of nutrients which have not been translocated to the produce. On an average crop residues could supply about 5.60 million tonnes of N + P_2O_5 + K_2O to soil (Manna *et al.,* 2012). Crop residues in general, are low density fibrous materials. The quantity and quality of crop residues greatly influence its organic matter and nutrient contents. Out of the total residues generated about 50 percent is contributed by cereals and oilseeds. Normally these residues restrain about 0.5percent N, 0.2 percent P_2O_5 and 1.5 percent K_2O. The average mineral composition of various crop residues are shown in Table 2.1. Assuming utilization

Table 2.1. Average mineral composition of crop residues

Plants parts	P	K	Ca	Mg	Na	Fe	Zn	Cu	Mn	References
	(%)				(mg 100g^{-1})					
Banana pseudostem	0.2-0.3	5-6.5	0.4-0.6	0.20	4-6	150-160	20-25	2-5	30-45	Wobiwo *et al.*, 2015
Rice straw	0.12	1.58	0.53	0.24	130	400-500	30-40	2-5	100-140	Sarnklong *et al.*, 2010
Rubber litter	0.5-1.0	1-2	24	4-5	-	500-550	15-20	5-10	160 -180	Murbach *et al.*, 2003

of 50 percent of the total residues as cattle feed and fuel, the nutrient potential of the residual biomass was 6.5 million tons of NPK per annum, which could manage 30 percent of total NPK consumption in India (Singh and Nain, 2014). Hence the reprocessing of crop wastes is not only an ecological necessity but, in a country like India, it is an economic compulsion.

2.1.2. As an energy source

Biomass energy is an abundant renewable energy resource which can be converted by thermochemical, thermal, and biochemical ways to bioenergy in the form of biofuels, power and heat. The total energy supply capacity of biomass was expected approximately to 900 EJ year^{-1} which could provide global energy demand (Rahman *et al.,* 2016). Researchers at Kennedy Space Center (KSC) Advanced Life Support Breadboard Project had taken lead to utilize the higher plants as bioreactors on bio-regenerative aspects of space life supporting system for the production of food, oxygen and clean water (Strayer and Atkinson, 1997).

2.1.3. Technologies for residue reprocessing

A number of efficient crop residue recycling technologies had been emerged and proved their merits. However, fresh crop residues contain various forms of nutrients which may lead to salt build up and leaching losses on dumping in open places. It may also contain some weed seeds, pathogens and insects which may cause harm to the surroundings. Moreover, it is bulky in nature and difficult to handle. Among the technologies, composting is an excellent proven waste management strategy, which yield biologically stable organic matter, free of unpleasant odours and bulkiness. In addition, raw crop residues contain the nutrients in their recalcitrant forms which on composting transforms to humified matter through the activity of soil biota.

2.1.4. Thermophilic composting

Composting was reported as a self-heating, aerobic, solid state, oxidative, bio-degradative conversion of organic substrates under controlled conditions into a hygienic, humus rich bio-stable product *i.e.* compost (Manna *et al.*, 2012). Al-Barakah, *et al.* (2013) distinguished three phases of temperature during composting. The decomposition began with an initial a phase of dormancy during which microbes got adapted to the composting conditions to produce temperatures between 34 – 36 °C, secondly, a phase of rapid increase in temperature up to 64 °C followed by a phase of curing so as to return to its starting values of 34-38 °C.

Chandna *et al.* (2013) pointed out that the number of mesophilic bacteria had increased rapidly (1.7- 2.84 $\times$ 10^9 cfu g^{-1}) within ten days of composting. *Bacillus spp., Cellumonas spp., Aspergillus spp.* and *Fusarium spp.* dominated in the mesophilic stage of decomposition. (Manna *et al.,* 2012). Thermophilic bacteria were dominant from 11 to 32 days of composting, with a count in between 10^7 to10^8 cfu g^{-1}. In the thermophilic phase, Bacillus *spp., Humicolla spp., Micromonosperma spp., Nocardia spp.,* and *Streptomyces spp.*, led the decomposition process as reported by Manna *et al.* (2012). After cooling period, mesophilic population again dominated with a stabilized count between 10^5 and 10^6 cfu g^{-1}. It was also reported by Chandna *et al.* (2013) that 84.8 percent of isolates were Gram-positive, out of which 85.7 percent were rods and 14.3 percent were cocci, whereas, the remaining 15.2 percent of the isolates were Gram-negative rods. The most active period of decomposition was noticed at high temperature periods. Composting essentially reduces waste volume, destroys weed seeds and pathogenic microorganisms and produces valuable soil amendment and hence it can be easily applied in the field. It also curtailed the emission of greenhouse gases and could serve as best alternative to chemical fertilizers for vegetable production through reduction of disease symptoms as reported by Al-Barakah *et al.* (2013).

2.1.5. Factors affecting composting process

The major factors affecting composting process are moisture content, temperature, carbon to nitrogen ratio. Anand and Apul, (2014) recorded that aeration and moisture content of 50 to 60 percent, temperature 40 to 65 °C, carbon to nitrogen ratio 25 to 35, pH 5.5 to 8.0, and porosity 35 to 50 percent were the optimum values for composting,. In a study on composting using agricultural by-products, Chandna, *et al.* (2013) reported an increase in initial substrate electrical conductivity of 3.8 dS m^{-1} to 4.9 dS m^{-1} at 40 days of composting. Loss of biomass through the biotransformation of organic materials and subsequent mineralization of nutrient elements could have attributed to the increment in EC. The pH showed a stagnant value of 7.5 up to 30 days of the process, and thereafter declined slightly to 7.0 and continued till 50th day. Al-Barakah *et al.* (2013) ascribed the change in pH to formation of organic acids during the metabolism of relatively readily available carbohydrates, consumption of ammonia by microorganisms and as a result of volatilization of free ammonia to the air. Finally, the pH tended to stabilize due to humus formation with its buffering capacity on termination of composting activity.

Chandna *et al.* (2013) opined that during the composting of agricultural substrates, organic C decreased, whereas total N, P and K increased with time. Finally C: N ratio was observed to be stabilized at 11:1 at the end of composting during 40–50 days. The decrease in organic carbon was due to evolution and volatilization of CO_2 all through the biodegradation process by aerobic heterotrophic microorganisms.

Moldes *et al.* (2007) mentioned that, there was no fixed level of organic matter that is ideal for good quality compost, rather the qualities must be observed with regard to the age of compost, N content and proposed use. The increase in total nitrogen percent according to Al-Barakah *et al.* (2013) was due to increased oxidation of non- nitrogenous organic materials and partially to the non-symbiotic N_2- fixation by nitrogen fixing bacteria. Carbon to nitrogen ratio serves as a reliable parameter for the maturity of compost. Al-Barakah *et al.* (2013) demonstrated a decrease in C: N ratio during composting of agricultural waste mixed with different rates of sheep manure as organic activator from 64.8 - 39.2 to a progressive narrowing and stabilization up to 21.2- 13.6 after 90 days of composting. Many authors demonstrated that the C: N ratio of mature compost should ideally be about 10 (Gaur, 2009; Sushama *et al.*, 2010; Manna *et al.*, 2012), but this is scarcely ever attainable due to the presence of recalcitrant organic compounds, or materials which resist decomposition due to their physical or chemical properties. However, it is customarily accepted that compost might be considered as mature when C: N ratio was approximately 17 or less, unless lignocellulolytic materials remain (Moldes *et al.*, 2007; Al-Barakah *et al.*, 2013).

Composting could concentrate micronutrients (Zorpas *et al.,* 2002). The higher Fe content in compost than the other micronutrients was reported by Al-Barakah *et al.* (2013). Conversely, the contents of Mn, Zn and Cu were also recorded as moderate and increased until the maturity stage.

2.1.6. Methods or modes of Composting

Traditional methods implemented an approach of anaerobic or aerobic decomposition based on inactive aeration through little and occasional turnings or static aeration provisions like perforated poles or pipes which are time-taking. Alternatively, rapid methods accelerated the aerobic decomposition process and brought down the composting period around four to five weeks. In-vessel composting refers to a group of methods which confine the composting materials within a building, container, or vessel (Misra *et al.*, 2003).

Sommer, (2001) exhorted that covering the compost with a porous tarpaulin or compacting the compost reduced emission losses to 12–18 percent of total-N compared with a loss of 28 percent during composting of untreated deep litter. Covering the compost bed also reduced the leaching loss (8 -16 %) of K and volume of liquid leaching from the heaps.

2.1.7. Vermicomposting

Vermicomposting is composting using earthworms which are detritivores. They feed on relatively un-decomposed plant material, soil microorganisms, including fungi, bacteria, protozoa, amoebae, and nematodes. Though microorganisms are responsible for biochemical decomposition of substrates, earthworms are the drivers of decomposition. Their foregut mechanically blend the substrate and physically modify them. Worms are reported to develop a symbiotic relationship with microbes inhabiting their digestive tract (Manna *et al.*, 2012). The mucus found in the worm's intestine provides a favorable substrate for microorganisms, which in turn decompose complex organic compounds into simpler substances that are digestible by the worm. Some of the worm's mucus is excreted along with the casts and it continues to stimulate microbial growth and activity in the soil or compost. The high levels of ammonia and partially decomposed organic matter in casts provide a favorable substrate for microbial growth. Owing to the high levels of microbial activity and high decomposition rates, vermicompost was referred as potential biological manure or biofertilizer (Elvira *et al.,* 1998). Composting reduced the particle size, whereas particle size increased during vermicomposting due to the amalgamation of small particles. The organic residues forming the base of the compost food web are consumed by fungi, actinomycetes and other bacteria, and invertebrates including millipedes, sowbugs, nematodes, snails, slugs, and earthworms. It was reported that greenhouse gases were emitted during composting and vermicomposting process (Wang *et al.*, 2014). However, alternating aeration, bulking agents and earthworm abundance might reduce the greenhouse gases emissions. Meera (1998) reported that significantly higher contents of Ca, Mg and micronutrients were found in soils of vermicompost coated treatments at maximum flowering stage.

Chan *et al.*, (2010) reported that total Green House Gas emissions including N_2O and CH_4 were least (463 mg CO_2 equivalent m^{-2} h^{-1}) for vermicomposting, aerobic composting (504 mg CO_2 equivalent m^{-2} h^{-1}) and anaerobic digestion (694 mg CO_2 equivalent m^{-2} h^{-1}) respectively. Green House Gas emissions varied substantially with time and were synchronized with temperature, moisture content and the waste properties. Economic assessments of composting and vermicomposting technologies show that these technologies are generally viable (Lim *et al.*, 2016).

Singh and Mustaffa, (2009) reported that vermicompost obtained from decomposition of *Musa paradisiaca* waste by *Eudrilus eugeniae* was an effective bio-fertilizer which facilitated the uptake of nutrients by plants and resulted in higher growth and yield.

2.1.8. Type of earthworm species suitable for vermicomposting

Cleopatra declared earthworms as “sacred”. The use of vermicompost as a soil supplement was assumed to file by the Roman Statesman Cato circa 4 AD for the first time. It was started in Ontario, Canada in 1970. The legendary environmentalist Darwin (1881) pioneered in performing observations systematically on the role of earthworms in vegetable mould formation a century back. Since then, researchers all over the world conducted investigations on vermicomposting. Earthworms are omnipresent invertebrates belonging to the phylum *Annelida* and class *Oligochaeta.* They are long, thread like, elongated, cylindrical, soft bodied animals with segmented body. Based on the nature of diet, the earthworms are classified in to detrivorous and geophagous. Earthworms create tunnels in the soil through their movement. They eat away the compact soil and burrows of 3 to 12 mm in diameter are formed (Gajalakshmi, and Abbasi, 2004). The burrows are cemented internally by worm mucus. The food is moistened by alkaline enzyme secretions to digest starch. Earthworms excrete small organic waste as compact, concentrated, slimy worm casts.

Surface dwellers or epigeic species of earthworms were reported to have greater waste decomposing potential. *Eudrilus eugeniae*, *Eisenia foetida*, and *Perionyx excavatus* are the commonly used epigeic species of earthworms due to their high growth and multiplication rate on humus laden upper earth and manure pits (Gajalakshmi and Abbasi, 2004). These earthworms do not burrow much into the soil and hence had proved as efficient converters of organic wastes. Among these, *Eisenia foetida* has a tolerance over wide range of temperatures (5°C to 43°C). Hence are suitable for composting in tropical countries.

Nielson (1965) reported the first substantiation for the occurrence of indole compounds in the tissues of earthworm species *Aporrectodea caliginosa*, *Lumbricus rubellus*, and *Eisenia foetida*. Misra *et al.* (2003) exhorted the remarkable potential of *Eudrilus euginiae* for decomposing vegetable substrates with banana leaves (1:1) in terms of yield of humified fraction (39.24 %), higher population of actinomycetes and bacteria in the resultant compost and biomass production of young ones and cocoon production per 100gm of earthworm. Bijulal (1997) attributed through an incubation study of soil treated with vermicompost that there was an increase in the pH of the soil with vermicompost addition due to formation of ammonia through excretion of nitrogenous matter.

Srikanth *et al.* (2000) reported a slight decrease in bulk density of the soil amended with compost compared to inorganic fertilizer treatment. El Harti *et al.* (2001a, 2001b) ascribed the stimulation of rooting in bean seeds when treated with crude extract of the earthworm *Lumbricus terrestris* to the presence of indole compounds of endogenous origin. *Perionyx 'excavatus* is endemic species of earthworm suited better to Southern India (Gajalakshmi and Abbasi, 2004).

Comparative studies on life cycle assessment of two earthworm species by Tripathi and Bhardwaj (2004) found that cocoon production was higher for *Eisenia foetida* than *Lampito mauritii.* The net reproductive rate was 9 month^{-1} in the case of *Eisenia foetida* and one month^{-1} for *Lampito mauritii.* Fertilized eggs of *Eisenia foetida* and *Lampito mauritii* developed into adults within 4 to 5 and a quarter months, respectively. Padmavathiamma *et al.* (2008) reported that earthworm had absorbed more calcium from their diet to calciferous glands and excreted through digestive tract. Calciferous glands contained carbonic anhydrase enzyme which catalyse conversion of CO_2 to $CaCO_3$.

Eisenia foetida had been proved as efficient breeder by many authors (Tripathi and Bharadwaj, 2004; Suthar and Gairola, 2014). In another study on composting efficiency, Singh *et al.* (2014) recorded that the mean individual live weight, growth rate (mg worm $^{-1}$ day^{-1}) of earthworm were higher for *Perionyx excavatus* as compared to *Eisenia foetida.* Amaravathi and Reddy (2015) reported that the substrate having a mixture of organic waste, cow dung and soil in the proportion of 2:1:1 ratio were proved to be best for the earth worm *Eisenia foetida* whereas two substrates, mixture of organic waste, cow dung and soil in the proportion of 2: 1: 1 ratio and other mixture having organic waste and soil in the ratio of 3:1, showed better performance in the case of *Perionyx excavatus.* Effect of vermicomposting on growth stimulation and soil nutrient enhancement was brought out by many authors (Rajalekshmi, 1996; Arancon *et al.,* 2005)

2.1.9. Characterization of vermicomposts/ composts

Composting and vermicomposting are two aerobic bio-oxidative processes which differ in certain relevant aspects. In composting, the material transformation was mediated by microorganisms alone which have thermophilic phase and low water consumption, which ensured material hygiene. Vermicomposting on the other hand, occurs at an ambient temperature and high humidity (~80 %). It would seem that these factors affect the rate of organic matter transformation and quality of final products obtained, compost and vermicompost (Fornes *et al.*, 2012).

Traditional composts are reported to cause salinity, N immobilization and pathogen levels and become problematic when used as organic fertilizer (Sims 1990; O'Brien and Barker 1996; Chaoui *et al.*, 2003). On the other hand vermicomposts have been recommended by many authors (Chaoui *et al.*, 2003; Guo *et al.*, 2015) as a safe fertilizer to plants. Swarnam *et al.* (2016) prepared vermicompost from coconut husk mixed with either pig slurry or poultry manure and reported that compost maturity parameters significantly differed and well correlated among the treatments. The characteristics of different treatments established the maturity indices as C: N ratio of 15–20; Humic C/Fulvic C ratio > 1.5 and Humification Index > 15.0.

Nutrient contents in compost are critical indices for determining composting quality. Considerable nitrogen losses can occur during the composting (Wu *et al.*, 2010). Evaporation of ammoniacal nitrogen and denitrification together with leaching losses accounting to the total of 77 percent were reported by Martins and Dewes (1992). According to Steniford (1987), the compost quality produced through traditional compost technology was inferior and did not emphasize the nutritional values especially for N. Therefore, development of compost technology should be oriented to control nutrient losses.

Padmavathiamma *et al.* (2008) reported that humic acid content in vermicompost was 28 percent higher than that of compost. Miezah *et al.* (2008) confirmed the presence of plant growth hormones in compost using the relative fluidity (Rf) values of the chromatography and also bioassay. They also reported that compost contained 42 to 248.8 mg kg^{-1}, 33.1 to 198.3 mg kg^{-1} and 10.1 to 200.2 mg kg^{-1} of auxins, cytokinins and gibberellins respectively. Activity of β-Glucosidase, alkaline phosphomonoesterase and proteases were significantly higher in the vermicompost amended soil than in those treated with inorganic fertilizer (Lazcano and Domínguez, 2011).

2.1.10. Spectroscopic characterization of compost/ vermicompost

Amir *et al.* (2003) confirmed by Fourier Transform Infra-Red and ^{13}C Nuclear Magnetic Resonance spectroscopy that initial compost substrates were composed of heterogeneous, etherified aromatic structures with long-chain lipidic, peptidic and carbohydrate structures. They also reported that during the progress of composting there had been an increase in aromaticity.

2.1.11. Quality of vermicompost

Esakkiammal *et al.* (2015) revealed that the population of beneficial organisms like P solubilizing bacteria, N fixing organisms and entomophagous fungi was in the range of 10^5 and 10^6 in vermicompost. On an average vermicompost contained 1.5 to 2.2 percent N, 1.8 to 2.2 percent P and 1.0 to 1.5 percent K. According to Adhikary (2012), earthworms fed on various organic wastes and reduced the volume by 40 to 60 percent. Single earthworm weighs to about 0.5 to 0.6 g and eats wastes equal to its body weight. It generates casts corresponding to about 50 percent of the waste ingested per day. The moisture content of worm castings ranged from 32 to 66 percent and the pH was roughly 7.0 (Adhikary, 2012).

Experiment on changes in the chemical composition of banana peel-based wastes alone (B) and in conjunction with either cow dung (BC) or poultry litter (BP) under aerobic and anaerobic conditions revealed a significant mineralization in the order BP > BC > B. Rate of decomposition was remarkably faster under aerobic than anaerobic composting conditions (Kalemelawa *et al.*, 2012). An investigation on efficacy of lignophenolic compost on suppression of soil borne plant pathogen by Mathew *et al.* (2015) revealed that the composting along with microbial consortium resulted in drastic reduction of C: N ratio of composts from 47 to 81percent. Nair and Sushama (2014) mentioned that enrichment of substrates with lignin degraders like *Aspergillus flavus* and *Bacillus subtilis* was found effective in vermicomposting elephant dung with *Eudrilus eugineae.* Study on role of micro and microfauna on *in-situ* decomposition of elephant dung by Nair and Sushama (2014) revealed that the temperature of degrading dung was always higher and confirmed that natural decomposition is a continuous process.

Haynes and Zhou (2016) compared chemical, physical and microbial properties of thermophilic composts and vermicomposts using the same municipal green waste-based feed stocks and claimed that greater organic matter decomposition had occurred during composting than vermicomposting. Thermophilic composts had significantly lower organic C content and a greater content of total N, extractable Mg, K, Na, P, and mineral N, a higher EC and a lower C: N ratio than the vermicomposts. They had also reported that irrespective of the feedstocks, vermicomposts had a lower bulk density and greater total porosity and macroporosity than composts.

Preetha (2003) reported that the composting of oushadhi waste enriched with cowdung and or quail manure using biotic agents like *Eisenia foetida* manifested 3.62 percent N, 0.85 percent P and 0.89 percent K within a maturity period of 48 days. An investigation on enrichment of coir pith through organic amendments by Sushama *et al.* (2010) revealed that the microbial population was significantly higher in thermophilic stage. In an experiment to assess quality of composts and vermicomposts produced from cattle manure and green wastes blended at different ratios under tropical conditions by Sierra *et al.* (2013), it was reported that carbon losses were greater (55 %), of which one third during stabilization phase of vermicomposting for products with a high green waste content. Although organic matter content was similar for all the final composts, respiration measurements indicated that organic matter stability was greater for vermicomposts due to the simultaneous humification and decomposition during vermicomposting. Sierra *et al.* (2013) also demanded that vermicomposts had a higher microbial biomass C than the composts and among all three feed stocks, basal respiration and metabolic quotient were greatest for vermicomposts. According to them, composting was a robust process suitable for treatment of a range of organic wastes but, because of the nutritional requirements of the earthworms, vermicomposting was lesser robust and was only suitable for the cattle manure-amended feedstocks.

Ngo *et al.* (2012) reported that compost and vermicompost amendment significantly retained higher lignin content than the mineral fertilizers. Pant *et al.*

(2009) ascribed crop growth stimulatory effect of vermicompost to N uptake by plants. The four basic ways with which humic and fulvic acids in humus were essential to plants as listed by Canellas et al. (2000) sighted by Sivananthi and Paul (2014) were the capability for nutrient extraction from soil; dissolution of unavailable minerals to make organic matter; stimulation of root growth; augmenting stress tolerance.

2.2. Nutrition in banana

Banana is a major staple food crop for millions of people as well as provides income through local and international trade. According to Singh *et al.* (2011), Banana was grown around 150 countries across the world on an area of 4.84 million ha generating 95.6 million tons of produce. India is the largest producer of banana in the world, with 28.45 million tonnes of production from an area of 8 lakh hectares with a productivity of 35.7 million tonnes ha^{-1}. Although India has only 11.9 percent of world's banana grown area, it accounts for 37.2 percent of world's production (NHB, 2014). Owing to the versatile uses and high economic returns, it was referred to as "kalpatharu" i.e. a plant of virtues (Kathirvel, 2007). Banerjee (2010) reported while discussing on the economics of banana cultivation under organic and inorganic cultivation regimes, that cost of cultivation of organic bananas stood lower (₹39750/-) as against inorganic farming (₹ 56300/-). Though organic cultivation of banana could manifest lower yield difference of 10 tonnes ha^{-1} only as against inorganic farming, health consciousness of the people made them pay premium prices for the organic bananas which encouraged farmers to bring more area under organic banana and fetched more income per unit volume of produce.

2.2.1. Studies in laterite soils of Kerala

Yield and quality of banana are much affected by nutrition. In Kerala, the farmers are applying 300:115:450g N: P_2O_5: K_2O plant^{-1} + FYM at the rate of 20 kg plant^{-1} as per KAU (2011). This is applied in six split doses which coincided with the plant development.Nambiar *et al.* (1979) reported that split application of fertilizers produced higher bunch weight for banana plants in laterite soil. Murthy *et al.* (1995) studied the absorption of fertilizer N by *robusta* banana and reported that the fertilizer N applied at early and late vegetative stage was absorbed rapidly which decreased gradually at harvest. Robinson (1996) reported that banana plants had a higher demand for N and K. Sheela and Nair (2001) reported that increase in height and girth of pseudostem from fifth month after planting was attributed to increased hormonal activity at bunch initiation stage. The positive effect of increasing plant height due to increased levels of K was reported by Sheela and Nair (2001).

2.2.2. Yield and yield attributes of banana as influenced by organic and inorganic nutrition

Banana need optimum fertilization for production of bunches with maximum bunch weight, fruit size. An undiminished hike in the use of chemical fertilizers could impose irreversible damage to land and environment. Experts pointed out that the fertilizer use efficiency of the crops was only 30 to 35 percent and the remaining 65 to 70 percent of fertilizers reached the underground water resources, which along with phosphates pollutes water bodies (Katyal, 1989). To avert this, immeasurable decrease in fertilizer consumption without compromising on yield and quality could be achieved, by the inclusion and massive of generation of eco-friendly nutrient generating components such as organic manures, biofertilizers and biocontrol agents so as to prevent chemical contamination of food and to make sick soil healthy and productive.

Banana fruits accounted for removal of 49 to 56 percent primary nutrients, 32 to 45 percent secondary nutrients, and 4 to 55 percent micronutrients from the plants with a production of 50 tonnes ha^{-1} (Robinson and Sauce, 2010). Hence there is an immense urgency to replenish the nutrients back to the soil by on-farm residue recycling. Due to heavy mining of nutrients by banana, nutrient efficient variety should be integrated with application of organic manures in tune with crop needs. Vermicomposting enabled production of high quality organic manures for use in organic culture from crop residues using compost worms. Vermicomposts significantly stimulated the growth of a wide range of plant species including several crops such as tomato (Hashemimajd *et al.*, 2004), pepper (Arancon *et al.*, 2004, Arancon *et al.*, 2005), and fruit crops such as banana and papaya (Cabanas-Echevarria *et al.*, 2005). Increased productivity of crops, in response to vermicompost amendments had been attributed to greater availability of mineral nutrients, (Werner and Cuevas, 1996), rich microbial populations (Nisha, 2007) and presence of plant growth-influencing substances such as plant growth hormones and humic acids (Arancon *et al.*, 2003; Bindhu, 2010)

Bhalerao *et al.* (2010) reported that application of 25 percent N through FYM and 75 percent through inorganic fertilizer significantly increased the growth and yield parameters with reduced crop duration in banana cv. *Rajapuri.* Studies conducted by Vanilarasu and Balakrishnamurthy (2014) on the effect of organic manures, organic amendments and green manures in comparison with inorganic fertilizers reported that pseudostem height and girth was maximum in inorganic fertilizer treated plots due to the effect of chemical fertilizers that supply nutrients in readily available form to the plants immediately after application particularly for nitrogen. The absorbed nitrogen ultimately leads to the formation of complex nitrogenous substances like proteins and amino acids to build up new tissues.

Ability of vermicompost to sustain soil fertility for long period of time had already been brought out by Bijulal (1997). Padmavathiamma *et al.* (2008) reported that vermicomposts treated banana plants produced more number of functional leaves, pseudostem girth, bunch height, number of hands per bunch, number of fingers per bunch and girth of fingers. Abraham (1998) reported that application of fertilizers in combination with organic matter or FYM had recorded significantly N, P and K uptake by banana *cv. nendran.*

Bijulal (1997) recommended that lower doses of vermicompost (10t ha^{-1}) could be equated with higher doses of farm yard manure and ordinary compost (20 t ha^{-1}). Athani and Hulamani (2000) reported that combination of recommended dose of fertilizers recorded the maximum days of ripening and yield in both plant and ratoon crop of banana *cv. Rajapuri.* Saha *et al.* (2008) claimed that soil phosphatase activities were significantly correlated with available P in vermicompost. The application of earthworm casts induced faster transformation of organic P by facilitating better environment to microbes and plant roots (Saha *et al.*, 2008).

2.2.3. Growth characteristics of banana as influenced by modes of nutrition

The third leaf in the succession of leaves from top at the time of shooting was the best for leaf analysis to determine the nutrient status of the plant (Hewitt, 1955). Thangaselvabai *et al.* (2009) observed a direct relationship between leaf N, P, Ca and Mg and reciprocal relationship between leaf N and K. Any crop management practice should aim in keeping the physiological processes of the plants in a favourable condition so as to attain maximum yield. Indole Acetic Acid is a premier bioregulator regulates the growth of meristematc tissues. IAA oxidase is the enzyme responsible for the destruction of auxin. Therefore the high enzymatic activity causes reduction in auxin content and decrease in yield (Abraham, 1998). The concentration of auxins in plants are regulated by the activity of the IAA oxidase enzyme.

Combination of inorganic fertilizers with organic manures, biofertilizers and bioagents significantly increase growth parameters, leaf characteristics, and leaf nutrient status of banana (Thangaselvabai *et al.*, 2009; Rajput *et al.*, 2015). The leaf characteristics in terms of functional leaves, total number of leaves, phyllochron, leaf area, and leaf area index were significantly influenced by the combination of inorganic fertilizers with different biofertilizers and organic manures (Aremu *et al.,* 2012). Similarly, a study conducted by Hazarika *et al.* (2015) reported that leaf nutrient status like nitrogen, phosphorus pentoxide, potassium dioxide, and leaf relative water content were also influenced greatly by different nutrients. Treatment involving combination of 100 percent recommended dose of fertilizer + arbuscular mycorrhizal fungi + *Azospirillum* + *Trichoderma harzianum* showed overall superiority in the growth parameters of banana. (Hazarika *et al.*, 2015).

2.2.4. Chemical and biochemical quality of banana fruit

Quality improvement of banana fruits in terms of total, reducing and non-reducing sugars and shelf life was higher for vermicompost treated plants had been reported by many authors (Padmavathiamma *et al.*, 2008; Selvamani and

Manivannan, 2009). *In-situ* vermiculturing @1, 25,000 worms ha^{-1} recorded higher fruit quality in terms of shelf life, total soluble solids (TSS) and TSS: acid ratio in banana *cv Rajapuri* (Athani and Hulamani, 2000). Sreedevi and Suma (2015) opined that general intake of all nutrients by banana plants were improved with organic manure application which was attributed to slow and sustained release of nutrients in comparison to chemical fertilizers. Sreedevi and Suma, (2015) also evaluated the quality of organically grown banana cv. *palayankodan* and concluded that organic fruit samples scored higher in sensory qualities like colour, texture and taste and nutritional qualities like moisture and minerals.

2.3. Generation of farm residues in banana

For every ton of banana harvested, approximately four tons of bio wastes were generated including three tons of pseudostems, 160 kg of stems, 480 kg of leaves and 440 kg of banana peels, and approximately 100 kg of fruit were rejected due to export regulations (Fernandes *et al.*, 2012). After the production of the banana bunch, most of the banana tree got discarded and only 50 cm of the pseudostem will be left to serve as source of nutrition to the sprouts. Considering that pseudostem and adult plant reached about 1.2 to 1.8 meters high with a weight of approximately 10 to 100 kg, a huge amount of waste would be generated after harvest (Carvalho *et al.*, 2012). According to Memon *et al.* (2010), the annual nutrient uptake from banana ranged from 3.6 to 16.1 kg N, 0.6 to 1.9 kg P and 14.9 to 73.7 kg K ha^{-1} which if could be effectively tilled back to the soil to replenish the depleted soil fertility. This offers larger scope of recycling of wastes to value added, nutrient rich composts or vermicomposts.

2.3.1. Decomposition of farm residues

Raphael *et al.* (2012) reported that banana residues could store two thirds of nitrogen at harvest which corresponded to great N reserve for the growing daughter plant and hence contributed to reduction in fertilizer requirements. The root residues had proved to be a minor N source for the daughter plant. In the field, above-ground residues decomposed according to first order kinetics. According to Raphael *et al.* (2012), the proportion of N at the time of harvest of the daughter plant were 39 percent of residue N in the plant, 54 percent in the topsoil, three percent in the remaining residues and about four percent of residue N lost by leaching. The study also showed that above-ground residue N was an effective N source for the daughter plant, with a good overlap between the period of N release and that of greatest plant demand which reduced the risk of N leaching.

Lekasi *et al.* (1999) studied the decomposition and nutrient release of banana pseudostems, leaves and peels, maize stover and bean trash reported that decomposed followed the order bean trash > banana peel > maize stover = banana pseudostem > banana leaves. Exclusion of soil macrofauna (2-5 mm) delayed decomposition of banana pseudostems, when applied as mulch. Considering the availability and tissue nutrient concentrations were taken into account, banana leaves and bean trash had the greatest potential to recycle N(25 and 29 kg ha^{-1} yr^{-1} respectively) and banana leaves and pseudostem recycle the greatest amounts of K (43 and 26 kg ha^{-1} yr^{-1} respectively). The combined contribution of banana leaves, pseudostems, maize stover and bean trash to recycling nutrients was 69 kg N and 147 kg K ha^{-1} (Lekasi *et al.*, 1999). Flavel *et al.* (2005) could establish a highly significant relationship between CO_2–C evolution and gross N mineralization (r^2 = 0.95) in the compost treated soil. Raphael *et al.* (2012) reported that banana (*Musa* sp.) residues contained two thirds of the plant N content at harvest which represent a large N source for the daughter plant and contribute to reducing fertilizer rates.

2.3.2. Nutrient dynamics during crop residue decomposition

An aerobic incubation experiment by Bernal *et al.* (1998) using different organic manures when incorporated in soil revealed that carbon mineralization decreased as the composting time lengthened. The lowest values of C mineralization were found for the mature samples, and only compost which had not attained an advanced degree of maturation gave results higher than 25 percent of C. According to them, carbon mineralization followed a combined first and zero order kinetic model, suggesting that the organic C of the composting wastes was made up of two organic pools of differing degrees of stability. However, the differences in the slow C mineralization pool at the end of the active phase and after maturation were very small, indicating that the organic matter at both stages had a similar microbial stability. Comparing the C mineralization in soil during composting, Bernal *et al.* (1998) concluded that composting was the best way for obtaining maximum C stabilization.

Analysis of residue decomposition under laboratory and field conditions by Raphael *et al.* (2012) using ^{15}N-labelled above-ground residues revealed that in the laboratory, residue decomposition showed a longer immobilization phase followed by shorter re-mineralization for roots due to their higher C: N ratio and lignin content. In the field, above-ground residues decomposed according to first order kinetics. Residue half-life was 2 days in the laboratory and 32 days in the field, which was due to poorer soil–residue contact in the field. From this study, it was clear that above-ground residue N was an effective N source for the daughter plant, with a good overlap between the period of N release and that of greatest plant demand which reduced the risk of N leaching (Raphael *et al.*, 2012).

2.4. Soil health as influenced by *in-situ* incorporation of crop residues

Soil health is defined as 'the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, promote the quality of air and water environments, and maintain plant, animal, and human health'(Doran and Safely, 1997). A study was conducted by Huang *et al.* (2014) aimed to investigate the effect of earthworms on physicochemical and microbial properties during vermicomposting of fresh fruit and vegetable wastes with and without earthworms for 5 weeks. Compared to control treatment (without earthworms), vermicomposting treatment resulted in a rapid decrease in electrical conductivity and losses of total carbon and nitrogen from the 2nd week. Quantitative Polymerase Chain Reaction displayed that earthworms markedly enhanced bacterial and fungal densities, showing the higher values than control, during the whole decomposition process. In addition, denaturing gradient gel electrophoresis combined with sequencing analysis revealed that earthworms modified bacterial and fungal community structures, through broadening the community diversities of *Actinobacteria, Bacteroidetes, Proteobacteria*, and *Ascomycotina*. The application of vermicomposts, composts improved substrate dynamics of soil thereby increasing the population of beneficial microorganisms and protected the soil from soil-borne pathogens, making it self-sustainable (Singh and Mustaffa, 2009).

Trevisan *et al.* (2010) opined that humic substances derived from compost had positive effects on plant physiology by improving soil structure and fertility and by influencing nutrient uptake and root architecture. Humic acids derived from compost showed higher humification levels, higher aliphatic nature, higher nitrogen, lower oxidation degree, lower charge development, differences in acidity strength of the acidic functional groups and differences in the heterogeneity than soil. The acidic functional groups of the HA from composted materials were stronger than those of the HA from vermicomposted materials and the former have similar acidic strength in comparison with soil HA. Humic Acids from composted materials were reported to contribute much to soil buffer capacity and cation exchange capacity than those isolated from vermicomposting treatments. Humic acids isolated from mature organic matter could be an instrument for predicting the biological maturity, chemical stability of the organic amendment and their contribution to cation exchange capacity and buffer capacity of the soil, and thus considered as an indicator for a successful agronomic performance of compost and vermicompost in soil (Campitelli and Ceppi, 2008).

Organic agriculture promoted disease suppression through healthy soils by increasing biological activity and diversity in the soil. Organic soils from the survey showed higher microbial activity and lower disease symptom expression (both with tomatoes and bananas) than conventional soils (Geense *et al.*, 2015). Organic soils were lower in plant-parasitic nematodes and sulphate sulphur levels and higher in nematode diversity, labile soil C and microbial indicators. Geense *et al.* (2015) claimed that soil conduciveness or suppression of *Fusarium* wilt appeared to be largely governed by competition for carbon. Measurement of soil microbial enzyme activity, nematode community structure and diversity and possibly sulphate sulphur seemed to provide a relatively reliable indicator for general disease suppression. Differences between organic and conventional agriculture could not be related to single management practice, but could be linked to synergies among system components (Geense *et al.*, 2015). An increase of 52 percent of soil organic carbon and (22 to 108%) dehydrogenase activity at application rate equivalent to the recommended dose of fertilizers by three year continuous vermicompost addition were reported by Saha *et al.* (2008).

2.4.1. Impact of crop residues on soil health and crop yield

In order to feed the escalating population, developing nations like India need to increase the food production by 2.5 percent per annum. The enhancement of crop yields and soil quality through improvement in soil carbon pool had numerous implications. It was reported that significant increase in food grain production to the tune of 32million Mg per annum can be achieved by with every 1Mg ha^{-1} year^{-1} increase in soil organic carbon pools in the rhizosphere (Lal, 2005).

Application of crop residues as mulch has significant positive influence in the maintaining soil organic carbon, nitrogen and available soil nutrients. Mulching of crop residues improve hydraulic conductivity, reduce bulk density of soil, raises soil temperature during winter and decreases soil temperature during summer due to shading effect. Retention of crop residues slows runoff by acting as miniature dams, shrinks surface crust formation and improves infiltration. Reduced evaporation from upper strata of soil coupled with improved soil characteristics leads to higher crop yield in diverse cropping and climatic situations. Higher amounts of crop residues over the soil surface reduces wind and water erosions, boosts water penetration and moisture preservation, reduces surface sediment and water runoff (IARI, 2012).

Crop residues also play an important role in amelioration of soil acidity through the release of hydroxyls and soil alkalinity. Due to high organic matter content, crop residues also augment carbon sequestration in soils which has its influence on climate change and greenhouse gases (GHGs) mitigation. Crop residues affect the biological diversity in soil. Crop residues generally increase diversity of useful microbes, arthropods and help in reducing pest pressure. The surface residues may ensure survival of a number of insects, both harmful and beneficial.

Materials and Methods

3. MATERIALS AND METHODS

The present investigation entitled "Efficiency of vermiconversion and decomposition of farm residues on soil health, yield and quality of banana (*Musa spp.*) was undertaken at College of Horticulture and Banana Research Station, Kannara during 2013-2015 in order to meet the objectives as detailed in chapter 1.

3.1. Vermicomposting efficiency of native and exotic earthworms

A field experiment with seven treatments and three replications was laid out in randomized block design in silpaulin vermibeds (size 3 m x 1.2 m x 0.9 m) and in banana planting pits (50cm^3) along with soil as absolute control.

3.1.1. Experimental details (Table 3.1)

Design : Randomized Block Design (RBD)
Number of treatments : 7
Number of replications : 3
Substrates : Coconut leaves, *Gliricidia* leaves, banana residues and 1:1 cowdung slurry in the ratio 1:1:1:1
Earthworm species : Exotic earthworm : *Eisenia foetida*
Native earthworm: *Perionyx excavatus*.
Location : Banana Research Station, Kannara

3.1.3. Preparation of vermibeds

Vermibeds were prepared both in silpaulin vermibeds and in banana planting pits.

Silpaulin vermibeds

Vermibeds made of silpaulin (size 3 m x 1.2 m x 0.9 m) were procured from M/S. Pauljo and Co., Irinjalakuda. The beds were provided with netted ventilators on the sides and a netted drainage vent on one of the bottom corner. The vermibeds were positioned straight by using plastic ropes and wooden poles under the shade.

Banana planting pits

After laying out the field, pits of size 50cm^3 were dug and lined with silpaulin sheets in order to restrict the physical movement of inoculated earthworms to the adhering soil. For each replication four pits were prepared.

Table 3.1. Treatment details – Experiment 1.

Treatments	Description	Notation
T_1	Absolute control (Soil)	S
T_2	*Ex-situ* compost in silpaulin vermibed (without earthworms)	Ex-C
T_3	*Ex-situ* vermicompost in silpaulin vermibed using *Perionyx excavatus*	Ex-P
T_4	*Ex-situ* vermicompost in silpaulin vermibed using *Eisenia foetida*	Ex-E
T_5	*In-situ* vermicompost in banana planting pits using *Perionyx excavatus*	In-P
T_6	*In-situ* vermicompost in banana planting pits using *Eisenia foetida*	In-E
T_7	*In-situ* compost in banana planting pits (without earthworms)	In-C

3.1.4. Compost substrates

Equal proportions of *Gliricidia* leaves, banana residues, dried coconut leaves and cowdung slurry were used as substrates for vermicomposting (Plate 3.1). Since fresh coconut leaves take longer periods for decomposition, a pre - water soaking of fresh coconut leaves was done from two months before the start of experiment. The moistened and partially decomposed coconut leaves chopped using electrical chaff cutter and were used. All the other substrates were used afresh for composting.

3.1.5. Earthworm species

The exotic or compost earthworm species *Eisenia foetida* culture was procured from the vermicomposting unit of College of Horticulture, Vellanikkara (Plate 3.2a). Indigenous earthworms were collected from Banana Research Station, Kannara through digging and hand sorting. The earthworm species were identified as *Perionyx excavatus* (Plate 3.2b).

3.1.6. Vermibed preparation (Plates 3.3a to d ; 3.4a to c)

All substrates were chopped using an electrical stainless steel chaff cutter in order to hasten the decomposition. The vermibeds were prepared by spreading chopped substrates in layers. Cowdung was made into thick slurry for facilitating easy adhesion. Coconut husks were spread on the bed floor with their concave side upwards to facilitate drainage and aeration. Above that a layer of chopped coconut leaves, *Gliricidia* leaves and banana residues were added in layers. Two more stacks were also laid out above the basal layers in the above mentioned sequence of materials. A total of 400 kg substrates (each component 100 kg) in vermibeds and a total of 100 kg (each component 25 kg) were used in pits. Cowdung slurry (1:1) was spread over each layer as a primary source of microbial inoculum. Finally wet jute sacs were smeared over the compost dome and left undisturbed for decomposition. Sufficient moisture was maintained throughout the experiment by occasional sprinkling of water. Temperature of the compost pile was recorded at weekly intervals using a digital thermometer. After the temperature stabilization of the compost collected earthworms were introduced at the rate of 100 and 50 clitellate worms to each bed *(ex-situ)* and pit *(in-situ)*

Plate 3.1. Substrates used in vermicomposting

Plate 3.2a. Exotic earthworm species : ***Eisenia foetida***

Plate 3.2b. Native earthworm species: *Perionyx excavatus*

Plate 3.3a. Steps involved in *ex-situ* compost bed preparation: Layering of coconut husks

Plate 3.3b. Steps continued : Layering of substrates

Plate 3.3c. Steps continued : Prepared *ex-situ* vermibed

Plate 3.3d. Steps continued : Turning of vermibed

Plate 3.4a. Steps involved in *in-situ* compost bed preparation

respectively. Churning of the beds was done at weekly intervals to facilitate aeration. For each vermicompost treatment, a control treatment (without earthworms) was also maintained both in silpaulin vermibeds and pits for studying the effect of microbial decomposition and thermophilic composting

3.1.7. Analysis of compost substrates

Fresh substrate samples were cut into small pieces and pH (1:2 substrate: water suspension) was measured. Composite samples of compost substrates (coconut leaves, *Gliricidia* leaves, banana residues and cowdung slurry) were dried at 70 °C in hot air oven, powdered, labelled and stored in separate polythene covers for further analysis. Analyses of C, N, and S were carried out using CHNS analyser (Model: Elementar Vario EL Cube). Powdered substrates were sieved through 2 mm sieve and sample (0.5g) was taken and digested with concentrated HNO_3 in microwave digestion system (Model : MARSX 250/40) and made up to 100ml with double distilled water. The acid extract was fed to Inductively Coupled argon Plasma Optical Emission Spectrometer (ICP OES, Model: Optima® 8x00) for estimating nutrient contents. The standard procedures adopted are shown in Table 3.2.

3.1.8. Characterization of compost

Maturity of compost was judged by physical and chemical characteristics like temperature, pH and C: N ratio. Fresh compost samples were transported to the laboratory in polythene bags for biochemical analysis. The mature compost samples were air dried and passed through 4 mm sieve and stored in polythene bags prior to analysis. The quality standards of the compost were judged by physical and chemical characterization using the standard procedures given in Table 3.3.

Spectroscopic techniques for humic acid characterization

3.1.9. Fourier Transform Infrared Spectroscopy (FTIR)

Fourier Transform Infrared Spectra (FTIR) were calculated on pellets formed by pressing a mixture of humic acid samples (≈1 mg) and dried KBr (≈400 mg) under reduced pressure, using a Thermo Nicolet Avatar 370 FTIR spectrophotometer.

Table 3.2. Standard procedures followed for the characterization of substrates used for vermicomposting

Sl. No.	Characteristics	Method		Reference
		Extraction	Estimation	
1	pH	1:2 plant : water suspension	Potentiometry	GOI, 1985
4	Total Carbon	CHNS Analyser Model :Elementar's vario EL cube		
5	Total Nitrogen			
6	Total Phosphorus	Microwave digestion system (HNO_3)	Colorimetry	Piper, 1966
7	Total Potassium		Flame photometry	
8	Total Calcium		ICP OES (Model: Optima® 8x00 series)	
9	Total Magnesium			
10	Total Sulphur	CHNS Analyser Model :Elementar's vario EL cube		
11	Total micronutrients Fe, Mn, Zn, Cu	Microwave digestion system (HNO_3)	ICP OES (Model: Optima® 8x00 series)	
12	Heavy metals As, Cd, Cr, Ni, Pb			

Table 3.3. Standard analytical procedures followed for physicochemical characterization of vermicompost

Sl. No.	Characteristics	Method		Reference
		Extraction	Estimation	
1	Moisture	Ignition	Loss in weight	GOI, 1985
2	pH	1:2 organic fertilizer solution	Potentiometry	
3	Electrical Conductivity	1:5 Organic fertilizer solution	Conductometry	
4	Total C	CHNS Analyser Model : Elementar's vario EL cube		
5	Total N			
6	Total P	Microwave digestion system (HNO_3)	Colorimetry	Watanabe and Olsen, 1965
7	Total K		Flame photometry	Piper, 1966
8	Total Ca		ICP OES (Model: Optima® 8x00 series)	
9	Total Mg			
10	Total S	CHNS Analyser Model :Elementar's vario EL cube		
11	Fe, Mn, Zn, Cu	Microwave digestion system (HNO_3)	ICP OES (Model: Optima® 8x00 series)	
12	As, Cd, Cr, Ni, Pb.	Triacid digestion (HNO_3:H_2SO_4: $HClO_4$)		

Table 3.3 Continued

13	Auxin equivalents	Phosphate buffer (pH 7.5) + glucose + 4 ml of 1% L-tryptophan	Colorimetry	Wohler, 1997
14	Organic matter	Sequential fractionation using 0.1N NaOH and Conc. HCl	Precipitation	Schintzer, 1982
15	Dehydrogenase	Tri Phenyl Tetrazolium Chloride (TTC)	Tri phenyl formazan (TPF)	Casida *et al.*, 1964
16	Total microbial Count	Serial Dilution Plate Technique		Wollum, 1982
17	Humic acid characterization	KBr Pellets	Fourier Transform Infrared spectrophotometer	

3.2. Effects of vermicomposting on crop of banana

Field experiment to assess the growth, yield and crop quality of banana *var. nendran* was conducted using composts prepared against recommended doses of fertilizers.

3.2.1. Experiment Details

Field experiment was formulated with seven treatments replicated thrice and laid out as RBD. The treatment details are given in Table 3.4.

3.2.2. Location

The experiment was conducted at Banana Research Station, Kannara. The field was located at D block of Banana Research Station (Plate. 3.5).

3.2.3. Land preparation

The experimental field was located at D block of Banana Research Station, Kannara. The field was kept fallow before the cropping. The field was ploughed, levelled and laid out for experiment.

3.2.4. Layout

Pits of size 50 cm x 50 cm x 50 cm were dug and vermicompost prepared from silpaulin vermibeds were transported to field. Composts were applied to the pits one week before planting. For the control pits, only pits were dug. For POP treatment, the pit was dug and filled with green leaves and lime at the rate of one kg pit^{-1} as per KAU (2011) and left for decomposition. In all *ex-situ* compost treatments, composts from silpaulin vermibeds were applied at the rate of 20kg pit^{-1}. After compost application, all the pits were covered with soil and allowed the compost to decompose for one week. For each treatment a border row was also maintained. For *in-situ* treatments, compost/ vermicompost was prepared at the rate of 20kg pit^{-1}

3.2.5. Test crop

Three month old tissue culture banana *cv. nendran* plants were used as test crop. The plants were hardened in the mist chamber and poly house. For each replication, four plants were selected. A total of 12 plants constituted a treatment.

Table 3.4. Treatment details – Experiment 2.

Treatments	Description	Notations
T_1	Absolute control (soil alone)	S
T_2	300:115:450g N: P_2O_5: K_2O plant^{-1} + FYM at the rate of 20 kg plant^{-1}	POP (Package of Practices and Recommendations, KAU, 2011)
T_3	*Ex-situ* vermicompost in portable vermibeds with *Perionyx excavatus* at the rate of 20 kg plant $^{-1}$	Ex-P
T_4	*Ex-situ* vermicompost in portable vermibeds with *Eisenia foetida* at the rate of 20 kg plant $^{-1}$	Ex-E
T_5	*In-situ* vermicompost in crop pits with *Perionyx excavatus* at the rate of 20 kg plant $^{-1}$	In-P
T_6	*In-situ* vermicompost in crop pits with *Eisenia foetida* at the rate of 20 kg plant $^{-1}$	In-E
T_7	*In-situ* compost at the rate of 20 kg plant $^{-1}$	In-C

Plate 3.5. Field view of experimental site at Banana Research Station, Kannara

Plate 3.6. Bunch care

3.2.6. Planting

The banana plants were planted on 5th and 6th of May, 2014. All the plants were watered and each plant was covered with coconut fronts for protection from sun. Watering of the plants was done using plastic pots.

3.2.7. Intercultural operations

The intercultural operations included fertilizer application, weed control, irrigation, plant protection, covering bunches with paper and plastic bags.

Fertilizer application

Banana plants grown under POP, were given fertilizers N: P_2O_5: K_2O at the rate of 300 : 115 : 450 g plant^{-1} in six split doses through urea, *rajphos* and muriate of potash respectively as per KAU (2011).

Weed control

Hand weeding was done at monthly intervals till harvest of crop. Harrow weeding combined with soil mounds around plant trunk were done at 5th month after planting. No chemical measures were done.

Irrigation

Irrigation basins were formed around each blocks and replications so as to prevent the mixing of water from one treatment to other.

Plant protection

Since the plants were grown under organic nutrition, no chemical plant protection measures were taken. The major pests and diseases and control measures taken are listed in Table 3.5.

Bunch care

Bunches after removal of flower head was wrapped with paper and plastic covers to protect from sun scorching and birds (Plate 3.6).

3.2.8. Foliar analysis

Petiole of index leaves (3rd opened leaf from top at four months after planting at bud differentiation stage) were collected and analysed for primary, secondary, micronutrient and heavy metal contents.

Table 3.5. List of major pests and diseases and control measures undertaken during period of experimentation

Months after planting	Pest/ Disease	Control measures
2	Bihar hairy caterpillar Spodoptera caterpillar Cercospora leaf spot Kokkan disease Rhinoceros beetle	Sprayed Neem oil emulsion at the rate of 1% solution Sprayed *Bauveriana bassiana* suspension 1% solution Applied of bar soap on the holes.
4	Leaf rolling caterpillar	Sprayed neem oil emulsion at the rate of 1% solution
7 – 10	Pseudostem weevil Rhizome weevil	Preventive care was undertaken by mud swabbing Sprayed of neem oil emulsion at 1% as prophylactic measure Mechanical measures were also attempted like killing of weevils by hand

3.2.9. Harvest

Matured bunches (~three months old) were harvested when all the leaves started drying. Harvested bunches were weighed and observed for biometric characters. Fingers were selected and stored for ripening.

3.2.10. Analysis of soil

Representative soil samples were collected from the field prior to experiment. Collected soil samples were immediately transported to the laboratory for biochemical analysis. For elemental analysis the samples were air dried, sieved and kept in polythene bags. After the harvest of banana, soil samples were collected from rhizosphere (0-30 cm depth) and analysed as per standard procedures listed in Table 3.9.

3.2.11. Analysis of plant

Petiole of the index leaves were dried in oven at 70 °C powdered, sieved and stored in polythene bags. For phytohormone analysis, fresh leaf samples were wrapped in butter paper cover and transported to the laboratory and stored in refrigerator (Table 3.6.).

3.2.12. Phytohormone analysis

Indole acetic acid oxidase activity (µg unoxidized auxin g^{-1} hr^{-1})

The auxin concentration is expressed in terms of Indole acetic acid oxidase activity, which catalyses the auxin to inactive form of auxin. Hence the content of unoxidised auxin is indirectly represented as the activity of indole acetic acid activity and *vice versa.* Two hundred milligrams of fresh leaf material was homogenized and extracted with sodium phosphate buffer (pH 7.5) and incubated with substrate standard (1ml 100ppm Indole acetic acid pure). Intensity of red colour produced by un-oxidized auxin, when treated with $FeCl_3$-$HClO_4$ reagent was read spectrophotometrically at 540nm as per the procedure given by Parthasarathy *et al.* (1970) with little modifications.

Gibberellic Acid (µg g^{-1} of plant tissue)

Gibberellic Acid (GA) in the plant tissue was analysed using procedures laid out by Sunderbarg (1990) and Kojima (1995). Two hundred and fifty milligram of leaf tissue was extracted with chilled methanol at 4°C for 4 hours in

Table 3.6. Standard analytical procedures followed for characterisation of banana plants/ plant parts

Sl. No.	Characteristics	Method		Reference
		Extraction	Estimation	
1	Total Carbon	CHNS Analyser Model :Elementar's vario EL cube		
2	Total Nitrogen			
3	Total Phosphorus	Micro wave digestion system (HNO_3)	Colorimetry	Watanabe and Olsen, 1965
4	Total Potassium		Flame photometry	Piper, 1966
5	Total Calcium		ICP OES (Model: Optima® 8x00 series)	
6	Total Magnesium			
7	Total Sulphur	CHNS Analyser Model :Elementar's vario EL cube		

Table 3.7. Standard analytical procedures followed for characterisation of banana fruits

Sl. No.	Characteristics	Reference
1	Titratable acidity	A.O.A.C. Official method of analysis (2000)
2	Total sugars	
3	Reducing and non-reducing sugars	
4	Vitamin C	

dark. The extract was centrifuged and filtered to get clear supernatant. This step was repeated twice. The combined methanolic extract was concentrated in vacuum at 50°C for 1 hour. The volume was adjusted to 10ml with phosphate buffer (pH 7.5) and partitioned in separating funnel with 10ml diethyl ether by stirring for 3 minutes. After discarding ether phase, pH of aqueous phase was adjusted to pH 2.7 with 1.6M HCl. The extract was further partitioned with 0.4M $NaHCO_3$ followed by addition of ethyl acetate. Two ml of methanol was added to it and methanolic residue was treated with zinc acetate and potassium ferrocyanide and filtered. The filtrate was mixed with equal proportion of 30 percent HCl and the turbidity was read at 254nm using a spectrophotometer using pure GA as working standards.

3.2.13. Biometric observations of banana at harvest

Biometric observations like pseudostem height, girth, no of functional leaves, no. of suckers were recorded at the time of harvest of the bunch. Bunch characters like weight of bunch, no. of fingers, no. of hands per bunch and length of peduncle and finger characters like weight of finger, days to ripening and shelf life were also recorded.

3.2.14. Assessment of fruit quality

After harvest of bunches, fingers from 2nd hand, were kept for ripening at ambient conditions on a well aerated store room over jute sacs. Uniformly ripened fruits were subjected to quality analysis listed in Table 3.7.

3.2.15. Sensory evaluation

Sensory evaluation of banana fruits from various treatments was carried out by a group of judges. The judges who took part in the evaluation were 10 postgraduate students aged between 20 and 28 years old. Ripened fruits were subjected for sensory rating by 9 point hedonic scale according to Amerine *et al.* (1965). The sensory evaluation chart is annexed in appendix 5. The 9 point hedonic scale for scores and inferences of sensory evaluation of banana fruits are shown in Table 3.8.

Table 3.8. Nine point hedonic scale for sensory evaluation of banana fruits

Scores	Inference
9	Like extremely
8	Like very much
7	Like moderately
6	Like slightly
5	Neither like nor dislike
4	Dislike slightly
3	Dislike moderately
2	Dislike very much
1	Dislike extremely

Table 3.9. Standard procedures followed for the soil analysis

Sl. No.	Characteristics	Method		Reference
		Extraction	Estimation	
1	pH	1:2.5 Soil Water suspension	Potentiometry	Jackson, 1973
2	EC		Conductometry	
3	Texture	International pipette Method	Sedimentation	Piper, 1966
4	Organic Carbon	Wet digestion		Walkely and Black, 1934
5	Available N	Alkaline permanganometry		Subbiah and Asija, 1956
6	Available P	Bray No 1	Colorimetry	Bray and Curtz, 1945
7	Available K	1N NH4OAc	Flame photometry	Hesse, 1994
8	Available Ca		ICP OES (Model: Optima® 8x00 series)	
9	Available Mg			

Table 3.9 Continued

10	Auxin concentration	Phosphate buffer (pH 7.5) + glucose + 4 ml of 1% L-tryptophan	Wohler, 1997	
11	Dehydrogenase activity	TTC	TPF	Casida *et al.,* 1964
12	Urease activity	Toluene +THAM +Urea	Distillation with MgO	Tabatabai and Bremner, 1972
15	L-Asparaginase activity	Toluene +THAM + Asparagine mono hydrate		Frankenberger and Tabatabai, 1991
16	Phophatase activity	*p*-nitrophenol phosphate	Colorimetry	Tabatabai and Bremner, 1969
17	Microbial biomass carbon	Chloroform fumigation	Wet oxidation	Jenkinson and Powlson, 1976
18	Total microbial count	Serial Dilution Plate technique		Wollum, 1982
20	Total nitrogen	CHNS Analyser Model : Elementar's vario EL cube		
21	Total carbon			

3.3. Studies on *in-situ* decomposition of banana residues (Plate 3.7)

After the harvest of bunches, entire residues of banana from each plant was incorporated in the respective crop pits and complete degradation of the same was monitored.

3.3.1. Field lay out

The third experiment was continued in the same lay out of experiment II. After harvesting bunches, banana plants were chopped and heaped in the respective pits for decomposition. Churning of the heap was done at weekly intervals.

3.3.2. Analysis of soil

Composite soil samples were collected from experimental field, homogenized and transported to laboratory in polythene bags. Fresh field moist soil samples were analysed for microbial biomass carbon, total microbial count, phytohormones and enzymes like dehydrogenases, urease, asparaginase and phosphatases. Soil samples were air dried, processed and sieved through 2mm sieve and labelled for further chemical analysis. The standard procedures followed for soil analysis are listed in Table 3.9.

3.3.3. Estimation of Auxin concentration in soil

Auxin concentration in soil was determined colorimetrically as per Wohler, (1997). Fresh field moist soil samples were treated with phosphate buffer (pH 7.5) with glucose (1 g glucose per 100 ml phosphate buffer) and 4 ml of 1 percent L-tryptophan. The samples were incubated at 37 °C for 24 hours in dark. After the incubation, 2 ml of 5% trichloroacetic acid solution was added followed by addition of 1 ml of 0.5 M $CaCl_2$ solution to inactivate the IAA oxidase enzyme. After filtering (Whatman No.2), 3 ml of the filtrate were put in a test tube, and to this 2 ml of salper solution (2 ml 0.5 M $FeCl_3$ and 98 ml 35% $HClO_4$) was added. This mixture was incubated for 30 minutes at 25 °C in the dark. The absorbance of the red solution was measured with a spectrophotometer at a wavelength of 535 nm. From the standard graph, the auxin concentration of the compost was calculated and expressed as auxin equivalents (μg of auxin g^{-1} of compost).

Plate 3.7. Chopping and heaping of banana residues for experiment III

3.3.4. Kinetics of residue decomposition

The change in concentration of C, N, Available P, K, Ca and Mg were recorded and models of nutrient transformation kinetics were worked out.

3.4 Statistical analysis

Analysis of variance (ANOVA) was done using SPSS (Version No. 20) to test the level of significant difference between treatments means (Das and Giri, 1986).

Results

4. RESULTS

Field experiments were conducted on lateritic soils of Banana Research Station, Kannara, Thrissur to evaluate the effect of vermiconversion and decomposition of farm residues on soil health, yield and quality of banana (*Musa spp.*). As a part of the study, both *in-situ* and *ex-situ* vermicomposts were prepared and tested on the crop of banana cv. *nendran*. The decomposition dynamics of banana residues after its incorporation into the pits were monitored with special emphasis to carbon and nitrogen. The climate of the region is humid tropical with a mean annual temperature of 29°C and mean annual rainfall 2500 mm. The soils belong to inceptisol order. The results of the various experiments conducted as part of the study are detailed below.

4.1. Composting efficiency of native and exotic earthworms

The composting efficiency of native and exotic earthworms were evaluated in terms of chemical parameters like compost yield, time taken for compost maturity and variations in temperatures during composting. The structural analysis of humic acids derived from the composts prepared using native and exotic earthworms under different modes of composting was also analysed.

4.1.1. Chemical characterization of substrates used for composting

Equal proportions of shredded *Gliricidia* leaves, banana residues, dried coconut leaves along with 1:1 cowdung slurry were used as the substrates for vermicomposting. Chemical composition of substrates used for composting are furnished in Table 4.1.

pH

The pH (1:2 substrate: water suspension) of the substrates ranged from 6.4 to 8.9 (Table 4.1). The highest pH of 8.9 was recorded for 1: 1 cowdung slurry and the lowest pH (6.4) was recorded for *Gliricidia* leaves.

Carbon to Nitrogen (C: N) ratio

The C: N ratio of the substrates varied from the lowest value of 9.8:1 to the highest value of 28.1: 1. Banana pseudostem recorded the highest C: N ratio (28.1:1) and *Gliricidia* leaves recorded lowest (9.8:1)

Table 4.1. Chemical parameters of the substrates used for composting

Characteristics	Substrates			
	Glyricidia Leaves	Banana pseudostem	Dry coconut leaves	1:1 Cowdung slurry
pH (1:2 plant : water suspension)	6.4	6.9	7.5	8.9
C: N ratio	9.80	28.10	25.60	15.00
C (%)	32.59	30.93	22.02	27.40
N (%)	3.34	1.10	0.86	1.82
P (%)	0.77	0.59	0.51	1.09
K (%)	1.52	0.58	3.92	0.40
Ca (%)	1.54	1.07	0.40	1.79
Mg (%)	0.30	0.14	0.12	0.63
S (%)	0.21	0.07	0.09	0.24
Fe (mg kg^{-1} of substrate)	687.40	1143.40	543.40	1543.40
Mn (mg kg^{-1})	82.60	566.60	103.00	480.60
Zn (mg kg^{-1})	30.50	8.06	1.40	0.03
Cu (mg kg^{-1})	3.80	6.20	2.00	24.00
Ni (mg kg^{-1})	4.20	2.60	2.20	10.60
Cr (mg kg^{-1})	7.40	9.80	4.00	20.60
As (mg kg^{-1})	Traces	Traces	Traces	Traces
Pb (mg kg^{-1})	Traces	Traces	Traces	Traces
Cd (mg kg^{-1})	Traces	Traces	Traces	Traces

Total carbon content (%)

Among the substrates, highest carbon content was recorded by *Gliricidia* leaves (32.59%) and the lowest carbon content was recorded in dry coconut leaves (22.02%).

Nitrogen content (%)

The highest N content of 3.34 percent was recorded by *Gliricidia* leaves and the lowest value of 0.86 percent was recorded by coconut leaves.

Phosphorus content (%)

Phosphorus content of substrates ranged from 0.51 to 2.09 percent. The highest P content was recorded in cowdung and the lowest in dry coconut leaves

Potassium content (%)

Potassium content of the substrates varied from 3.92 percent for banana pseudostem to 0.40 percent in cowdung slurry.

Calcium content (%)

Calcium content of the substrates varied from 0.40 to 1.79 percent. The highest Ca content was recorded for cowdung (1.79%) and lowest for coconut leaf residues (0.40%).

Magnesium content (%)

Cowdung recorded maximum content of Mg (0.63%) and coconut residues recorded minimum Mg content (0.12 %) among the different substrates.

Sulphur content (%)

Sulphur content was the highest in cowdung (0.24%). Minimum S content of 0.07 percent was shown by banana pseudostem among the different substrates

Content of micronutrients (mg kg^{-1}) of the substrates used for the study

Content of micronutrients varied among the substrates. Cowdung recorded maximum Fe (1543.40 mg kg^{-1}) and Cu (24 mg kg^{-1}) contents whereas, banana pseudostem recorded maximum Mn content (566.60 mg kg^{-1}). Coconut leaves recorded minimum Fe (543.40 mg kg^{-1}) and Cu (2.00 mg kg^{-1}) contents. The lowest Mn content of 82.60 mg kg^{-1} was shown by *Gliricidia* leaves. Zinc content of all the substrates ranged from 0.03 to 30.50mg kg^{-1}. The highest Zn content was recorded in banana residues followed by *Gliricidia* leaves (30.50 mg kg^{-1})

and banana pseudostem with 8.06 mg kg^{-1}. The lowest Zn content was recorded in cowdung slurry with 0.03 mg kg^{-1}.

Content of heavy metals (mg kg^{-1}) of the substrates used for the study

Contents of heavy metals like As, Pb and Cd were below detectable limit in all the substrates. Cowdung recorded maximum concentration of Ni (10.60 mg kg^{-1}) and Cr (20.60 mg kg^{-1}). Coconut leaves recorded minimum Ni (2.20 mg kg^{-1}) and Cr (4.00 mg kg^{-1}).

4.1.2. Maturity assessment of composts/ vermicomposts

Daily variations in mean temperature (°C) up to 15 days of composting

Daily variations in temperature of the compost pile along with air and soil temperature (°C) were recorded and presented in Table 4.2. In Ex-C (*ex-situ* compost) the temperature fluctuated from 46.38 °C on the first day to 48.91 °C on third day of bedding and to 40.64 °C on the 15th day of bedding. In Ex-P (*ex-situ* vermicompost using *Perionyx excavatus*), the highest temperature of 52.60 °C on the first day got reduced gradually to the lowest temperature of 42.22 °C on 15th day of composting. In Ex-E (*ex-situ* vermicompost using *Eisenia foetida*), the highest temperature of 50.46 °C on the first day dropped to 40.97 °C by the 15th day of composting.

In case of *in-situ* treatments, In-P (*in-situ* vermicompost using *Perionyx excavatus*), recorded the highest temperature of 44.85 °C on the 1st day which gradually reduced to 38.96 °C on the 15th day of composting. In In-E (*in-situ* vermicompost using *Eisenia foetida*), the highest temperature of 42.85 °C was recorded on the first day and thereafter it got decreased to 35.76 °C on the 15th day of composting. In In-C (*in-situ* compost), the temperature on the first day of composting was 44.97 °C which increased to 45.35 °C and thereafter reduced to 38.42 °C on 15th day of composting. The atmospheric temperature fluctuated between a maximum of 28.55 °C and a minimum of 26.85 °C during 15 days of composting. The soil temperature varied from 29.00°C to 31.50 °C during the same period.

Variations in mean temperature (°C) at 10 days interval of the compost beds as influenced by modes of composting compared to soil and atmospheric temperature

After 15 days of composting, variations in temperature were recorded at 10 day interval up to 100th day of composting (Table 4.3). The mean atmospheric temperature fluctuated from 27.05 °C to 28.43 °C during the period up to 100th day of composting. Mean soil temperature (S) varied from 28.80 °C to 31.00 °C within 30 cm depth of soil up to 100th day of composting. In *ex-situ* compost (Ex-C) prepared in silpaulin vermibeds without earthworms, mean temperature gradually decreased from 42.69°C (10-20 days of composting) to 33.11 °C at 80-90 days of composting. Under *ex-situ* vermibeds prepared using *Perionyx excavatus* (Ex-P), highest mean temperature of 42.46 °C was recorded at 10-20 days of composting, which got reduced to 34.11°C at 60 -70 days of composting. In *ex-situ* vermibeds prepared using *Eisenia foetida* (Ex-E), there was a gradual decrease in the mean temperatures of vermibeds from 42.47 °C (10-20 days of composting) to 33.06°C (40-50 days of composting).

Under *in-situ* conditions, vermibeds were prepared in banana planting pits using *Perionyx excavatus*, the highest mean temperature of 41.18°C was recorded at 10-20 days of composting which reduced to 34.55°C at 50-60 days of composting. In In-E (*in-situ* vermicompost using *Eisenia foetida*), the highest mean temperature was 38.44°C recorded at 10-20 days of composting which stabilized at 33.09°C at 40-50 days of composting. Under *in-situ* composting without earthworms (In-C), the highest mean temperature of 41.41 °C recorded at 10-20 days of composting finally stabilized at 36.75°C at 60-70 days of composting.

Compost yield (%, w /w basis) and time taken for compost maturity (days)

Yield (%) of compost and time taken for compost maturity (days) from *ex-situ* and *in-situ* treatments are shown in Table 4.4. The compost yield (%) from *ex-situ* treatments ranged from 60.41 to 70.83 percent whereas that from *in-situ* treatments ranged from 62.00 to 70.67 percent. Among the *ex-situ* treatments, the highest per cent yield (70.83%) was recorded for *ex-situ* compost (Ex-C). Among

Table 4.2. Daily variations in mean temperature (°C) in the compost beds as influenced by modes of composting, compared to soil and atmospheric temperature

Day/s of composting	Temperature (°C)							
	Atmosphere	Soil	Ex-C	Ex-P	Ex-E	In-P	In-E	In-C
1	28.50	31.00	46.38	52.60	50.46	44.85	42.85	44.97
2	28.55	30.50	47.06	50.43	48.62	44.23	43.76	45.35
3	27.90	31.00	48.91	44.93	45.36	43.52	40.99	43.76
4	28.20	30.50	46.39	42.85	46.55	43.87	41.91	41.85
5	28.15	29.00	46.38	43.00	45.10	42.92	43.67	40.64
6	26.85	31.50	45.05	42.50	45.82	40.52	42.61	41.15
7	28.25	30.90	45.12	44.73	44.51	42.00	40.73	40.21
8	27.65	30.50	45.86	43.53	43.99	42.96	39.82	40.62
9	27.10	30.60	43.66	40.50	42.82	40.07	39.91	39.43
10	27.80	30.90	44.38	41.20	42.67	40.91	38.61	40.73
11	28.65	30.10	42.79	41.90	43.25	41.05	40.49	41.08
12	28.35	29.61	43.38	43.00	43.10	41.95	39.94	40.98
13	29.00	31.11	43.45	42.64	42.91	40.08	38.09	38.24
14	28.50	30.31	41.52	43.83	41.90	41.90	37.76	39.01
15	28.30	29.61	40.64	42.22	40.97	38.96	35.76	38.42

Table 4. 3. Variations in mean temperature (°C) of the compost beds laid *ex-situ* (in silpaulin vermibeds) and *in-situ* (banana planting pits) at 10 day intervals of study

Period of composting (Days)	Temperature (°C)							
	Atmosphere	Soil	Ex-C	Ex-P	Ex-E	In-P	In-E	In-C
10-20	28.43	30.00	42.69	42.46	42.47	41.18	38.44	41.41
20-30	28.38	29.00	41.02	39.77	39.97	39.74	35.24	40.19
30-40	28.63	31.00	39.25	36.63	35.57	37.28	33.29	39.31
40-50	28.40	30.00	37.61	35.89	33.06	35.36	33.09	38.94
50-60	27.60	29.00	36.32	34.77	33.38	34.55	33.77	37.07
60-70	27.38	30.00	35.77	34.11	31.00	34.97	34.75	36.75
70-80	27.05	28.80	33.55	30.07	28.94	32.84	33.62	36.94
80-90	27.15	30.70	33.11	28.91	28.49	30.17	33.56	37.27
90-100	27.05	30.60	30.64	29.46	29.86	32.82	32.19	36.21

the *in-situ* compost treatments, In-C recorded the highest compost yield of 70.67 percent. Among the species of earthworms, the vermicompost prepared using *Perionyx excavatus* (In-P) recorded higher yield of 69% under *in-situ* conditions. Time taken for compost maturity was lower for *ex-situ* and *in-situ* vermicompost prepared using *Eisenia foetida* (Ex-E and In-E) (40-50 days of composting). However, under *ex-situ* mode of vermicomposting using *Perionyx excavatus* (Ex-P), time taken for compost maturity was higher (up to 60-70 days of composting) as compared to *in-situ* vermicomposting that took upto 50-60 days for composting (In-P).

4.1.3. Evaluation of compost quality

Quality of compost was evaluated with respect to the chemical and biochemical characteristics.

pH

It is clear from Table 4.5 that pH (1:2 compost: water suspension) of the mature compost ranged from 4.7 to 8.3. The highest pH of 8.3 was recorded for Ex-P (*ex-situ* vermicompost using *Perionyx excavatus*) followed by Ex-E (*ex-situ* vermicompost using *Eisenia foetida*) with a pH of 8.2 and Ex-C (*ex-situ* compost) with a pH of 7.9.

The pH was significantly higher for *ex-situ* mode of composting than *in-situ* mode of composting. The pH of the *in-situ* treatments were also significantly superior to control. However species of earthworms had no significant effect on the pH of the compost.

The vermicomposting treatments had higher pH than composting under *ex-situ* mode of composting whereas under *in-situ* mode of composting, pH of In-C was greater than that of In-P and In-E. However, irrespective of the mode of composting, there was no significant difference between composting and vermicomposting treatments.

Electrical Conductivity (EC)

The electrical conductivity varied among the treatments from 0.08 dSm^{-1} to 1.11 dSm^{-1} (Table 4.5). The highest value of EC was on par with *ex-situ* vermicompost produced by *Eisenia foetida* (1.11dSm^{-1}) and *Perionyx excavatus*

4.4. Compost yield and days taken for compost maturity

Treatments	Compost yield (%)	Time taken for compost maturity (days)
S	-	-
Ex-C	70.83	80-90
Ex-P	60.41	60-70
Ex-E	62.50	40-50
In-P	69.00	50-60
In-E	62.00	40-50
In-C	70.67	60-70

Table 4.5. Physico-chemical properties of compost as influenced by different treatments

Treatments	**pH**	**EC (dSm^{-1})**
S	4.7	0.08
Ex-C	7.9	1.05
Ex-P	8.3	1.11
Ex-E	8.2	1.11
In-P	7.1	0.32
In-E	7.2	0.36
In-C	7.3	0.32
CD(p=0.05)	0.4	0.46

Table 4.6. Chemical properties of compost under different modes of composting and species of earthworms

Treatments	Total Carbon	Ash content
	%	
S	0.69	89.33
Ex-C	23.27	12.00
Ex-P	27.81	13.33
Ex-E	27.04	10.67
In-P	12.82	54.33
In-E	16.31	46.33
In-C	12.78	54.67
CD(p=0.05)	6.23	21.11

Table 4.7. Content of primary nutrients as influenced by the modes of composting and species of earthworms

Treatments	N	P (As P_2O_5)	K (As K_2O)	$N+P_2O_5+K_2O$
	(%)			
S	0.05	0.39	0.29	0.73
Ex-C	1.62	1.91	0.94	4.47
Ex-P	1.97	1.76	0.93	4.67
Ex-E	1.87	1.99	0.96	4.82
In-P	0.96	0.69	0.29	1.93
In-E	1.22	1.10	0.32	2.64
In-C	0.92	0.97	0.35	2.24
CD(p=0.05)	0.43	0.34	0.57	0.77

($1.10 dSm^{-1}$) and *ex-situ* compost (Ex-C) ($1.05 dSm^{-1}$). *Ex-situ* composts had significantly higher EC than composts produced under *in-situ* mode of composting.

Total Carbon

Total Carbon content of all the composts ranged from 0.69% to 27.81% (Table 4.6) Compost prepared in silpaulin vermibeds (Ex-C) had significantly higher C content than those prepared in pits. *Ex-situ* vermicompost prepared by *Perionyx excavatus* (Ex-P) recorded the highest C which closely followed by *Eisenia foetida.* and *ex-situ* compost without earthworms (Ex-E). *In – situ* composts had much lower carbon content varying from 12 -1 6 percent only

Ash content

Ash content represents the mineral matter present in the compost. Soil had the highest value of mineral matter content (Table 4.6). Compost prepared *in-situ* recorded significantly superior values of ash content than that in silpaulin vermibeds. Ash content of the *in-situ* compost (54.67%) was on par with the vermicompost with *P. excavatus* (54.33 %) while *E. foetida* recorded an ash content of 46.33 percent. *Ex – situ* composts had much lower ash contents of 11 - 13 percent.

4.1.3.1. Content of primary nutrients

The results of the contents of N (%), P (as P_2O_5 %) and K (as K_2O %) in the mature composts produced under different treatments are shown in Table 4.7.

Nitrogen content

Ex-situ vermicompost produced in the silpaulin vermibeds recorded significantly higher and were on par in the total N content than those produced from banana planting pits (Table 4.7). The highest N content of 1.97 percent was recorded on vermicompost produced by *Perionyx excavatus* under *ex-situ* mode of composting (Ex-P). However it was on par with the N content (1.87%) of vermicompost produced by *Eisenia foetida* (Ex-E) and *ex-situ* compost (1.62%) (Ex-C). Among the composts produced *in-situ,* the highest N content of 1.22 percent was recorded in vermicompost produced by *Eisenia foetida* which was on par with the N content of *ex-situ* compost (1.62%). Comparing the total N content of composts produced by two earthworm species, irrespective of mode of composting, vermicompost of *P. excavatus* and *E. foetida* were on par.

Phosphorus content

The highest P content was recorded in *ex-situ* vermicompost produced by *Eisenia foetida* (1.99%) (Ex-E) which was on par with the *ex-situ* compost produced in silpaulin vermibeds (1.91%) (Ex-C) and vermicompost produced by *Perionyx excavtus* (1.76%) (Ex-P).The silpaulin vermibeds were significantly superior in yielding vermicompost with significantly higher P content than that produced from banana planting pits (Table 4.7). Among the *in-situ* composts the highest P content was recorded in vermicompost produced by *Eisenia foetida* (1.10%) (In-E) which was on par with that of produced in *in-situ* compost (0.97%) (In-C). The lowest content of P (0.39%) was recorded in absolute control (S). Among the earthworm species, *Eisenia foetida* was significantly superior to *Perionyx excavatus* irrespective of the mode of composting.

Potassium content

The *ex-situ* composts prepared in silpaulin vermibeds recorded significantly superior content of K than that *in-situ* composts produced from banana planting pits as shown in Table 4.7. The highest K content was recorded in Ex-E (*ex-situ* vermicompost by *Eisenia foetida*) (0.96%) which was on par with Ex-C (*ex-situ* compost) (0.94%) and Ex-P (*ex-situ* vermicompost produced by *Perionyx excavatus*) (0.93%). Among the *in-situ* composts, the highest content of K was recorded in *in-situ* compost (0.35%) which was on par with the K content of *in-situ* vermicompost prepared using *Eisenia foetida* (In-E) (0.32%). Among the earthworm species, *Eisenia foetida* produced significantly higher K content which was on par with *Perionyx excavatus* both in *ex-situ* and *in-situ* conditions.

Tolerance limit or Sum of primary nutrients

The sum of contents of primary nutrients varied significantly with the modes of composting (Table 4.7). The highest tolerance limit of 4.82 percent was recorded in *ex-situ* vermicompost produced by *Eisenia foetida* which was on par with that of Ex-P (*ex-situ* vermicompost by *Perionyx excavatus*) (4.66%) and Ex-C (*ex-situ* compost) (4.47%). Among the *in-situ* treatments, the highest tolerance limit was recorded in In-E (*in-situ* vermicompost produced by *Eisenia foetida*) (2.64%) which was on par with that of In-C (*in-situ* compost) (2.24%) and In-P (*in-situ* vermicompost by *Perionyx excavatus*) (1.93%).

4.1.3.2. Content of secondary nutrients (%)

The results given in Table 4.8 indicated that modes of composting have significant effect on content of secondary nutrients in the composts.

Calcium content

Results on content of Ca provided in Table 4.8 revealed that *in-situ* vermicompost by *Eisenia foetida* had significantly superior Ca content (0.69%) which was on par with *ex-situ* treatments (Ex-C; Ex-E; and Ex-P) and *in-situ* compost (In-C). Among the species of earthworms, *Eisenia foetida* produced significantly superior content of Ca in vermicompost than *Perionyx excavatus*. Hence it is concluded that the mode of composting and species of earthworms had significant influence on the content of Ca.

Magnesium content

Enhancement of Mg in the compost with respect to all treatments could not attain the level of significance (Table 4.8). Numerically though not to a significant level, the highest Mg content was recorded in *in-situ* compost produced by *E.foetida* (In-E) and the lowest value by control (S). Hence the modes of composting and species of earthworms had little significant effect on Mg content of the composts.

Sulphur content

Results on S content of composts showed that among the various treatments *ex-situ* vermicompost produced by *Eisenia foetida* (0.81%) and *Perionyx excavatus* (0.75%) had significantly superior S content which was on par with *ex-situ* compost (0.60%) (Table 4.8). Among the *in-situ* treatments, vermicompost produced by *Eisenia foetida* (0.42%) was on par with that of *ex-situ* compost. The S content of Ex-P and Ex-C was significantly superior to control and was on par. The modes of composting had significant effect on S content of composts than the species of earthworms.

Table 4.8. Content of secondary nutrients as influenced by the modes of composting and species of earthworms

Treatments	Ca (As CaO)	Mg (As MgO)	S (As SO_4^{2-})
		(%)	
S	0.10	0.15	0.03
Ex-C	0.56	0.22	0.60
Ex-P	0.53	0.22	0.81
Ex-E	0.55	0.22	0.75
In-P	0.36	0.23	0.27
In-E	0.69	0.32	0.42
In-C	0.46	0.30	0.39
CD(p=0.05)	0.25	NS	0.21

Table 4.9. Content of micronutrients as influenced by the modes of composting and species of earthworms

Treatments	Zn (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})
S	0.02	8209.00	116.30	7.17
Ex-C	34.34	1694.93	122.71	5.28
Ex-P	37.27	1843.60	150.80	5.27
Ex-E	40.33	1333.00	131.69	4.93
In-P	22.93	9512.67	289.13	12.37
In-E	41.09	8494.00	329.93	13.50
In-C	25.80	10525.33	329.47	14.67
CD(p=0.05)	21.63	2970.94	73.43	3.53

4.1.3.3. Micronutrient content (mg kg^{-1} of compost)

The results of content of micronutrients of the different composts are shown in Table 4.9.

Zinc content of compost

The content of Zn was significantly higher in all the composting treatments (Table 4.9). The highest Zn content (41.09 mg kg^{-1}) was reported in *in-situ* vermicompost produced by *Eisenia foetida.* All the composting treatments were significantly superior to control (soil). The species of earthworms and modes of composting had played a big role in enriching the vermicompost with zinc.

Iron content of compost

The content of Fe was significantly higher in all *in-situ* treatments and was on par with absolute control (soil) (Table 4.9). The highest Fe content was reported in *in-situ* compost (10525.33 mg kg^{-1}) (In-C) which was on par with *in-situ* vermicompost produced by *Perionyx excavatus* (9512.67 mg kg^{-1}) and *Eisenia foetida* (8494.00 mg kg^{-1}) and absolute control (S) (8209.00 mg kg^{-1}). Among the *ex-situ* treatments, the highest Fe content was found in vermicompost produced by *Perionyx excavatus* (Ex-P) (1843.60 mg kg^{-1}) which was on par with *in-situ* compost (Ex-C) and vermicompost produced by *Eisenia foetida* (Ex-E).

Manganese content of the compost

Results of content of Mn given in Table 4.9 showed that all composts produced *in-situ* were significantly superior to those produced *ex-situ.* Among the treatments, the highest Mn content (329.93 mg kg^{-1}) was recorded in *in-situ* vermicompost prepared using *Eisenia foetida* (In-E) and it was on par with *in-situ* compost (In-C) (329.47 mg kg^{-1}) and *in-situ* vermicompost produced by *Perionyx excavatus* (In-P) (289.13 mg kg^{-1}). Among the *ex-situ* treatments, the highest Mn content (150.80 mg kg^{-1}) was recorded in vermicompost produced by *Perionyx excavatus* and was on par with absolute control (116.30 mg kg^{-1}).

Copper content of compost

Statistical data on Cu content of compost provided in Table 4.9 revealed that among the treatments, the highest Cu content of 14.67 mg kg^{-1} was shown by *in-situ* compost and was on par with *in-situ* vermicompost produced by *Eisenia* *foetida* (In-E) and *Perionyx excavatus* (In-P). The experimental soil had Mn content of 7.17 mg kg^{-1}, which was on par with compost prepared *ex-situ* and *ex-situ* vermicompost produced by *Perionyx excavatus* and *Eisenia foetida*

4.1.3.4. Heavy metal (other than micronutrients) content

Results of the statistical analysis of content of heavy metals of the composts prepared *ex-situ* and *in-situ* are given in Table 4.10. The contents of Cr and Pb (mg kg^{-1}) were below detectable level.

Content of Ni of the compost

Results of the content of Ni revealed that among the treatments, *in-situ* vermicompost produced by *Perionyx excavatus* (30.75 mg kg^{-1}) recorded the highest content of Ni which was on par with the *in-situ* compost (25.42 mg kg^{-1}) (Table 4.10). The content of Ni was on par in *in-situ* compost, *in-situ* vermicompost produced by *Eisenia foetida* (25.42 mg kg^{-1}) and absolute control (soil) (17.87 mg kg^{-1}). The lowest content of Ni was shown by *ex-situ* vermicompost produced by *Perionyx excavatus* (6.8 mg kg^{-1}) (Ex-P) which was on par with *ex-situ* compost and *ex-situ* vermicompost produced by *Eisenia foetida* (Ex-E).

Content of Cr of the compost

Chromium content of the various treatments varied from 20.87 to 54.10 mg kg^{-1} (Table 4.10). The content of Cr was significantly higher (54.10 mg kg^{-1}) in *in-situ* vermicompost prepared by *Perionyx excavatus* (In-P) which was on par with *in-situ* compost (44.70 mg kg^{-1}). The content of Cr was on parity between In-C (*in-situ* compost), S (absolute control), In-E (*in-situ* vermicompost by *Eisenia foetida*) and Ex-C (*ex-situ* compost). The lowest content of Cr was reported in *ex-situ* vermicompost produced by *Perionyx excavatus* (Ex-P) and was on par with Ex-E (*ex-situ* vermicompost by *Eisenia foetida*) and Ex-C (*ex-situ* compost).

4.1.4. Biochemical properties of composts

Auxin content

Auxin content of the prepared composts ranged from 2.13 to 26.02 µg g^{-1} of compost (Table 4.11). The highest auxin content of 26.02 µg g^{-1} of compost

Table 4.10. Content of heavy metals as influenced by the modes of composting and species of earthworms

Treatments	Ni (mg kg^{-1})	Cr (mg kg^{-1})	Cd (mg kg^{-1})	Pb (mg kg^{-1})
S	17.87	37.72	Traces	Traces
Ex-C	9.85	32.12	Traces	Traces
Ex-P	6.80	20.87	Traces	Traces
Ex-E	11.03	29.93	Traces	Traces
In-P	30.75	54.10	Traces	Traces
In-E	20.90	37.22	Traces	Traces
In-C	25.42	44.70	Traces	Traces
CD(p=0.05)	7.81	13.80	-	-

Table 4.11. Biochemical properties of composts as influenced by the modes of composting and species of earthworms

Treatments	Auxin equivalents (µg g^{-1} of compost)	Dehydrogenase activity (µg TPF day^{-1} g^{-1} of compost)
S	2.13	7.89
Ex-C	9.86	64.43
Ex-P	18.69	1798.63
Ex-E	26.02	1394.86
In-P	6.05	249.89
In-E	7.75	423.56
In-C	4.91	218.53
CD(p=0.05)	3.28	93.83

was recorded from *ex-situ* vermicompost prepared using *Eisenia foetida* (Ex-C) and the lowest content was recorded in *in-situ* vermicompost prepared using *Eisenia foetida* (In-E) and was on par with *in-situ* compost (In-C). Among the *in-situ* compost treatments, the highest content of auxin was recorded in vermicompost prepared using *Eisenia foetida* (7.75 μg g^{-1}) which was on par with *in-situ* vermicompost produced by *Perionyx excavatus* (6.05 μg g^{-1}).

Dehydrogenase activity (DA) of the compost

Vermicompost prepared *ex-situ* using *Perionyx excavatus* (Ex-P) recorded the highest DA (1798.63 μg TPF day^{-1} g^{-1} of compost) (Table 4.11) followed by *ex-situ* vermicompost prepared using *Eisenia foetida* with a DA of 1394.85 μg TPF day^{-1} g^{-1} of compost. Among the *in-situ* treatments, the highest DA was recorded in *in-situ* vermicompost prepared using *Eisenia foetida* (423.56 μg TPF day^{-1} g^{-1} of compost). The DA of *in-situ* compost (In-C) and *in-situ* vermicompost using *Perionyx excavatus* (In-P) was on par.

Total Microbial Count of composts

The results of the viable microbial cell count of the composts are shown in Table 4.12. Among the treatments, the highest bacterial count of 720 $x10^4$ cfu g^{-1} was recorded in *ex-situ* compost (Ex-C) which was on par with that of *in-situ* vermicompost produced by *Eisenia foetida* (In-E) ($650x10^4$ cfu g^{-1}) of the compost. The bacterial count was on par in *ex-situ* vermicompost produced by *Perionyx excavatus* (Ex-P), *in-situ* compost (In-C) and *in-situ* vermicompost produced by *Perionyx excavatus* (In-P) and *ex-situ* vermicompost produced by *Eisenia foetida* (Ex-E). Among the treatments, the highest fungal count of 1x 10^4 cfu g^{-1} was recorded in *in-situ* compost (In-C) which was on par with that of *in-situ* vermicompost produced by *Perionyx excavatus* (In-P) (0.94 $x10^4$ cfu g^{-1}) of the compost. The viable count of actinomycetes cell was significantly higher for *ex-situ* vermicompost prepared using *Eisenia foetida* with 4.80 x 10^4 cfu g^{-1} of compost. The lowest actinomycetes count was recorded in Ex-P.

Content of humic acid

The content of humic acid (%) of the compost as influenced by modes of composting and species of earthworms are shown in Table 4.13. Among the

Table 4.12. Viable cells of bacteria, fungi and actinomycetes of the composts at maturity as influenced by the modes of composting and species of earthworms

Treatments	Viable bacterial cells (10^4 cfu g^{-1})	Viable fungal Count (10^4 cfu g^{-1})	Viable actinomycetes count (10^4 cfu g^{-1})
S	360.00	0.22	3.20
Ex-C	720.00	0.64	2.70
Ex-P	480.00	0.38	0.01
Ex-E	440.00	0.54	4.80
In-P	450.00	0.94	4.20
In-E	650.00	0.26	1.79
In-C	460.00	1.00	2.08
CD(p=0.05)	71.54	0.08	0.47

Table 4.13. Humic acid content of compost at maturity as influenced by the modes of composting and species of earthworms

Treatments	Humic Acid content (%)
S	7.46
Ex-C	28.61
Ex-P	24.99
Ex-E	32.79
In-P	17.71
In-E	25.99
In-C	42.15
CD(p=0.05)	10.49

treatments, the significantly superior content of humic acid of 42.15% was shown by *in-situ* compost (In-C) and was on par with that of Ex-E (*ex-situ* vermicompost by *Eisenia foetida*). The humic acid content of Ex-C (*ex-situ* compost), In-E (*in-situ* vermicompost by *Eisenia foetida*) and Ex-P (*ex-situ* vermicompost by *Perionyx excavatus*) was on par that of Ex-E.

4.1.5. Humic acid characterization by spectroscopic techniques

The Fourier Transform Infra-Red spectra of humic acids from different treatments indicated significant differences between them (Figure 4.1 to 4.7). As the main absorption band was above 3000 cm^{-1} the humic acids are likely to be unsaturated (contains C = C) or aromatic. Two set of bands in the region 1615 - 1495 cm^{-1}, with one set around 1600 cm^{-1} (aromatic ring stretch) and the other around 1500 cm^{-1} (aromatic ring stretch) confirmed that the structures were indeed aromatic. Moreover, medium-to-strong absorptions, sometimes more than one, between 850 and 670 cm^{-1}, can be assigned to C-H out-of-plane bending on an aromatic ring.

Quantitative evaluation of the composting process and maturity was done based on a comparison of the relative intensity ratio of absorbance bands at 2925–2930 cm^{-1} to 1034–1040 cm^{-1}.The ratio of the intensity of bands at 2930 cm^{-1} to 1034cm^{-1} testified that Ex-P (*ex-situ* composts prepared using *Perionyx excavatus*) and In-P (*in-situ* composts prepared using *Perionyx excavatus*) had humic acids with high aromaticity resulting from higher decomposition degree. Weak adsorption bands in the 2500 - 2000 cm^{-1} region in humic acids extracted from different treatments points to a possibility of triple bonded carbon (stretching) in the skeletal structure.

With respect to the functional groups, a relatively sharp and common band found at 3415 - 3380 cm^{-1} in all the analyzed samples can be assigned to non-hydrogen-bonded hydroxy group which can be an alcohol or phenol with a sterically hindered OH group. In spectra of humic acids from treatments Ex-C, Ex-P and In-P there were absorption bands at 2935 and 2860 cm^{-1} attributed to aliphatic methylene groups and assigned to fats and lipids. This confirmed the presence of some long linear aliphatic chain along with the aromatic rings in the

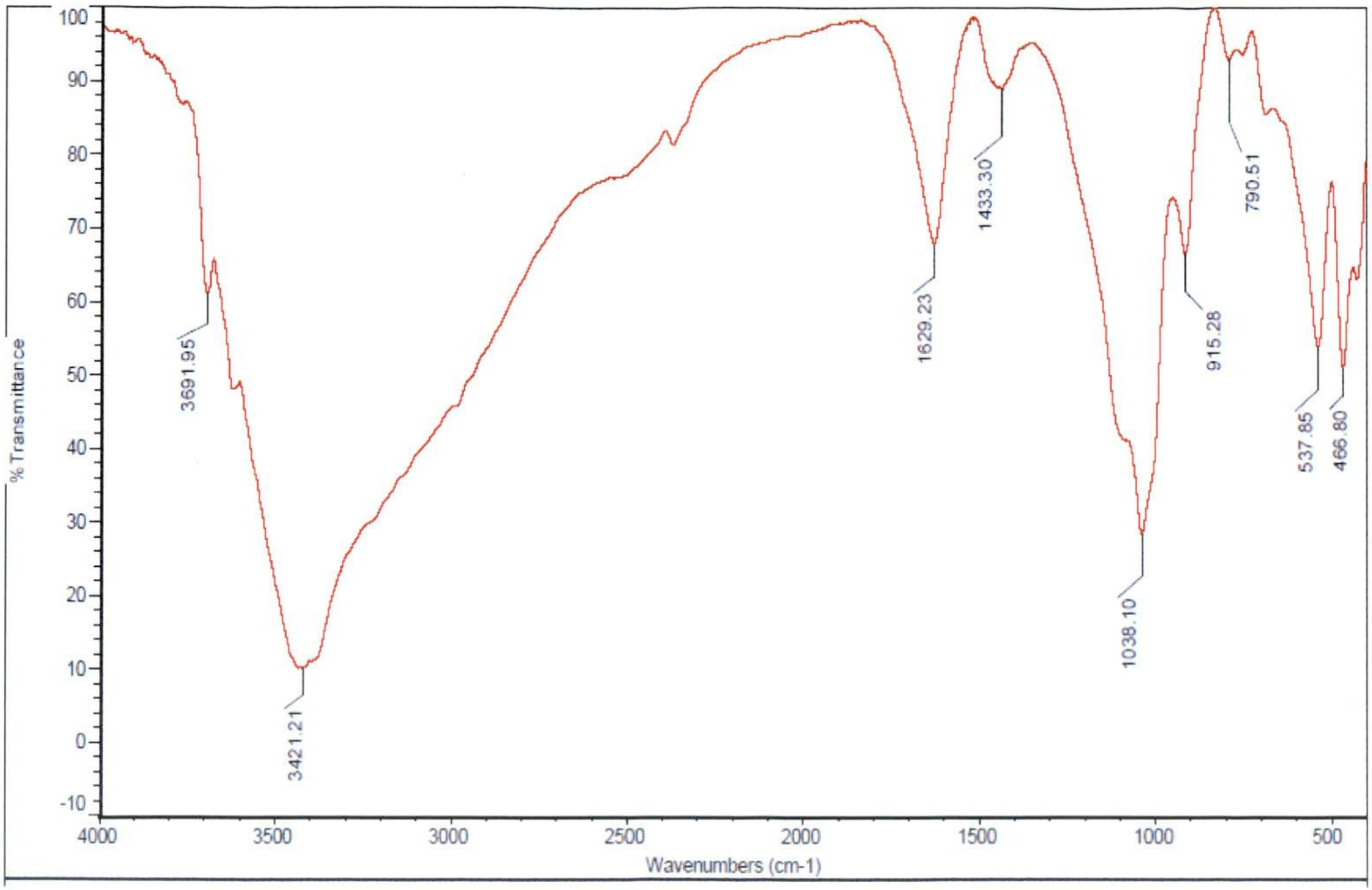


Figure 4.1. Fourier Transform Infra-Red spectra of humic acids produced from soil (S)

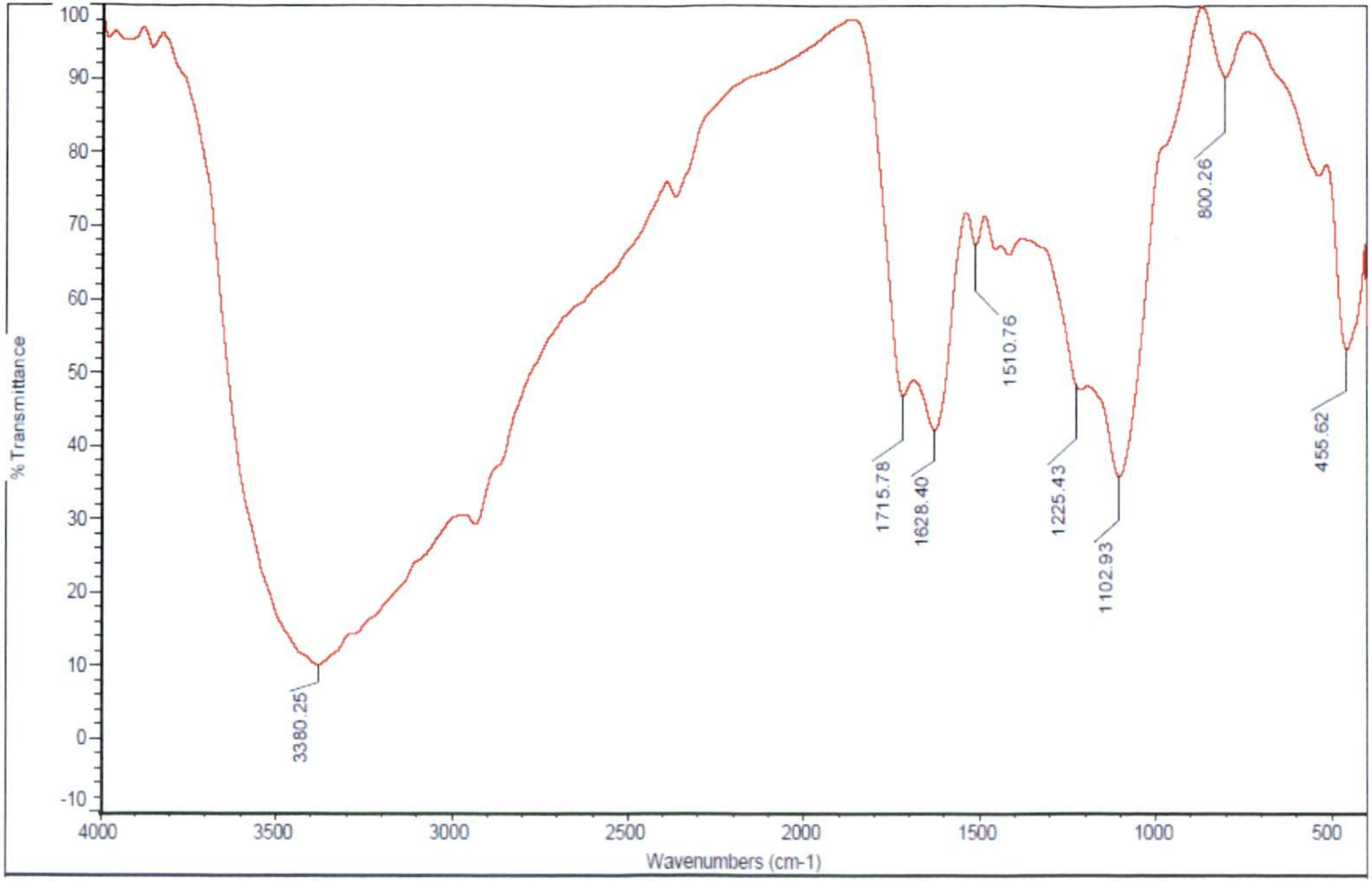


Figure 4.2. Fourier Transform Infra-Red spectra of humic acids produced from Ex-C

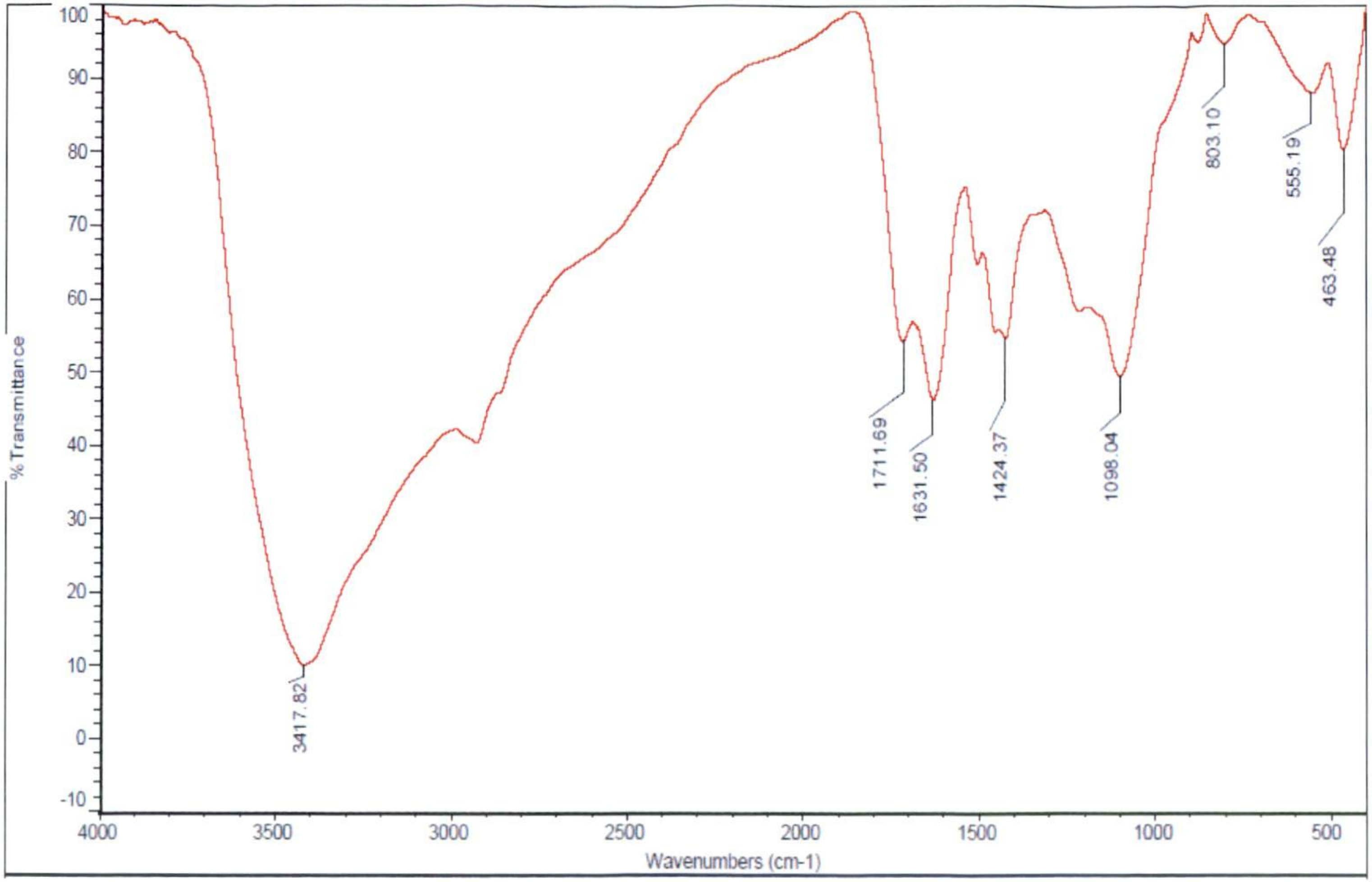


Figure 4.3. Fourier Transform Infra-Red spectra of humic acids produced from Ex-P

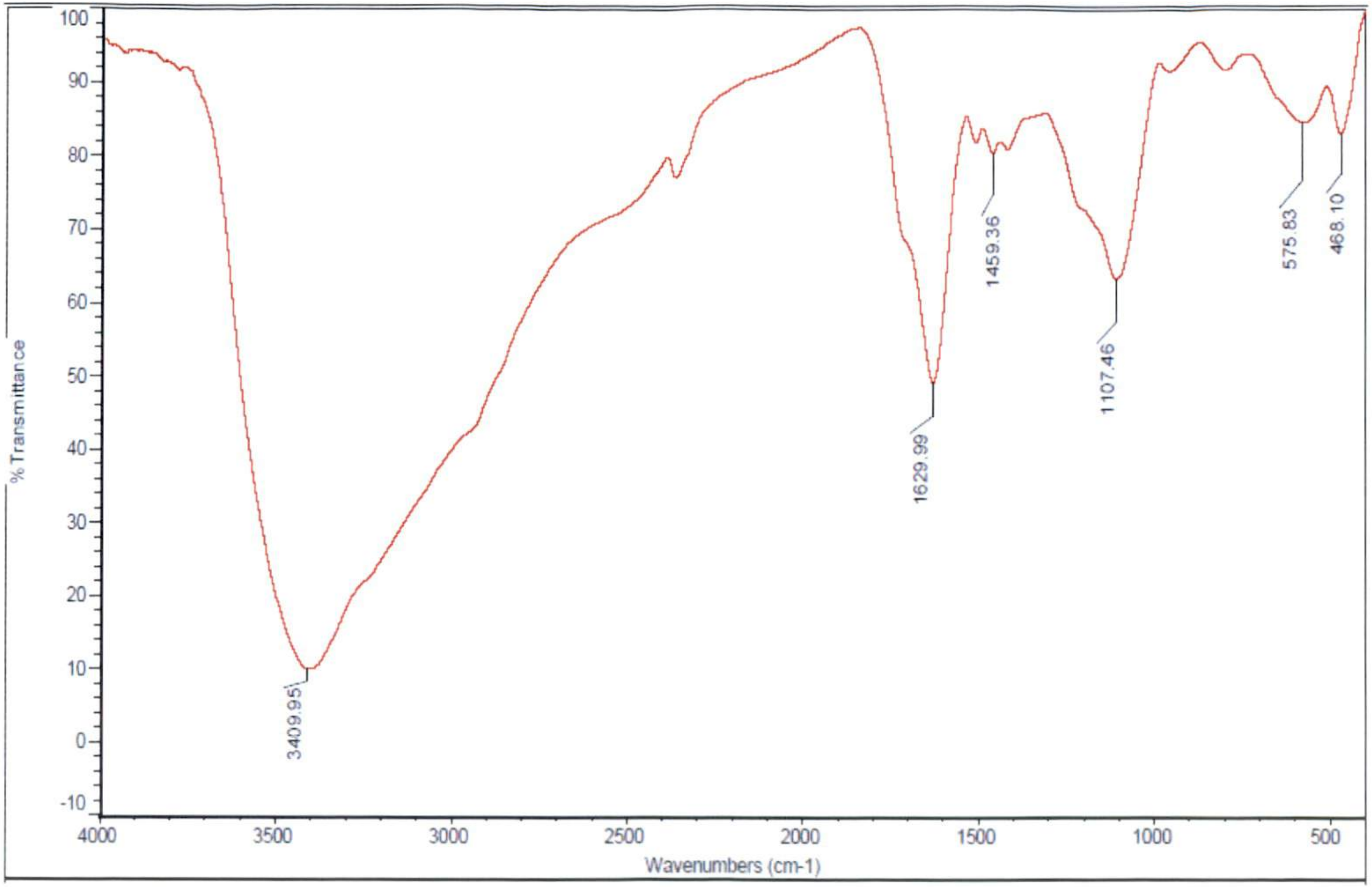


Figure 4.4.Fourier Transform Infra-Red spectra of humic acids produced from Ex-E

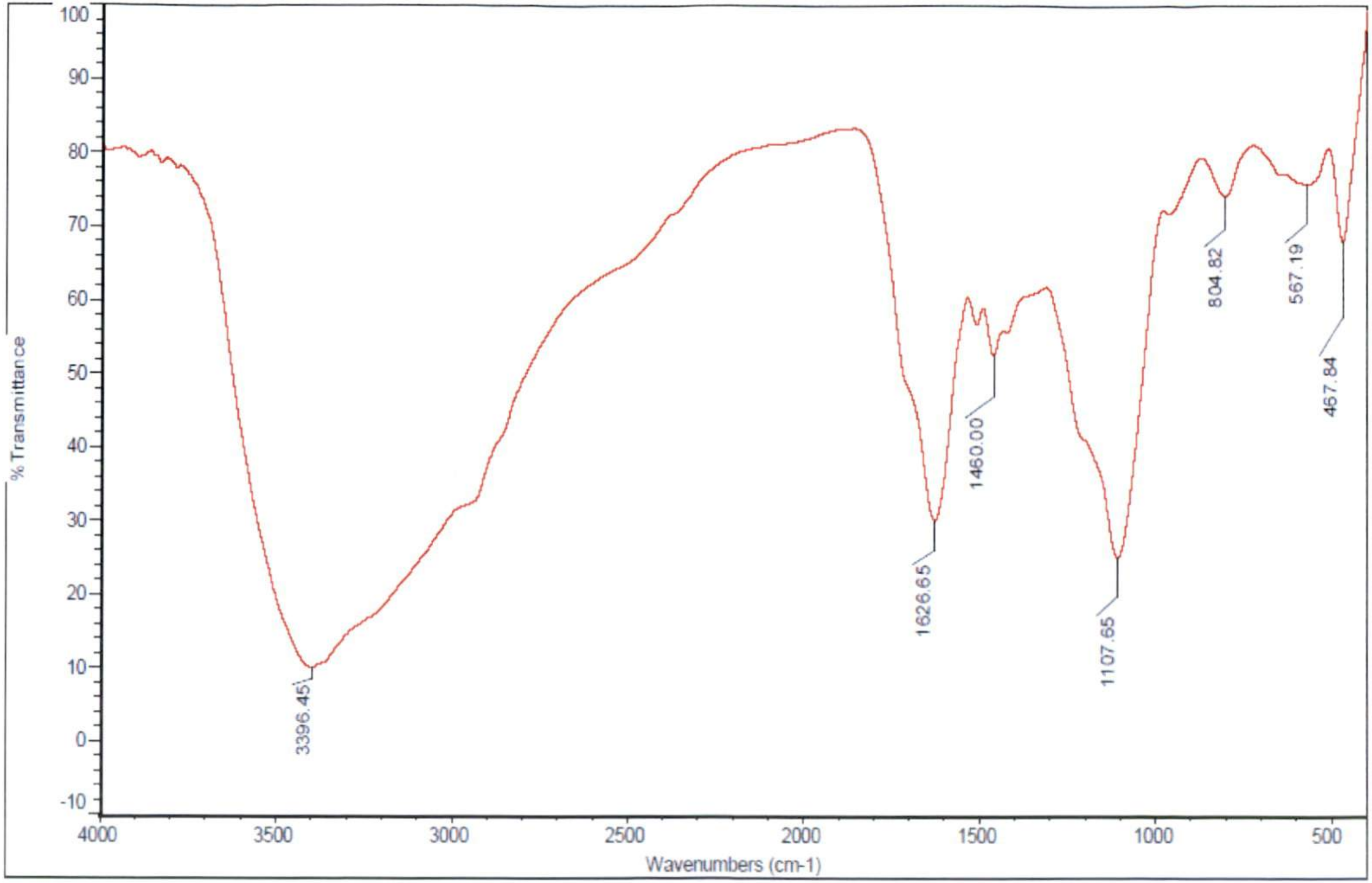


Figure4.5. Fourier Transform Infra-Red spectra of humic acids produced from In-P

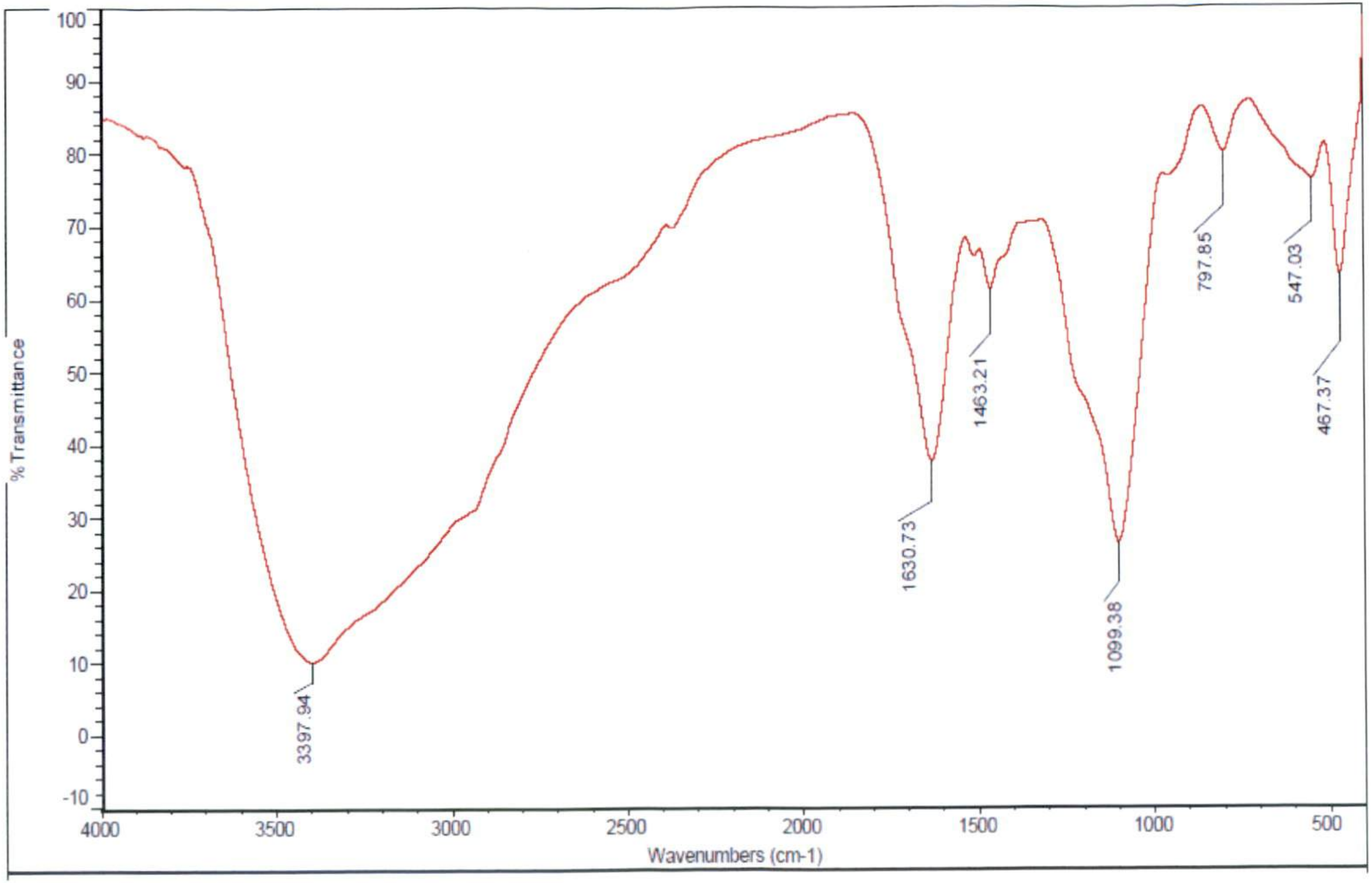


Figure 4.6. Fourier Transform Infra-Red spectra of humic acids produced from In-E

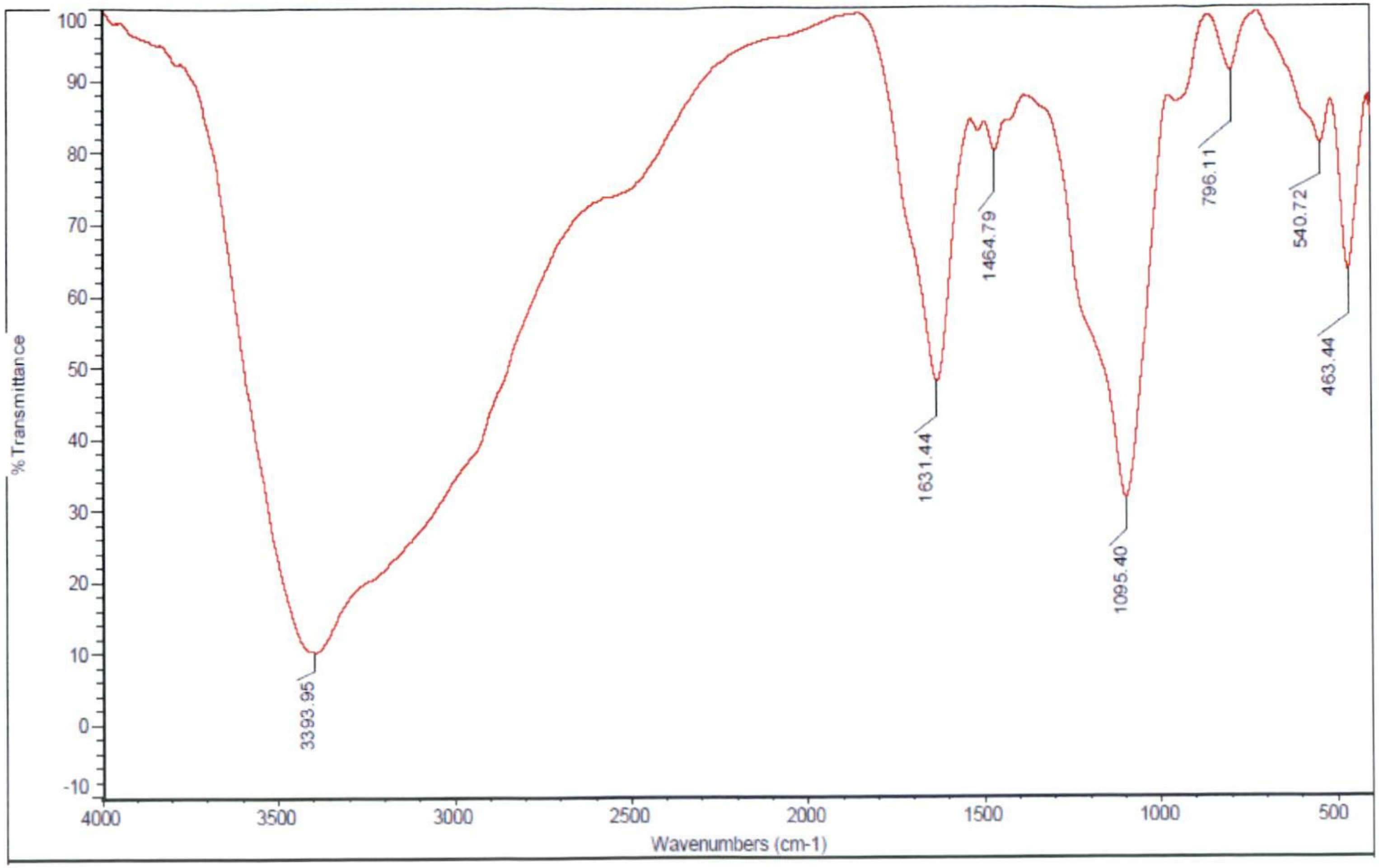


Figure 4.7. Fourier Transform Infra-Red spectra of humic acids produced from In-C

polymeric HA structures in these treatments. The prominent bands at 1740 - 1690 cm^{-1} in all the analyzed humic acids is most relevant, since in this region rarely other functional groups than C=O show intense absorption bands and they are not affected by water content of the samples. The intensity of the C=O band was relatively more in treatments Ex-P, Ex-E, In-P, In-E and In-C than Ex-C and control treatments (S). The most obvious differences in the spectra of humic acids was the band observed at 1350– 1400 cm^{-1} region where a nitrate band of characteristic shape appeared prominently for *ex-situ* vermicompost prepared using *Perionyx excavatus* (Ex-P).

4.2. Effect of treatments on yield and bunch characteristics banana plants

The data on effect of composts and recommended dose of fertilizers on yield and bunch characteristics of tissue culture banana plants are presented below (Table 4.14).

4.2.1. Bunch yield (kg $plant^{-1}$) of banana

The bunch yield of banana plants ranged from 4.25 - 10.81 kg $plant^{-1}$ (Table 4.14).The highest bunch yield (10.81 kg $plant^{-1}$) was recorded in plants grown under the recommended dose of fertilizers (POP) and was significantly superior to all other treatments. Bunch yield of all the treatments was significantly superior to control (S) (4.25 kg $plant^{-1}$). Among the composting treatments, the highest yield of 7.24 kg $plant^{-1}$ was recorded in plants grown under *in-situ* compost (In-C) and the lowest was recorded in Ex-E (6.73 kg $plant^{-1}$). However all the composting treatments recorded comparable yield.

4.2.2. Bunch characteristics

Number of hands per bunch

The data on effect of treatments on number of hands per bunch are presented in Table 4.14. The number of hands per bunch ranged from 5 to 6 in all the plants. Number of hands per bunch was significantly higher for plants grown under POP (recommended dose of fertilizers), In-C (*in-situ* compost at the rate of 20 kg plant $^{-1}$) and Ex-P *(Ex-situ* vermicompost with native worms at the rate of 20 kg plant $^{-1}$). The number of hands per bunch of In-C, Ex-P and In-P were on par. The plants grown under In-E (*In-situ* vermicompost with exotic worms at the

Table 4.14. Effects of treatments on the yield and bunch characteristics of banana plants

Treatments	Bunch yield (kg plant^{-1})	Number of hands per bunch	Number of fingers per hand	Weight of one finger (g)
S	4.25	4.67	6.67	101.67
POP	10.81	6.33	10.33	178.67
Ex-P	7.02	6.00	8.67	147.33
Ex-E	6.73	5.33	8.33	150.67
In-P	6.77	5.67	9.00	155.00
In-E	6.79	5.33	9.33	140.67
In-C	7.24	6.00	9.00	146.33
CD(p=0.05)	1.62	0.64	1.92	29.15

*POP: Package of Practices and Recommendations, Kerala Agricultural University.

Table 4.15. Effect of treatments on growth characteristics of banana plants at the time of bunching

Treatments	No. of functional leaves	Pseudostem		Time taken (days) for	
		Height (cm)	Girth (cm)	bunching	harvest
S	6	247.17	39.66	340	431
POP	10	351.75	51.83	264	345
Ex-P	9	295.89	45.89	248	333
Ex-E	9	288.39	42.42	234	321
In-P	9	298.67	44.25	221	293
In-E	9	295.25	44.33	232	310
In-C	9	296.08	43.83	206	297
CD(p=0.05)	1.54	48.49	4.55	33.52	49.79

rate of 20 kg plant $^{-1}$) and Ex-E (*Ex-situ* vermicompost with exotic worms at the rate of 20 kg plant $^{-1}$) were significantly superior to S (control) and were on par with In-P (*In-situ* vermicompost with native worms at the rate of 20 kg plant $^{-1}$).

Number of fingers per hand

Number of fingers per hand ranged from 7 to 10 (Table 4.14). The highest number of fingers per hand of bunch that yielded under POP (recommended dose of fertilizers) was significantly superior to all other treatments and on par with that of In-E (9), In-C (9), In-P (9) and Ex-P (9). Among composting treatments, plants grown under *in-situ* vermicompost with exotic worms at the rate of 20 kg plant $^{-1}$ (In-E), *In-situ* compost at the rate of 20 kg plant $^{-1}$ (In-C), *in-situ* vermicompost with native worms at the rate of 20 kg plant $^{-1}$ (In-P) and *ex-situ* vermicompost with native worms at the rate of 20 kg plant $^{-1}$(Ex-P) were on par. The number of fingers per hand of plants grown under Ex-E was on par with control (S).

Weight of one finger

Weight of one finger ranged from 101.67g to 178.67g (Table 4.14). The plants grown under POP (recommended dose of fertilizers) recorded significantly higher weight of one finger (178.67g). The plants that received organic nutrition through In-P (*in-situ* vermicompost with *Perionyx excavatus* at the rate of 20 kg plant $^{-1}$) and Ex-E (*ex-situ* vermicompost with *Eisenia foetida* at the rate of 20 kg plant $^{-1}$) were on par with that of POP.

Weight of fingers of plants grown under Ex-P (*ex-situ* vermicompost with native worms at the rate of 20 kg plant $^{-1}$), In-C (*in-situ* compost at the rate of 20 kg plant $^{-1}$) and In-E (*in-situ* vermicompost with exotic worms at the rate of 20 kg plant $^{-1}$) were significantly superior to control and were on par. Plants grown under vermicompost prepared by *in-situ* and *ex-situ* modes of composting did not differ in finger weight. Among the species of earthworms, the plants grown under *in-situ* vermicompost prepared using *Perionyx excavatus* and *ex-situ* vermicompost prepared using *Eisenia foetida* were on par to POP.

4.2.3. Effect of treatments on growth characteristics banana plants

Biometrical observations were also recorded at the time of bunching to find out the effect of treatments on the growth characteristics of tissue culture banana plants. The results are presented in Table 4.15 and explained below.

Number of functional leaves at bunching

Number of functional leaves at bunching had values ranging from 6 to 10. (Table 4.15) The highest number of functional leaves (10) were observed in POP (300:115:450g N: P_2O_5: K_2O plant^{-1} + FYM at the rate of 20 kg plant^{-1}) and lowest number of functional leaves were recorded in S (soil). All the treatment means were significantly superior to control with respect to the number of functional leaves. Modes of composting and species of earthworms had no significant difference among themselves.

Pseudostem height at bunching

Statistical scrutiny on height of pseudostem recorded that plants grown under POP (300:115:450g N: P_2O_5: K_2O plant^{-1} + FYM at the rate of 20 kg plant^{-1}) were significantly taller than all the other treatments with a height of 352 cm (Table 4.15). Pseudostem height of plants grown under In-P with 299 cm (*in-situ* vermicompost with *Perionyx excavatus* at the rate of 20 kg plant $^{-1}$); *in-situ* compost (In-C) with 296cm and Ex-P (*ex-situ* vermicompost with *Perionyx excavatus* at the rate of 20 kg plant $^{-1}$) with 296cm were on par. The pseudostem height of plants grown under In-E (*in-situ* vermicompost with *Eisenia foetida* at the rate of 20 kg plant $^{-1}$) and Ex-E (*ex-situ* vermicompost with *Eisenia foetida* at the rate of 20 kg plant $^{-1}$) were on par with control. Among the modes of composting, composts prepared under *in-situ* mode of composting (In-P and In-C) and Ex-P had significant effect on the pseudostem height of the plants. However, the plants grown under vermicompost prepared using *Perionyx excavatus* irrespective of modes of composting had significant influence on the height of pseudostem.

Pseudostem girth

As shown in Table 4.15, girth of pseudostem varied significantly among the treatments from 39.67cm to 51.83cm. The highest pseudostem girth of 51.83cm was recorded for plants grown under POP (300:115:450g N: P_2O_5: K_2O plant^{-1} + FYM at the rate of 20 kg plant^{-1}). Girth of plants grown on *ex-situ* vermicompost with *Perionyx excavatus* (Ex-P) with 45.89 cm, *in-situ* vermicompost produced by *Eisenia foetida* (In-E) with 44.33 cm and *in-situ* vermicompost with *Perionyx excavatus* (In-P) with 44.25 cm were on par. The lowest pseudostem girth of 39.67cm was recorded in absolute control (S).

Time taken for bunching

The results of the statistical analysis showed that plants grown under soil (control) had significantly longer duration for bunching (flowering) than all other treatments (Table 4.15). The plants grown under absolute control (S) recorded the lengthiest period (340 days) for bunching followed by plants of POP treated plots (264 days). The number of days to bunching for plants grown under In-C (*in-situ* compost) was significantly shorter with 206 days but was on par with that of plants grown under Ex-E, In-E and In-P (234days, 232 days and 221 days respectively). However, the number of days to bunching for plants grown under POP (300:115:450g N: P_2O_5: K_2O plant^{-1} + FYM at the rate of 20 kg plant^{-1}) was statistically on par with Ex-P (*ex-situ* vermicompost with *Perionyx excavatus* at the rate of 20 kg plant^{-1}), Ex-E and In-E.

Time taken for harvest

Statistical analyses of number of days to harvest of banana plants grown under various treatments are shown in Table 4.15. The days to harvest of banana plants ranged from 293 to 431. Among the various treatments, plants grown under control (soil) recorded the highest number of days to harvest (431days). The shortest crop duration in terms of number of days to harvest (293 days) was shown by plants grown under *in-situ* vermicompost using *Perionyx excavatus* (In-P) and was statistically on par with In-C (297 days), In-E (310 days), Ex-E (321 days) and Ex-P (333 days).

4.2.4. Effect of treatments on foliar nutrient contents in index tissues of banana plants

The elemental analysis details of index tissue (petiole of the 3rd open leaf from apex at bud differentiation stage) of banana plants at four months after planting (MAP) are given in Table 4.16.

Total N content of index tissues of banana plants at 4 MAP

Total N content of the petiole of banana plants at 4 MAP showed significant variations among themselves (Table 4.16). Significantly higher N content of 0.61 percent was recorded in index tissues of plants grown under POP (300:115:450g N: P_2O_5: K_2O.plant^{-1} + FYM at the rate of 20 kg plant^{-1}). The N content of plants grown under control plot (0.48%), Ex-E (0.47%) and In-E (0.46%) were on par at four months after planting.

Among the species of earthworms, the highest N content was recorded for plants receiving N through vermicompost prepared by *Eisenia foetida* under both modes of composting.

Total P content (%) of index tissues of banana plants at 4 MAP

The results of index tissue analysis for P content of treatments at four months after planting are shown in Table 4.16. The highest P content of 0.33 percent was recorded in Ex-P (*ex-situ* vermicompost with *Perionyx excavatus* at the rate of 20 kg plant $^{-1}$). However, it was on par with the P content of plants grown under soil (0.29%), In-C (*in-situ* compost at the rate of 20 kg plant $^{-1}$) (0.25%) and In-E (*in-situ* vermicompost with *Eisenia foetida* at the rate of 20 kg plant^{-1}) (0.25%). Among the *in-situ* treatments, the highest P content was recorded in In-C (0.25%) followed by In-E (0.24%). The lowest P content of 0.13 percent was recorded in POP (300:115:450g N: P_2O_5:K_2O plant^{-1} + FYM at the rate of 20 kg plant^{-1}).

Total K content of index tissues of banana plants at 4 MAP

The K content of petiole of banana plants of various treatments are shown in Table 4.16. Among the various treatments, banana plants grown under *ex-situ* vermicompost at the rate of 20 kg plant^{-1} (Ex-P) showed significantly higher K content of 0.84 percent which was on par with banana plants of Ex-E (*ex-situ* vermicompost at the rate of 20 kg plant^{-1} using *Eisenia foetida*) (0.82%) and that of plants grown under POP (0.79%).

Among the modes of composting, the plants that received *ex-situ* vermicompost irrespective of the earthworm species (Ex-P and Ex-E), and *in-situ* vermicompost prepared by *Eisenia foetida* (In-E) recorded significantly higher content of K in the index leaves. However among the species of earthworms, both native and exotic earthworms under *ex-situ* environment increased K content of the index leaves of banana plants.

Total Ca content of index tissues of banana plants at 4 MAP

Total Ca content varied significantly among the treatments (Table 4.16). Banana plants treated with *in-situ* vermicompost produced by *Eisenia foetida* at the rate of 20 kg plant^{-1} (In-E) showed significantly higher content of Ca (0.56%). The Ca content of plants that received *ex-situ* vermicompost (Ex-P) (using *Perionyx excavatus* at the rate of 20 kg plant^{-1}) (0.51%); *in-situ* compost (In-C) (0.48%) and *ex-situ* vermicompost (Ex-E) (using *Eisenia foetida* at the rate of 20 kg plant^{-1}) (0.47%) were on par with In-E. The Ca content of plants grown under POP (300:115:450g N: P_2O_5:K_2O plant^{-1} + FYM at the rate of 20 kg plant^{-1}) and In-P (*in-situ* vermicompost produced by *Perionyx excavatus* at the rate of 20 kg plant^{-1}) were significantly superior to control and were on par with Ex-P, In-C and Ex-E.

Total Mg content (%) of index tissues of banana plants at 4MAP

Magnesium content of treatments varied significantly (Table 4.16). Banana plants grown under In-E (*in-situ* vermicompost produced by *Eisenia foetida* at the rate of 20 kg plant^{-1}) had significantly superior content of Mg (0.13%) among the treatments and was on par with Mg content of plants under In-C (*in-situ* compost at the rate of 20 kg plant^{-1}) (0.11%) and Ex-P (*ex-situ* vermicompost using *Perionyx excavatus* at the rate of 20 kg plant^{-1}) (0.10%). Plants grown under In-P (*in-situ* vermicompost by *Perionyx excavatus* at the rate of 20 kg plant^{-1}) and Ex-E (*ex-situ* vermicompost using *Eisenia foetida* at the rate of 20 kg plant^{-1}) were on par with In-C and Ex-P. The plants grown under recommended package of

Table 4.16. Effect of treatments on content of nutrients in the index tissue of banana at four months after planting

Treatments	Total N	Total P	Total K	Total Ca	Total Mg
S	0.48	0.29	0.26	0.16	0.02
POP	0.61	0.13	0.78	0.42	0.05
Ex-P	0.43	0.33	0.83	0.51	0.09
Ex-E	0.47	0.22	0.81	0.47	0.09
In-P	0.42	0.17	0.73	0.38	0.09
In-E	0.46	0.25	0.78	0.56	0.13
In-C	0.42	0.25	0.77	0.48	0.11
CD(p=0.05)	0.05	0.09	0.07	0.13	0.03

Table 4.17. Effect of treatments on content phytohormones in the index tissue of banana at four months after planting

Treatments	Un-oxidized Auxin ($\mu g\ g^{-1} hr^{-1}$)	Gibberellic acid ($\mu g\ g^{-1}$)
S	0.37	1.06
POP	0.35	1.23
Ex-P	0.28	1.78
Ex-E	0.28	0.56
In-P	0.27	1.08
In-E	0.36	0.53
In-C	0.36	0.84
CD(p=0.05)	0.07	0.63

practices (POP) showed Mg content which was on par with that of absolute control (S).

4.2.5. Effect of treatments on phytohormone content of index tissues of banana plants

Petiole of index leaf tissues were collected and content of phytohormones like auxins and gibberellins were calculated and results are presented in Table 4.17.

Indole acetic acid oxidase activity (µg of un-oxidized auxin g^{-1} of plant tissue)

The content of un-oxidized auxin varied significantly among the treatments (Table 4.17). The highest concentration of (0.37 µg g^{-1} of leaf tissue) un-oxidized auxin was recorded in S (absolute control). The content of un-oxidized auxin in In-E (0.36 µg g^{-1} of leaf tissue) was on par with In-C (0.36 µg g^{-1} of leaf tissue) and POP (0.36 µg g^{-1} of leaf tissue). The lowest concentration of un-oxidized auxin (0.28 µg g^{-1} of leaf tissue) was reported in plants grown under *in-situ* vermicompost with *Perionyx excavatus* at the rate of 20 kg plant $^{-1}$ (In-P) which was on par with Ex-E (*ex-situ* vermicompost with *Eisenia foetida* at the rate of 20 kg plant $^{-1}$) (0.0.28 µg g^{-1} of leaf tissue) and Ex-P (*ex-situ* vermicompost with *Perionyx excavatus* at the rate of 20 kg plant $^{-1}$) (0.29 µg g^{-1} of leaf tissue).

Content of gibberellins (µg g^{-1} of plant tissue)

Content of gibberellins varied significantly with the treatments (Table 4.17). Among the treatments, plants grown under *ex-situ* vermicompost with *Perionyx excavatus* at the rate of 20 kg plant^{-1} (Ex-P) showed significantly ($p \leq 0.05$) higher content of gibberellins (1.77 µg g^{-1} of leaf tissue) which was on par with POP (recommended dose of fertilizers) (1.22 µg g^{-1} of leaf tissue). *In-situ* vermicompost with *Perionyx excavatus* at the rate of 20 kg plant^{-1} (1.08 µg g^{-1} of leaf tissue) recorded on par content of gibberellins in plants grown under soil (S) (1.06 µg g^{-1} of leaf tissue) and *in-situ* compost (In-C) (0.84 µg g^{-1} of leaf tissue). The lowest content of gibberellins (0.53 µg g^{-1} of leaf tissue) was observed for plants grown under *ex-situ* and *in-situ* vermicompost at the rate of 20 kg plant^{-1} by *Eisenia foetida* (0.53 µg g^{-1} of leaf tissue).

4.2.6. Effect of treatments on quality attributes of banana fruits

The quality attributes like vitamin C content, total sugars, reducing and non-reducing sugars, shelf life were calculated and results are presented in Table 4.18.

Vitamin C (mg of ascorbic acid 100g^{-1} of fruit)

The content of Vitamin C varied among the treatments (Table 4.18). Significantly higher content of vitamin C of 20.58 mg 100g^{-1} of fruit was observed in plants treated POP (300:115:450g N: P_2O_5:K_2O plant^{-1} + FYM at the rate of 20 kg plant^{-1}) and was on par with *in-situ* compost (In-C) (19.03mg 100g of fruit^{-1}) followed by In-P (*in-situ* vermicompost at the rate of 20 kg plant^{-1} using *Perionyx excavatus*) (17.93 mg 100g^{-1} of fruit) followed by Ex-E (*ex-situ* vermicompost at the rate of *Eisenia foetida* at the rate of 20 kg plant^{-1}) (17.86 mg 100g^{-1} of fruit), followed by *ex-situ* vermicompost at the rate of 20 kg plant^{-1} using *Perionyx excavatus* (Ex-P) (17.74 mg 100g^{-1} of fruit). The content of vitamin C of all treatments was significantly superior to control. The content of vitamin C in plants grown under *in-situ* and *ex-situ* compost treatments was on par except In-E.

Titratable Acidity (g of citric acid 100g^{-1} of fruit)

The results of titratable acidity of fruits are shown in Table 4.18. The acidity of various treatments ranged from 0.29 to 0.96 g of citric acid 100g^{-1} of fruit. Among the treatments, the titratable acidity varied as In-E (0.29 g of citric acid 100g^{-1} of fruit) = In-C (0.43 g of citric acid 100g^{-1} of fruit) < Ex-P (0.49 g of citric acid 100g^{-1} of fruit) < In-P (0.50 g of citric acid 100g^{-1} of fruit) < Ex-E (0.54 g of citric acid 100g^{-1} of fruit). The control plot recorded significantly higher titratable acidity (0.96g of citric acid 100g^{-1} of fruit) than the other treatments. However, the acidity of fruits grown under POP (0.63 g of citric acid 100g^{-1} of fruit) (300:115:450g N: P_2O_5:K_2O plant^{-1} + FYM at the rate of 20 kg plant^{-1}) were similar to fruit acidity that were obtained from composting treatments (In-C, In-P, Ex-E, Ex-P).

Shelf life (Days)

Shelf life of fruits varied significantly among the treatments (Table 4.18). The shelf life of the fruits was found to be highest in POP (300:115:450g N: P_2O_5:K_2O plant^{-1} + FYM at the rate of 20 kg plant^{-1}) followed by plants grown under *in-situ*

Table 4.18. Effect of treatments on vitamin C content, titratable acidity and shelf life of banana fruits

Treatments	Vitamin C (mg $100g^{-1}$ of fruit)	Titratable Acidity (g of citric acid $100g^{-1}$ of fruit)	Shelf life* (days)
S	9.78	0.97	10
POP	20.58	0.63	20
Ex-P	17.74	0.49	18
Ex-E	17.86	0.54	14
In-P	17.93	0.50	18
In-E	17.12	0.29	13
In-C	19.03	0.43	15
CD (p=0.05)	2.92	0.29	4.98

*** From harvest to fully ripened stage**

Table 4.19. Effect of treatments on content of total sugars, reducing sugars and non-reducing sugars of ripened banana fruits

Treatments	Total sugars	Reducing sugars	Non-reducing sugars
S	8.30	1.65	6.66
POP	13.35	2.72	10.63
Ex-P	17.82	2.55	15.27
Ex-E	16.42	2.55	13.87
In-P	20.96	3.71	17.25
In-E	22.41	3.61	18.80
In-C	22.27	3.54	18.74
CD (p=0.05)	3.55	0.79	3.06

(In-P) and *ex-situ* vermicompost prepared by *Perionyx excavatus* (Ex-P) (18 days each). Lowest shelf life of fruits was observed for plants grown under control (S) (10 days).

Content of total sugars (%) of ripened fruit

The content of total sugars and reducing and non-reducing sugars were calculated and presented in Table 4.19.

Total sugars (%)

Significantly higher content of total sugars (22.42%) was recorded in plants that received vermicompost prepared *in –situ* using *Eisenia foetida* (In-E) followed by those received organic nutrition through compost prepared *in-situ* (22.28%) (In-C) followed by plants that received *in-situ* vermicompost prepared by *Perionyx excavatus* (20.96%) (In-P). The total sugar content of fruits from plants that received vermicompost *in-situ* by *Perionyx excavatus* (In-P) was on par with those received organic nutrition through *ex-situ* vermicompost prepared by *Perionyx excavatus* in silpaulin vermibeds (Ex-P). The total sugar content of plants receiving recommended dose of fertilizers (POP) was on par with that of plants that received vermicompost prepared *ex-situ* using *Eisenia foetida* (Ex-E).

Reducing sugars (%)

The content of reducing sugars varied significantly among the treatments (Table 4.19). Plants receiving organic nutrition through *in-situ* vermicompost prepared using *Perionyx excavatus* (In-P) recorded the highest content of reducing sugars (3.71%) which was on par with *in-situ* vermicompost prepared by *Eisenia foetida* (3.61%) (In-E) and *in-situ* compost (In-C) (3.54%).

Non-reducing sugars (%)

The content of non-reducing sugars is presented in Table 4.19. Content of reducing sugars ranged from 6.66% to 18.80%. Significantly superior and on-par contents of non-reducing sugars were recorded in *in-situ* vermicompost prepared using *Eisenia foetida* (In-E) (18.80%), *in-situ* compost (In-C) (18.74%) and *in-situ* vermicompost prepared using *Perionyx excavatus* (In-P) (17.26%). The content of non-reducing sugars in fruits of In-P was on par with that of plants receiving vermicompost prepared *ex-situ* using *Perionyx excavatus* (Ex-P) (15.27%).

4.2.7. Effect of treatments on sensory characteristics of banana fruit

The various sensory characteristics like colour, taste, texture, flavour, appearance, sweetness and overall acceptability of fruits from various treatments were analysed and are presented in Table 4.20.

The scores for colour of fruits varied from 5.63 to 8.33. The highest score for colour was obtained for plants supplied with recommended dose of fertilizers (8.33) (POP). On par scores were recorded for plants receiving *in-situ* compost (In-C) (7.43) followed by *in-situ* vermicompost (In-P) (6.90) closely followed by *ex-situ* vermicompost produced by *Eisenia foetida* (Ex-E) (6.87) (Appendix 5).

The scores for taste of fruits ranged from 5.33 to 8.17. The highest score of 8.17 for taste of fruits was recorded for plants gown under recommended dose of fertilizers (POP) and was on par with plants that received organic nutrition through *in-situ* compost (In-C) (7.47). However score for taste of fruits of plants grown under *in-situ* vermicompost using *Perionyx excavatus* (In-P) (7.10) was on par with that of In-C.

A score of 7.77 was recorded for the texture fruits harvested from plants receiving recommended dose of fertilizers. However it was on par with that of plants grown under *in-situ* vermicompost using *Perionyx excavatus* (In-P) (7.40) and *in-situ* compost (In-C) (7.30).

Scores given for the flavour of fruits ranged from 6.33 (S) to 7.83 (POP). However the scores given for flavour of fruits grown under different treatments were non-significant.

Appearance of fruits scored from 5.67 to 8.27. The significantly superior score of 8.27 for appearance was recorded for recommended dose of fertilizers (POP). However it was on par with plants grown under *in-situ* compost (In-C) (7.57) followed by *in-situ* vermicompost prepared using *Perionyx excavatus* (7.27) (In-P) which was further followed by *in-situ* vermicompost prepared using *Eisenia foetida* (7.00) (In-E).

4.20. Effect of treatments on sensory characteristics * of banana fruits

Treatments	Colour	Taste	Texture	Flavour	Appearance	Sweetness	Overall acceptability
S	6.33	5.33	6.00	6.33	5.66	4.66	5.66
POP	8.33	8.16	7.76	7.83	8.26	8.26	8.50
Ex-P	5.63	6.46	6.03	6.50	6.73	6.66	6.26
Ex-E	6.86	6.23	5.80	6.66	6.70	6.23	6.33
In-P	6.90	7.10	7.40	6.83	7.26	7.06	6.93
In-E	6.53	6.60	6.33	7.00	7.00	7.00	6.86
In-C	7.43	7.46	7.30	7.50	7.56	7.63	7.50
CD(p=0.05)	0.81	0.82	1.07	NS	1.37	0.94	0.69

***Average of scored data**

Table 4.21. Effect of treatments on nutrient contents of banana fruits

Treatments	C	N	P	K	Ca	Mg
S	33.75	2.51	0.13	0.27	0.09	0.05
POP	39.97	2.83	0.15	0.52	0.09	0.10
Ex-P	35.91	3.46	0.26	0.60	0.16	0.15
Ex-E	38.43	2.67	0.22	0.49	0.15	0.13
In-P	39.59	2.59	0.22	0.51	0.08	0.12
In-E	36.65	2.38	0.20	0.43	0.07	0.11
In-C	36.35	2.56	0.25	0.59	0.12	0.14
CD(p=0.05)	1.02	0.18	0.01	0.01	0.02	0.01

The sensory evaluation of sweetness of fruits revealed that the highest score of 8.27 was scored by fruits of plants receiving recommended dose of fertilizers (POP). The fruits of *in-situ* compost treatment recorded a mean score of 7.63 which was on par with that of POP. However, score for sweetness of fruits for plants grown under *in-situ* compost (In-C) was on par with that of plants grown under *in-situ* vermicompost using *Perionyx excavatus* (In-P) (7.07) and In-E (*in-situ* vermicompost prepared by *Eisenia foetida*) (7.00).

The score for overall acceptability of fruits grown under various treatments ranged from 5.67 to 8.50. Among the treatments, the highest score (8.5) for overall acceptability of fruits was recorded for plants receiving recommended dose of fertilizers and FYM (POP). The overall acceptability of *in-situ* treatments (In-C, In-P and In-E) (7.50, 6.93, and 6.87 respectively) were on par.

4.2.8. Effect of treatments on elemental composition of fruit

The ripened fruits from each treatment were subjected to chemical analysis and the results are presented below (Table 4.21).

Total carbon content of fruits of banana

Content of C in fruits of banana varied significantly with the treatments (Table 4.21). The highest C content of 39.97% was recorded in fruits of banana plants that received POP (recommended dose of fertilizers and FYM). However it was on par with that of plants grown under *in-situ* vermicompost applied at the rate of 20 kg plant^{-1} (In-P) and prepared using *Perionyx excavatus* (39.59%). Carbon content of fruits of all treatments were significantly superior to control.

Among the different modes of composting, the highest C content was recorded in fruits harvested from soils that received In-P (*in-situ* vermicompost at the rate of 20 kg plant^{-1} prepared using *Perionyx excavatus*).

Native earthworm *Perionyx excavatus* worked vermicompost prepared in banana planting pits produced significantly superior content of C in fruits of banana than exotic *Eisenia foetida.*

Total nitrogen content of fruits of banana

Nitrogen content of fruits of plants receiving different treatments varied significantly (Table 4.21). The highest content of N (3.46%) was recorded in plants that received *ex-situ* vermicompost prepared using *Perionyx excavatus* at the rate of 20 kg plant^{-1}. The fruits harvested from plots supplied with recommended dose of fertilizers and FYM (POP) also registered significantly higher N content (2.84%) and was on par with that of fruits harvested from Ex-E treatment (2.67%). Similar to C the content of N was significantly higher in fruits of plants treated with *Perionyx excavatus* worked *ex-situ* vermicompost applied at the rate of 20 kg plant^{-1}.

Total Phosphorus content of fruits of banana

Significantly superior content of P (0.26%) was recorded in fruits harvested from plots receiving *ex-situ* vermicompost prepared using *Perionyx excavatus* at the rate of 20 kg plant^{-1} and that from plots receiving *in-situ* compost at the rate of 20 kg plant^{-1} (Table 4.21). The P content of fruits from plants supplied with *Eisenia foetida* worked *ex-situ* vermicompost and *Perionyx excavatus* worked *in-situ* vermicompost were on par.

Total potassium content of fruits of banana

Potassium content of fruits harvested from plants of different treatments ranged from 0.27% to 0.6% (Table 4.21). The highest K content (0.6%) was recorded in fruits of plants receiving organic nutrition through *ex-situ* vermicompost at the rate of 20 kg plant^{-1} prepared using *Perionyx excavatus* which was on par with that of fruits from *in-situ* compost applied at the rate of 20 kg plant^{-1} treated plots (0.59%). However the K content of fruits from plants receiving inorganic nutrition through recommended dose of fertilizers and FYM (POP) were on par with that of fruits of plants that received organic nutrition through *in-situ* vermicompost at the rate of 20 kg plant^{-1} prepared using *Perionyx excavatus*.

Total calcium content of fruits of banana

The content of Ca varied significantly among treatments from 0.07 to 0.16 percent (Table 4.21). Significantly superior Ca content of 0.16 and 0.15 percent was recorded in fruits of plants receiving organic nutrition through *ex-situ* vermicompost at the rate of 20 kg plant^{-1} prepared using *Perionyx excavatus* and that of fruits from *Eisenia foetida* worked *ex-situ* vermicompost applied at the rate of 20 kg plant^{-1} respectively. Fruits of plants that received organic nutrition through *in-situ* compost at the rate of 20 kg plant^{-1} also registered significantly superior Ca content (0.12%).

Total magnesium content of fruits of banana

Magnesium content of fruits of different treatments varied from 0.05 to 0.15 percent (Table 4.21). Significantly superior content of Mg (0.15%) was recorded in fruits harvested from plots that received *ex-situ* vermicompost prepared using *Perionyx excavatus* at the rate of 20 kg plant^{-1} (Ex-P). The Mg content of fruits harvested from plots supplied with *in-situ* compost at the rate of 20 kg plant^{-1}(In-C)was significantly superior (0.14%) and on par with that of *Eisenia foetida* worked *ex-situ* vermicompost applied at the rate of 20 kg plant^{-1} (Ex-E) (0.13%).

4.3. Effect of treatments on chemical properties of experimental soil

4.3.1. Characterization of experimental soil

Representative composite soil samples (0-30 cm) were drawn from experimental field and were analyzed for physical and chemical properties (Table 4.22).

Experimental soil recorded a pH of 4.7 and electrical conductivity of 0.08 dSm^{-1}. Content of Walkley and Black carbon was 0.59% and C:N ratio was 13.8. The contents of available of N was 264.03 kg ha^{-1}, P was 46.65 kg ha^{-1}, and K was 299.52 kg ha^{-1}.

The exchangeable Ca was 308.93 mg kg^{-1} and Mg was 83.39 mg kg^{-1}. The concentration of indole acetic acid (IAA) was 49.15 µg g^{-1} of soil. The activity of enzymes like dehydrogenase, acid and alkaline phospomonoesterases, ureases and L-asparaginase were 7.3µg TPF day^{-1}g^{-1}; 106.79 µg PNP g^{-1}hr^{-1}; 5.81 µg PNP g^{-1}hr^{-1}; 92.08 µg N-NH$_4$ hr^{-1}; 73.67 µg N-NH$_4$ hr^{-1} respectively. In the control treatment microbial biomass carbon content of was 142.56 µg C g^{-1} of soil was reported.

Post experimental soil chemical analysis

The soil samples from 0-30cm depth were collected after the harvest of banana and tested for the residual fertility in terms of chemical and biochemical parameters. The results are presented below.

Table 4.22. Initial characterization of experimental soil

Characteristics	Values
pH (1:2.5 plant : water suspension)	4.7
EC (1:2.5 plant : water suspension, dSm^{-1})	0.08
C: N ratio	13.8
Walkley and Black Carbon (%)	0.59
Available N (kg ha^{-1})	264.03
Available P (kg ha^{-1})	46.65
Available K (kg ha^{-1})	299.52
Available Ca (mg kg^{-1})	308.93
Available Mg (mg kg^{-1})	83.39
Auxin equivalents (µg of IAA g^{-1} of soil)	49.15
Dehydrogenase activity (µg TPF day^{-1} g^{-1} of soil)	7.30
Alkaline phosphomonoesterase activity (µg PNP hr^{-1} g^{-1} of soil)	5.81
Acid phosphomonoesterase activity (µg PNP $g^{-1}hr^{-1}$)	106.79
L-Asparaginase activity (µg N-NH_4 hr^{-1} g^{-1} of soil)	73.67
Urease activity (µg N-NH_4 hr^{-1} g^{-1} of soil)	92.08
Microbial Biomass Carbon (µg C g^{-1} of soil)	142.56

Soil pH

The pH (1:2.5 soil: water suspension) of the banana rhizosphere soils after harvest of crop is shown in Table 4.23. Modes of composting and species of earthworms had a significant influence on the rhizosphere pH of the experimental soil after harvest of crop of banana. The initial pH of the experimental soil was 4.7. On analysis of data after harvest of banana, the highest pH of 5.9 was recorded in the rhizosphere soils which received *ex-situ* vermicompost (Ex-E) and was on par with rhizosphere of soil that received *in-situ* compost at the rate of 20 kg plant^{-1} (5.8). *In-situ* vermicompost at the rate of 20 kg plant^{-1} by *Perionyx excavatus* (In-P) was found to have a pH of 5.6. Plots that received *ex-situ* vermicompost prepared using *Perionyx excavatus* (Ex-P) (5.3) and plots that received recommended dose of fertilizers (5.3) were on par.

Among the different modes of composting and species of earthworms, the highest pH was recorded in plots receiving *ex-situ* vermicompost at the rate of 20 kg plant^{-1} prepared by *Eisenia foetida*. However it was on par with that of plots that received *in-situ* compost at the rate of 20 kg plant^{-1} and *in-situ* vermicompost prepared by *Perionyx excavatus* at the rate of 20 kg plant^{-1}.

Electrical Conductivity (EC)

The electrical conductivity of the rhizosphere soils varied significantly among the treatments (Table 4.23). The soils from plots receiving *ex-situ* vermicompost prepared by *Eisenia foetida* (Ex-E) (0.046dSm^{-1}) and those receiving recommended dose of fertilizers (POP) (0.043 dSm^{-1}) recorded significantly superior EC among the different treatments.

Among the different modes of composting, the highest EC of 0.046 dSm^{-1} was recorded in plots that received *ex-situ* vermicompost at the rate of 20 kg plant^{-1} prepared by *Eisenia foetida.* Among the species of earthworms the highest EC was recorded in plots receiving nutrition through vermicompost prepared using *Eisenia foetida.*

Walkley and Black Carbon (WBC)

The highest WBC content of 1.26 percent was recorded in rhizosphere soils that received *in-situ* compost at the rate of 20 kg plant^{-1}(In-C) and it was on par with soils applied with *ex-situ* vermicompost prepared using *Perionyx excavatus* at the rate of 20 kg plant^{-1} (Ex-P) (1.18%) (Table 4.23).

With respect to the species of earthworms, native earthworms (*Perionyx excavatus*) produced the highest WBC content under both modes of composting. The exotic earthworms (*Eisenia foetida*) significantly enriched the rhizosphere soil WBC only under *ex-situ* mode of composting (Ex-E).

Available nitrogen

The results of the mineralizable N content of soil at 0-30 cm depth are presented in Table 4.23. The highest content of mineralizable N (kg ha^{-1}) was recorded in rhizosphere soils receiving *in-situ* vermicompost at the rate of 20 kg plant^{-1} using *Eisenia foetida* (312.58 kg ha^{-1}) (In-E) which was on par with In-C (*in-situ* compost at the rate of 20 kg plant^{-1}) (310.00 kg ha^{-1}), POP (recommended dose of fertilizers and FYM) and soils receiving *ex-situ* vermicompost (Ex-E) at the rate of 20 kg plant^{-1} using *Eisenia foetida* (291.22 kg ha^{-1}).

With respect to the species of earthworms, exotic earthworms *Eisenia foetida* produced vermicompost with significantly higher mineralizable N content (312.58 kg ha^{-1}) under *in-situ* and *ex-situ* conditions.

Available phosphorus

Table 4.23 revealed the effect of treatments on the available P content (kg ha^{-1}) of rhizosphere soils. Available P content (kg ha^{-1}) in the rhizosphere soils varied among the treatments. The highest available P content of 72.95 kg ha^{-1} was recorded in soils receiving recommended dose of fertilizers and FYM (POP). Soils that received *ex-situ* vermicompost at the rate of 20 kg plant^{-1} prepared using *Eisenia foetida* (Ex-E) with available P of 63.93 kg ha^{-1} was on par with soils supplied with *ex-situ* vermicompost at the rate of 20 kg plant^{-1} prepared by *Perionyx excavatus* (62.86 kg ha^{-1}).

With respect to the modes of composting, the highest P content was recorded in soils receiving *ex-situ* vermicompost irrespective of the species of earthworms.

Table 4.23. Effect of treatments on chemical properties of rhizosphere soils (0-30cm depth) after the harvest of banana

Treatments	pH	EC dSm^{-1}	WBC (%)	Av. N	Av. P	Av. K
				(kg ha^{-1})		
S	4.5	0.013	0.59	232.88	35.47	229.84
POP	5.3	0.043	0.76	295.64	72.95	638.38
Ex-P	5.3	0.026	1.18	267.99	62.85	510.44
Ex-E	5.9	0.046	0.98	291.22	63.93	370.98
In-P	5,6	0.016	1.04	280.86	47.08	579.63
In-E	4.8	0.017	0.78	312.58	50.89	410.68
In-C	5.8	0.016	1.26	310.00	33.60	447.21
CD(p=0.05)	0.4	0.001	0.11	26.64	4.56	166.27

Table 4.24. Effect of treatments on available calcium and available magnesium of rhizosphere soils (0-30cm depth) after the harvest of banana

Treatments	Available Ca	Available Mg
	mg kg^{-1} of soil	
S	307.41	90.07
POP	656.47	90.94
Ex-P	417.31	93.93
Ex-E	371.25	90.31
In-P	540.07	91.59
In-E	449.64	92.65
In-C	587.12	103.27
CD(p=0.05)	46.02	3.74

Available potassium

Results of available K content of rhizosphere soils (Table 4.23) after harvest of crop of banana revealed that available K varied significantly among the treatments. Available K content of rhizosphere soil ranged from 229.84 to 638.38 kg ha^{-1}. The highest content of available K (638.38kg ha^{-1}) was recorded in plots that received recommended dose of fertilizers and FYM (POP), which was on par with those plots receiving *in-situ* and *ex-situ* vermicompost at the rate of 20 kg $plant^{-1}$ produced by *Perionyx excavatus* (In-P) (579.63kg ha^{-1}, 510.44kg ha^{-1} respectively).

With respect to the modes of composting the available K was significantly higher in *in-situ* treatments (In-P). The native earthworm, *Perionyx excavatus* mediated vermicompost produced significantly higher content of available K in rhizosphere of banana both under *in-situ* and *ex-situ* conditions.

Available calcium

The results of the available Ca content of the rhizosphere soils is shown in Table 4.24. On perusal, data revealed that the available Ca content of the rhizosphere soils ranged from 307.41 to 656.47 mg kg^{-1} of soil. The available Ca content (656.47 mg kg^{-1} of soil) of the rhizosphere soils supplied with recommended dose of fertilizers and FYM was significantly superior among all the treatments.

The modes of composting had significant influence in the available Ca content of soils. Compost prepared *in-situ* in banana planting pits produced significantly higher content of available Ca in the rhizosphere soils (587.12 mg kg^{-1} of soil). Among the species of earthworms, the native earthworm, *Perionyx excavatus* recorded significantly superior available Ca content (540.07 mg kg^{-1} of soil) through *in-situ* vermicomposting.

Available magnesium

The data on available Mg content of rhizosphere soils revealed that the highest content (103.27 mg kg^{-1} of soil) of available Mg was recorded in *in-situ* compost at the rate of 20 kg $plant^{-1}$ (In-C) (Table 4.24). Plots receiving *in-situ* compost at the rate of 20 kg $plant^{-1}$ prepared using *Perionyx excavatus* (In-P)

Table 4.25. Effect of treatments on microbial biomass carbon, auxin concentration and total microbial count of rhizosphere soils (0 -30cm depth) after the harvest of banana

Treatments	Microbial biomass carbon	Auxin equivalents	Total microbial count
	$\mu g\ g^{-1}$ of soil		10^5 CFU g^{-1} of soil
S	80.94	50.80	30.03
POP	117.51	128.72	62.04
Ex-P	144.68	117.86	109.01
Ex-E	268.16	61.21	21.32
In-P	280.72	61.43	44.01
In-E	504.61	65.82	69.16
In-C	427.92	144.14	89.31
CD(p=0.05)	17.94	16.73	9.29

Table 4.26. Effect of treatments on biochemical properties of rhizosphere soils (0-30cm depth) after the harvest of banana

Treatments	Urease activity	Asparaginase activity	Dehydrogenase activity	Alkaline phosphatase	Acid phosphatase
	mg kg^{-1} of soil		(μg TPF day^{-1} kg^{-1})	(μg PNP g^{-1} hr^{-1})	
S	62.66	101.61	72.87	25.01	21.86
POP	87.91	163.31	178.81	356.18	622.35
Ex-P	70.90	154.02	143.56	82.48	120.66
Ex-E	87.79	149.65	74.36	183.33	27.40
In-P	101.29	163.68	88.07	35.96	337.30
In-E	100.06	203.42	113.43	28.10	64.09
In-C	141.81	168.29	223.78	60.46	267.20
CD(p=0.05)	8.75	16.13	14.52	11.75	12.35

recorded significantly superior content of available Mg (93.93 mg kg^{-1} of soil) when compared to *Eisenia foetida.*

Among the modes of composting, compost prepared in banana planting pits recorded significantly superior content of available Mg (In-C).

4.3.2. Effect of treatments on biochemical properties of soil after harvest of banana

Microbial biomass carbon (MBC) (mg kg^{-1} of soil)

Data on MBC of rhizosphere soils are shown in Table 4.25. The microbial biomass carbon content of rhizosphere soil was dependent on the treatments. Content of MBC ranged from 80.94 to 504.61 μg g^{-1} of soil. The highest MBC of 504.61 μg g^{-1} of soil was recorded in plots that received *in-situ* vermicompost at the rate of 20 kg $plant^{-1}$ (In-E) prepared by *Eisenia foetida.* Microbial biomass carbon content varied with modes of composting. Among the different modes of composting, significantly higher MBC was recorded in plots supplied with compost or vermicompost prepared *in-situ* (banana planting pits).

Among the two different earthworm species, *Eisenia foetida* under *in-situ* (banana planting pits) conditions was significantly superior to *Perionyx excavatus* in enriching the soil with high content of MBC.

Auxin equivalents

The data on auxin equivalents are shown in Table 4.25. Activity of auxins ranged from 50.80 - 144.14 μg g^{-1} of soil. The highest auxin equivalents (144.14 μg g^{-1} of soil) were recorded in soils which received *in-situ* compost at the rate of 20 kg $plant^{-1}$ and was on par with those receiving recommended dose of fertilizers and FYM (POP) (128.72 μg g^{-1} of soil). Among the different species of earthworms, the highest auxin concentration of 117.86 μg g^{-1} of soil was recorded for Ex-P (*ex-situ* vermicompost at the rate of 20 kg $plant^{-1}$prepared by *Perionyx excavatus*).

Total microbial count

The results of the total microbial count presented in Table 4.25 revealed significant influence of treatments on total microbial count under soils that received Ex-P (*ex-situ* vermicompost at the rate of 20 kg $plant^{-1}$ prepared using

Perionyx excavatus) (109.01 x 10^5 cfu g^{-1} of soil). Significant influence on modes of composting and species of earthworms was brought out in this study. The significant role of native earthworms (*Perionyx excavatus*) over *Eisenia foetida* was evident from total microbial count of soils receiving *ex-situ* vermicompost at the rate of 20 kg $plant^{-1}$ prepared using *Perionyx excavatus* (Ex-P).

Urease activity

The data on urease activity is shown in Table 4.26. Significant influence of treatments on soil urease activity was noticed in this experiment. Urease activity of rhizosphere soils ranged from 62.66 µg N-NH_4 hr^{-1} to 141.81 µg N-NH_4 hr^{-1}. The urease activity of rhizosphere soils (141.81 µg N-NH_4 hr^{-1}) was significantly higher in soils that received *in-situ* compost at the rate of 20 kg $plant^{-1}$ (In-C). The urease activity of soils receiving *in-situ* vermicompost at the rate of 20 kg $plant^{-1}$ produced by *Perionyx excavatus* (101.29 µg N-NH_4 hr^{-1}) was on par with that received *in-situ* vermicompost prepared using *Eisenia foetida* (In-E) (100.06 µg N-NH_4 hr^{-1}).

L-asparaginase activity

Activity of L-asparaginase enzyme soils are shown in Table 4.26. L-asparaginase activity of rhizosphere soils was significantly higher in plots which received *in-situ* vermicompost at the rate of 20 kg $plant^{-1}$ produced by *Eisenia foetida* (203.42 µg N-NH_4 hr^{-1}). Activity of L-asparaginase was on par in rhizosphere soils receiving In-C (*in-situ* compost at the rate of 20 kg $plant^{-1}$) (168.29 µg N-NH_4 hr^{-1}), In-P (*in-situ* vermicompost produced by *Perionyx excavatus* at the rate of 20 kg $plant^{-1}$) (163.68 µg N-NH_4 hr^{-1}) and POP (recommended dose of fertilizers and Farm Yard Manure) (163.31 µg N-NH_4 hr^{-1}) and Ex-P (*ex-situ* vermicompost produced by *Perionyx excavatus* at the rate of 20kg $plant^{-1}$).

Among the modes of composting, the vermicompost prepared *in-situ* in banana planting pits (In-E) recorded significant activity of L-asparaginase than that produced in silpaulin vermibeds (Ex-E). Among the species of earthworms, the highest activity of L-asparaginase was reported with *in-situ* vermicompost produced by *Eisenia foetida* (In-E) than native *Perionyx excavatus* (In-P).

Dehydrogenase activity

The results of the activity of dehydrogenase enzyme is shown in Table 4.26. The highest activity of dehydrogenase (223.78 μg TPF day^{-1} g^{-1} of soil) was recorded in rhizosphere soils receiving *in-situ* compost (In-C) at the rate of 20 kg plant^{-1}. The activity of dehydrogenase was significantly higher in plots that received POP (recommended dose of fertilizers and FYM) (178.81 μg TPF day^{-1} g^{-1}). Among the modes of composting, composts prepared *in-situ* (banana planting pits) recorded significantly superior dehydrogenase activity than any other treatment.

Among the species of earthworms, the highest activity of dehydrogenases was recorded in vermicompost prepared using *Perionyx excavatus* in silpaulin vermibeds.

Phosphatase activity

The results of the phosphatase activity of rhizosphere soils are shown on Table 4.26. The activity of alkaline phosphomonoesterases in the rhizosphere soil was significantly higher in POP (recommended dose of fertilizers and FYM) (356.18 μg PNP g^{-1} hr^{-1}).

The modes of composting significantly influenced alkaline phosphomonoesterases activity in rhizosphere soils. Among the composting treatments, the highest activity of alkaline phosphomonoesterases (183.33μg PNP g^{-1} hr^{-1}) was recorded in plots that received *ex-situ* vermicompost at the rate of 20 kg plant^{-1} prepared using *Eisenia foetida.* Among the earthworm species, the highest activity of alkaline phosphomonoesterases was recorded in soils that received *ex-situ* vermicompost prepared using *Eisenia foetida* (Ex-E) than that by *Perionyx excavatus.*

The activity of acid phosphatases in rhizosphere soils under different treatments are shown in Table 4.26. Among the various treatments, the highest activity of acid phosphomonoesterases was reported in plots which received recommended dose of fertilizers and FYM (POP) (622.36 μg PNP g^{-1} hr^{-1}). With respect to the modes of composting, the *in-situ* treatments had significantly superior values for acid phosphomonoesterases with 337.30 μg PNP g^{-1} hr^{-1} for soils that received *in-situ* vermicompost at the rate of 20 kg plant^{-1} prepared using *Perionyx excavatus*.

Among the species of earthworms, *Perionyx excavatus* recorded significantly superior activity of acid phosphomonoesterases (337.30 µg PNP g^{-1} hr^{-1}) in soils that received In-P (*in-situ* vermicompost at the rate of 20 kg plant^{-1}) than that of *Eisenia foetida*.

4.3.3. Addition of nutrients through *in-situ* incorporation of crop residues to the soil

After the harvest of bunches, the remaining residues (leaves, pseudostem and rhizome) was shredded and added to the respective pits. The addition of nutrients through crop residues were worked out and results are presented below.

Quantity of C added to soil through banana residues

The quantity of C added through the incorporated banana residues from different treatments ranged from 7.6 to 37.07 g kg^{-1} of soil as shown in Table 4.27. The highest quantity of C added was 37.07 g kg^{-1} of soil by the plants receiving combination of recommended dose of fertilizers and FYM (POP). The quantity of C added through plants that received In-E (*in-situ* vermicompost at the rate of 20 kg plant^{-1} prepared by *Eisenia foetida*) and Ex-P (*ex-situ* vermicompost at the rate of 20 kg plant^{-1} prepared by *Perionyx excavatus*) were 31.93 and 30.86 g kg^{-1} of soil respectively.

Quantity of N added through banana residues

The quantity of N added through banana biomass varied significantly among the treatments (Table 4.27). Significantly superior content of N was added by plants receiving POP (combined application of recommended dose of fertilizers and FYM) (4.34 g kg^{-1} of soil). The plants that received *ex-situ* vermicompost at the rate of 20 kg plant^{-1} prepared by *Perionyx excavatus* was on par with In-C and In-P.

Quantity of P added through banana residues

Phosphorus added through the different treatments varied significantly (Table 4.27) The quantity of P added through different treatments ranged from 0.08 to 0.54 g kg^{-1} of soil. The highest P was added in plots that received Ex-E

Table 4.27. Effect of treatments on total content of nutrients added to soils through banana biomass at the time of incorporation

Treatments	C	N	P	K	Ca	Mg
	(g kg^{-1} of soil)					
S	7.6	0.77	0.09	0.18	0.16	0.06
POP	37.07	4.34	0.46	1.25	1.17	0.41
Ex-P	30.86	3.41	0.27	0.88	0.84	0.27
Ex-E	23.34	3.10	0.54	0.65	1.14	0.27
In-P	25.60	3.10	0.51	1.13	1.59	0.29
In-E	31.93	2.99	0.38	0.81	0.59	0.19
In-C	26.10	3.15	0.26	0.62	1.07	0.29
CD(p=0.05)	2.13	0.31	0.09	0.06	0.07	0.03

Table 4.28. Cumulative C and N mineralization from banana residues after 160days of composting in banana pits

Treatments	C	N
	(mg kg^{-1} of soil)	
S	5.44	9.07
POP	18.29	12.85
Ex-P	10.21	7.89
Ex-E	13.29	8.85
In-P	13.96	13.39
In-E	26.75	13.47
In-C	19.94	13.98
CD (p=0.05)	1.36	0.73

(0.54 g kg^{-1} of soil) which was on par with plots receiving In-P (0.51 g kg^{-1} of soil) and POP (recommended dose of fertilizers and FYM) (0.46 g kg^{-1} of soil).

Quantity of K added through banana residues

The amount of K added through banana residues from different treatments ranged from 0.18 g kg^{-1} of soil to 1.25 g kg^{-1} of soil (Table 4.27). The highest quantity of K added was 1.25 g kg^{-1} of soil through recommended dose of fertilizers and FYM (POP). However, among the composting treatments, the plants grown under In-P added significantly higher K (1.13 g kg^{-1} of soil) through its residues.

Quantity of Ca added through banana residues

Banana residues from different treatments added significant amount of total Ca ranging from 0.16 to 1.59 g kg^{-1} of soil. (Table 4.27). The highest total Ca added was through the banana residues from plots receiving In-P (*in-situ* vermicompost at the rate of 20 kg $plant^{-1}$) (159 g kg^{-1} of soil). However, the Ca added through banana residues of POP (recommended dose of fertilizers and FYM) (1.17 g kg^{-1} of soil) was on par with that of Ex-E (1.15 g kg^{-1} of soil).

Quantity of Mg added through banana residues

The quantity of Mg added through banana residues ranged from 0.06 to 0.41 g kg^{-1} of soil (Table 4.27). The highest quantity of Mg added was from plots receiving POP (recommended dose of fertilizers and FYM) (0.41 g kg^{-1} of soil). However quantity of Mg added from plant residues that received organic nutrition (In-P, In-C, Ex-P and Ex-E) through compost or vermicompost except that of In-E was comparable.

In general, among the organic treatments, the highest quantity of C was added through *in-situ* composting and was on par with *ex-situ* vermicomposting pre-treatment. Composting treatments Ex-P, In-C and In-P were equally effective in adding N to soil among the different modes of composting. However, the *in-situ* vermicomposting treatments were significantly higher in adding P, K, Ca and Mg to soil.

Among the earthworm species, the exotic earthworm *Eisenia foetida* excelled in enriching the residues with C whereas native earthworm *Perionyx* *excavatus* excelled in enriching the soil with N, P, K, Ca and Mg. However both species were statistically on par ($p<0.05$) in enriching the soil with C, P and Mg. The significance of native earthworms in addition of nutrients especially K and Ca to soil was brought out in this study.

4.3.4. C and N mineralization from banana residues after *in-situ* incorporation

The rate of decomposition of banana residues with time as well as cumulative mineralization were calculated and presented in Table 4.28. Banana residues were incorporated in the pits taken in the standing crop site itself after harvest and mineralization of the added wastes was analysed. The decomposition kinetics is supposed to be aided by earthworm propagules or microbial consortium that was added to the soil before raising the first crop.

The carbon mineralized ranged from 5.44 mg kg^{-1} soil in absolute control (S) to 26.75 mg kg^{-1} soil in *in-situ* vermicompost (In-E) in different treatments during the pit composting process. Cumulative organic carbon mineralization during 160 days of composting was highest in plots treated with In-E (*in-situ* vermicompost at the rate of 20 kg $plant^{-1}$) (26.75 mg kg^{-1} soil). (Table 4.28).

Cumulative N mineralization among the treatments ranged from 7.89 mg kg^{-1} soil to 13.98 mg kg^{-1} soil (Table 4.28). The highest cumulative N mineralization was recorded in plots receiving In-C (*in-situ* compost at the rate of 20 kg $plant^{-1}$) with 13.98 mg kg^{-1} soil and was on par with that receiving *in-situ* vermicompost prepared by *Eisenia foetida* (In-E) (13.47 mg kg^{-1} soil) followed by *in-situ* vermicompost prepared by *Perionyx excavatus* (In-P) (13.39 mg kg^{-1} soil).

Carbon mineralization kinetics derived from the single pool exponential model show that mineralization rates in the wastes generated from different treatments varies from 0.002 mg C day^{-1} kg^{-1} to 0.044 mg C day^{-1} kg^{-1} (Table 4.29 and Figure 4.1 to 4.7). The lowest mineralization rate was noted for composting without earthworms (0.002 mg C day^{-1} kg^{-1} of soil) and the highest for POP treatment (0.044 mg C day^{-1} kg^{-1} of soil). In POP treated plots, the largest increase of mineralized C was observed during the first 30 days of incorporation (Figure

Table 4.29. Derivatives of C and N mineralization parameters from single pool exponential model fitting of composting in banana pits

Treatments	Carbon			Nitrogen		
	A_C	k	$S_{1/2}$	A_N	k	$S_{1/2}$
S	6.96	0.009	5.4	3.10	0.0003	8.86
POP	16.10	0.044	3.8	18.0	0.010	5.29
Ex-P	15.66	0.006	5.7	18.0	0.003	6.42
Ex-E	17.49	0.009	5.4	91.0	0.015	4.86
In-P	28.35	0.004	6.2	42.0	0.002	6.65
In-E	24.78	0.014	4.9	76.0	0.001	7.32
In-C	61.79	0.002	6.6	0.16	0.005	5.92

A_C: Potentially mineralizable C (mg kg^{-1} of soil); k = rate constant (mg C day^{-1} kg^{-1} soil); $S_{1/2}$: Half-life in days

A_n: Potentially mineralizable N (mg kg^{-1} of soil); k = rate constant (mg N day^{-1} kg^{-1} soil)

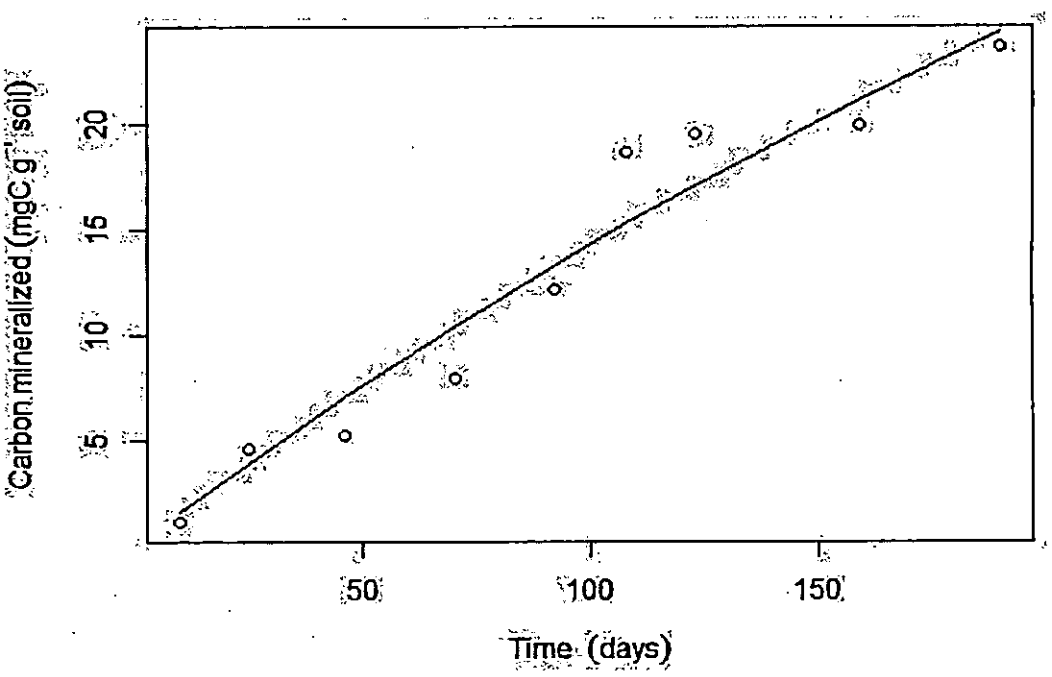


Figure 4.8. Single pool exponential model fits for carbon mineralization from banana residues after *in-situ* incorporation from control (S)

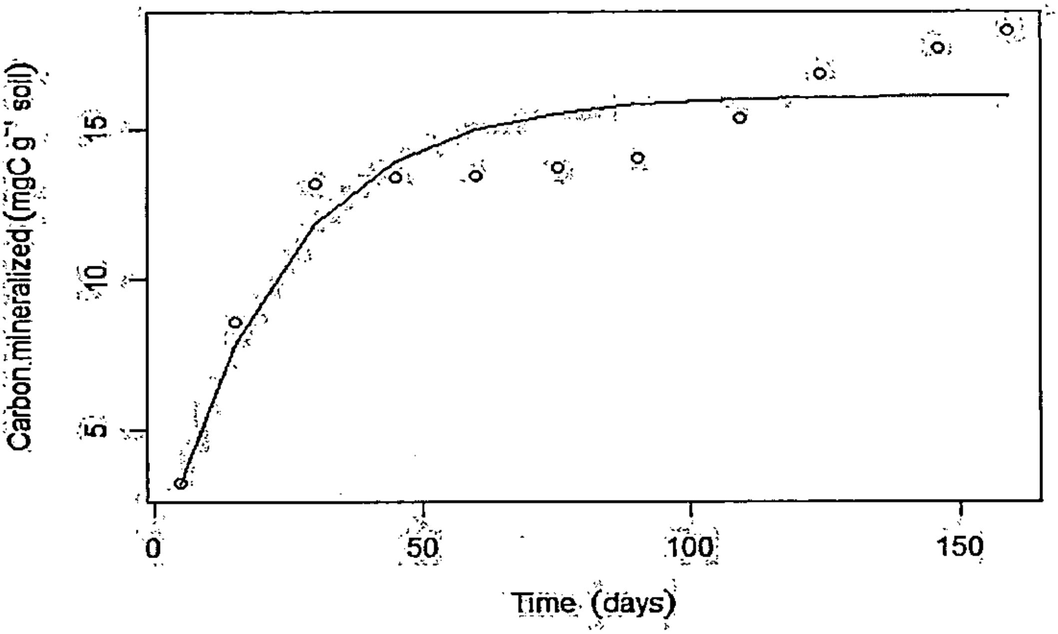


Figure 4.9. Single pool exponential model fits for carbon mineralization from banana residues after *in-situ* incorporation from POP

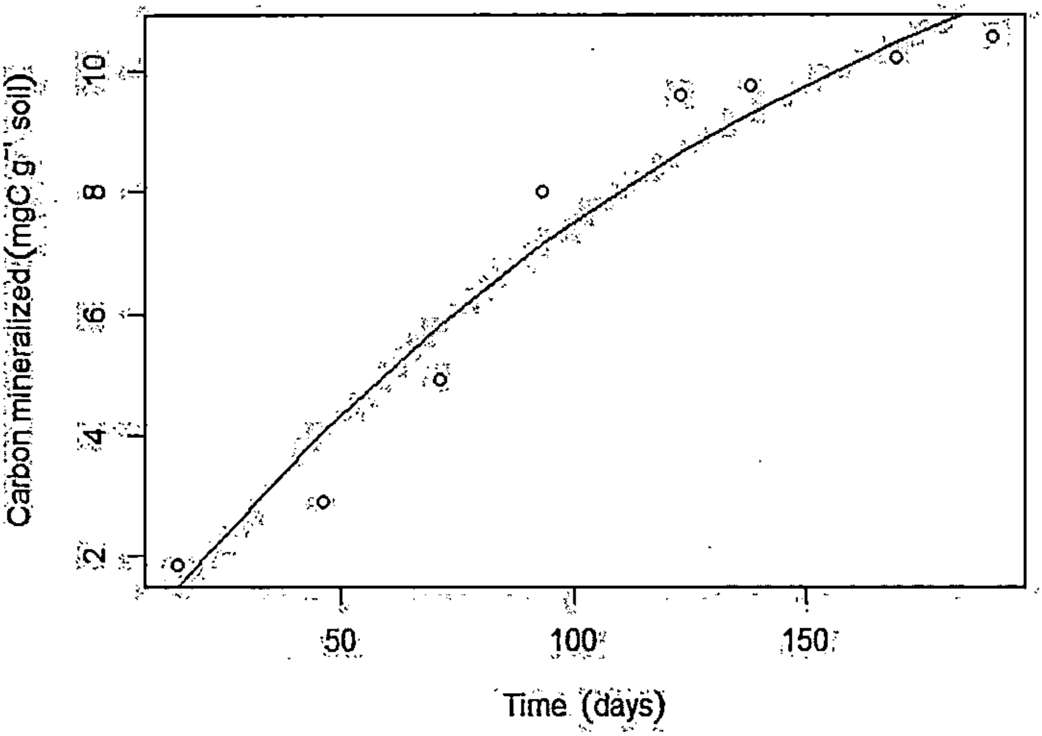


Figure 4.10. Single pool exponential model fits for carbon mineralization from banana residues after *in-situ* incorporation from Ex-P

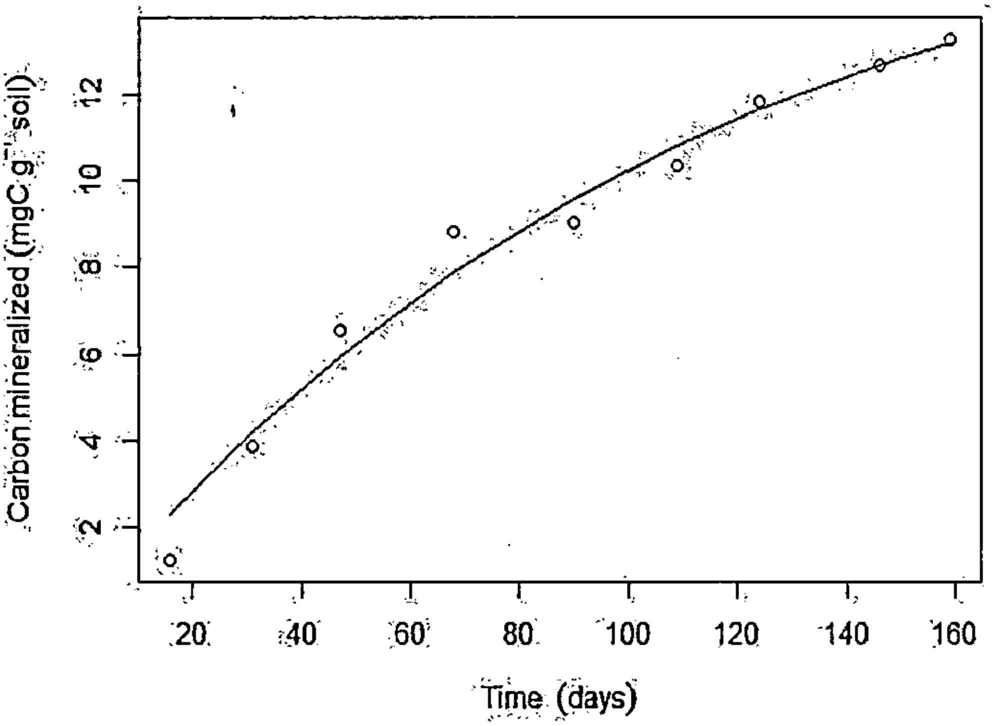


Figure 4.11. Single pool exponential model fits for carbon mineralization from banana residues after *in-situ* incorporation from Ex-E

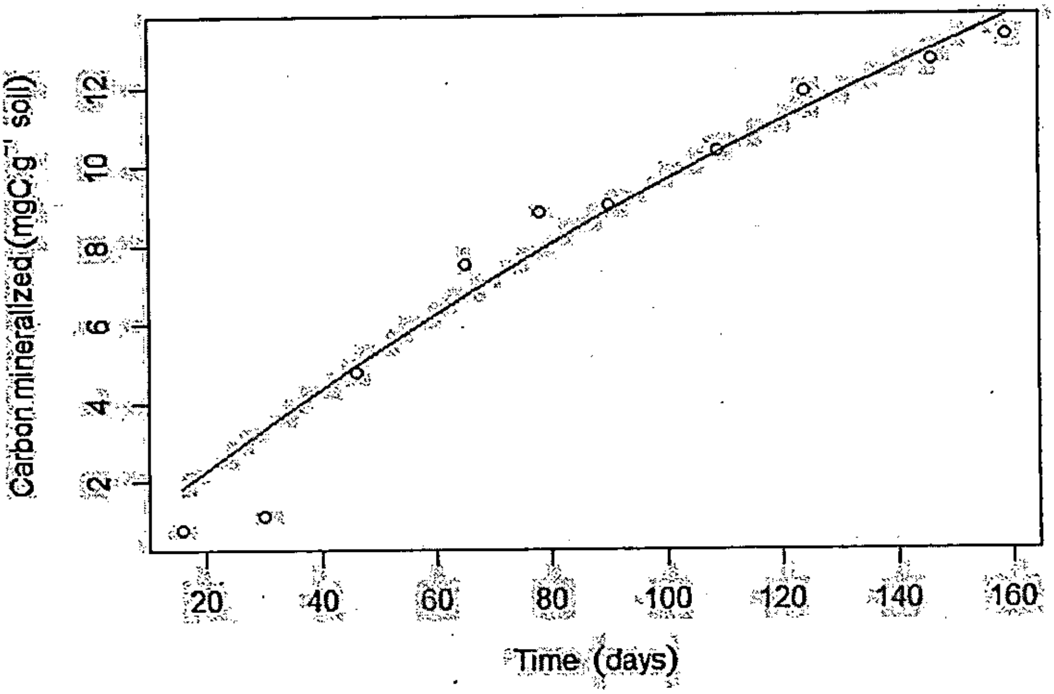


Figure 4.12. Single pool exponential model fits for carbon mineralization from banana residues after *in-situ* incorporation from In-P

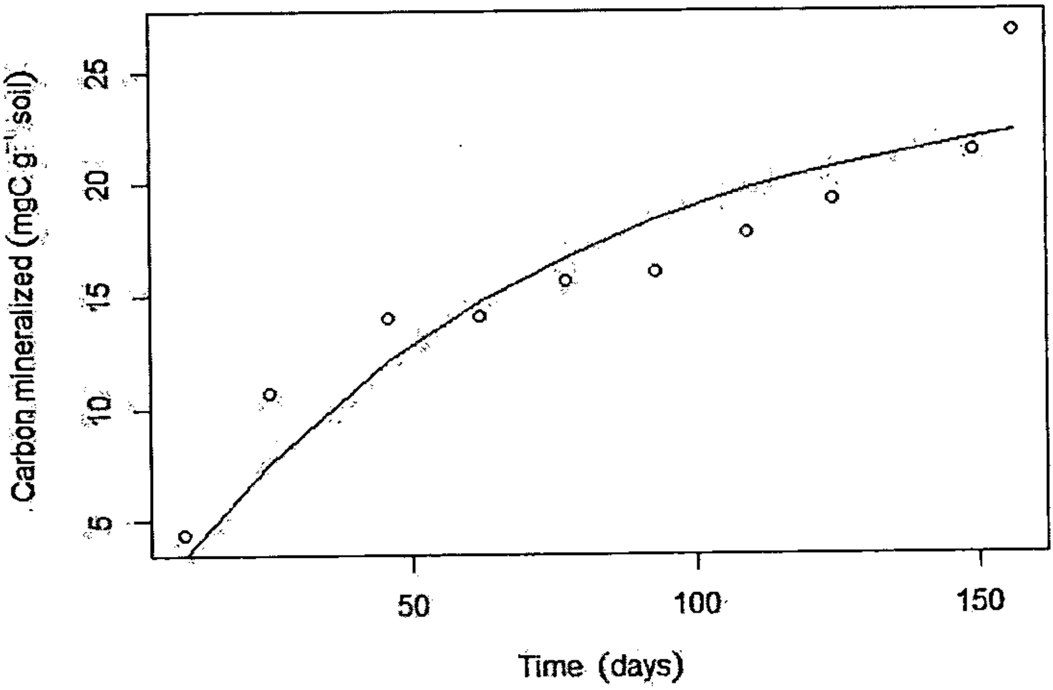


Figure 4.13. Single pool exponential model fits for carbon mineralization from banana residues after *in-situ* incorporation from In-E

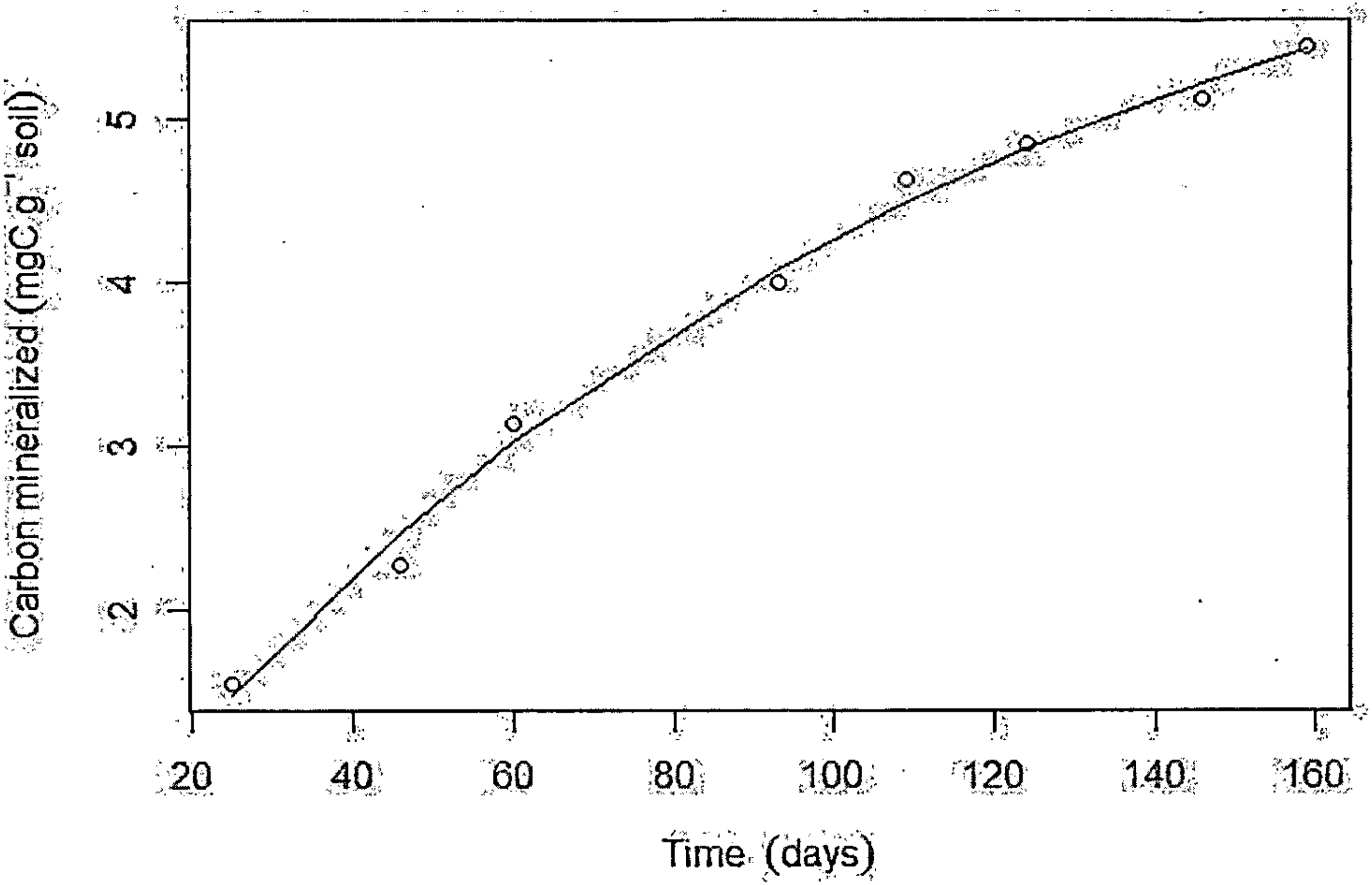


Figure 4.14. Single pool exponential model fits for carbon mineralization from banana residues after *in-situ* incorporation from In-C

4.2), whereas in all the compost treated plots the mineralization gave a positive slope up to 90 days (Figure 4.3 to 4.7). Unlike the other treatments used, residues treated with In-C (*in-situ* compost at the rate of 20 kg plant^{-1}) and In-P (*in-situ* vermicompost at the rate of 20 kg plant^{-1} prepared by *Perionyx excavatus*) was found to maintain a steady mineralization rate and took 190 days to decompose the banana waste (Figure 4.7 and 4.5). Among the different composting treatments, In-C, In-P, In-E followed by Ex-E had the highest carbon mineralization and the compost reached maturity within 160 days. The $S_{1/2}$ values were found to be minimum for POP treatment (4 days), whereas composting treatments took 5 – 7 days. The potentially mineralizale carbon was found to vary as In-C > In-P > In-E > Ex-E > POP > Ex-P > S and the values ranged from 6.96 to 61.79 mg kg^{-1} of soil.

The first order rate kinetics of nitrogen during the banana waste decomposition showed that nitrogen release rate was the highest for Ex-E (0.015 mg C day^{-1} kg^{-1} soil) followed by POP (0.01mg C day^{-1} kg^{-1} soil) (Table 4.29 and Figure 4.8 to 4.14). The nitrogen mineralization rate in Ex-E was 55 times higher than the absolute control. Composting without earthworms was found to be a better option in terms of cumulative release of nitrogen from banana residues (Table 4.28). Though the mineralization rates were higher, the *ex-situ* treatments were found to add lesser amounts of total nitrogen than *in-situ* composting treatments (In-P, In-E and In-C) and POP at compost maturity. During 160 days of banana residue composting in pits, In-P (*in-situ* vermicompost at the rate of 20 kg plant^{-1} prepared by *Perionyx excavatus*), In-E (*in-situ* vermicompost at the rate of 20 kg plant^{-1} prepared by *Eisenia foetida*) and In-C (*in-situ* compost at the rate of 20 kg plant^{-1}) were found to add 13.39, 13.47 and 13.98 mg N respectively to the soil. The recommended dose of fertilizers and FYM was found to add 12.86 mg N and was better than all the *ex-situ* treatments. Carbon and nitrogen mineralization in POP treatment can be considered a two phase system with an increasing positive slope up to 45 days and a decreasing marginal output from 45 – 160 days.

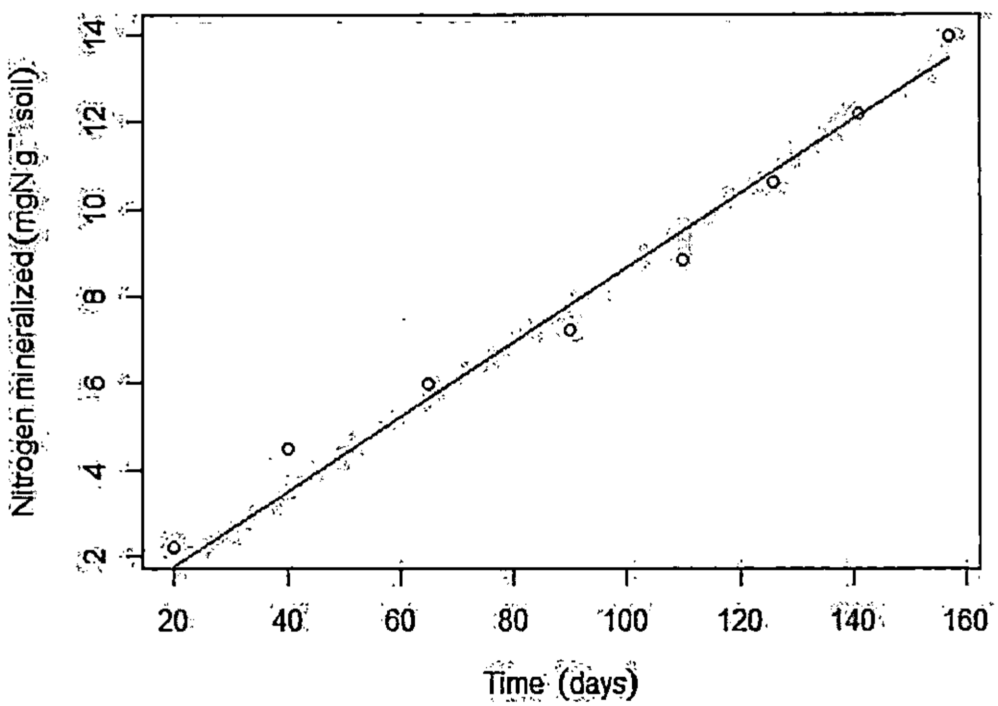


Figure 4.15. Single pool exponential model fits for nitrogen mineralization from banana residues after *in-situ* incorporation from control

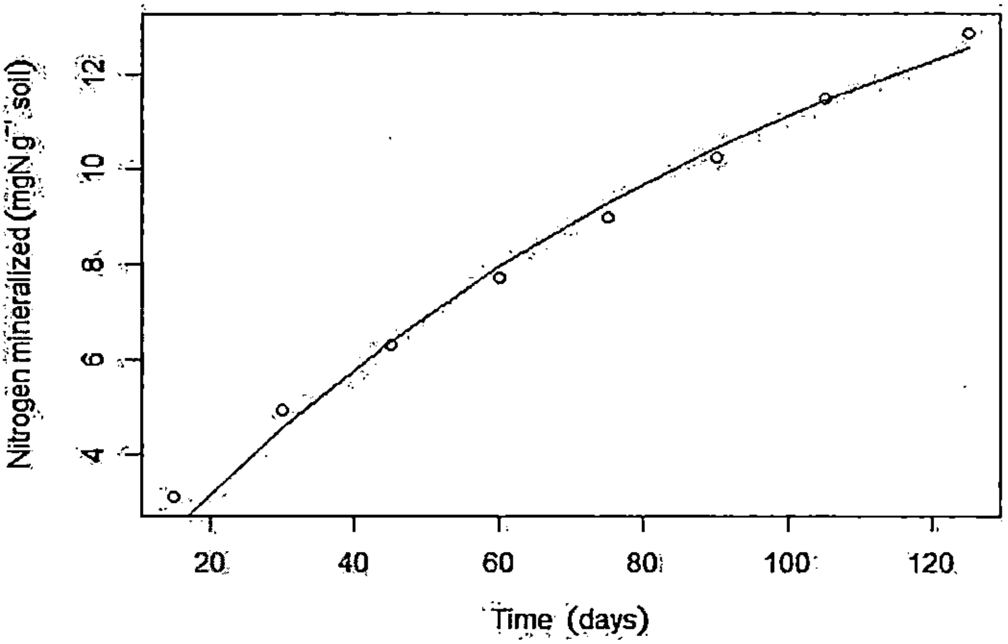


Figure 4.16. Single pool exponential model fits for nitrogen mineralization from banana residues after *in-situ* incorporation from POP

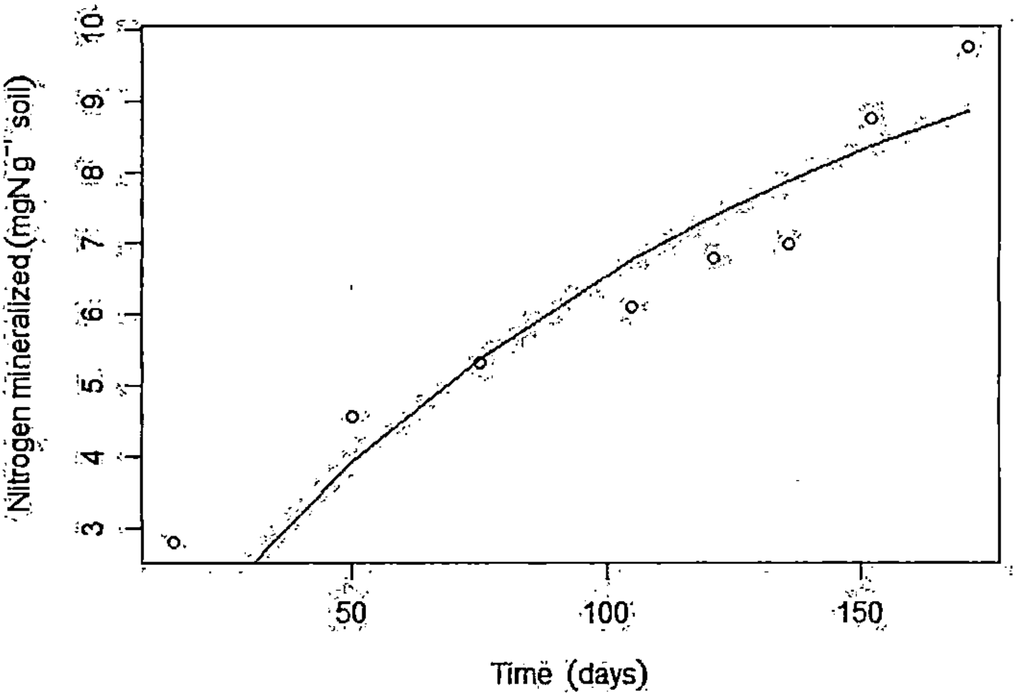


Figure 4.17. Single pool exponential model fits for nitrogen mineralization from banana residues after *in-situ* incorporation from Ex-P

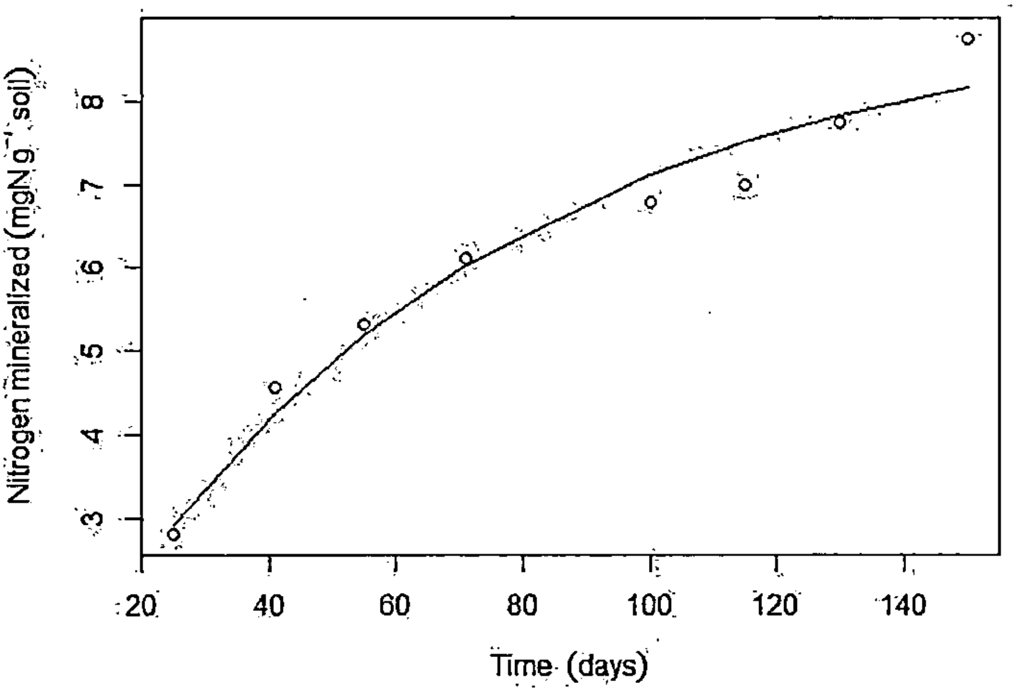


Figure 4.18. Single pool exponential model fits for nitrogen mineralization from banana residues after *in-situ* incorporation from Ex-E

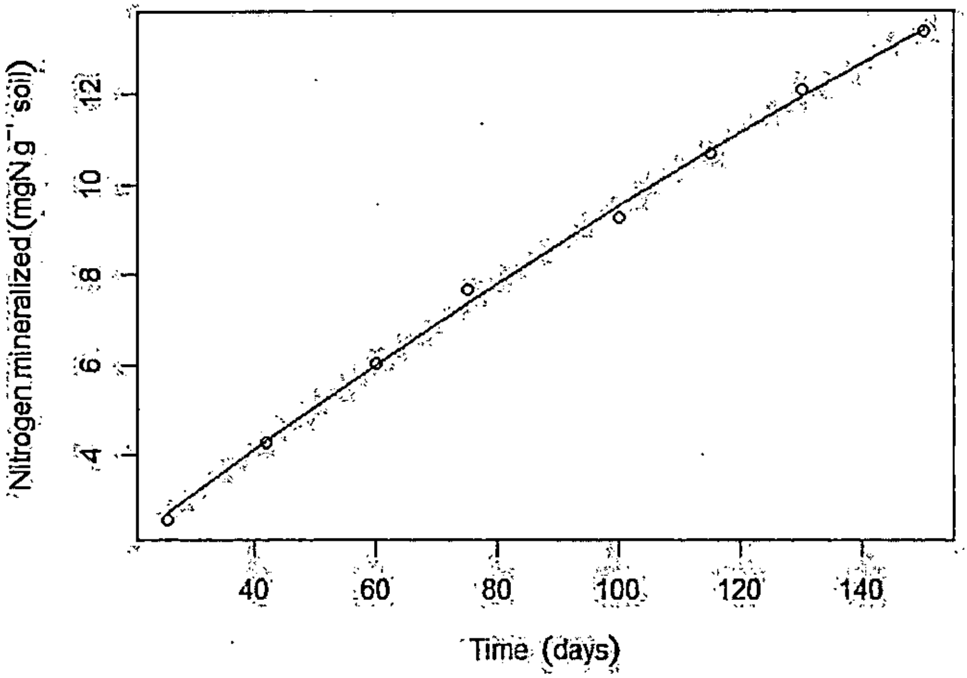


Figure 4.19. Single pool exponential model fits for nitrogen mineralization from banana residues after *in-situ* incorporation from In-P

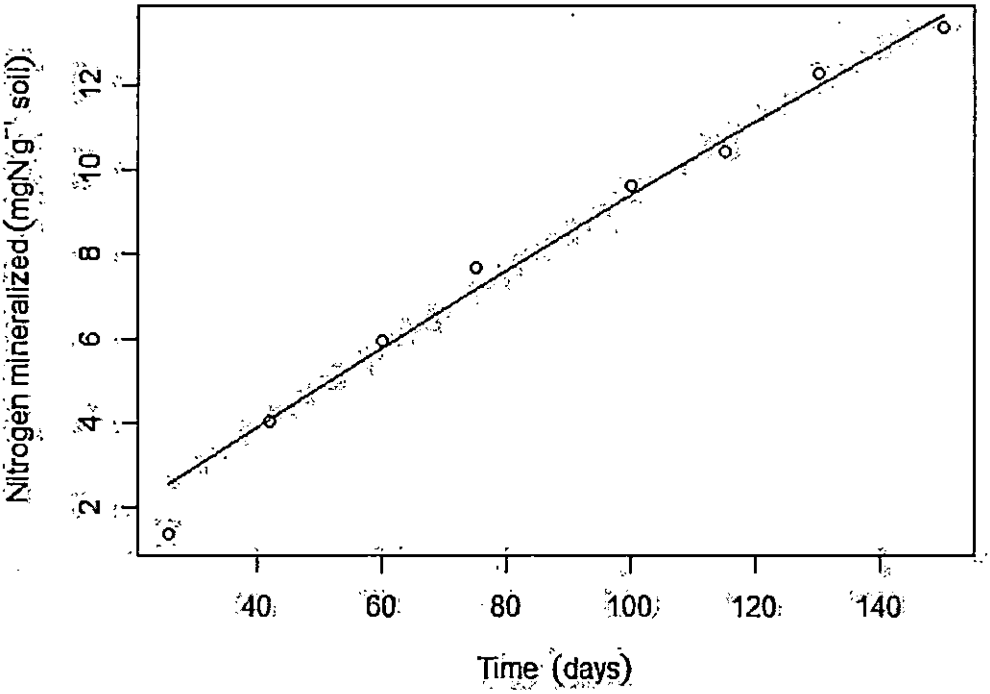


Figure 4.20. Single pool exponential model fits for nitrogen mineralization from banana residues after *in-situ* incorporation from In-E

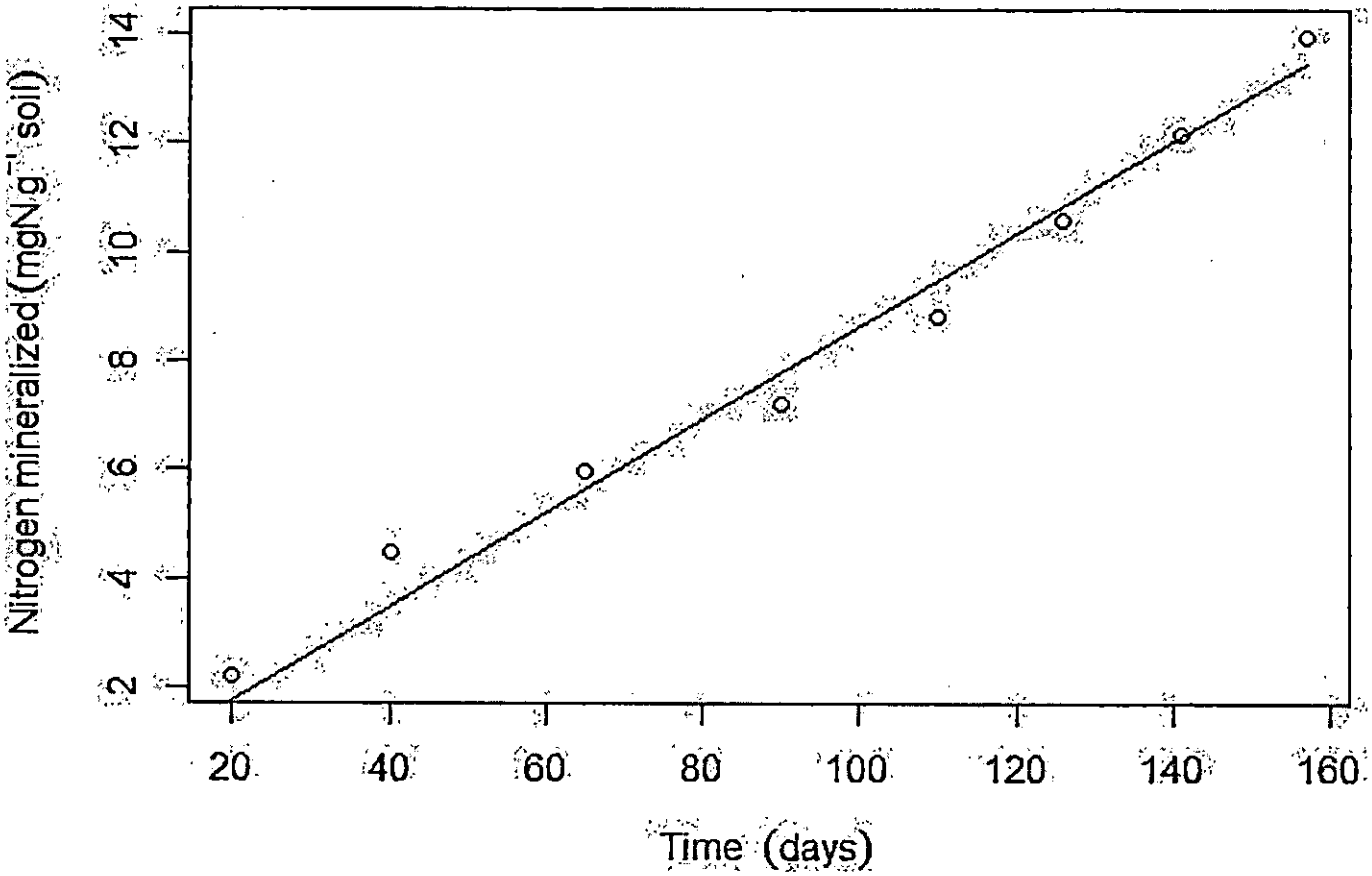


Figure 4.21. Single pool exponential model fits for nitrogen mineralization from banana residues after *in-situ* incorporation from In-C

4.3.5. Periodical release of available nutrient content of soil after *in-situ* incorporation of banana residues

Table 4.30 shows the periodical release of available P content up to 160 days after *in-situ* incorporation of banana residues to the pits. There was significant difference between the treatments in improving the available P content of soil after banana residue incorporation. The highest P content of 39.28 mg kg^{-1} of soil was recorded from soils incorporated with residues from Ex-E. The concentration of P was on par in soils receiving residues from plants treated with In-E (37.82 mg kg^{-1} of soil) and POP (37.76 mg kg^{-1} of soil). Among the different modes of composting, the soils incorporated with residues from Ex-E recorded higher available P.

The time period after incorporation of residues had a significant influence on the content of available P in soil. The highest P content was recorded at 90 days after *in-situ* incorporation of residues. Up to 90 days there was a gradual release of P to the soil and a decreasing trend was noticed thereafter. However the change in available P was significant in all the time intervals up to 160 days of *in-situ* incorporation except between 60 and 75 days after incorporation, where the P content was on par. Significant interaction between the treatments and time period of incorporation of residues was also observed with respect to available P content of soil.

The periodical release of available K was significant with respect to treatments and time period after incorporation of residues (Table 4.31). However, a significant interaction was also found to exist between the treatments and time period after incorporation of residues regarding the K content of soil. The highest concentration of available K was recorded from residues of POP treatment (294.82 mg kg^{-1} of soil). Among the composting treatments, the highest K concentration was recorded from residues of In-P (267 mg kg^{-1} of soil). Among the modes of nutrition, the *in-situ* modes of vermicomposting had a significant influence in the concentration of P in the rhizosphere soil after the incorporation of residues.

Table 4.30. Periodical release of available P in the rhizosphere soils after *in-situ* incorporation of banana residues

Treatments	Time in days									
	0	15	30	60	75	90	105	130	160	T
S	15.83	17.53	18.40	21.73	22.37	27.07	18.33	17.933	16.07	19.47
POP	32.60	28.37	35.30	36.90	38.57	45.70	42.97	41.37	38.00	37.76
Ex-P	28.07	25.47	42.90	42.43	44.33	45.63	38.80	35.10	32.77	37.28
Ex-E	28.53	34.97	34.46	39.13	36.33	45.73	47.23	42.50	39.60	39.28
In-P	21.03	34.10	33.93	37.03	39.27	37.30	36.33	34.60	32.60	34.02
In-E	22.70	18.03	43.57	42.77	43.40	43.70	47.07	40.83	38.27	37.82
In-C	15.03	15.40	21.67	25.67	23.90	23.83	21.60	17.40	17.07	20.17
D	23.40	24.83	33.61	35.09	35.45	38.43	36.05	32.81	30.63	
CD (p=0.05)	Treatments (T) : 0.51; Days (D) : 0.58; T x D : 1.51									

Table 4.31. Periodical release of available K in the rhizosphere soils after *in-situ* incorporation of banana residues

Treatments	Days after *in-situ* incorporation									
	0	15	30	60	75	90	105	130	160	T
S	102.60	104.17	104.07	103.97	104.27	104.50	105.23	104.47	105.97	104.47
POP	285.00	298.93	291.63	291.07	302.97	296.93	298.90	295.40	292.50	294.82
Ex-P	227.90	242.40	247.60	244.17	248.83	241.30	240.17	240.17	242.83	241.70
Ex-E	165.60	175.57	175.17	175.40	176.30	177.20	178.20	180.50	178.63	175.85
In-P	258.77	266.10	266.93	266.93	268.10	268.40	269.53	273.13	269.67	267.50
In-E	183.33	190.90	188.57	196.17	192.57	191.93	188.73	191.77	198.07	191.33
In-C	199.67	205.80	209.27	211.50	205.30	203.27	203.40	208.90	209.00	206.23
D	203.27	211.99	211.89	212.75	214.05	211.93	212.03	213.61	213.81	
CD (p=0.05)	Treatments (T) : 20.78; Days (D) : 23.57; T x D : 62.35									

Table 4.32. Periodical release of available Ca in the rhizosphere soils after *in-situ* incorporation of banana residues

Treatments	Days after *in-situ* incorporation									
	0	15	30	60	75	90	105	130	160	T
S	307.43	310.17	310.97	311.53	312.57	312.63	311.67	311.80	311.10	311.09
POP	656.47	662.10	662.27	661.97	662.73	663.30	662.13	662.00	661.83	661.65
Ex-P	417.30	424.70	422.13	421.97	419.40	426.17	422.93	425.67	423.57	422.64
Ex-E	371.27	376.53	377.07	376.77	377.57	377.20	378.90	377.53	381.10	377.11
In-P	540.03	544.90	544.43	545.63	546.83	544.67	545.97	547.70	548.60	545.42
In-E	449.63	455.97	455.03	453.77	454.47	454.93	456.23	455.43	456.47	454.65
In-C	587.13	592.67	593.33	594.87	594.53	594.97	593.40	594.97	594.43	593.37
D	475.61	481.01	480.75	480.93	481.15	481.99	481.61	482.15	482.45	
CD (p=0.05)	Treatments (T) : 12.87; Days (D) : 14.59; T x D : 38.61									

Table 4.33. Periodical release of available Mg in the rhizosphere soils after *in-situ* incorporation of banana residue

Treatments	Days after *in-situ* incorporation									
	0	15	30	60	75	90	105	130	160	T
S	90.07	90.47	90.52	90.59	90.45	90.51	90.53	90.51	90.49	90.47
POP	90.94	91.36	91.34	91.37	91.35	91.69	91.36	91.35	91.35	91.35
Ex-P	93.93	94.36	94.70	94.71	94.70	94.68	94.74	94.49	94.41	94.53
Ex-E	90.32	90.74	90.73	90.73	90.74	90.74	90.74	90.75	90.73	90.69
In-P	91.59	91.97	92.00	92.00	92.01	91.98	92.01	92.02	92.00	91.95
In-E	92.65	93.07	93.09	93.07	93.07	93.07	93.07	93.07	93.08	93.03
In-C	103.27	103.73	103.74	103.72	103.72	103.72	103.68	103.68	103.71	103.66
D	93.26	93.68	93.74	93.74	93.72	93.78	93.74	93.69	93.68	
CD (p=0.05)	Treatments (T) : 1.04; Days (D) : 1.18 ; T x D : 3.13									

The concentration of available Ca had a significant influence on the different modes of nutrition and time period of incorporation of residues (Table 4.32). The highest concentration of available Ca was recorded after incorporation of residues of POP with 661.65 mg kg^{-1} of soil. Among the composting treatments, the highest Ca content of 593.37 mg kg^{-1} of soil was noticed in the rhizosphere soils that received residues from In-C (*in-situ* compost at the rate of 20 kg $plant^{-1}$). The available Ca content increased from 475.61 mg kg^{-1} of soil to 482.45 mg kg^{-1} of soil at 160 days after incorporation of residues. The interaction of treatments with time period after incorporation of residues with respect to available Ca content of soil was found to be significant.

The different modes of nutrition had a significant influence on the content of Mg in soil as can be observed from Table 4.33. The highest concentration of Mg (103.66 mg kg^{-1} of soil) was recorded in the rhizosphere soils that received In-C (*in-situ* compost at the rate of 20 kg $plant^{-1}$). Available Mg also varied significantly with respect to time period up to 160 days after incorporation of residues. From Table 4.33 a significant interaction was also observed between the treatments and time period of incorporation of residues.

In general, all the treatments had significant influence in improving the concentration of nutrients in soil. However, available P status was more influenced by the addition of residues of *ex-situ* vermicompost prepared using exotic earthworms (Ex-E). The residues from POP had significant influence in enhancing the concentration of available K and Ca to soil through its incorporation. The *in-situ* compost had a significant role in improving the available Mg status of soil among the different treatments under study. The undeniable worth of residue incorporation back to the soil to improve its general health and well-being in terms of fertility and ecosystem sustainability was clearly highlighted by the study.

Discussion

5. Discussion

The results of the various experiments conducted on "Efficiency of vermiconversion and decomposition of farm residues on soil health, yield and crop quality of banana (*Musa* spp.)" were studied and presented in chapter 4. The details pertaining to the various findings are discussed below

5.1. Composting efficiency of native and exotic earthworms

5.1.1. Earthworm species

Epigeic species of earthworms like *Eisenia foetida* are known for efficiency for rapid multiplication (Siddique *et al.*, 2005). The indigenous nature of *Perionyx excavatus* also helps it to acclimatize to the abiotic environmental conditions with the production of higher number of cocoons, juveniles and adults (Pattnaik and Reddy, 2010) that contribute to the large biomass and abundance in Indian soils. Hence to compare the efficiency of vermiconversion of residues, exotic compost worm *Eisenia foetida* and indigenous *Perionyx excavatus* were selected for vermicompost preparation.

5.1.2. Chemical characterization of compost substrates

Equal proportion of substrates comprising of *Gliricidia* leaves (*Gliricidia sepium*), banana pseudostem (*Musa spp.*) and coconut leaves (*Cocos nucifera*) were selected along with cowdung slurry so as to enrich the vermicomposts used for the study. *Gliricidia* leaves contained higher N and are easily decomposable. Hence addition of its residues accelerated the composting process. Agyeman *et al.*, (2013) testified a positive synergy between the nutrient release from *Gliricidia* leaf residues and nutrient uptake by maize plant during decomposition. *Gliricidia* could be a versatile ingredient in composting due to its insecticidal, repellent and rodenticide action. It is known to survive dry moist, acidic soils or even poor degraded soils under rainfed conditions (Rao *et al.*, 2011). Banana pseudostem is reported to contain high P as well as moisture and was selected as one of the substrates to keep up the moisture requirement. More or less banana fibres can act as small pipes to facilitate the water movement in the compost pile (Li *et al.*, 2010). Coconut leaf residues were selected to enrich the compost with K. Cowdung slurry was chosen as an organic enrichner. The plant growth promoting properties with huge population of microbes in cowdung manure was already reported by Lee (1985) and Nattudurai *et al.* (2014). Hence an ideal mixture of substrates were chosen for compost preparation. Moreover 1:1 cowdung slurry improves the feed quality by adding decomposing microorganisms (Pattnaik and Reddy, 2009).

The substrates were also characterized for the chemical parameters in order to assess their composting nature and decomposability.

pH

Figure 5.1 shows that the pH (1:2 substrate: water suspension) of the substrates varied in the order: 1:1 cowdung slurry (8.9) > coconut leaves (7.5) > banana pseudostem (6.9) > *Gliricidia* leaves (6.4) > i.e. from strongly alkaline to slightly acidic range. The pH of the substrates determined growth and survival of both earthworms and its gut microorganisms. Earthworms prefer pH form neutral to slightly alkaline for better activity (Lee, 1985).

However, earthworms were introduced only after partial decomposition of bedding materials which had a more or less stable neutral pH, which was not detrimental to the growth and multiplication of earthworms. The change in pH of the substrates during decomposition was due to microbial conversion and subsequent release of organic acids and ammonia from residues (Bisen *et al.*, 2011).

Carbon: Nitrogen ratio

Ratio of C to N is an index of decomposition and microbial mineralization of residues. The substrates with narrow C: N ratio can easily be attacked by microbes and hence mineralized immediately to release the nutrients. Figure 5.2 depicted the C: N ratio of compost substrates used in the study. Analysis of C: N ratio of substrates revealed the following sequence: Banana pseudostem > dry coconut leaves > 1:1 cowdung slurry > *Gliricidia l*eaves and hence the order of decomposition of the substrates are found to be in the reverse order.

Content of primary nutrients

The content of primary nutrients N, P and K varied among the substrates (Figure 5.3). Content of N, in the different substrates followed the order:

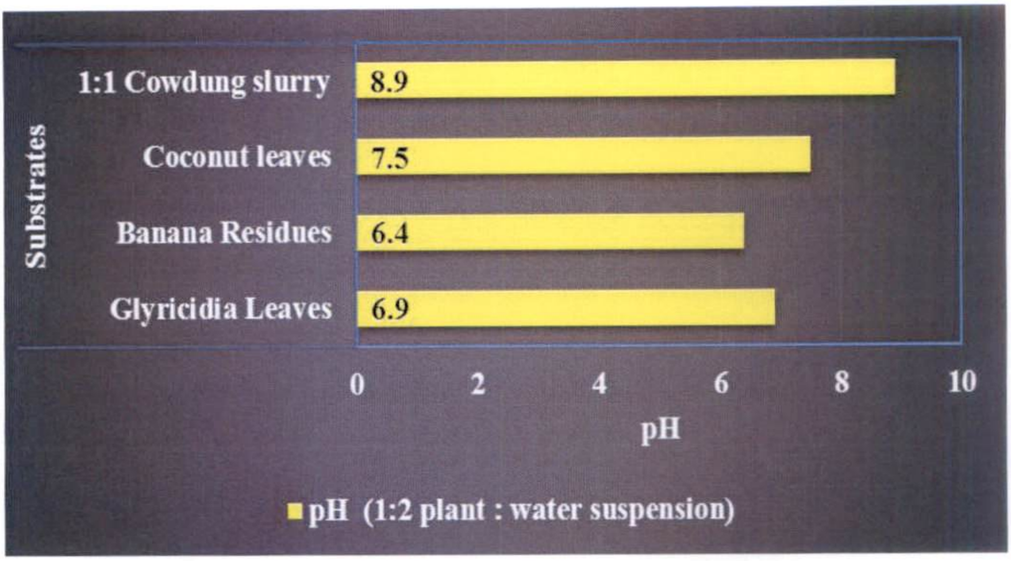


Figure 5.1. Variations in pH of the substrates used for the study

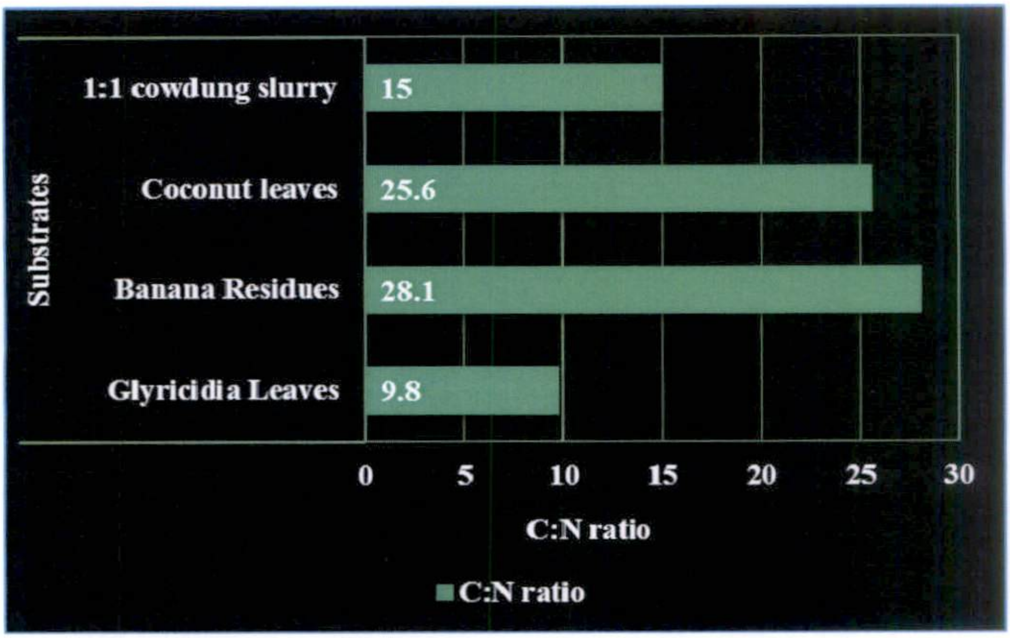


Figure 5.2. Variations in C: N ratio of compost substrates

Gliricidia leaves (3.34%) > 1:1 cowdung slurry (1.82%) > banana pseudostem (1.10%) > coconut residues (0.86%). Cowdung slurry (1:1) recorded the maximum of 2.09% P content followed by *Gliricidia* leaves (0.77%), banana pseudostem (0.59%) and coconut leaves (0.51%). Potassium content varied as follows: Coconut leaves (3.92%) > *Gliricidia* leaves (1.52%)> banana pseudostem (0.58%) > 1:1 cowdung slurry (0.40%). The coconut leaves were reported to absorb and accumulate large quantities of K (Robinson *et al.,* 2008).

Due to the high content of N in *Gliricidia* leaves, there was higher evolution of ammonia gas during the initial days of composting. High P content in cowdung was due to the action of microbial mineralization of P through secretion of alkaline phosphatase enzyme (Nattudurai *et al*., 2014).

Content of secondary nutrients in compost substrates

Secondary nutrients like Ca, Mg and S varied among the substrates (Figure 5.4). Among the different substrates, Ca content ranged in the order, 1:1 cowdung slurry (1.79%) > *Gliricidia* leaves (1.54%) > banana pseudostem (1.07%) > coconut leaves (0.40%). Like Ca, Mg content also established same trend of variation among the different substrates. The S content recorded a slightly different trend with 1:1 cowdung slurry (0.24%) > *Gliricidia* leaves (0.21%) > coconut leaves (0.09%) > banana pseudostem (0.07%). Since the feed of animals are mainly concentrates which are rich in calcium and micronutrients, the cowdung also contains relatively higher contents of the same.

Content of micronutrients of the substrates

On analysis of micronutrient status of various substrates (Figure 5.5) it was seen that among micronutrients, Fe content was remarkably high in all the substrates. Among the substrates, the Fe content varied as follows. 1:1 cowdung slurry (1543.40mg kg^{-1}) > banana pseudostem (1143.40 mg kg^{-1}) > *Gliricidia* leaves (687.40 mg kg^{-1}) >dry coconut leaves (543.40 mg kg^{-1}). The higher content of Fe in the substrates is due to the preferential uptake and translocation of Fe by the plants and which was plentiful in the soil under study. The excretion of mineral nutrients through cowdung was also reported by Garg and Mudgal (2007).

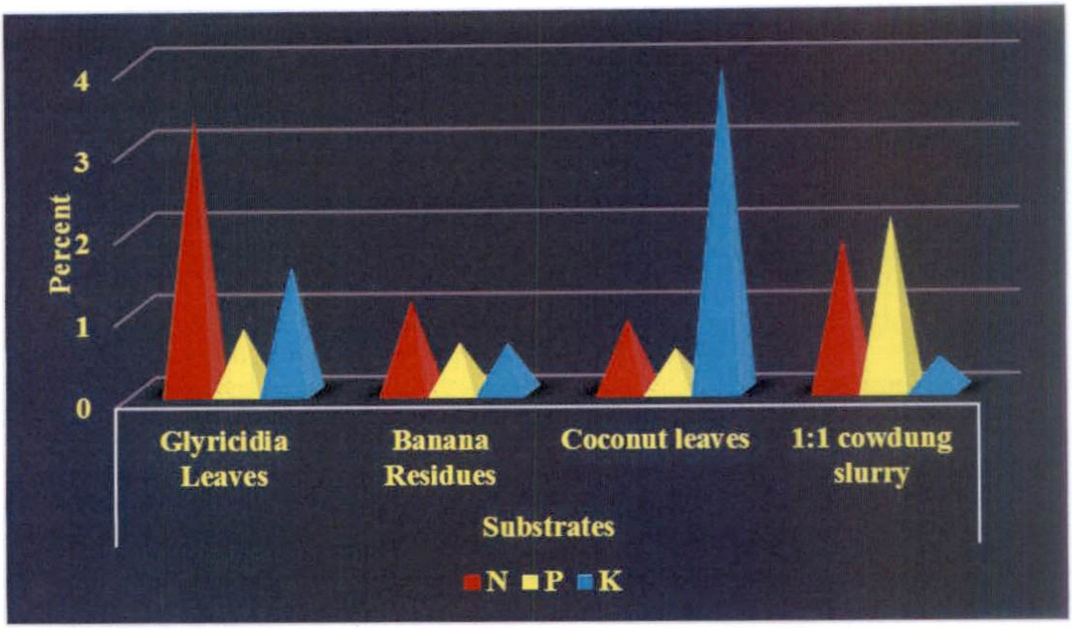


Figure 5.3. Content of primary nutrients in compost substrates

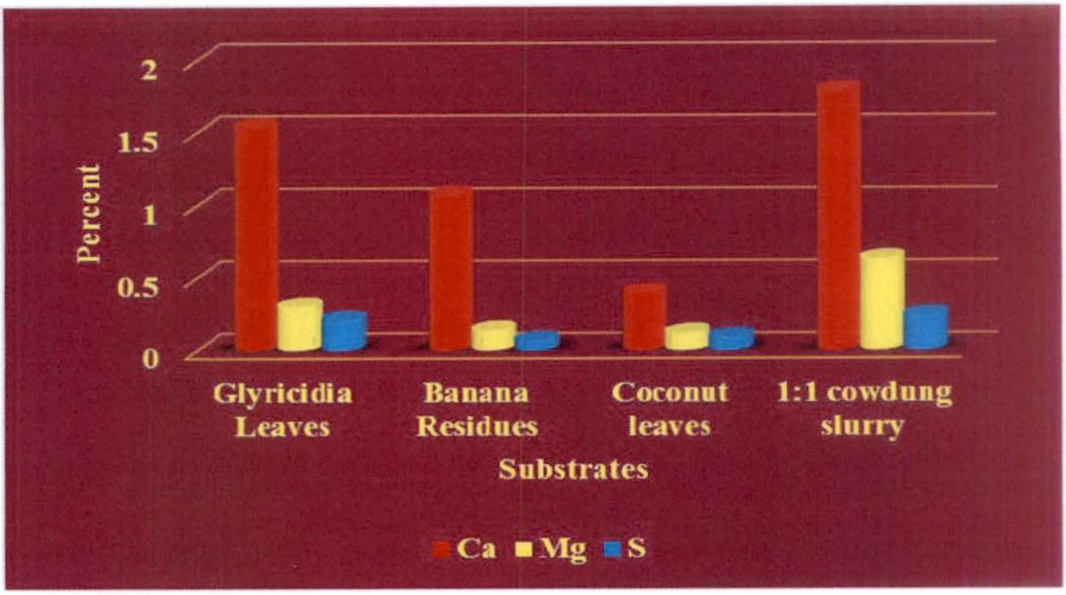


Figure 5.4. Content of secondary nutrients in compost substrates

Manganese content of substrates ranged in the order banana pseudostem (566.60 mg kg^{-1}) > 1:1 cowdung slurry (480.60 mg kg^{-1}) > dry coconut leaves (103.00 mg kg^{-1}) > *Gliricidia* leaves (82.60 mg kg^{-1}). Zinc content ranged from 0.03 mg kg^{-1} to 30.50 mg kg^{-1}.

Copper content followed a decreasing trend from 1:1 cowdung slurry (24.00 mg kg^{-1}) > banana pseudostem (6.20 mg kg^{-1}) > *Gliricidia* leaves (3.80 mg kg^{-1}) > dry coconut leaves (2.00 mg kg^{-1}).

Among the substrates, 1:1 cowdung slurry contributed maximum Fe and Cu content followed by banana pseudostem and *Gliricidia* leaves. Hence for enriching compost with micronutrients, all the substrates under study were found to be effective.

Content of heavy metals in the substrates

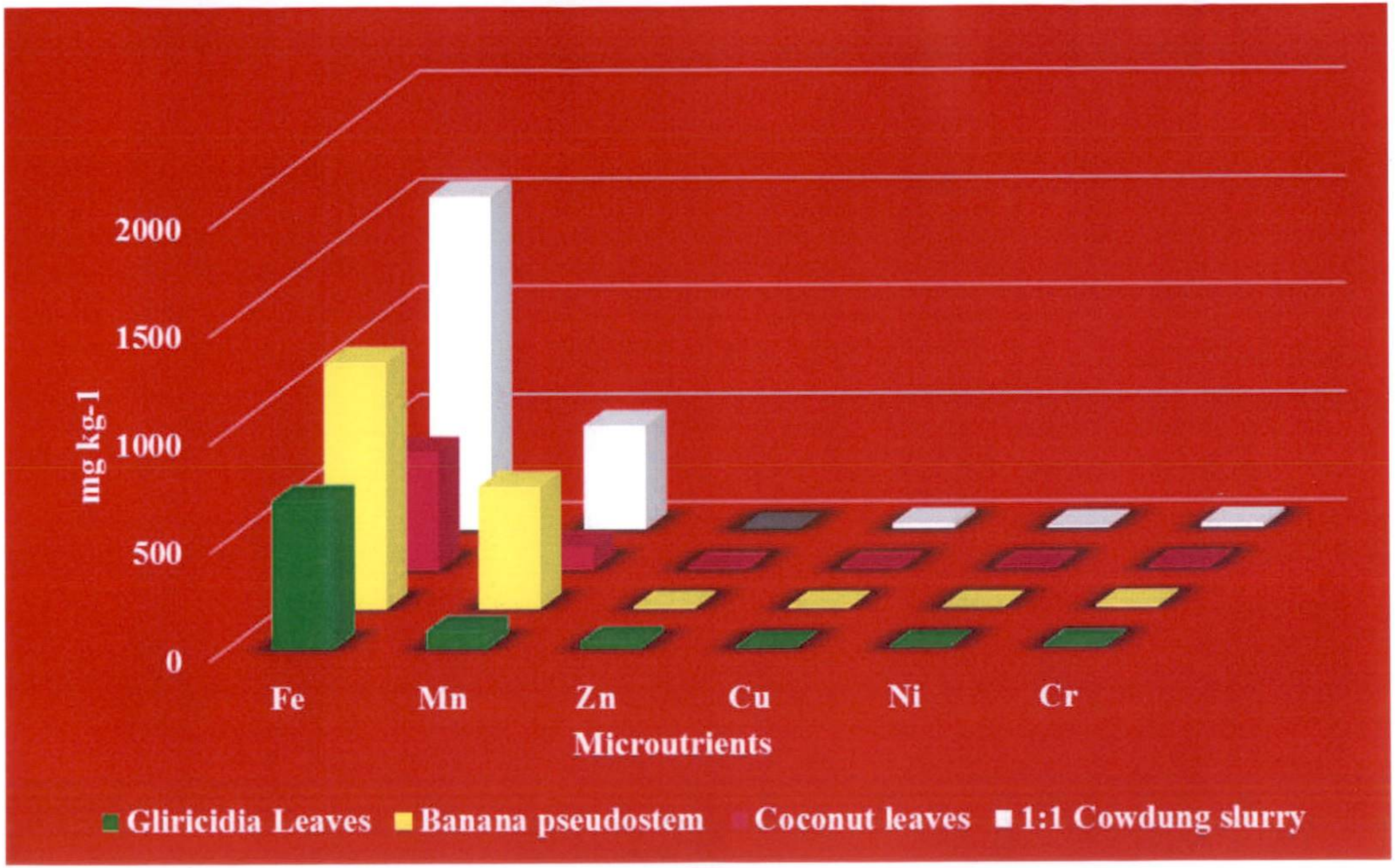
The content of heavy metals in compost substrates is shown in Figure 5.5. Among the heavy metals analysed, content of As, Pb, Cd were below detectable levels. Nickel content in compost substrates was in the order 1:1 cowdung slurry (10.60 mg kg^{-1}) > *Gliricidia* leaves (4.20 mg kg^{-1}) > banana pseudostem (2.60 mg kg^{-1}) > dry coconut leaves (2.20 mg kg^{-1}). The highest content of Cr was recorded in 1:1 cowdung slurry (20.60 mg kg^{-1}) > banana pseudostem (9.80 mg kg^{-1}) > *Gliricidia* leaves (7.40 mg kg^{-1}) > dry coconut leaves (4.00 mg kg^{-1}). Among the substrates, 1:1 cowdung slurry was the highest contributor of heavy metal content of substrates and the least by coconut leaves. The higher content of metals in cowdung was attributed to the presence of soluble organics in cowdung and formation of metal –humic complexes. The bioremediating effect of cowdung on heavy metals was evident from the result (Ojedokun and Bello, 2016).

5.1.3. Assessment of compost maturity

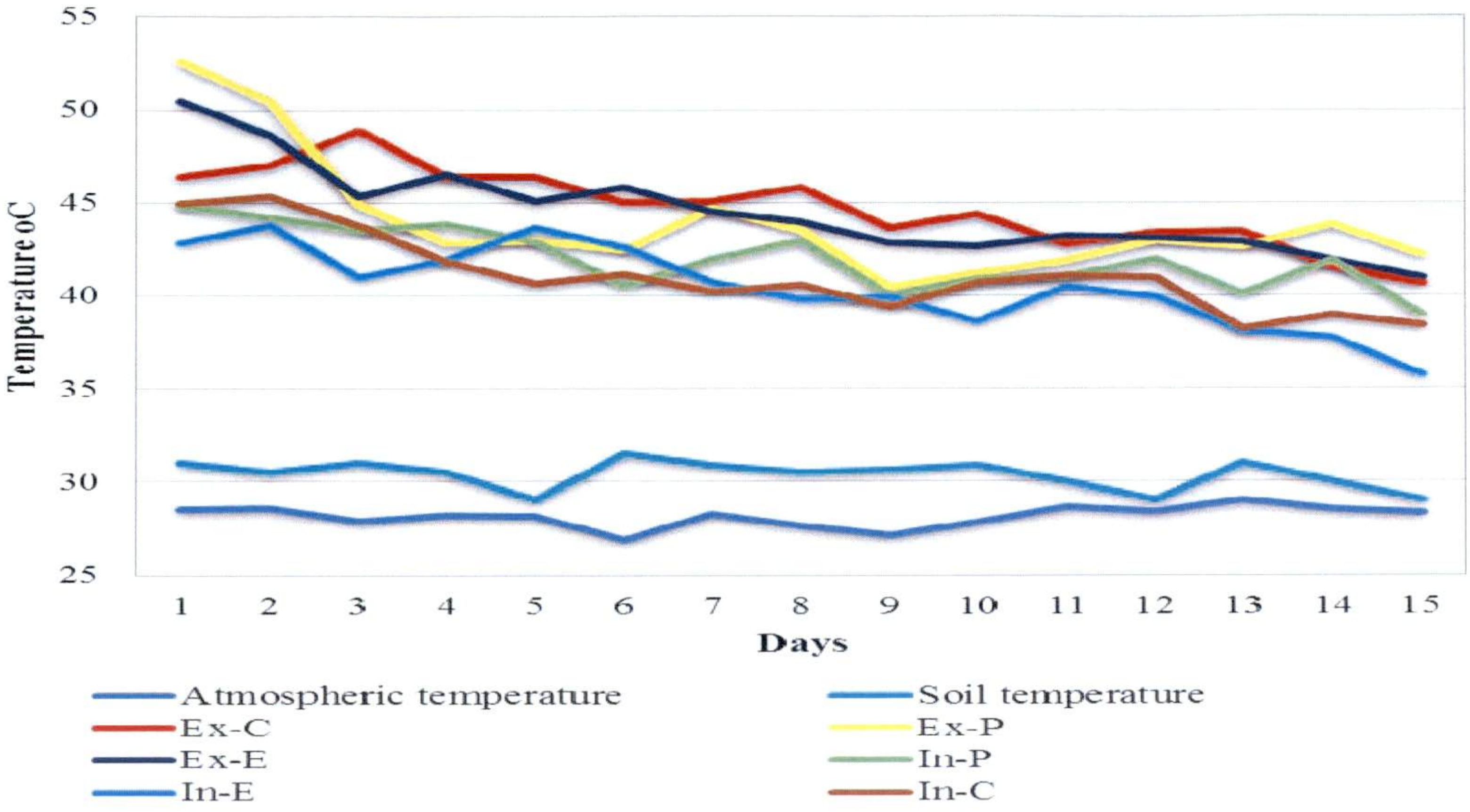
The compost was prepared both *ex-situ* and *in-situ* and was subjected to physico-chemical characterization.

Variations in temperature during composting of substrates up to compost maturity

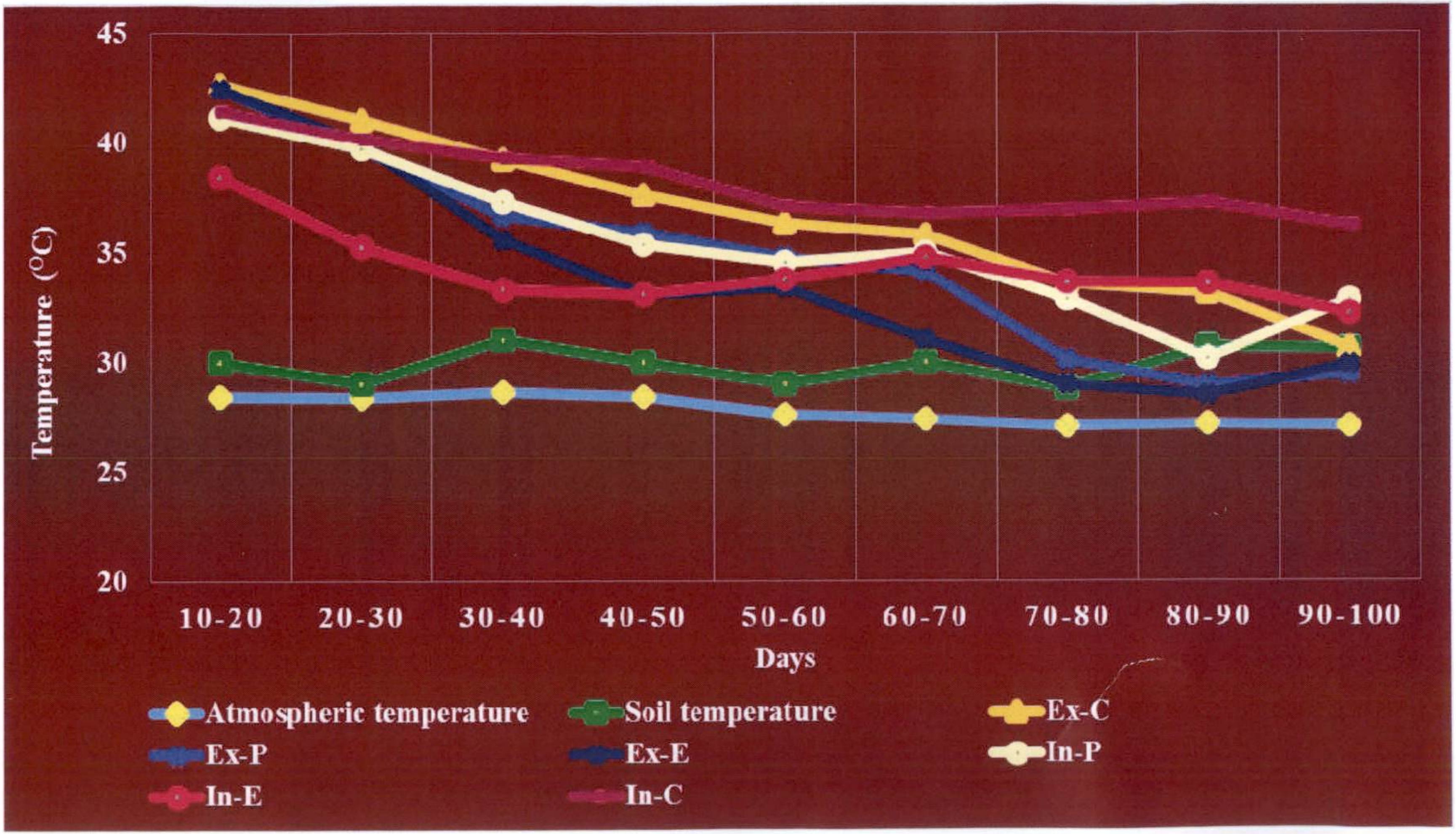
The data pertaining to the temperature variations of different treatments up to compost maturity are given in Figure 5.6 and 5.7.



5.5. Content of micronutrients and heavy metals in compost substrates



5.6. Daily variations in mean temperature of the compost beds up to 15 days of composting



Figre 5.7. Variations in mean temperature up to 100 days of composting

The prime factor determining maturity of a compost is its temperature and heat output. The temperature of a good quality mature compost would be 30 to 40°C (Gaur *et al.*, 2007). Both the *ex-situ* and *in-situ* composting treatments recorded temperature greater than atmospheric and soil temperature (Figure 5.6 and 5.7). However there was erratic variations in temperature during the initial stages of composting (up to 15 days). These inconsistent variations in temperature during the initial mesophilic and thermophilic phases were due to the proliferation of mesophilic and thermo-tolerant fungi, bacteria and actinomycetes. During this period, mesophilic bacteria rapidly break down soluble and easily degradable carbon sources followed by metabolizing proteins, cellulose and hemicellulose by actinomycetes and fungi. The availability of fresh organic substrates accelerated the degradation process with rapid beak down of soluble and easily degradable carbon sources (Manna *et al.*, 2012). After thermophilic stage, mesophilic microbes recolonized with a cooling phase. After stabilization of temperature at 35±5°C during cooling phase, earthworms were introduced to the respective beds.

The gradual decrease in temperature after introduction of earthworms was due to the crawling action of earthworms and activity of microorganisms under *ex-situ* mode of composting. Earthworms brought out churning of the compost pile and thereby increased the surface area for contact between microbes and earthworms. The rate of change in temperature was not uniform under *in-situ* composting treatments due to uncontrolled conditions and proximity to soil as detailed in section 4.1.2.

Sprinkling of water and weekly churning helped in providing better aeration and microbial proliferation. In silpaulin vermibeds, the conditions were more or less uniform and loss of water was limited. Hence the conditions of microbial proliferation and earthworm multiplication was favoured in the silpaulin vermibeds, whereas under *in-situ* field conditions, the pile was subjected to various losses of moisture.

5.1.4. Compost yield and time taken for compost maturity

The weight of compost obtained from a known weight of initially added substrates was recorded as the percent yield of compost. Compost yield of aerobic

(4.7). However *in-situ* mode of composting had a significant ameliorating effect on the soil pH of the crop pits under study. During decomposition, ammonium ions and humic acids will be released. The combined action of released ammonium ions and acidic humate ions regulated the pH of the final compost towards neutrality (Bisen *et al.*, 2011). Higher electrical conductivity in the vermibeds had significant positive correlation (r = 0.93** and 0.75** respectively) with the pH of the composts. The significant effect of C (r = 0.89**), N (r = 0.90**), P (r = 0.75**), K (0.75**) and Ca (0.74**) in maintaining the pH of the compost was clearly proved by the significant positive correlation obtained by the correlation analysis (Appendix 1).The excretion of neo-formed calcium carbonate concretions by earthworms assisted in raising the pH of the resultant compost under both modes of composting when compared to control (Padmavathiamma, *et al.*, 2008) which will be detailed in section 5.1.9.

Electrical conductivity (EC)

Figure 5.8 revealed the variations in EC among the different composts prepared. Electrical conductivity is a measure of concentration of soluble salts in compost at a given temperature. Higher EC indicated the higher accumulation of salts. Compost prepared under *ex-situ* mode of composting, irrespective of the earthworm species recorded EC which was superior to *in-situ* treatments. The *in-situ* treatments could not produce any remarkable change in EC. However none of the composts exceeded the threshold value of 3 dS m^{-1} (Lazcano *et al.*, 2008) and so these composts can be safely applied to soil. The significant influence of silpaulin sheets in preserving the nutrients from leaching losses was shown from the results detailed in section 4.1.3. The dissipation of nutrients from *in-situ* composting treatments to the surrounding soil caused a dilution in the soluble salt concentration in the composts prepared under *in-situ* mode of composting.

Decomposition of substrates and subsequent release of exchangeable bases would have increased electrical conductivity of the compost prepared under *ex-situ* mode of composting (Pattnaik and Reddy, 2010). Leaching of the bases in *in-situ* pits dilutes the soluble salt concentration, hence lowered electrical conductivity. The combined positive correlation between electrical conductivity composting (*ex-situ* and *in-situ* modes) was higher than vermicomposting due to increased mineralization brought about by earthworms and associated microorganisms. Among the species of earthworms, vermicompost prepared using native earthworm, *Perionyx excavatus* recorded higher yield under *in-situ* conditions.

The time required for stabilizing the temperature in the range of 30 to 35 °C was regarded as the period of compost maturity. A mature compost will be brown to black in colour, with earthy odour. Time taken for compost maturity (days) was higher for *ex-situ* compost among the different treatments (Table 4.4). Vermicompost prepared using exotic earthworms recorded the least time for compost maturity under both *in-situ* and *ex-situ* mode of vermicomposting. Native earthworms took longer days for compost maturity when prepared in silpaulin vermibeds than under banana planting pits. The enhanced rate of multiplication along with higher cellulase and β-glucosidases activity of *Eisenia foetida* (Zhang *et al.*, 2000) brought out quicker decomposition of organic residues and shortened time required for compost maturity. However, native earthworms gave higher compost yield under *in-situ* mode of composting, when compared to exotic worms due to higher adaptability of *Perionyx excavatus* to the soil (Pattnaik and Reddy, 2010). Correlation analysis of compost yield revealed that it was significantly and positively correlated with pH ($r = 0.69^{**}$), total Ca ($r = 0.61^{**}$), total Mg ($r = 0.63^{**}$), total Zn ($r = 0.56^{**}$), total Mn ($r = 0.62^{**}$) and total fungal count ($r = 0.66^{**}$) (Appendix 1).

5.1.5. Evaluation of compost quality

pH

Figure 5.8 shows the effect of modes of composting and type of earthworms on the pH of the resultant composts. All the composting treatments had significant effect on pH than the experimental soil. The pH of resultant composts ranged from neutral to moderately alkaline (7.1 to 8.3). On appraisal of the results, it was seen that composts prepared under *ex-situ* mode of composting recorded significantly higher pH than those prepared under *in-situ* mode of composting. The pH of the experimental soil was under strongly acidic range and total C (r =0.76**), total P (r = 1**), total K (r = 1**) and total S (r = 0.78**) supported the effect of these ions in maintaining electrical conductivity of the composts (Appendix 1).

Total carbon

Figure 5.9 reveals that the initial carbon content of the substrates was 50.5 percent which got reduced in the mature composts (0.69% to 27.81%). Soil carbon is the principal component of soil organic matter. The content of C in compost is the major source of energy for the microorganisms. Composting process essentially concentrate humified carbon which is resistant to microbial action. Carbon content of *ex-situ* vermicomposts were significantly ($P \leq 0.05$) greater than composts produced in crop pits. During vermicomposting, carbon content of all the treatments got reduced remarkably due to the combined action of earthworm ingestion and decomposition by microbes. The significant positive correlation between dehydrogenases and carbon content (r =0.70**) proved the greater biological activity in the compost. The higher C content in *ex-situ* treatments can be attributed to higher microbial decomposition under controlled environmental conditions.

Ash content

Ash content of compost represent the mineral matter present in the compost. It is clear that modes of composting influences the ash content of composts (Figure 5.9). Compost prepared under field conditions yielded significantly ($P \leq 0.05$) higher ash content than that in silpaulin vermibeds. However the ash content of the experimental soil was higher due to high mineral content.

Content of primary nutrients

Nitrogen content

Both the modes of composting and species of earthworms had commendable influence on the N content of composts. Data on N content of the composts in Figure 5.10, revealed that *ex-situ* mode of composting significantly ($P \leq 0.05$) contributed to the final N content of composts.

Among the *ex-situ* treatments vermicompost made with *Perionyx excavatus* recorded higher N content but was statistically similar to that of *ex-situ* vermicompost with *Eisenia foetida*. *Eisenia foetida* performed well both under *in-situ* and *ex-situ* mode of composting. Comparable N content was shown by all the compost treatments than control. Hence composting of organic wastes using earthworms had a significant influence on the N content of soil.

The increased N content of the compost is due to the mineralization of proteins present in the substrates to nitrate and ammoniacal forms. In *ex-situ* vermibeds much of these N forms are retained whereas in soil pits the different forms of N get diffused to adjacent soil layers. So the concentration of N in pits may be reduced. Singh *et al*., (2014) reported that due to loss of carbon as CO_2, N content of the vermicompost increases causing a decrease in C: N ratio.

Phosphorus content

The silpaulin vermibeds were superior in yielding vermicompost with significantly higher P content than that produced from banana planting pits (Figure 5.10). Among the earthworm species, *Eisenia foetida* produced compost with high P content. Under *in-situ* field conditions, the P enrichment in the vermicompost by *Eisenia foetida* and *Perionyx excavatus* was on par. However under field conditions, *Perionyx excavatus* could not perform well. Much of P in silpaulin vermibed was retained under *ex-situ* mode of composting whereas in pits there was high possibility of leaching and fixation (Khan *et al.,* 2011).

Potassium content

Similar to N and P, K content of *ex-situ* vermicompost was significantly higher ($P \leq 0.05$) than in banana planting pits (Figure 5.10). Earthworm species could not cause any distinct effect under both modes of composting.

The *in-situ* treatments could not produce any significant enrichment of K over control. The lower K content in compost prepared from pits might be due to the leaching loss of K from the compost prepared *in-situ.*

Tolerance limit for composts

Sum of N, P_2O_5 and K_2O are referred as the tolerance limit of nutrients as prescribed by the Fertilizer (Control) Order (GOI, 1985). In general, the sum total

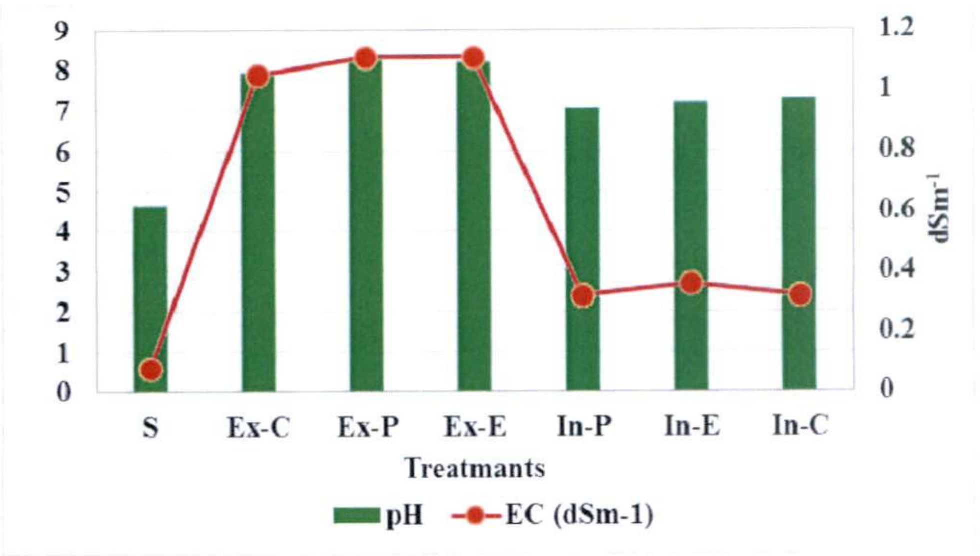


Figure 5.8. Effect of modes of composting and species of earthworms on pH and EC of the composts

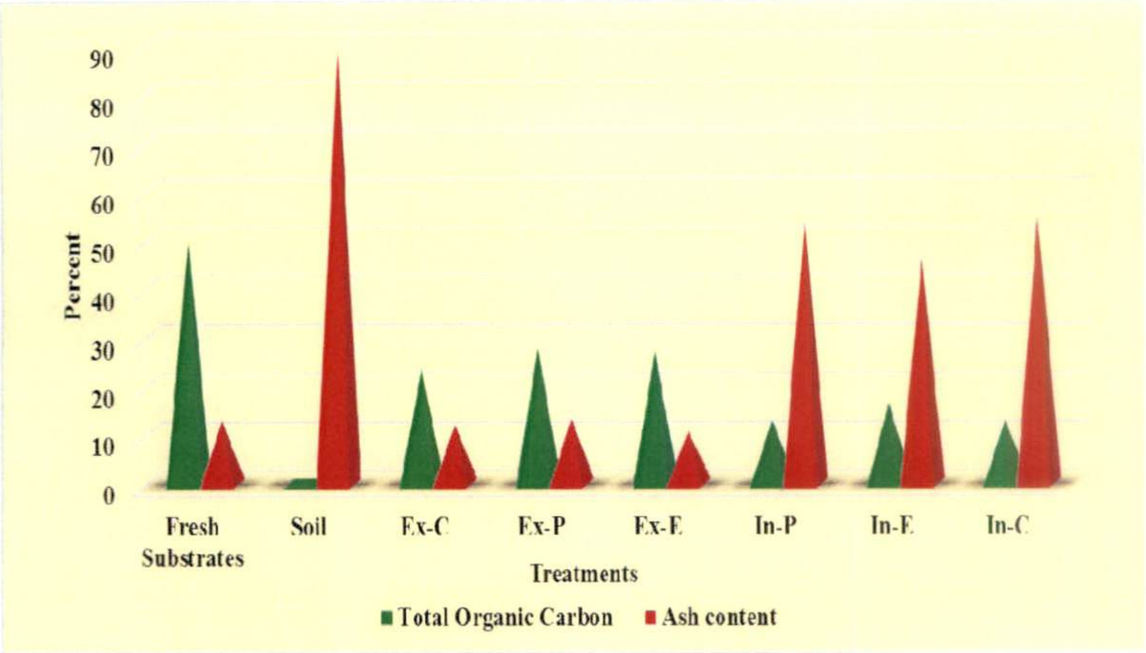


Figure 5.9. Effect of modes of composting and species of earthworms on content of carbon and ash in fresh substrates and composts

of N, P_2O_5 and K_2O produced by compost and vermicompost prepared *ex-situ* were above 2.5 percent as prescribed by The Fertilizer (Control) Order (GOI, 1985) for vermicompost. However the *in-situ* treatments using *Perionyx excavatus* could not attain the minimum level of tolerance under field conditions owing to the various losses of nutrients (Figure 5.10).

Content of secondary nutrients

The results on Ca content of composts indicated that modes of composting have more pronounced influence on Ca content than the type of earthworms used (Figure 5.11). *Eisenia foetida* in crop pits was the best treatment combination for enriching Ca in composts. Calcium enrichment was when the soil and substrates pass through the digestive tract of earthworms. Hence in all the composting treatments, Ca enrichment occurred significantly higher than control. The indistinguishable significance of composting and vermicomposting in enriching the compost with Ca content was brought out in the present study. Earthworms were reported to captivate Ca in excess from their food and transfer it to calciferous glands, which contain carbonic anhydrase enzyme which catalyse the fixation of CO_2 as $CaCO_3$ concretions before being excreted *via* digestive tracts (Padmavathiamma *et al.,* 2008).

Enhancement of Mg in the compost with respect to all treatments could not attain the level of significance. However numerically higher values for Mg content were recorded in *in-situ* vermicompost with *Eisenia foetida.*

S content was found to be more in compost prepared *ex-situ* and different modes of composting produced comparable values with respect to S content.

Micronutrient content

The content of micronutrients (Zn, Cu Fe, and Mn) are presented in Figure 5.12. The experimental soil initially recorded less amount of zinc. All the treatments (*in-situ* and *ex-situ*) had a significant effect on the Zn content of compost. So composting favoured enrichment of Zn, which is successfully brought out in this study. Humate ions and carboxylic functional groups of the compost have mobilized the Zn from the plant residues and made it available to the plants for absorption (Vanilarasu and Balakrishnamurthy, 2014). The

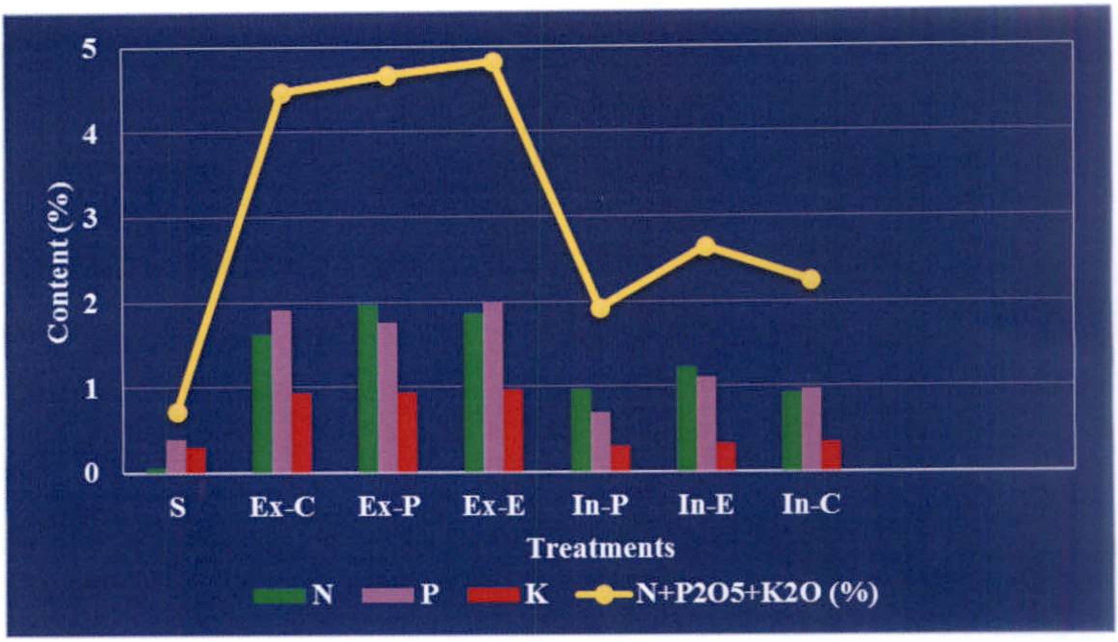


Figure 5. 10. Effect of modes of composting and species of earthworms on primary nutrient content of composts

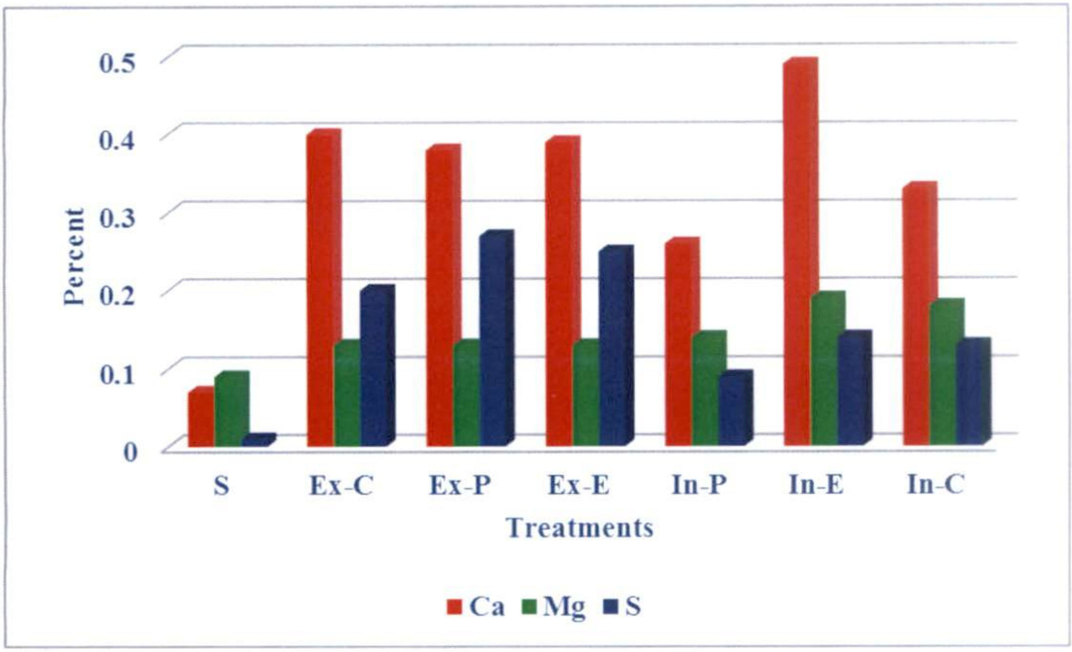


Figure 5.11. Effect of modes of composting and species of earthworms on secondary nutrient content of composts

significant positive correlation between Zn and C content (r = 0.76**), N (r = 0.80**), pH (r = 0.79**), Ca (r = 0.96**) and S (r = 0.77**) explained the mobilization of Zn by these factors. The significant correlation between Zn content and compost yield (r = 0.56**) explained the direct influence of Zn in compost yield (Appendix 1).

The mode of composting had significant influence on the Cu content of composts. The effect of *in-situ* composting had been clearly brought out by the results. *In-situ* treatments excelled in enriching the composts with Cu content. *Ex-situ* treatments could not attain a significant effect in Cu content over the control treatment. The significant positive correlation of Cu content with Fe (r = 0.89**) and Mn (r = 0.96**) explained the mobilization of these micronutrients from soil by the humate and carboxylic groups present in the compost (Appendix 1).

From the Figure 5.12, it was clear that the soil was rich in native Fe. Like Cu, Fe content was higher in *in-situ* treatments and soil. The higher Fe content of *in-situ* treatments is due to translocation and chelation effect of humate and phenolic functional groups in plant derived organic matter due to contact with surrounding soil environment. The lower Fe content in *ex-situ* composts clearly reason out the lack of soil for reaction with the compost substrates. The lower Fe content in the *ex-situ* composts explained the significant negative correlation obtained between the Fe content and pH (r = -0.56**), EC (0.-77**) (Appendix 1).

The content of Mn was significantly influenced by the modes of composting than the species of earthworms. *In-situ* treatments recorded significant increment in Mn content of compost than control (Figure 5.12). As an essential micronutrient, Mn need to be enriched in the soil. The mobilization of Mn from soil to compost and subsequent enrichment over the control is clearly brought out in *in-situ* composting. The Mn content was positively correlated with Fe content of the compost which was found to be significant (Appendix 1).

Soils are the richest store of micronutrients. The organic acids released during compost formation chelate these micronutrients and bring them into available form. Since this process is not occurring in silpaulin vermibeds, composts prepared *ex-situ* may not be enriched with micronutrients.

Heavy metal content of compost

Figure 5.13 shows the content of heavy metals in compost as influenced by the modes of composting and types of earthworms

Compost prepared in banana planting pits recorded the highest content of Cr. The highest Cr accumulation was observed in *in-situ* treatments than *ex-situ*. A significant reduction in Cr content was recorded in composts prepared in silpaulin vermibeds using *Eisenia foetida* and *Perionyx excavatus*. The *in-situ* treatments concentrated the Cr content within them due to chelation with organic acids contained in them. Among the *ex-situ* treatments, vermicompost produced by *Eisenia foetida* reduced Cr concentration of the compost. The reduced Cr concentration in *ex-situ* treatments can be explained by the significant negative correlation (r = -0.61**) with the dehydrogenase activity (Appendix 1). The microorganisms in the *ex-situ* vermibeds could effectively sequester the Cr in the compost substrates than that in the field conditions.

Nickel content of compost prepared in banana planting pits followed the same trend as in the Cr content. The higher accumulation of Ni was in *in-situ* treatments than *ex-situ*. A significant reduction in Ni content was recorded in composts prepared in silpaulin vermibeds. The increased accumulation of Ni in *in-situ* treatments was attributed to formation of metal humate complexes. Among the *ex-situ* treatments, vermicompost produced by *Eisenia foetida* was on par with soil. The effect of *ex-situ* treatments in reducing the Cr content of plant residues was brought out in the study. Like Cr, Ni content in the compost was significantly negatively correlated with dehydrogenase activity (r = -0.57**) (Appendix 1). The higher activity of microbes sequestered Ni in the compost and reduced its availability.

Higher content of Cr in laterite soils of Kerala was also reported by Vijayan (2015). The experimental soil also contained higher content of Cr as composed to any other heavy metals under study. However heavy metal

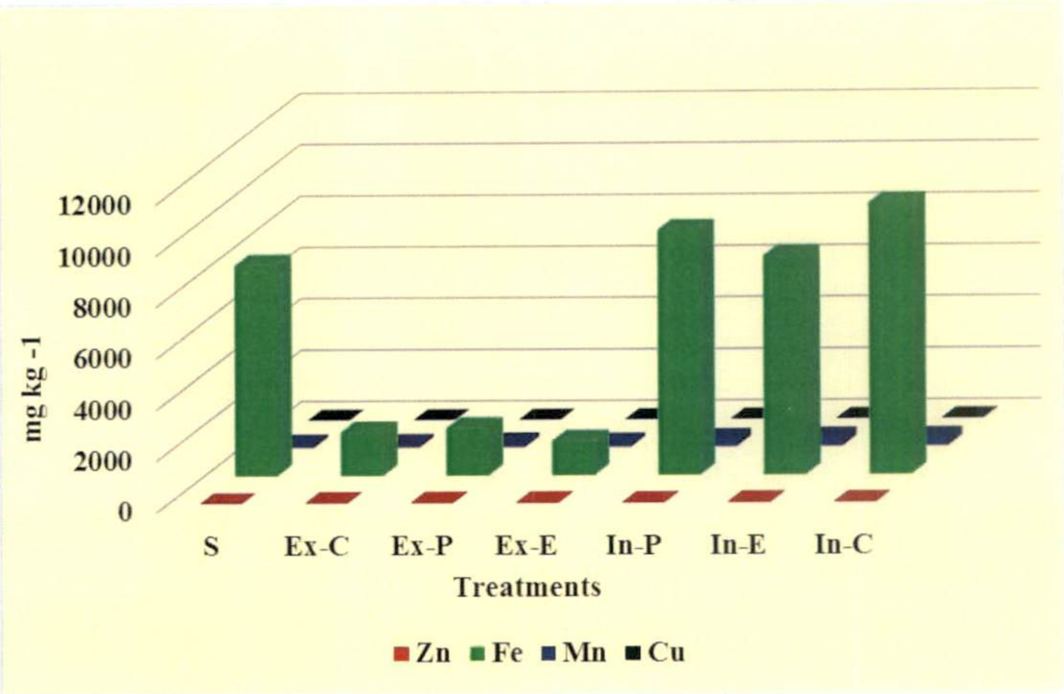


Figure 5.12. Effect of modes of composting and species of earthworms on the micronutrient content of composts

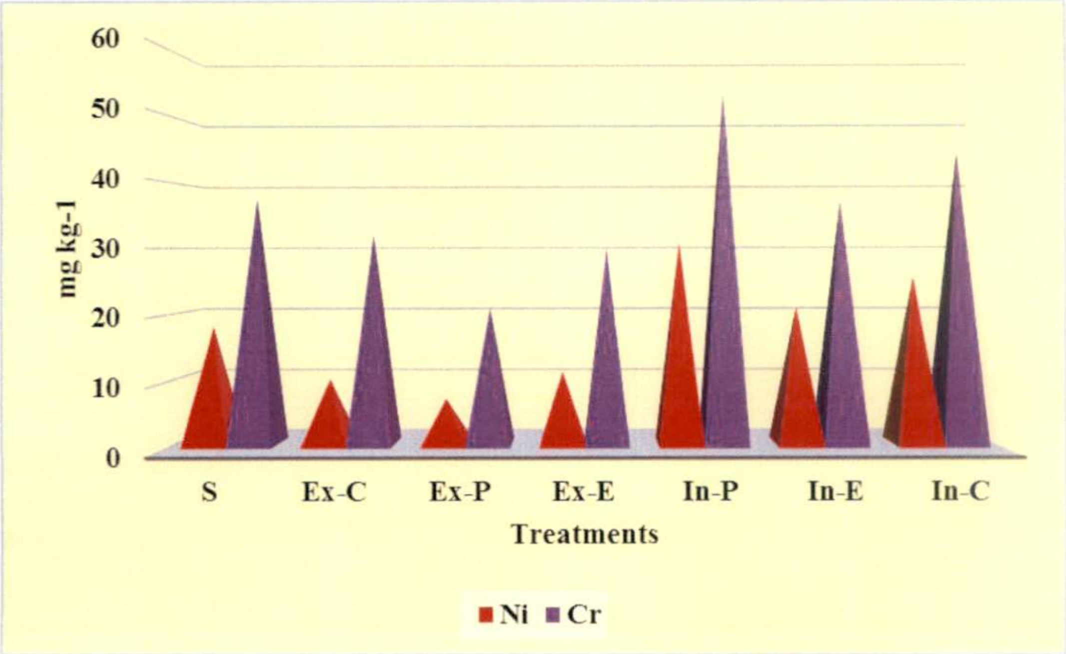


Figure 5.13. Effect of modes of composting and species of earthworms on the heavy metal content of composts

concentrations of all the composts were below the maximum permissible limit prescribed by The Fertilizer (Control) Order, Government of India (Appendix 2).

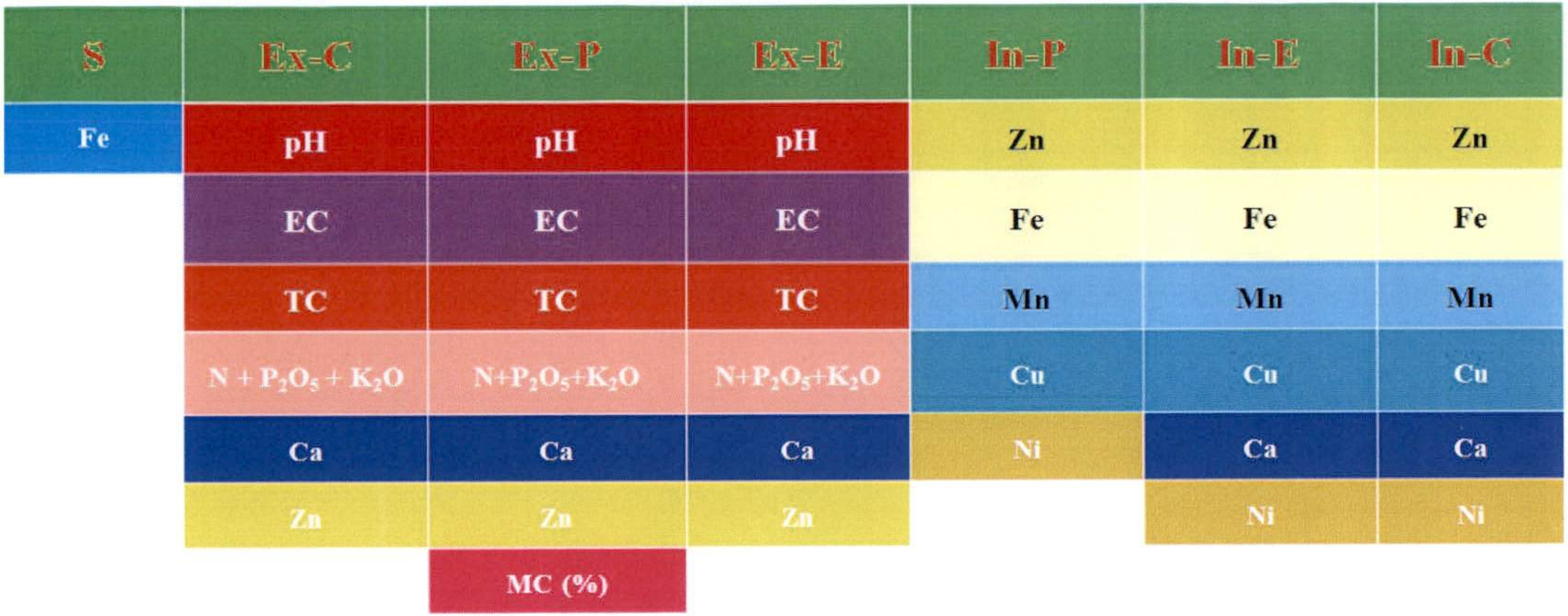
5.1.6. Physico-chemical properties contributing to the chemical composition and quality of composts prepared for the study.

Figure 5.14 revealed the various components that contributed to the chemical composition and quality of composts prepared for the study. Among them, pH is a dominant factor that influenced the yield and quality of the compost prepared, irrespective of the earthworm species, which ranged from neutral (6.6-7.3) to moderately alkaline (7.9 – 8.4). Under acidic environment, earthworms may secrete calcium carbonate to neutralize the acidity so as to avoid their mortality (Juarez *et al.,* 2011). Hence the prepared compost has got the advantage of safe application to acid soils of Kerala.

Electrical conductivity was found to be significantly superior in all *ex-situ* composting treatments. Earthworm castings exhibited high electrical conductivity (Wang *et al.,* 2014) due to high concentration of base forming cations like Ca, N, P and K. The content of total carbon (%) in the resultant composts was significantly superior in *ex-situ* treatments. The carbon present in the compost is stabilized and comparatively resistant to microbial degradation (Juárez *et al.,* 2011). Hence the application of stabilized organic carbon via compost to soils adds to the recalcitrant pool of soil carbon.

Tolerance limit or sum of $N+P_2O_5+K_2O$ (%) in compost had a significant contribution to the compost quality as well as yield. The higher nutrient concentration in compost with high C (%) and moisture (%) bring about net mineralization in the soils applied with *ex-situ* compost.

The significance of *in-situ* composts is more due to high concentration of micronutrients. Since the soil is the largest reservoir of micronutrients, the composting brought out the mineralization of micronutrients in soluble form and made available to the plants.



S	Ex-C	Ex-P	Ex-E	In-P	In-E	In-C
Fe	pH	pH	pH	Zn	Zn	Zn
	EC	EC	EC	Fe	Fe	Fe
	TC	TC	TC	Mn	Mn	Mn
	$N + P_2O_5 + K_2O$	$N+P_2O_5+K_2O$	$N+P_2O_5+K_2O$	Cu	Cu	Cu
	Ca	Ca	Ca	Ni	Ca	Ca
	Zn	Zn	Zn		Ni	Ni
		MC (%)				

- pH
- Electrical conductivity (EC dSm^{-1})
- Total C (%)
- Sum of $N + P_2O_5 + K_2O$ (%)
- Total Ca (%)
- Total Zn (mg kg^{-1} of compost)
- Total Fe (mg kg^{-1} of compost)
- Total Cu (mg kg^{-1} of compost)
- Total Ni mg kg^{-1} of compost)
- Moisture content (MC %)

Figure 5.14. Factors contributing to the chemical composition and quality of composts prepared for the study

5.1.7. Biochemical components contributing to the yield and quality of composts prepared for the study

Auxin content of compost

Significant effect of both modes of composting and species of earthworms were brought out in the auxin content of composts. Higher auxin content was recorded in *ex-situ* treatments than *in-situ*. This is due to the microbial population in the microenvironment of the compost bed which is proved by the significant positive correlation between auxin and dehydrogenase activity (r = 0.81**). Auxin formation is purely a biotic reaction which is dependent on the substrate concentration, phenotypic characteristics of microbiota in the rhizosphere, fertility status and organic matter content of the soil (Sarwar *et al.,* 1992). Groenigen *et al.*, (2014) suggested that earthworms stimulate plant growth primarily through releasing nitrogen locked in the substrates and soil organic matter. This fact is well explained in the significant positive correlation with auxins and other parameters such as C (r = 0.67**) and N content (r = 0.69**) of the composts. The presence of heavy metals like Fe, Ni, Cu might have indirect inhibitory action on the auxin producing microbes which was evident in the significant negative correlation between the auxin content and heavy metals like Cu (r = 0.61**), Fe (r = 0.71**) and Ni (r = 0.59**).

Dehydrogenase activity of compost

Ex-situ vermicompost prepared using *Perionyx excavatus* in silpaulin vermibed recorded the highest dehydrogenase activity than *in-situ* treatments. The higher moisture content (83.33%), higher earthworm count (r = 0.79**) and huge volume of organic residues (400kg) in *ex-situ* vermibeds favoured the respiratory action of microorganisms and thus reflected in the dehydrogenase activity. The availability of partially decomposed organic residues rich in N (r = 0.70**), P (r = 0.64**) and K (r = 0.63**) in the vermibed might have significantly influenced the activity of respiratory dehydrogenases of the compost. Dehydrogenases are the respiratory enzymes which is an index of biological activity of the medium (Chhonkar *et al.*, 2007).

Total Microbial count

Viable bacterial cells of *ex-situ* compost was on par with *in-situ* vermicompost produced by *Eisenia foetida* (Figure 5.15). The increased action of microorganisms in the *ex-situ* compost was balanced by the combined action of earthworms and microbial activity in the *in-situ* vermicompost using *Eisenia foetida*. The microclimate inside the silpaulin vermibeds with ambient temperature and availability of easily decomposable substrates might have stimulated the decomposition reaction and population of bacteria. Bacterial population might have reappeared in the second mesophilic or cooling stage. Prevalence of bacterial population was reflected in the yield of compost. The earthworms casts rich in Ca might have a stimulatory effect on the bacterial population of the compost. The increased bacterial population in the fresh *Eisenia foetida* worked worm casts were reported by Emperor and Kumar, (2015).

Total fungal population was significantly higher in the *in-situ* treatments (Figure 5.16). The anterior gut of *Perionyx excavatus* was reported to harbour maximum fungal flora by Chowdhury *et al.*, (2007). The increased progression of fungal populations observed in the study suggest the development of specific fungal communities focused in the decomposition of more complex organic compounds like lignin, cellulose and hemicellulose found in the latter stages of residue decomposition (Guillou *et al.,* 2012). Moreover the hyphae and spore of most of the fungi were reported to serve as food for earthworms (Chowdhury *et al.*, 2007). The lower N content of the *in-situ* treatments accelerated the lignin degradation by fungi (Manna *et al.,* 2012) and thereby increasing the fungal population.

The total count of actinomycetes was higher in *ex-situ* vermicompost using *Eisenia foetida* (Ex-E) (Figure 5.17). The higher number of actinomycetes count was favoured by the high pH (8.22) in Ex-E. Actinomycetes colonize on natural polymers after the degradation of simpler compounds by bacteria and fungi (Manna *et al.,* 2012). The larger population of actinomycetes revealed the continuance of advanced stage of degradation of plant residues.

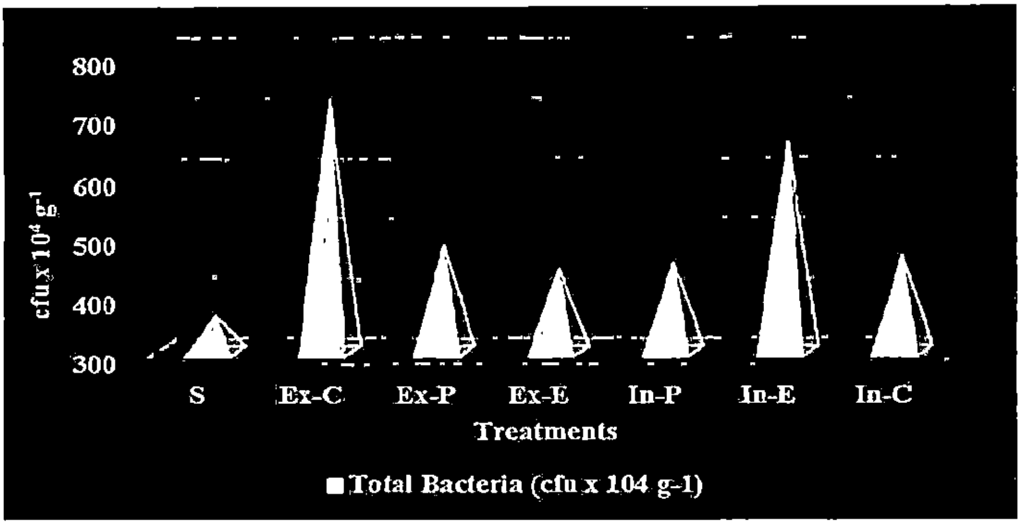


Figure 5.15. Effect of modes of composting and species of earthworms on the viable bacterial counts of composts

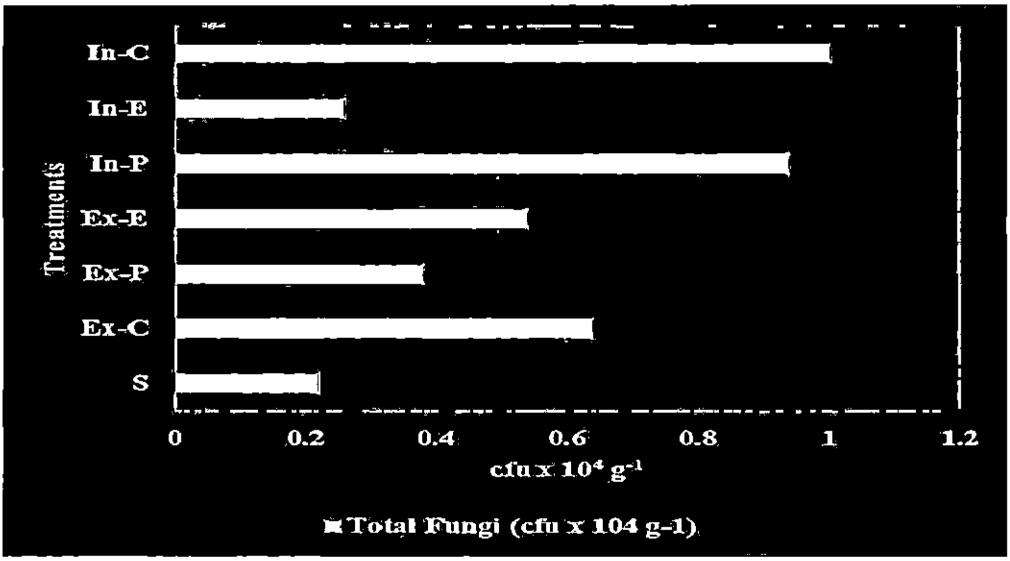


Figure 5.16. Effect of modes of composting and species of earthworms on the viable fungal counts of composts

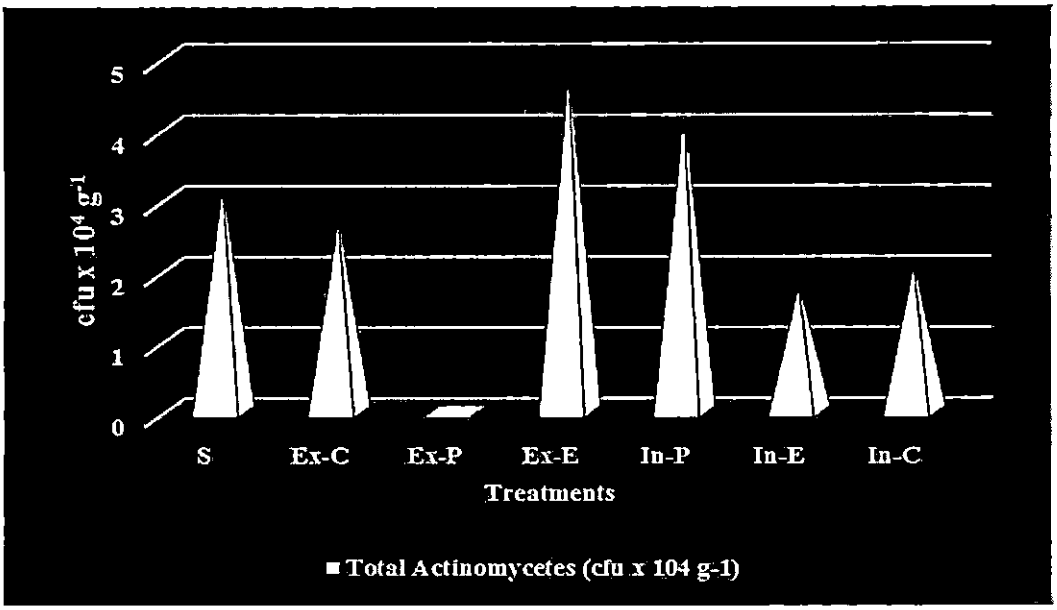


Figure 5.17. Effect of modes of composting and species of earthworms on the viable actinomycetes count of composts

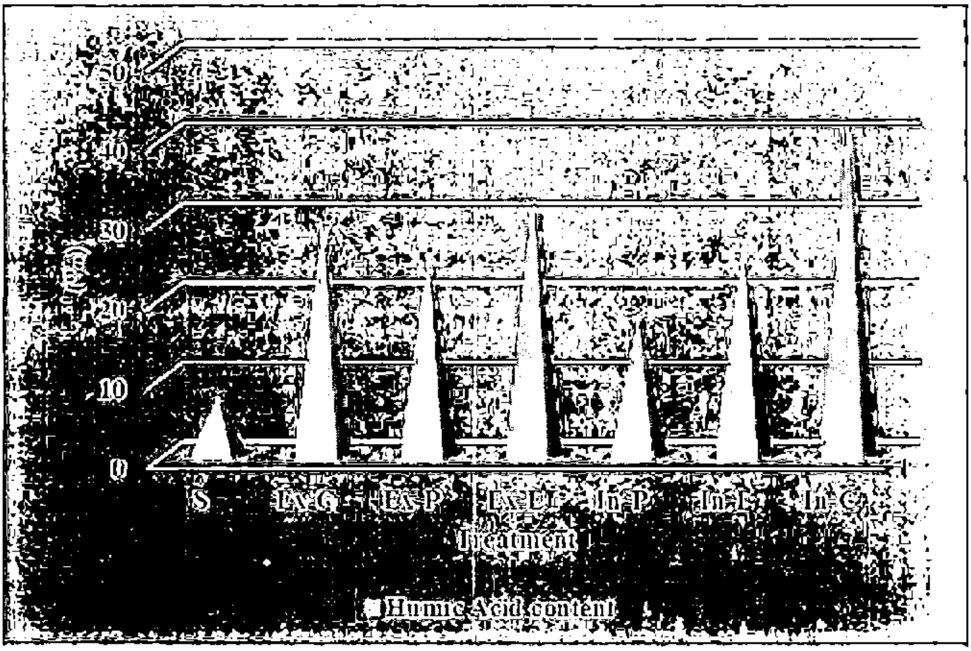
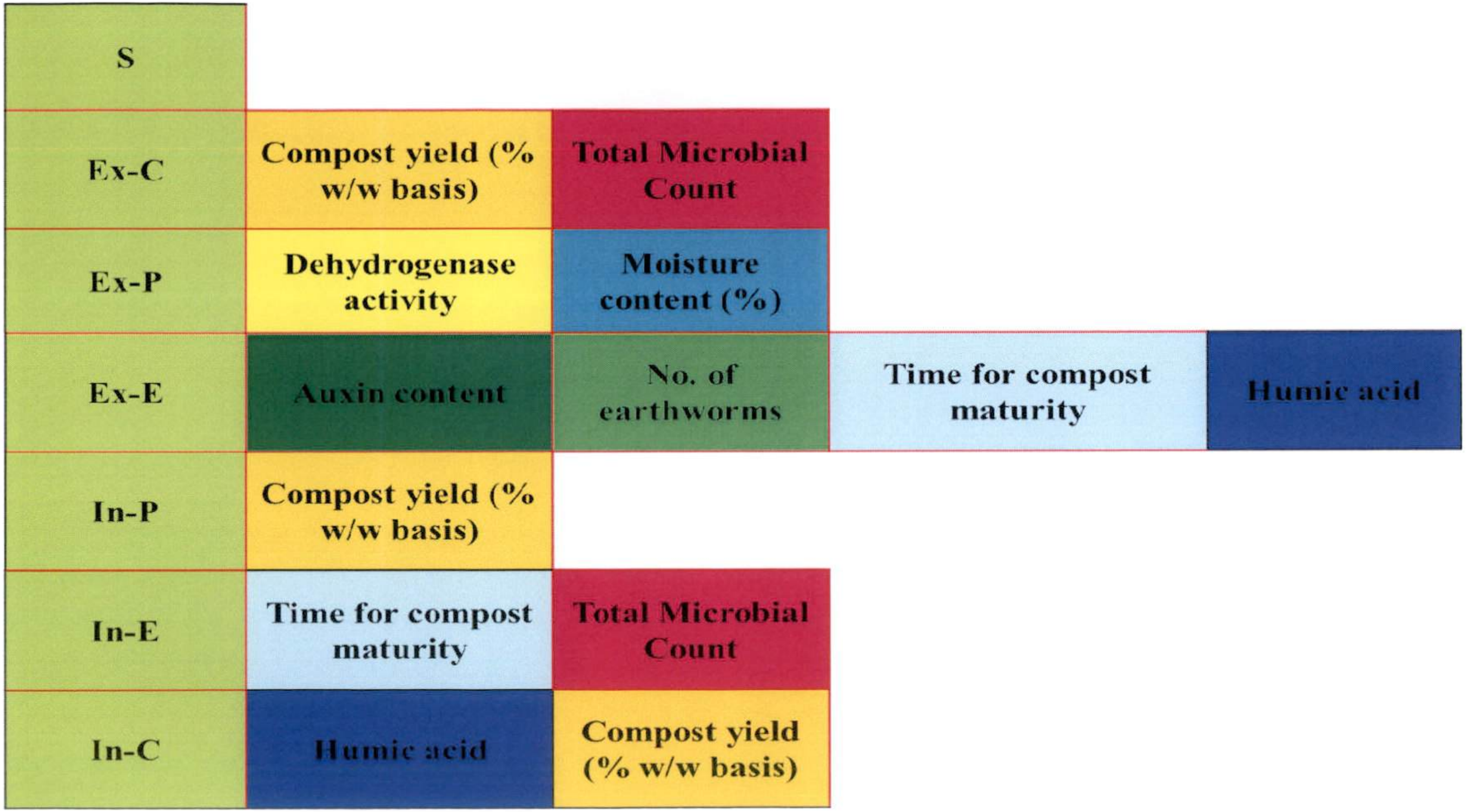


Figure 5.18. Effect of modes of composting and species of earthworms on the humic acid content of composts

Content of humic acid

Humic acid (%) content was higher in *in-situ* compost without earthworms which was on par with that of *ex-situ* vermicompost by exotic earthworm, *Eisenia foetida* (Figure 5.18). It is revealed that the humic acid prepared by *Eisenia foetida* was on par under both modes of composting. Exotic earthworms outperformed native earthworms under field conditions. The significant positive correlation obtained between humic acid content and pH (r = 0.55*), total C (r = 0.43*), total Ca (r = 0.54*), total Mg (r = 0.49*) and total Zn (r = 0.51*) revealed that these factors assisted in the quicker mineralization of organic residues by accelerating the microbial growth and earthworm activity.

Figure 5.19 revealed the various biochemical factors affecting the yield and quality of composts prepared for the study. Compost yield (%w/w basis) was higher for *ex-situ* compost than *in-situ* compost treatments. Under *ex-situ* compost, the higher microbial population caused an increase in compost yield (% w/w basis). Under *in-situ* vermicompost prepared using *Perionyx excavatus*, the high compost yield was contributed by the higher net individual weight gain and total biomass gain by indigenous *Perionyx excavatus* (Pattnaik and Reddy, 2010). Under *ex-situ* conditions, with high moisture content (>80%), *Perionyx excavatus* did not produce the desirable growth and multiplication (Parthasarathi, 2007). Hence the yield of compost was contributed by the dehydrogenase activity. Though the dehydrogenase activity was higher in *ex-situ* vermicompost prepared using *Perionyx excavatus*, the total microbial count was found to have no correlation with this biochemical factor. Earlier studies (Luo *et al.*, 2001; Bradford *et al.*, 2008) revealed microbial respiration can be partitioned into a series of carbon expenditures that do not contribute to microbial growth (Allison *et al.*, 2010; Wieder *et al.*, 2013). Each type of respiratory carbon expenditure may differ in its response to soil organic matter quality and availability. This differentiation can impact the dynamics of the microbial growth independent of enzyme concentration. The results of the present investigation confirm the above observations.



S				
Ex-C	Compost yield (% w/w basis)	Total Microbial Count		
Ex-P	Dehydrogenase activity	Moisture content (%)		
Ex-E	Auxin content	No. of earthworms	Time for compost maturity	Humic acid
In-P	Compost yield (% w/w basis)			
In-E	Time for compost maturity	Total Microbial Count		
In-C	Humic acid	Compost yield (% w/w basis)		

Figure 5.19. Biochemical factors affecting the yield and quality of composts prepared for the study

However, under *in-situ* compost treatment the possible mechanism for compost yield seems to be the increased content of humic acid formed due to the humifiction process by the microbial population acclimatized to that environment. The content of humic acid was significantly higher for *ex-situ* vermicompost prepared by *Eisenia foetida*. Under *ex-situ* vermicomposting by *Eisenia foetida*, the number of earthworms and high auxin content contributed to the production of humic acid content in the resultant compost (section 4.1.4). The higher number of earthworms contributed to the reduction in the time for temperature stabilization.

5.1.8. Interpretation of Fourier Transform Infra-Red spectra of humic acids prepared form different composts

The chemical composition of the humic acids was obtained through FTIR analysis. The presence or absence of spectral peaks for functional groups indicates the stabilization or degradation of the farm waste during bioconversion process. The humic acids from various treatments had indicated an aromatic poly-condensed structure. Humic acids from treatments Ex-C, Ex-P and In-P gave absorption bands at 2935 and 2860 cm^{-1} attributed to aliphatic methylene groups. Earlier studies have reported that aliphatic peaks are characteristic of composts and presence of these functional groups effectively keeps the soil organic matter in a labile state (Kaiser and Ellerbrock, 2005; Simon 2007).

A higher content of C=O groups (high intensity spectral bands at 1740 - 1690 cm^{-1}) was obtained in *in-situ* composting treatments (In-P to In-C) and *ex-situ* treatment (Ex-P and Ex-E). These results are in confirmation with the earlier studies (Gunzler and Bock., 1990; Ellerbrock *et al.*, 1999, 2001) that manure fertilization causes a higher content of C=O absorption bands than soils (control). Possibly the composting treatments Ex-E to In-C produces more stable organic matter which has undergone a rigorous humification process, since content of carboxylic groups is an indication of intensity of the humification process (Stott and Martin, 1990; Zsolnay, 1996). Also the higher C=O content would be expected to enhance the interaction of soil organic matter with predominant polyvalent cations such as Fe^{3+} and Mn^{4+} in laterite soils leading to the formation of organo-mineral complexes that stabilize organic manure (Stevenson, 1994) and eventually cause a slight enrichment of organic carbon in soils.

The FTIR spectra indicated the presence of large amounts of polysaccharides in the humic acids extracted from In-P, In-E and In-C. The polysaccharides in compost applied treatments are primarily of microbial and plant origin which can be either structural polysaccharides such as cellulose or storage polysaccharides like starch (Leifeld *et al.* 2002). The origin of the polysaccharides is from plant/ microbes in In-P, In-E and In-C and is confirmed from their absence in absolute control and *ex-situ* treatments like Ex-C, Ex-P and Ex-E. The enrichment of polysaccharides by way of treatments In-P, In-E and In-C can have multitude of effects on soil health by way of forming mineral organic complexes and reduced soil organic matter decomposition, non-nutritive compost carryover effects by enhancing soil-water retention as polysaccharide are strongly hydrophilic in nature and enhancing nutrient bio-availability by micronutrient complexing or microbial stimulation (Lowe, 1978; Ros *et al.*, 2006). The absorbance in the FTIR spectra of humic acids in the region 1170–950 cm^{-1} is assigned to C–O stretching of polysaccharides or polysaccharide-like substances, Si–O of silicate impurities, and clay minerals possibly in a complex with humic materials. Relatively higher intensities in this region for treatments In-P, In-E and In-C indicated higher polysaccharide like content in the humic materials produced. However, a similar higher intensity at 1038 cm^{-1} in absolute control was more possibly due to silicate impurities rather than polysaccharide content.

5.1.9. Interpretation of Scanning Electron Microscope (SEM) and Transmission Electron Microscope (TEM) images of humic acids prepared form different composts

The scanning electron microscope (SEM) images of various composts are given as Plate 5.1a and 5.1b. It revealed structure of humic acids produced under different modes of composting. Humic acids produced under different treatments varied in their structure. The most striking feature is the presence of neo-formed $CaCO_3$ crystals found enmeshed in the humic acids. The earthworms absorb Ca from the feed stock and transfer it to calciferous glands which have carbonic

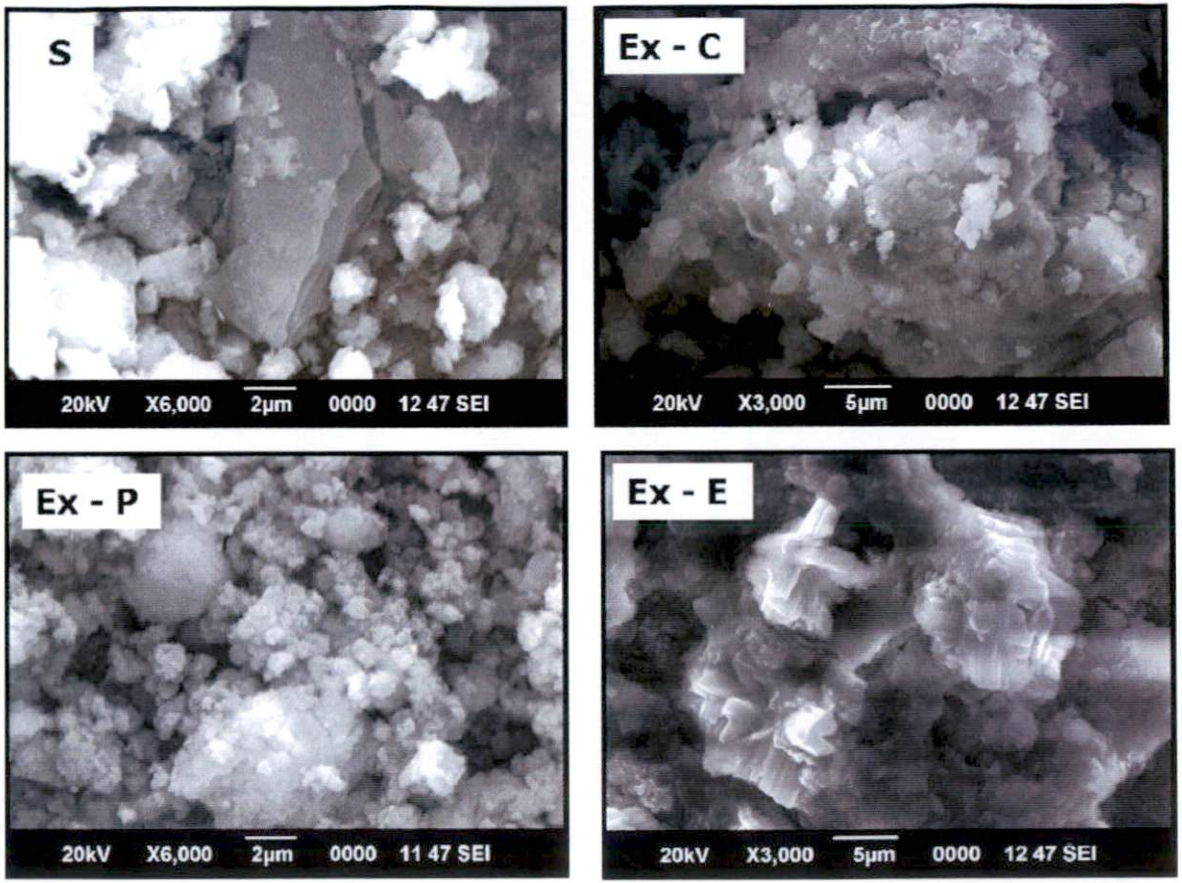


Plate 5.1a. Scanning Electron Microscope (SEM) images of humic acids derived from composts prepared *ex-situ*

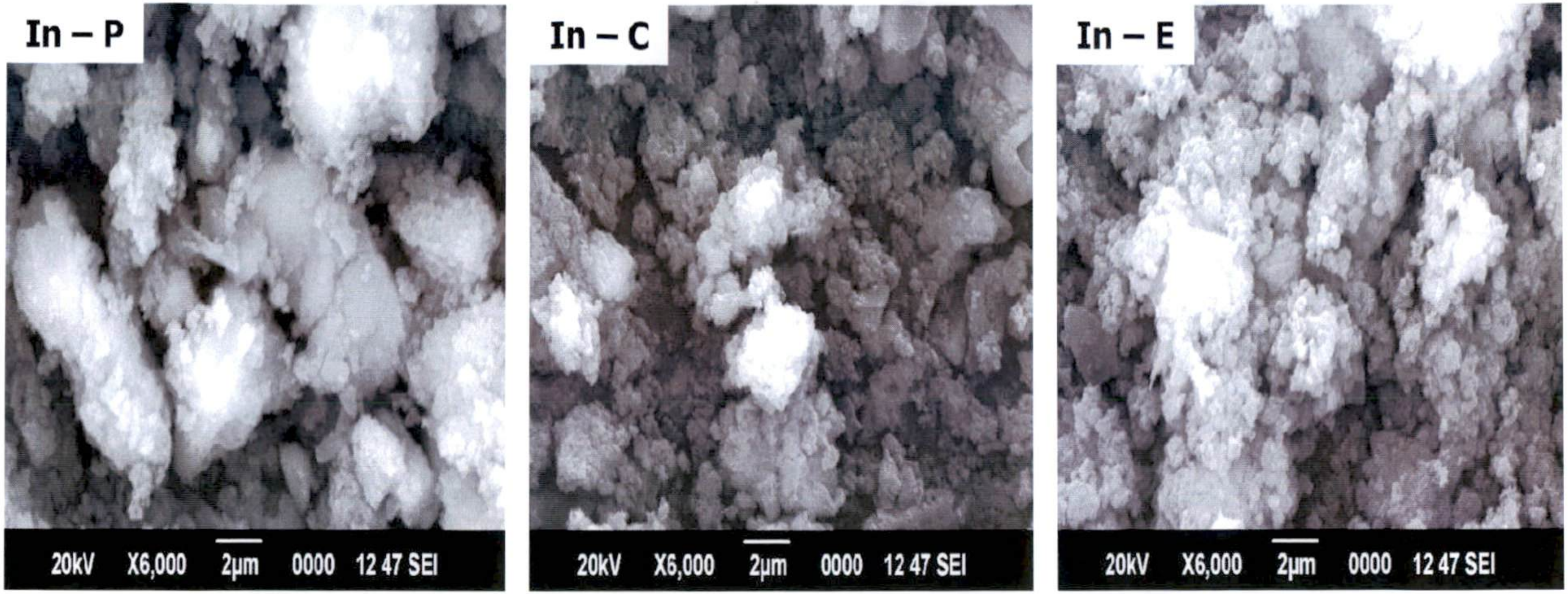


Plate 5.1b. Scanning Electron Microscope (SEM) images of humic acids derived from composts prepared *in-situ*

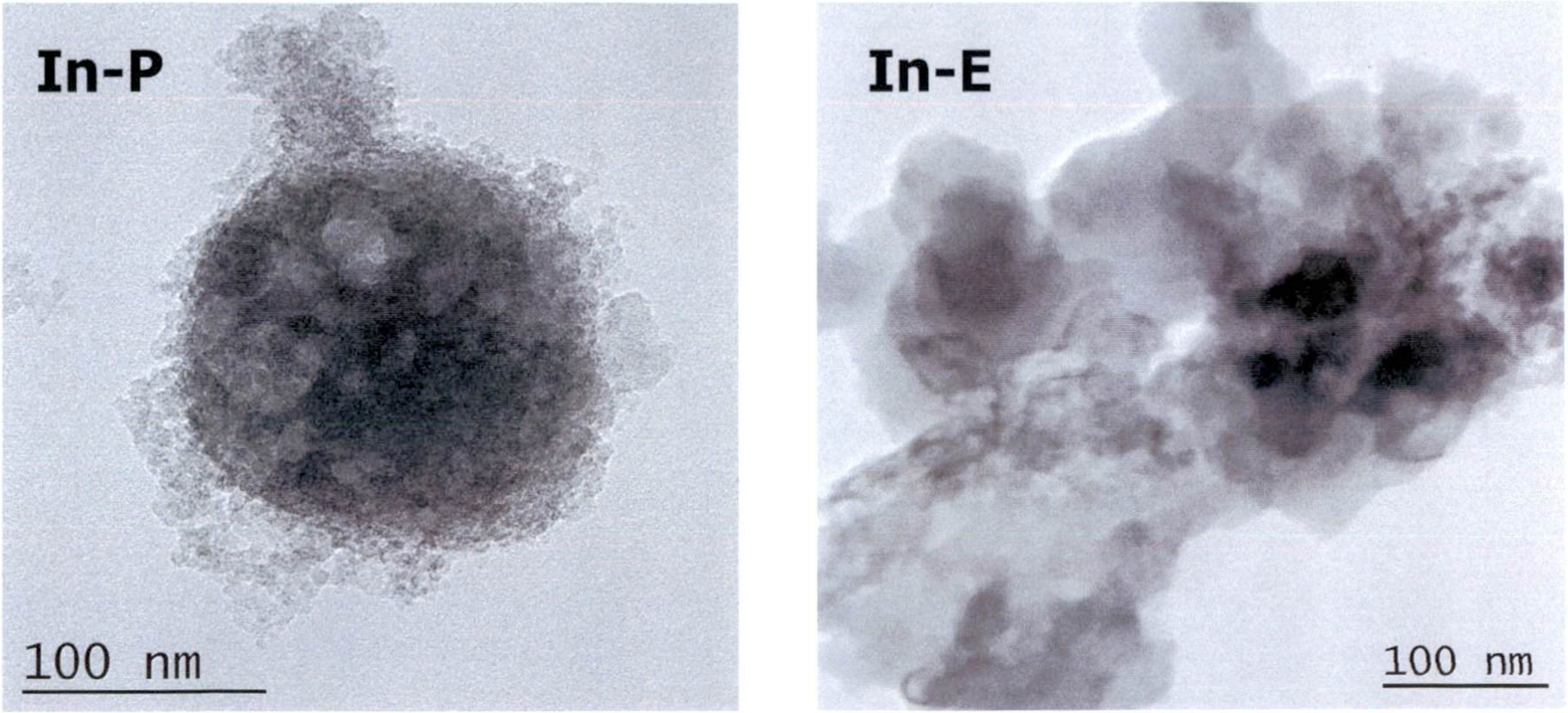


Plate 5.2. Transmission Electron Microscopy (TEM) images of humic acids from *in-situ* vermicompost prepared by *Perionyx excavatus* (In-P) and *in-situ* vermicompost prepared by *Eisenia foetida* (In–E)

anhydrase which catalyze the fixation of CO_2 as $CaCO_3$ (Padmavathiamma *et al.*, 2008). The humic acid particles produced by different earthworm species had variable sizes. The structure of humic acids produced by *Perionyx excavatus* was globular and that produced by *Eisenia foetida* was platy and small grained. Thorough disintegration and mineralization brought out by the *Eisenia foetida* was clear from this results.

The transmission electron microscopy (TEM) images of humic acids (Plate 5.3) derived from *Perionyx excavatus* and *Eisenia foetida* revealed that the structure of humic acids produced by *Perionyx excavatus* had a globular structure formed by hydrogen bond coiling. On the contrary, the presence of $CaCO_3$ in the humic acids caused alkalinity which causes de-protonation and reduction in H bonding. The combined action of $CaCO_3$ and coulombic repulsion caused the humic acid plates to attain a stable lamellar structure.

5.2. Effects of vermicomposting on crop of banana

5.2.1. Bunch yield of banana

Bunch yield was significantly affected by various treatments (Figure 5.20). Plants grown under POP recorded the highest bunch yield and the lowest was absolute control.

Being a heavy feeder of nutrients, a steady supply of nutrients right from planting to bunch maturity is essential to produce large and good quality bunches (Isaac and Podikunju, 2012). The split application of primary nutrients at critical growth stages ensured the balanced supply of nutrients for sustained growth and development of banana for plants grown under POP (Thangaselvabai *et al.*, 2009). All the composting treatments registered comparable yields under different modes of composting and species of earthworms. This may be due to the slow and gradual release of nutrients from the composting treatments (Khan and Ishaq, 2011). The efficient absorption and translocation of nutrients by the plants grown under different modes of nutrition was brought out in the present study.

The economic analysis in terms of benefit: cost ratio was found to be higher for composting treatments (Appendix 3).

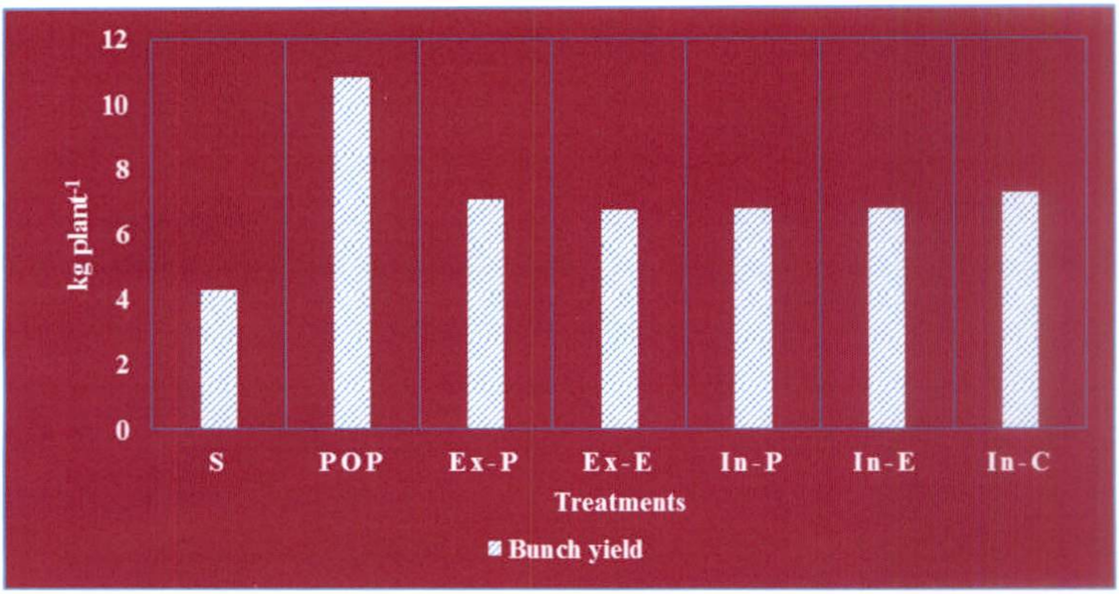


Figure 5.20. Effect of treatments on bunch yield of banana

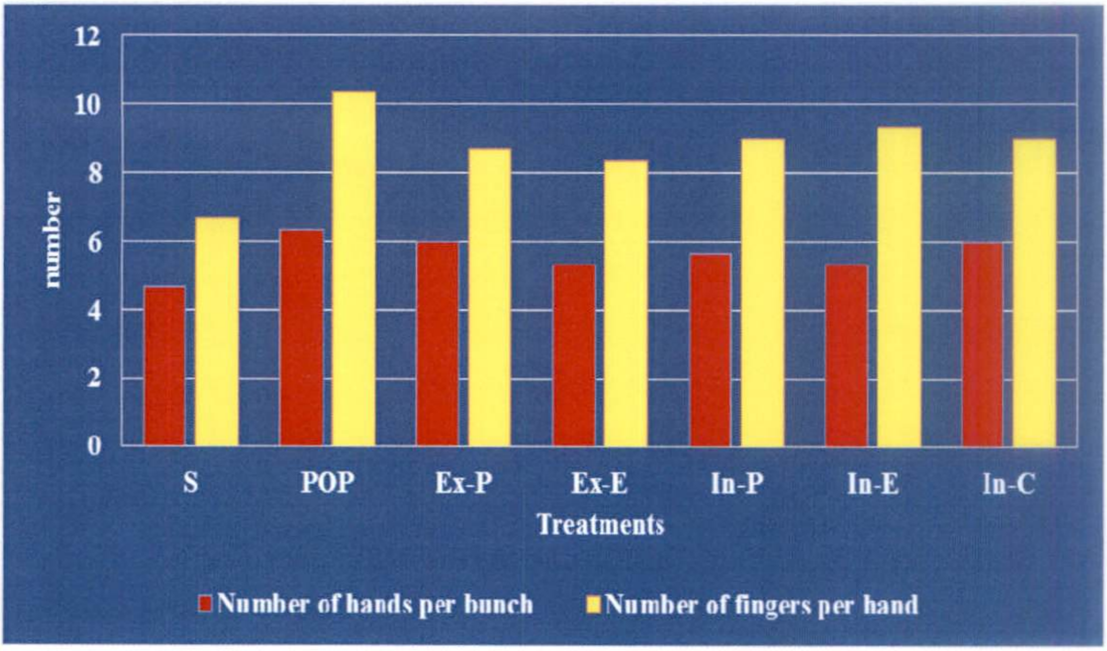


Figure 5.21. Effect of treatments on bunch characteristics of crop of banana

5.2.2. Effect of treatments on bunch characteristics of banana at harvest

The major bunch characteristics influencing the yield of banana are number of hands per bunch, number of fingers per hand and finally the weight of finger. On perusal of Figure 5. 21, it is clear that among the treatments, the highest number of hands per bunch and number of fingers per hand are recorded in plants that received recommended dose of fertilizers and FYM.

Different modes of composting had a significant and similar influence on the bunch characteristics of banana as that of POP. The number of hands per bunch and number of fingers per hand produced by plants receiving organic nutrition through *in-situ* vermicompost and *in-situ* compost were comparable to that of POP. This may be due to the sustained release of nutrients by the *in-situ* composting. This might have resulted in the increased dry matter of the fruit which ultimately contributed more number of hands per bunch and fingers per hand (Sreedevi and Suma, 2015).

Yield attributes like weight of finger varied significantly among the treatments (Figure 5.22). Plants that received recommended dose of fertilizers recorded the maximum weight of finger. The increased growth contributed by the quick release of nutrients from fertilizers contributed to the higher yield by POP treated plants (Al-Harthi and Al-Yahyai, 2009).

Plants receiving organic nutrition through *in-situ* vermicompost produced by native earthworms and *ex-situ* vermicompost produced by exotic earthworms were on par with POP with respect to the weight of fingers. The increased translocation of nutrients either by integrated nutrient management by POP or organic nutrition through composting techniques has ultimately resulted in the weight of fingers of the bunch.

5.2.3. Effect of treatments on growth characteristics of banana plants

The effect of different treatments on various growth characteristics of banana plants under study are discussed below. Growth and yield of banana plants are a function of number of functional leaves, girth and height of pseudostem, number of days to flowering and harvest (Robinson and Sauco, 2010). Functional leaves are the green leaves present from the appearance of inflorescence at the

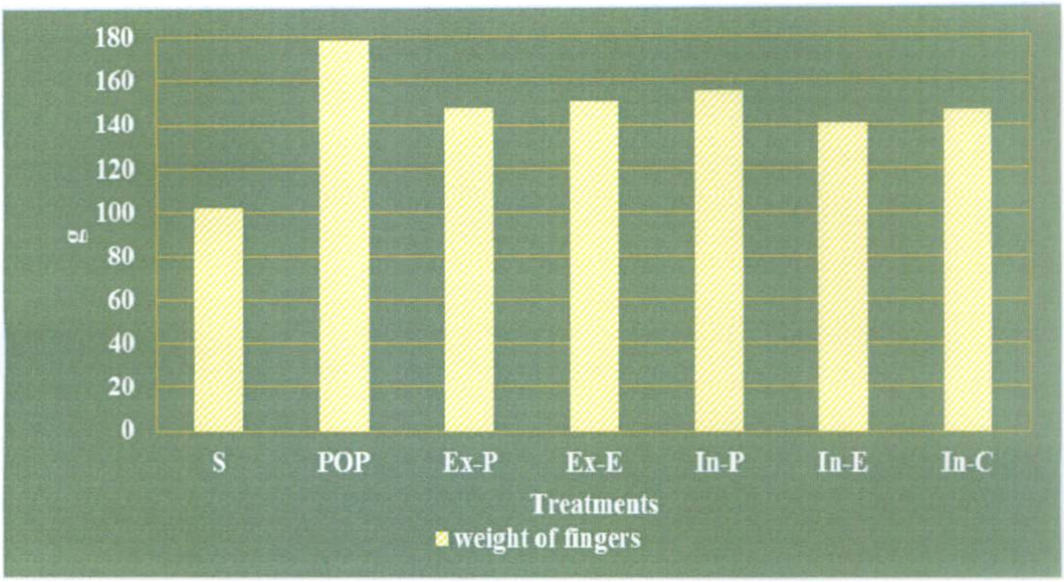


Figure 5.22. Effect of treatments on mean weight of one finger (g) of banana bunches

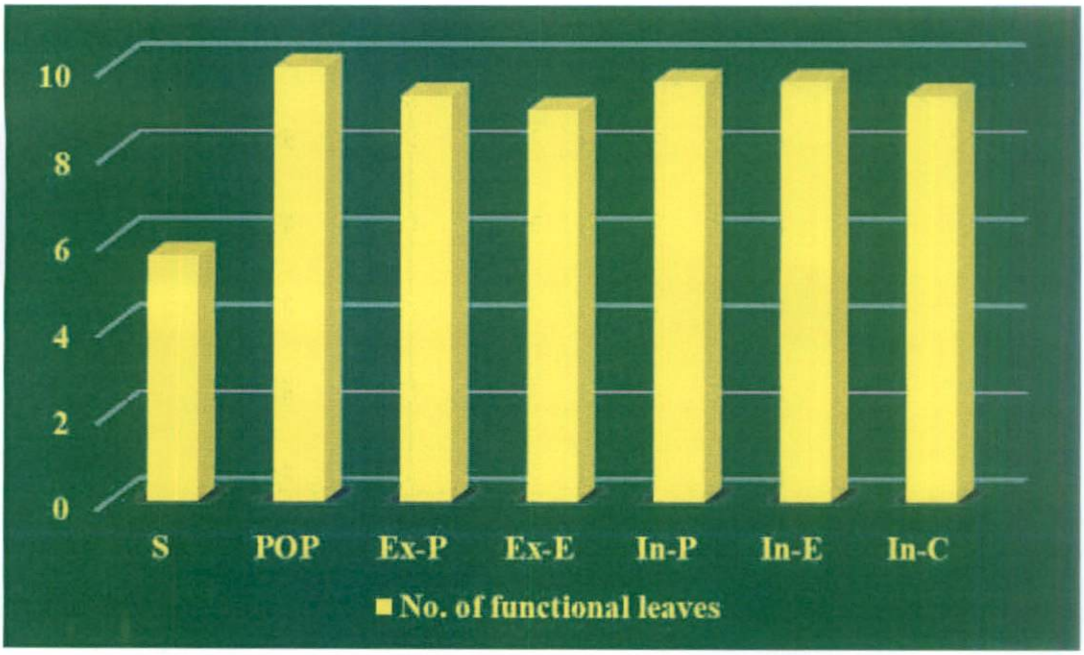


Figure 5.23. Effect of treatments on number of functional leaves of banana

apex of the pseudostem during fruit development (Gonzalez *et al*, 2012). The maximum number of functional leaves was recorded in plants treated with POP (Figure 5.23) which was on par with that of composting treatments except control. The growth stimulating effect of *Musa paradisica* vermicompost over chemical fertilizers on number of leaves of *Solanum lycopersicum* was reported by Achsah and Prabha (2013). The accumulation of dry matter in the bunch starts after flowering due to the supply of photoassimilates to the functional leaves and the mobilization of the previously accumulated reserves in the rhizome (Chaves *et al*., 2009). Plants grown under recommended dose of fertilizers recorded the highest pseudostem girth and height (Figure 5.24). The availability of all primary nutrients in easily available form might have helped in increasing the translocation of nutrients and thus towards the increased pseudostem girth (Rajput *et al.,* 2015).

However, all the composting treatments significantly influenced the growth of banana plants in terms of pseudostem girth and height. Vermicomposting treatments augmented the growth of banana plants. This may be attributed to the humic acids present in the composts which might have increased the number of lateral roots and thereby stimulated the nutrient uptake and plant development (Aremu *et al*., 2012). Vanilarasu and Balakrishnamurthy (2014) suggested the improved growth of plants grown under organic nutrition to the combined effect of various ingredients such as macro and micro nutrients, plant growth hormones (IAA, IBA and GA), vitamins and enzymes. The modes of nutrition had a significant influence on the flowering and total crop duration of banana plants. The largest interval for bunching as well as harvesting was taken by the plants grown without nutrition. The number of days to bunching and harvest were significantly higher in plants grown under control (Figure 5.25).

The plants grown under organic nutrition through composting under *in-situ* mode took significantly shorter duration for flowering than those grown under recommended dose of fertilizers. The earliness in bunching was more significant under organic nutrition of plants by way of *in-situ* composting. However the days to bunching for *in-situ* vermicomposting treatments were on par with that of *in-*

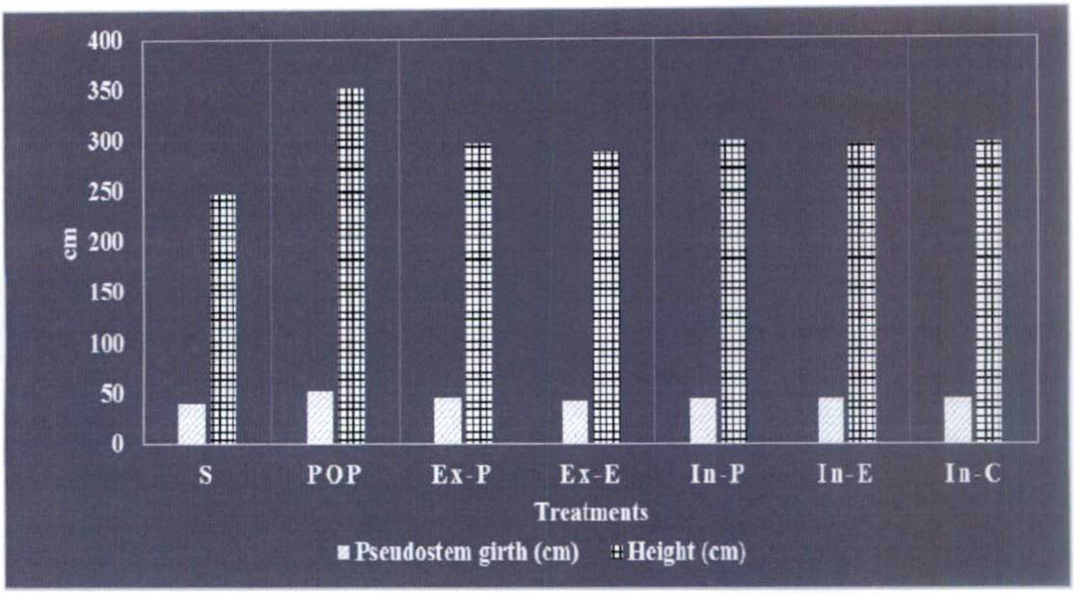


Figure 5.24. Effect of treatments on pseudostem girth and height of banana

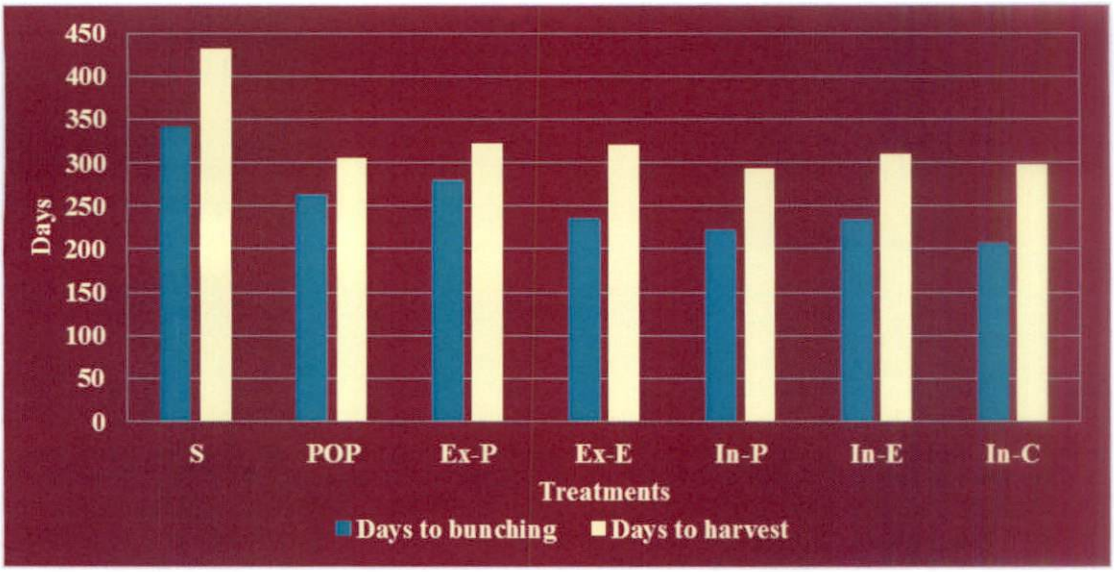


Figure 5.25. Effect of treatments on time taken for bunching and harvesting of banana

situ composting. Both modes of composting had a significant bearing on inducing the earliness in bunching in tissue culture *nendran* banana plants.

Combined action of plant growth regulator like activity and increased nitrate uptake (Trevisan *et al.,* 2010) of humic substances in compost enhanced the source-sink relationship and stimulated the translocation of photo-assimilates thereby helping in effective flower formation, fruit development and ultimately enhanced productivity of the crops (Zandonadi *et al.,* 2013). *In-situ* vermicomposting could be more promising due to enrichment of humic substances *in-situ,* which are more pertaining to that particular environment than those prepared outside the field (Masciandaro *et al.,* 2000)

5.2.4. Effect of treatments on foliar nutrient contents in index tissues of banana plants

Foliar analysis of index tissues were done to analyze the nutrient concentration of the plant at active growth stage. In banana, the petiole of the 3rd open leaf from apex at bud differentiation stage (Bhargava and Reddy, 1991) was analyzed. Details of analysis of index tissue of banana plants for N, P, K, Ca and Mg at four months after planting (MAP) are discussed below.

The treatment by way of recommended dose of fertilizers had significant effect on the N content of the plants at four month after planting (Figure 5.26). Recommended dose of urea (KAU, 2011) which is a quick nitrogen releaser in the available form (Gore and Sreenivasa, 2011) might have resulted in the highest N concentration in the index leaves of the same. In recording the N content in the index leaves, the composting treatments were found to be on par.

Organic manures on the other hand acts as a slow release fertilizer and hence could not supply nitrogen to the same extent as that of POP treatment (Sinha, 2009). Control plots having no such constraints could also supply enough nitrogen during the initial crop growth stages. Since N is required in large quantities by the plants during the initial stage, content of N was higher in all the plants (Thangaselvabai *et al.*, 2009).

The P content of the index tissues were significantly higher in plants receiving organic manures through *in-situ* and *ex-situ* composts (Figure 5.26).

Among the treatments, the best treatment was *ex-situ* vermicompost using *Perionyx excavatus* in enriching the plants with high P content. The humic substances produced by *Perionyx excavatus* had higher acidity which favoured its auxin like activity and promoted lateral root proliferation (Trevisan *et al*., 2010) favouring the absorption of P by the compost treated plants. The reasons for increased acidity in the particular treatments is already discussed in section 5.1.9. The lower content of P in the index leaves of banana grown under POP was due to the fixation of P with Ca as tricalcium phosphate which reduced the availability for plant absorption. The experiment was conducted in laterite soils which are typical acidic soils rich in iron oxides as discussed under section 4.1.3.3. with high degrees of crystallinity and high P-adsorption capacities. These factors might have contributed to the fixation of P in the soil and reduced P availability for plants grown under inorganic P fertilization. On the contrary, addition of organic manures substantially reduces the soil P-fixation in acid soils rich in sesquioxides due to the following reasons (i) the production of organic acids and dissolved organic matter also compete for P adsorption sites and repulse phosphates, thus reducing P adsorption sites (ii) organic manure combination with iron and aluminum oxides help to reduce the P-adsorption capacities of the oxides (iii) the soil enveloping effects of organic manures reduce P adsorption and (iv) increased availability and uptake of P due to organic manure promoted microbial and phosphatase enzyme activity (Shariatmadari *et al*., 2006; Hunt *et al*., 2007; Ma and Xu, 2010; Sabrina *et al*., 2013). The P solubilizers present in the vermicompost also render more P into solution by mineralizing organic P into soluble P (Kumari and Kumari, 2002).

The total K content was on par in plants grown under vermicomposting treatments (Figure 5.26). However, the K content of plants grown under composting treatments was on par with that of plants grown under recommended dose of fertilizers and FYM. Exotic and native earthworms were equally efficient in enriching the K content of the plants in the respective plots under silpaulin vermibeds. The earthworms increase the availability of K by shifting the equilibrium among the forms of K from unavailable to more labile forms (Kumari and Kumari, 2002). Since there is no leaching loss under *ex-situ* method of composting, there is more conservation of K in the compost which resulted in the higher K content of index leaves.

Calcium content in leaves was significantly influenced by the mode of nutrition. The highest calcium content was recorded in banana plants treated with *in-situ* vermicompost produced by exotic earthworms (Figure 5.26). The increased mobilization of immobile calcium to plant available forms during passage through the earthworm gut (Pathma and Sakthivel, 2012) was clearly revealed from the results. The *ex-situ* vermicompost prepared by earthworms irrespective of the species was found to be equivalent to *in-situ* compost in supplying calcium to banana plants. The significant role of organic amendments like vermicompost in enriching banana plants with calcium was also documented by Arancon and Edwards (2005).

Organic nutrition in the form of composting had a significant influence in the Mg content of plants. Plants grown under *in-situ* and *ex-situ* vermicompost by *Perionyx excavatus* were equally efficient in enriching the index tissues of plants with Mg content (Figure 5.26). Moreover, prepared vermicompost had considerable amount of secondary and micronutrients as detailed under section 4.1.3.2 and 4.1.3.3. Though the experimental soils are low (Sureshkumar and Sandeep, 2015) in the available Mg status (<120mg kg^{-1} of soil), the contents of Mg in the plants grown under the composting treatments are high due to the facts discussed above.

5.2.5. Effect of treatments on content of phytohormones at vegetative stage

Phytohormones are organic compounds that influence the growth of the plants at low concentration. The content and balance of major phytohormones drive the growth of plants. The concentration of phytohormones like auxins and gibberellins were analysed and the results are discussed in Figure 5.27.

Auxins are the first hormone discovered in plants and the most important morphogenetic compound which shapes the whole plant. Auxin signals trigger cell cycle and lateral root mitosis (Canellas and Olivares, 2014). The auxin concentration is regulated by the activity of indole acetic acid oxidase enzyme

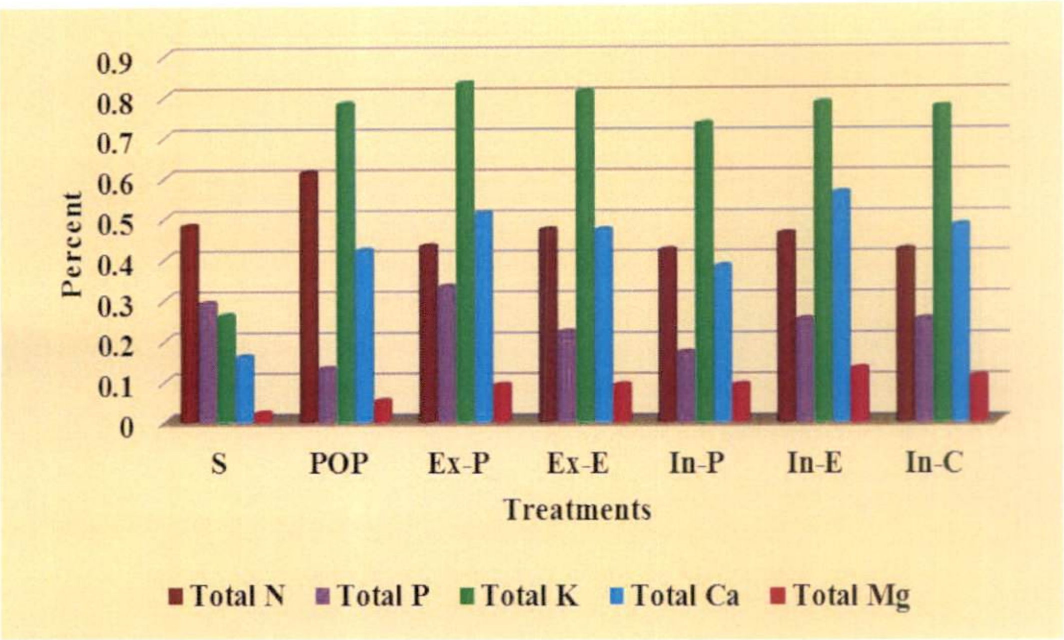


Figure 5.26. Effect of treatments on foliar N, P, K Ca and Mg contents (%) of banana at 4MAP

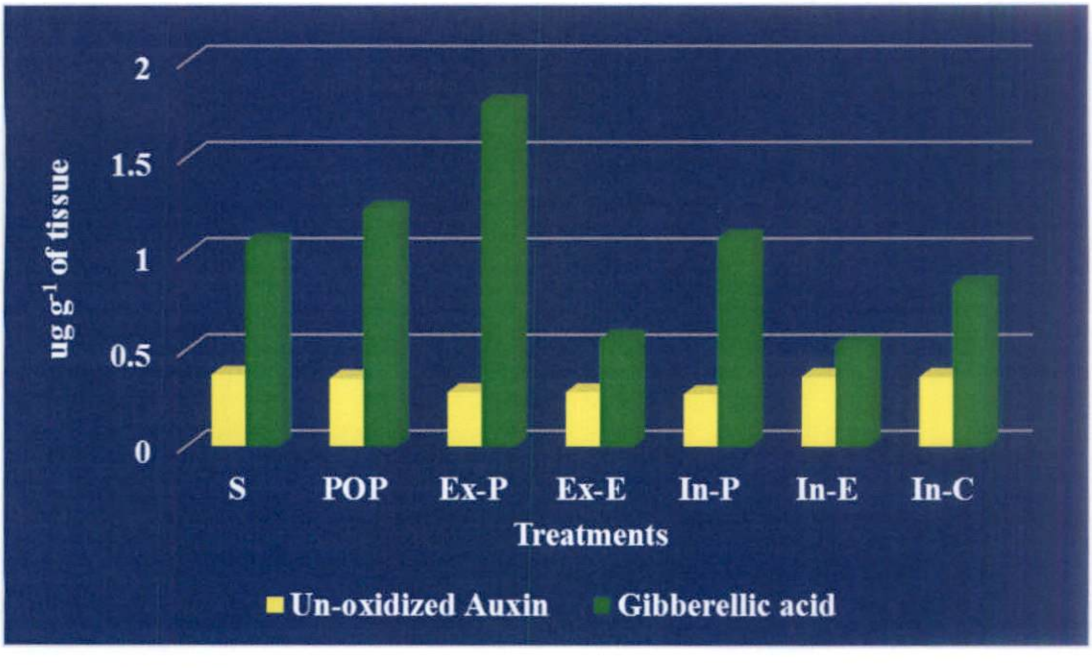


Figure 5.27. Effect of treatments on content of phytohormones at vegetative stage of banana

which degrade the excess auxins to oxindole-3-acetic acid which is inactive form of auxin. The activity of IAA oxidase should be low during vegetative stage for attaining good yields. Giberellins are the hormones responsible for cell elongation in plants and flowering (Jones and Kaufman, 1983).

The highest content of un-oxidized auxin was recorded in absolute control (Figure 5.27) which was on par with *in-situ* composting treatments. However, the un-oxidized auxin content was on par in *ex-situ* composting treatments. Vermicompost treated plants recorded lower concentration of un-oxidized auxins which may be due to sustained uptake of auxins from humic substances of vermicompost by the plants (Suthar, 2009; Atiyeh, *et al.*, 2002).

The content of gibberellins was found to be the highest in plants treated with vermicompost prepared using native earthworms and was on par with that of POP treated plants (Figure 5.27). The growth stimulating activity of vermicompost is due to presence of hormone like activity of humic acids from vermicompost or adsorption of plant growth hormones to humates of vermicompost (Atiyeh, *et al.*, 2002; Arancon *et al.,* 2005).

5.2.6. Effect of treatments on quality attributes of banana fruits

The quality attributes like vitamin C content, total sugars, reducing and non-reducing sugars and shelf life as influenced by different treatments are discussed below.

Significantly higher content of vitamin C was recorded in fruits from POP treated plots (Figure 5.28). All the composting treatments, except that produced by exotic earthworms under *ex-situ* conditions, show almost equal contents of vitamin C. Vitamin C levels in vegetables depend on several factors including cultivar, plant nutrition, production practice and maturity. High vitamin C content may serve as a protective strategy against drought injury. Higher rate of N fertilizers application are reported to decrease the vitamin C content in fruits (Lee and Kader, 2000). Therefore, from a nutritional point of view, horticultural crops grown under low nitrogen supply may be preferred due to high concentrations of vitamin C and low concentrations of nitrate (Lee and Kader, 2000). Though vermicomposts are equally effective in supplying the nutrients, most of the nutrients like nitrogen in the vermicomposts were bound to organic material which got released very slowly even at higher manurial levels (Hassan *et al.*, 2012).

The titratable acidity of fruits is a measure of the amount of acid present in a fruit (Appiah, 2011). Malic, citric and oxalic acids are known to be the major acids causing the acidity of fruits and during ripening the organic acids might undergo degradation due to respiratory mechanisms (Zomo *et al.,* 2014). The lowest acidity was recorded in fruits of plants that received nutrition through vermicompost and compost (Figure 5.29). However a significant reduction, though not up to the extent of organic treatments, was recorded in plants that received recommended dose of fertilizers. During ripening, a slow decrease in acidity of fruits leading to reduction in the sourness with a concomitant increase in the sugar content was reported by Appiah (2011). The decline in acidity during ripening imparted flavour to the fruit (Zomo *et al.*, 2014). The higher acidity of the plants grown under recommended dose of fertilizers was due to the high acid content of chemical fertilizers (Sreedevi and Suma, 2015).

Shelf life of banana fruits was significantly affected by various treatments (Figure 5.30). Plants which received recommended dose of fertilizers and FYM recorded the longest shelf life in days. However there was no significant difference in shelf life between the plants that received POP and vermicompost. Shelf life of banana is influenced directly by the pre-harvest nutritional status of the fruits. The extended shelf life observed for the plants grown under POP in the present study might be due to reduced weight and respiration losses. However the shelf life of plants grown organically was equal to that grown under inorganic fertilizers.

The content of total sugars, reducing and non-reducing sugars are depicted in Figure 5.31. The highest content of total sugars was recorded in plants grown under vermicompost prepared in banana planting pits using *Eisenia foetida* and was on par with *in-situ* compost. During ripening, the concentration of total sugars increases due to hydrolysis of stored starch and accumulation of sugars. The increased sugar content in vermicompost treated plants proved the direct effect of

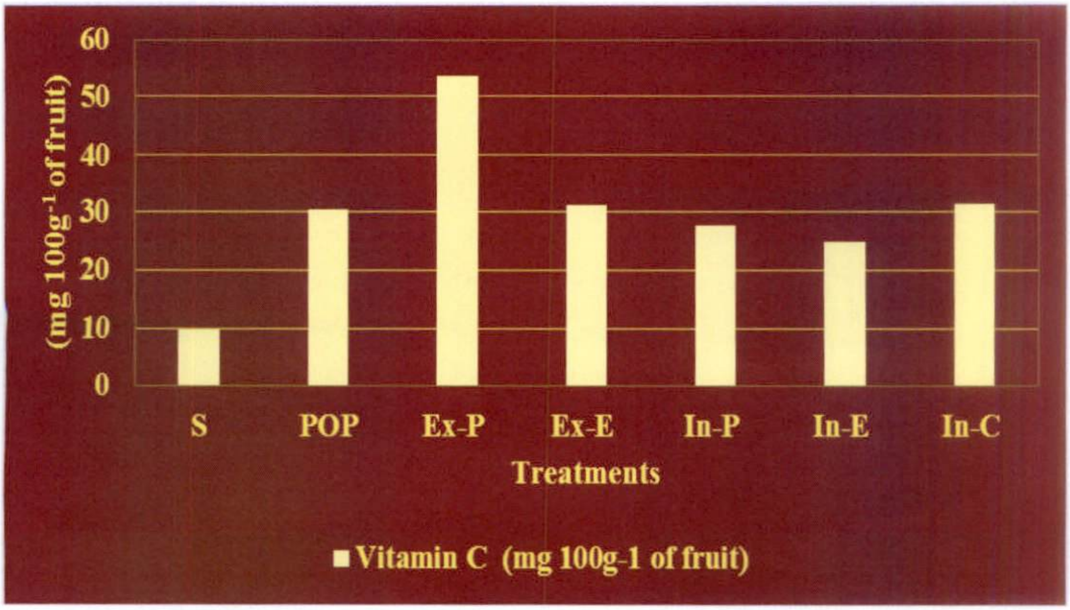


Figure 5.28. Effect of treatments on vitamin C content of banana fruit

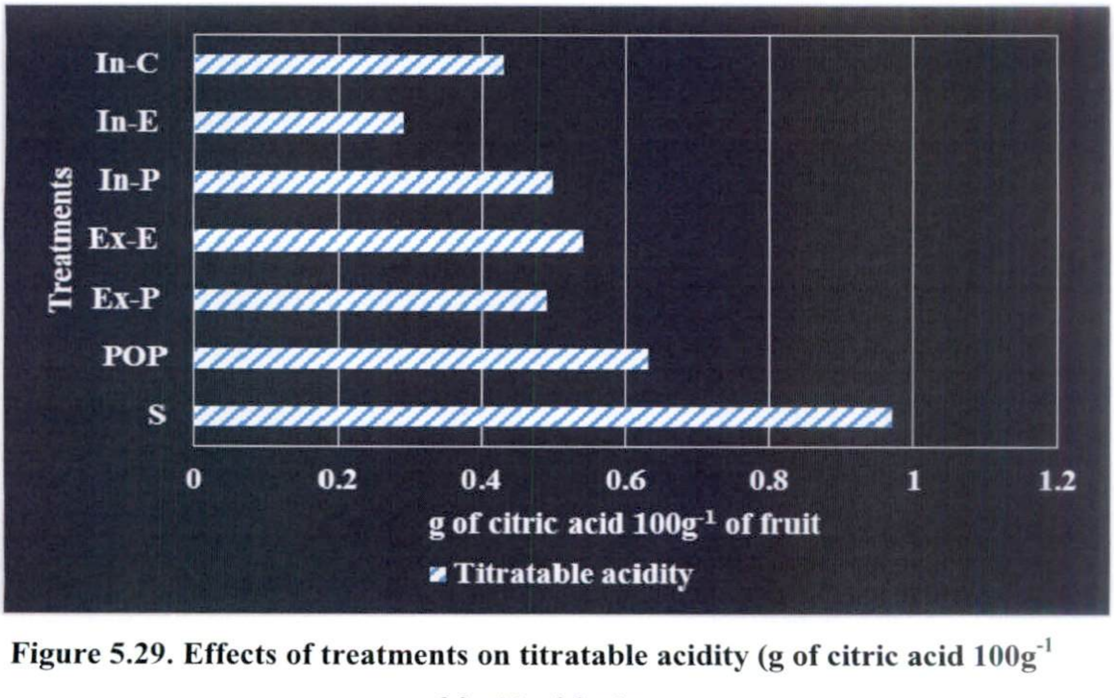


Figure 5.29. Effects of treatments on titratable acidity (g of citric acid $100g^{-1}$ of fruit) of fruits

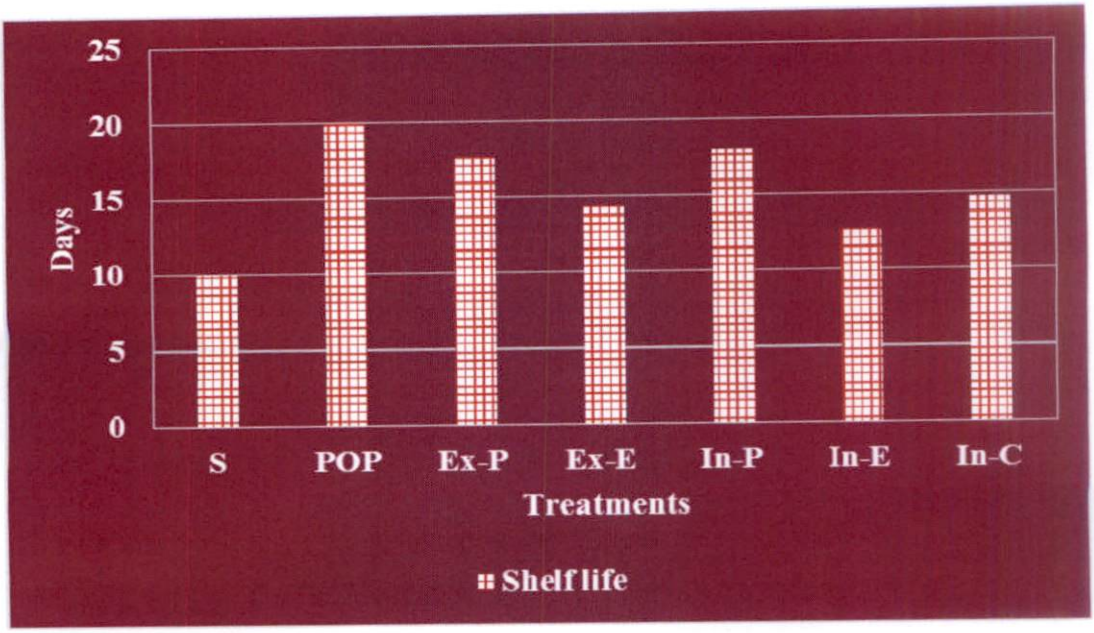


Figure 5.30. Effects of treatments on shelf life of banana fruits

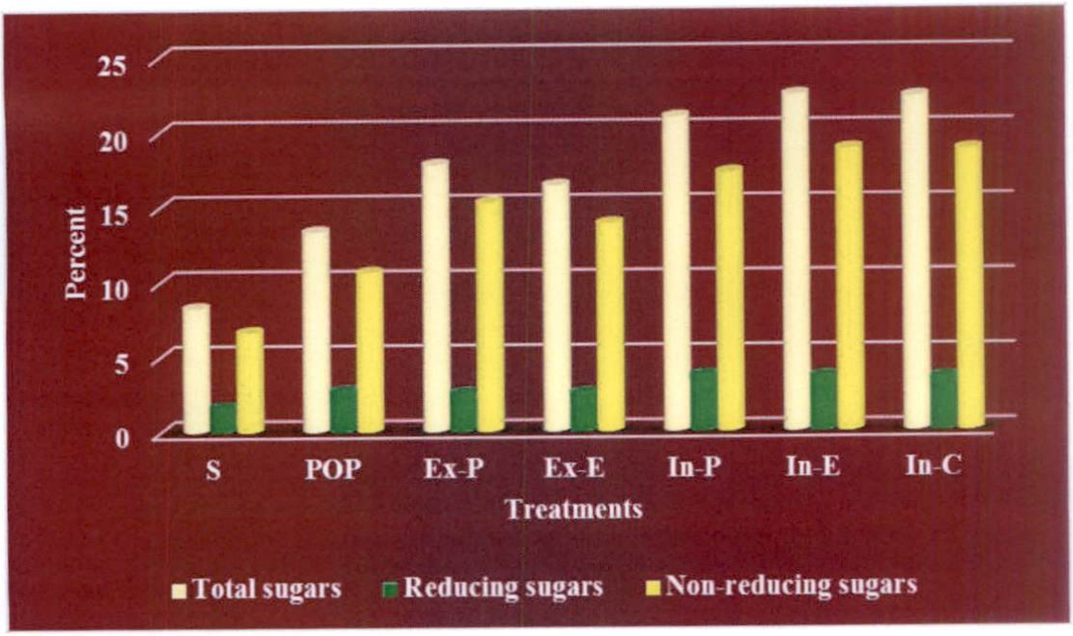


Figure 5.31. Effect of treatments on content of total sugars, reducing sugars and non-reducing sugars (%) of ripened banana fruits

availability of vital nutrients and indirect effect of sustained release of growth hormones and vitamins (Butani and Chovatia, 2014).

Content of reducing sugars were on par in vermicompost and compost prepared *in-situ* irrespective of the earthworm species. The content of reducing and non-reducing sugars were significantly higher in vermicompost treated plants. As discussed in section 4.1.5, *in-situ* composting process always favoured formation of humic acids rich in polysaccharides, which might have resulted in the translocation of assimilates.

5.2.7. Effects of treatments on sensory characteristics of banana

The statistical significance of sensory evaluation of fruits from different treatments revealed that there were significant differences in colour, taste, texture, appearance, sweetness and overall acceptability of fruits except flavour (Figure 5.32). Among the treatments, the fruits from POP treated plants were significantly superior in all the parameters. Plants grown under composting treatments under *in-situ* mode was on par with that of plants grown under POP with respect to taste, texture, appearance and sweetness.

However, owing to the larger size of fingers and lush yellow appearance, the maximum score for overall acceptability was awarded for ripened fruits grown under recommended dose of fertilizers. The overall acceptability of *in-situ* and *ex-situ* composting treatments were on par among themselves. The modes of composting and species of earthworms had significant influence on the overall acceptability of banana fruits grown under different nutrient managements. Compost or vermicompost prepared *in-situ* in banana planting pit indeed enrich the planting sites with sustained supply of nutrients (more or less similar to inorganic fertilizers) as well as vitamins and plant growth hormones which might have influenced the overall sensory, growth and quality of banana fruits.

5.2.8. Effect of treatments on elemental composition of fruit

The effects of treatments on content of C, N, P, K, Ca and Mg of fruits harvested are discussed below. Among the treatments, the highest content of C was recorded from plants which received POP and by those that received *in-situ* vermicompost prepared by native earthworms. The increased translocation of

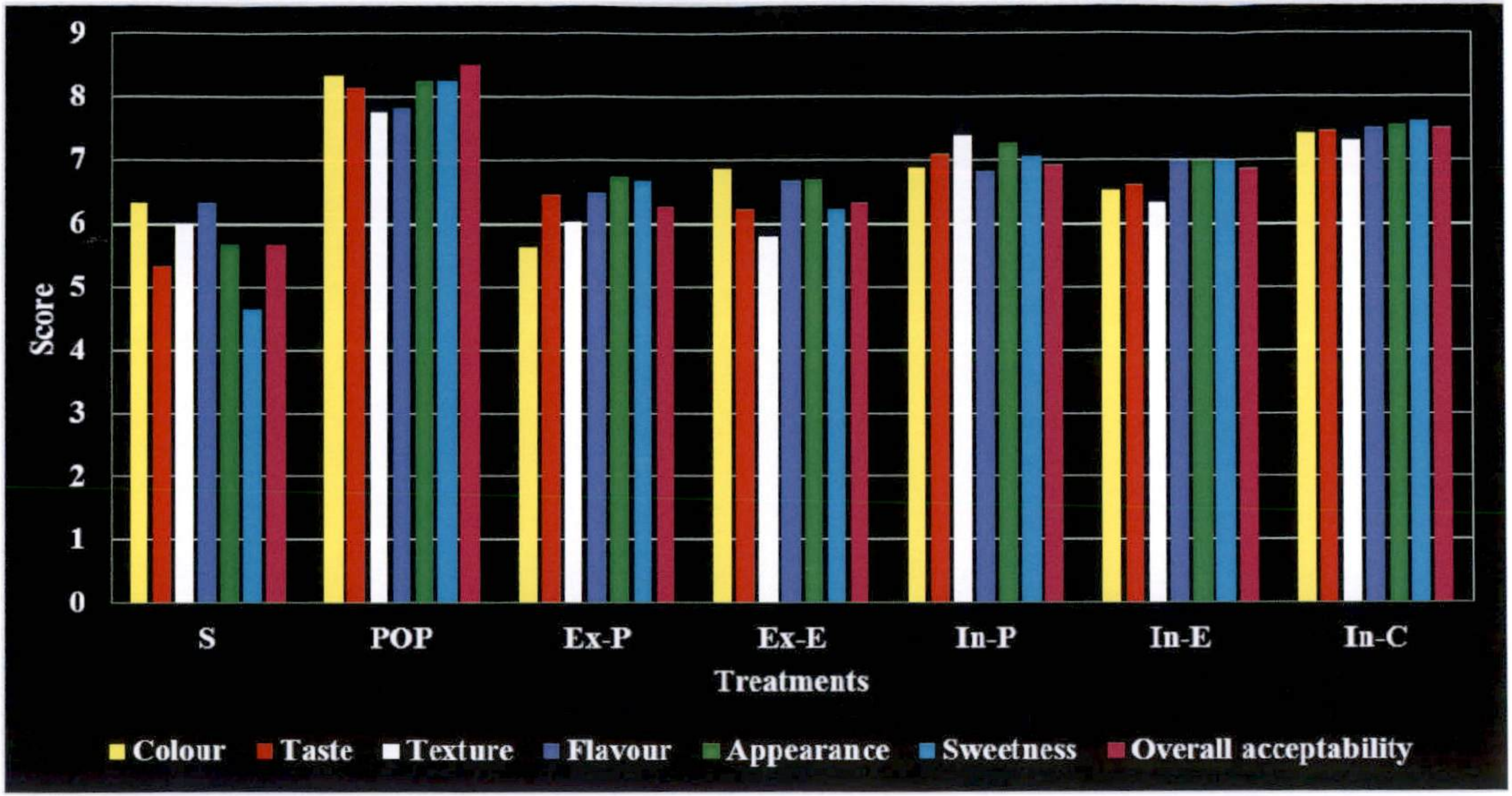


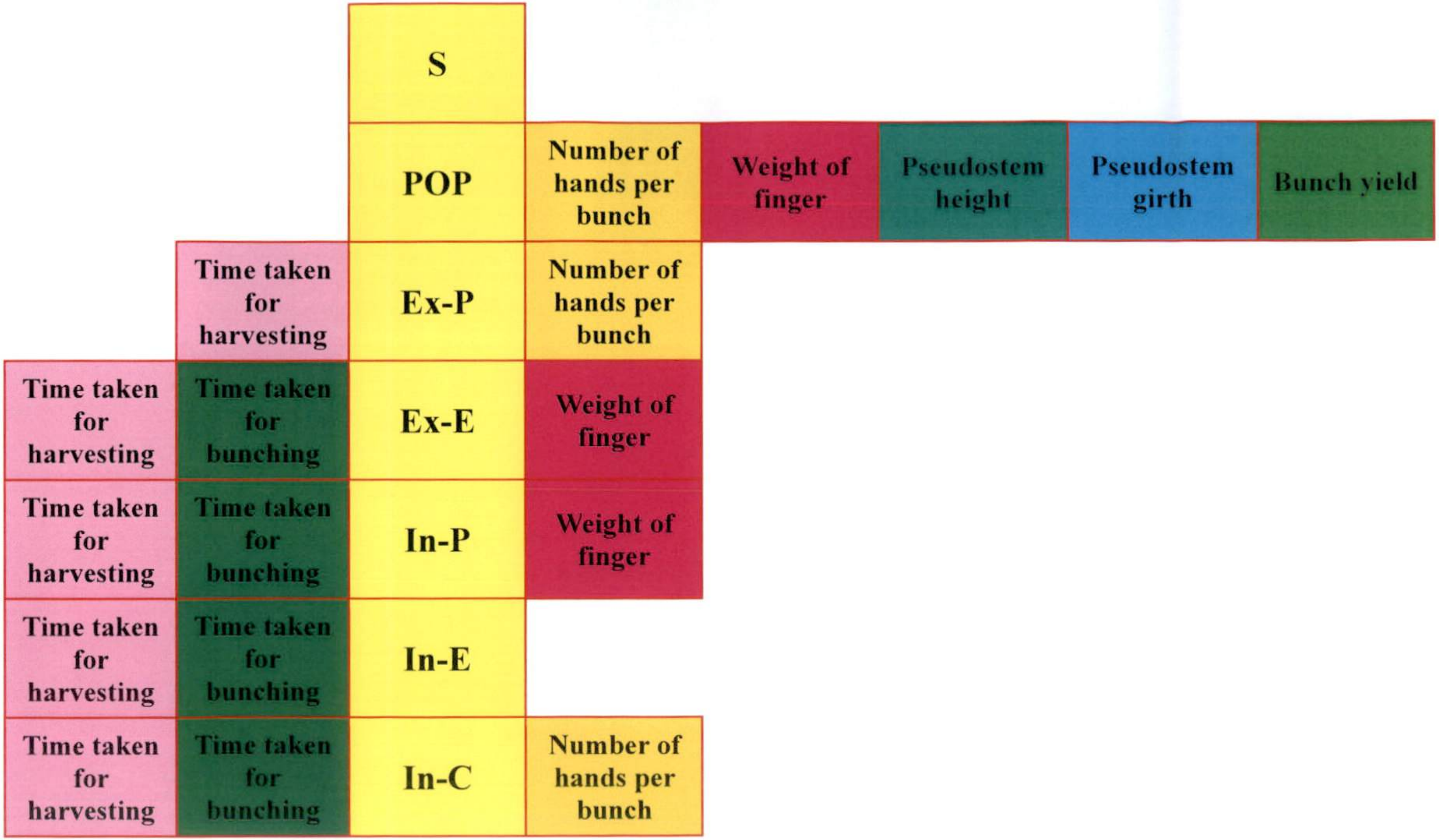
Figure 5.32. Effect of treatments on sensory characteristics of banana fruits

photosynthates to the sink under conjunctive application of inorganic fertilizers with FYM and vermicompost was proved from this study. This fact is again proved by the higher number of functional leaves and weight of finger obtained from those plants receiving recommended dose of fertilizers and FYM and vemicompost.

The content of P, K, Ca and Mg was significantly higher in fruits of plants that received native earthworm worked *ex-situ* vermicompost prepared in silpaulin vermibeds. However the P, K, Ca and Mg content of fruits were significantly higher in the *in-situ* compost treated plots. The presence of earthworm worked humic substances in the rhizosphere soils might have stimulated the proliferation of lateral roots and thereby increased the uptake and translocation of nutrients to fruits (Trevisan *et al.,* 2010). This interaction of humic substances with nutrients is more intense when they are present at low concentration (Vaughan and Malcolm, 1985). Uptake of nutrients by banana plants increases steadily throughout the life of the plant which got translocated to fruits during reproductive phase (Thangaselvabai *et al.,* 2009). The slow release coupled with constant uptake of nutrients had a stimulatory effect on the content of nutrients in the fruits received organic nutrition through vermicomposting. Herder *et al* (2010) stated that root architecture and nutrient uptake is directly affected by humus, improving plant yield. Undeniably, composts and vermicomposts from agricultural wastes have proved to be influential sources of natural organic fertilizers (Busato *et al.* 2012) with biological properties affecting plant physiology unlike in mineral fertilizers (Zandonadi and Busato, 2012). Significantly higher Ca content in fruits was recorded from plants receiving exotic earthworm worked vermicompost as discussed under section 5.1.5.

5.2.9. Factors contributing to the yield of banana

Figure 5.33 shows the factors contributing to the yield of banana plants grown under different modes of nutrition. An attempt to generalize the yield contributing characters on the basis of their significance with supporting correlation data are discussed hereunder. In general, it is concluded from the study that the effect of various modes of nutrition had significant influence on the yield



		S					
		POP	Number of hands per bunch	Weight of finger	Pseudostem height	Pseudostem girth	Bunch yield
	Time taken for harvesting	Ex-P	Number of hands per bunch				
Time taken for harvesting	Time taken for bunching	Ex-E	Weight of finger				
Time taken for harvesting	Time taken for bunching	In-P	Weight of finger				
Time taken for harvesting	Time taken for bunching	In-E					
Time taken for harvesting	Time taken for bunching	In-C	Number of hands per bunch				

Figure 5.33. Factors contributing to the yield of banana

of banana which was mediated mainly through the bunch and growth characteristics like number of hands per bunch, number of fingers per hand, weight of fingers and number of functional leaves. This was proved by the significant positive correlation obtained for yield of plants with weight of finger (r=0.88**), pseudostem girth (r=0.82**), number of fingers per hand (r=0.75**), number of functional leaves (r=0.74**), number of hands per bunch (r=0.70**) and pseudostem height (r=0.64**) (Appendix 4). In the POP treatment, the effect of pseudostem height and girth was significantly pronounced than the other treatments. This might be due to the combined application of N and K through high analysis fertilizers in the available form which is proved from the positive correlation established for pseudostem height and girth with foliar N (r=0.47* and 0.56**) and K (r=0.53*; 0.52*). Potassium is the key element in banana nutrition. The contribution of N and K to the dry matter production and ultimately to the yield and quality of banana was elaborately discussed in Ganeshmurthy *et al* (2011). The application of lime to correct the pH of the rhizosphere in the POP treatment might have solubilized the nutrients to the soil solution for plant uptake. The contribution from compost was found to be as effective as POP towards increasing the weight of fingers of banana plants. This may be due to the enhanced microbial activity leading to increased nutrient transformations in the soils receiving compost treatments. Further, studies (Zandonadi *et al.*, 2013) have established that compost treated soils have a capacity to modify the root morphology by gene modification thereby improving its nutrient uptake efficiency.

Soils fertilized with POP, receives a high concentration of nitrogen during the active growth stages which extends the vegetative phase, hence a delayed flowering and harvest. Nitrogen increases chlorophyll production by creating bigger leaf structures with larger surface areas for the photosynthesizing pigment. Excess nitrogen fuels fast foliage growth so that energy for flower growth is redirected to foliage proliferation leading to delayed development of necessary reproductive organs. Organic manures on the other hand, prevent an excessive nitrogen influx at any point of time thereby promoting the growth and reproductive phases to take its natural cycles.

5.2.10. Factors contributing to quality of banana fruits

According to Kramer (1965) quality of foods may be defined "as the composite of those characteristics that differentiate individual units of a product, and have significance in determining the degree of acceptability of that unit to the user". In reference to fruits and vegetables, the characteristics that impart distinctive quality may be described by four different attributes: 1) colour and appearance, 2) flavour (taste and aroma), 3) texture and 4) nutritional value (Barret *et al.*, 2010). In the present study, the sensory parameters in terms of overall acceptability were more significant in POP treated plants. However, both mineral and organic modes of nutrition had a more or less similar influence on the vitamin C content and shelf life of fruits. The titratable acidity was more pronounced under inorganic mode of nutrition whereas the sugar content of the fruits had superiority under *in-situ* mode of composting. The return of residues to soil as compost enriched the site with more biological activity, increased the growth and plant performances and ultimately enhanced yield and quality of crops (Figure 5.34).

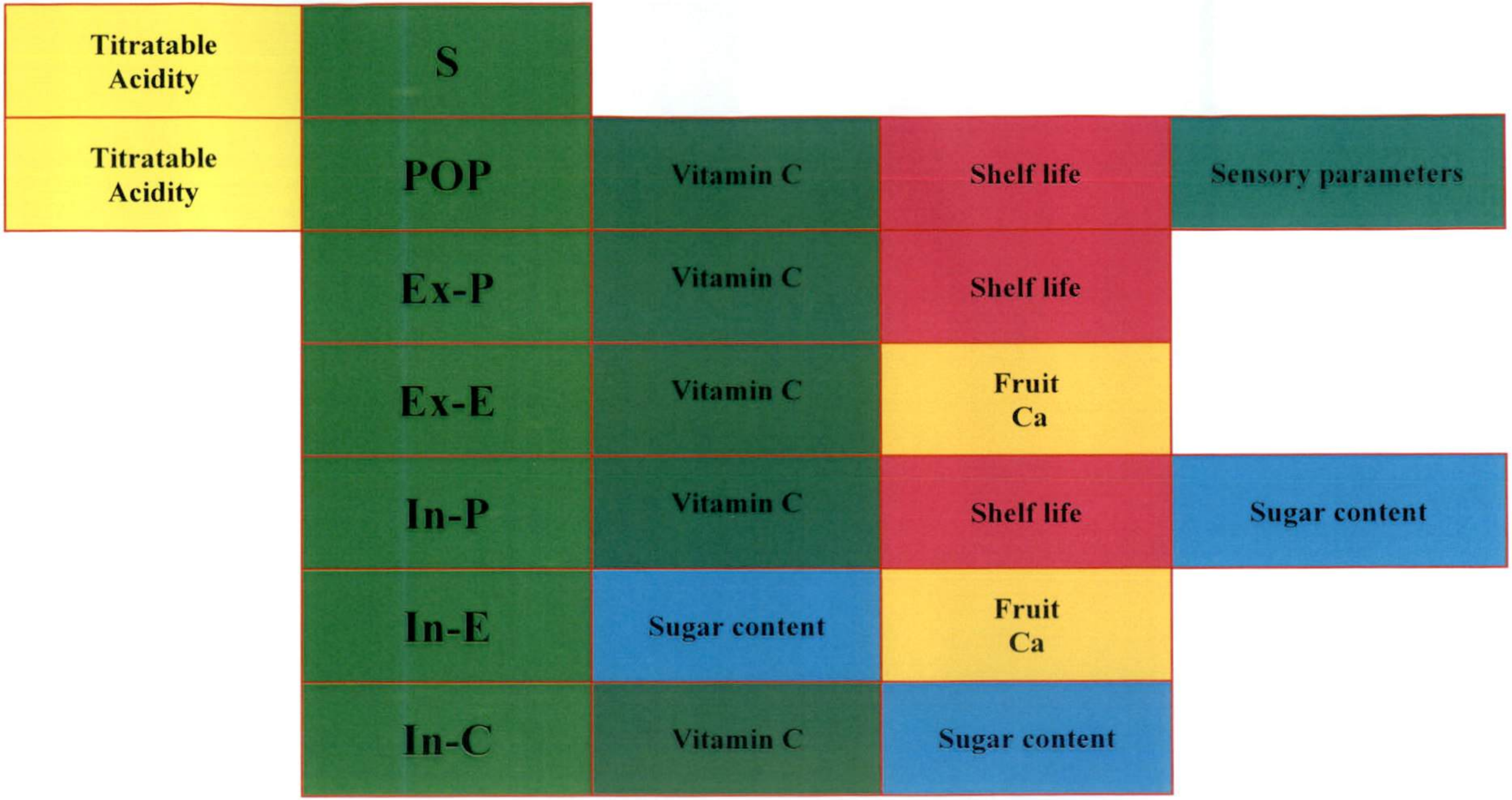
5.3.1. Pre and post experimental analysis of soil under study

Characterization of experimental soil

Representative soil samples at 0-30 cm depth was collected from experimental field and analyzed. The results of the chemical properties of are discussed below.

Experimental soil is rated as very strongly acid (4.5 – 5.0) with electrical conductivity within safe limit (< 4dSm^{-1}). The C: N ratio of the soil is narrow (13.8), which indicated net mineralization of nutrients in the soil (<15:1). The Walkley and Black C carbon status was medium.

Analysis of soils of experimental field revealed that available N is low (<280 kg ha^{-1}), available P is high (>24 kg ha^{-1}) and the available K is high (>276 kg ha^{-1}). The level of exchangeable Ca was sufficient but Mg was deficient (<120 mg kg^{-1} of soil) in the soil (Sureshkumar and Sandeep, 2015).



Titratable Acidity	S			
Titratable Acidity	POP	Vitamin C	Shelf life	Sensory parameters
	Ex-P	Vitamin C	Shelf life	
	Ex-E	Vitamin C	Fruit Ca	
	In-P	Vitamin C	Shelf life	Sugar content
	In-E	Sugar content	Fruit Ca	
	In-C	Vitamin C	Sugar content	

Figure 5.34. Factors contributing to the quality of banana fruits

Acuna *et al* (2011) reported that the concentration of indole acetic acid (IAA), a plant growth hormone well known for its role in root development and cell division stimulation was approximately 49.15 μg IAA equivalents (Auxins) g^{-1} of experimental soil. In soils, auxin production is purely biogenic and mainly by the action of microbes on L-tryptophan added through root exudates (Dakora and Phillips, 2002) which works as physiological precursor for the biosynthesis of auxin in plants and microorganisms. Dehydrogenase enzyme activity is recorded as 7.30 μg TPF day^{-1} g^{-1} of soil. Dehydrogenases are respiratory enzymes and provides information on the biological activity and microbial populations in soil (Wlodarczyk, 2000). The activity of phosphatase enzymes reflect the soil organic P mineralization and plant nutrition (Nannipieri *et al.*, 2011). In the experimental soil, acid phosphomonoesterases activity is recorded as 106.79 μg PNP g^{-1} hr^{-1} in soil which was higher due to acidic pH than alkaline phosphomonoesterases activity of 5.81 μg PNP g^{-1} hr^{-1}. Alkaline phosphatases are derived from microorganisms alone and acid phosphatases from both plant roots and soil inhabiting microbes. The microbial biomass carbon is a measure of labile fraction of C assimilated in the microbial body (Logah *et al.*, 2010). In the control treatment microbial biomass carbon content of 142.56 μg C g^{-1} was reported.

5.3.2. Post experimental soil chemical analysis

Collected soil samples were processed and analysed using standard procedures for the evaluation of residual soil fertility in terms of chemical and biochemical parameters. Application of organic manures significantly improved the pH of the soil. The modes of composting and species of earthworms had significant effect on the pH of the rhizosphere soil. Among the treatments, the highest increase in pH from the initial value is recorded in rhizosphere soils that received *ex-situ* vermicompost prepared using exotic earthworms and that of rhizosphere soils which received *in-situ* compost. However pH of rhizosphere soils that received *ex-situ* vermicompost was on par with that received *in-situ* vermicompost prepared using native earthworms. Due to the application of compost with pH ranging from 7 to 8.3, there was an increase in soil pH of acidic experimental soils (pH 4.7) which may be due to buffering action of organic colloids present in the compost (Petit, 2004). This fact is proved by the high content of humic acids in the prepared composts (42.14% in *in-situ* compost followed by 32.78% in *ex-situ* vermicompost using exotic earthworms). Due to the secretion of NH_4^+ ions and activity of calciferous glands in earthworm, pH of the vermicompost will be near neutral. NH_4^+ ions temporarily reduce the pool of H^+ ions when added to soil (Bisen *et al.,* 2011). The calciferous glands contain carbonic anhydrase which catalyse the fixation of CO_2 as $CaCO_3$, and prevent the fall in pH (Kale, 1995). Hence compost prepared in banana planting pits and vermicompost prepared using exotic earthworms in *ex-situ* mode of composting were equally effective in neutralizing the pH of the soil after harvest of banana from very strongly acidic to slightly acidic.

The data on electrical conductivity of rhizosphere soils revealed that irrespective of the treatments, cultivation of banana caused a reduction in the EC from the initial value (0.08dSm^{-1}). Among the treatments, soils which received *ex-situ* vermicompost prepared by exotic earthworms and that received recommended dose of fertilizers recorded comparable EC. Regarding the species of earthworms, exotic earthworm *Eisenia foetida* recorded significantly superior EC than native earthworms. The increase in salt concentration in the rhizosphere of vermicomposting treatments is due to the presence of various nutrient ions like nitrates (Atiyeh *et al.*, 2000)

On perusal of the data on Walkley and Black Carbon (WBC) of rhizosphere soil after the harvest of banana, it was revealed that application of *ex-situ* vermicompost prepared using native earthworms and *in-situ* compost could supplement significant organic carbon to the rhizosphere of banana. The vermicompost prepared by exotic earthworms under *ex-situ* vermibeds also enriched the rhizosphere with significantly higher WBC content.

Better adaptability and mineralization capacity of native earthworms to release C both under *ex-situ* and *in-situ* conditions is clear from these results. The enhanced mineralization to release carbon in the immediate vicinity of rhizosphere was augmented by the combined action of enzymes present in earthworm gut and microorganisms (Padmavathiamma *et al.,* 2008). The high

WBC content of *in-situ* composting is the contribution of high content of humic acids present in the compost and soil.

The mineralizable N is a measure of readily available form of N in soil. All the composting treatments were equally effective in enriching the rhizosphere soils with mineralizable N as that of recommended dose of fertilizers (Figure 5.35). The modes of composting had a significant influence in the residual soil fertility in terms of mineralizable N. The exotic earthworm is significantly superior to native earthworms under *ex-situ* and *in-situ* conditions. The better mineralization brought about by the combined action of earthworms and microbes in the rhizosphere might have ensured the constant supply of organically bound N to inorganic N in the rhizosphere soil (Vanilarasu and Balakrishnamurthy, 2014). Vermicompost application generally improves the soil environment particularly soil aeration, encouraging the proliferation of roots which in turn draw more water and nutrient from distant areas and helps to introduce and sustain beneficial microorganisms into the rhizosphere (Padmavathiamma *et al.*, 2008) in sufficient numbers for a longer period.

On perusal of results of available P in rhizosphere soils of different treatments, it was observed that the highest available P was associated with soils which received recommended dose of fertilizers after harvest of banana (Figure 5.35). Among the composting treatments, the *ex-situ* vermicomposts were on par in improving the P content of soil. Vermicomposts are known to provide a slow, balanced nutritional release pattern to plants, particularly in terms of release of plant available N, soluble K, exchangeable Ca, Mg and P (Edwards and Fletcher, 1988) which are subsequently used by plants efficiently.

The stimulatory effect of vermicompost on the available K content of rhizosphere soils of different treatments is discussed in Table 4.23. The highest available K content was recorded in soils that received recommended dose of fertilizers and FYM and it was on par with *in-situ* and *ex-situ* vermicompost produced by native earthworms (Figure 5.35). The better degradation of lignocellulosic coconut leaves by *Perionyx excavatus* might have released the K present in the coconut leaves. This fact was confirmed by Parthasarathy *et al.*,

(2016) who reported the presence of more cellulolytic, amylolytic, proteolytic and phosphate solubilizing microbes in the gut and casts of *Eisenia foetida*, *Lampito mauritii* and *Perionyx excavatus*. Moreover, the native earthworms produced higher number of cocoons, juveniles and adults due to its indigenous nature and better acclimatization to the environment (Pattnaik and Reddy, 2010). Garg *et al* (2006) also demonstrated that microbial flora in vermicompost enhanced the total potassium through acid production for solubilizing the insoluble potassium.

The details regarding the concentration of Ca in the rhizosphere soils are shown in Table 4.24. On perusal of the results, it was found that the rhizosphere soils were significantly enriched by the application of recommended dose of fertilizers and basal application of lime. This enrichment of Ca in subsoil layer is due to the basal application and slow release of Ca to rhizosphere soils. However the *in-situ* composting treatments significantly enriched soils with available Ca. The increased availability of Ca is due to the mineralization and enrichment of compost with Ca when it passes through earthworm gut. The calciferous glands have carbonic anhydrase which catalyse the fixation of CO_2 as $CaCO_3$ (Padmavathiamma *et al*., 2008).

The available Mg content varied significantly among the treatments. The soils that received compost prepared *in-situ* recorded the highest content of available Mg. The enrichment of secondary nutrients like Ca and Mg through mineralization and subsequent slow release by *in-situ* compost and or vermicompost was brought out in this study. However the experimental soil is deficient in available Mg irrespective of the treatments.

5.3.3. Effect of treatments on biochemical properties of soil after the harvest of banana

The highest content of MBC was recorded in plots that received vermicompost prepared *in-situ* under banana planting pits using exotic earthworms. The formation of vermicompost in the planting sites created a congenial environment for microbial multiplication in the soils receiving *in-situ* vermicompost prepared by exotic earthworms. The continuous addition of substrates with high C: N ratio will sustain the microbial population and maintain the weak equilibrium for mineralization of nutrients from substrates to soil. Microbes act as transient nutrient sink and MBC is that living pool of C which is fixed by microbial body cells (Cerney *et al*., 2008) and serves as a valuable tool for understanding changes in soil properties and in the degree of soil degradation or soil quality.

The quantity and quality of organic inputs are the most important factors affecting microbial biomass and community structure (Cerney *et al.,* 2008). According to Ross (1987), crop residues can have a large effect on soil microbial biomass and activity, which, in turn, affect the ability of soil to supply nutrients to plants through soil organic matter turnover. Efficient nutrient management in cropping systems could, therefore, lead to the build-up of microbial biomass over time. The present study revealed that the production of vermicompost in planting pits could manifest a 24 percent increase in MBC than control. Garcia-Gil *et al.* (2000) also reported a 29 percent increase of microbial biomass C in soils receiving manure at the annual rate of 20 t ha^{-1} than the control.

The results of the auxin concentration in soil by spectroscopic estimation revealed that the highest content of auxins was recorded in compost prepared *in-situ* which was on par with that produced under recommended dose of fertilizers and FYM. The action of compost derived humic acid at low IAA concentrations stimulated root growth by inducing the proliferation of lateral roots (Trevisan *et al.,* 2010). The activity of auxins in soils is strongly correlated to its organic carbon content (Szajdak and Maryganova, 2009). Eighty percent of bacteria isolated from the rhizosphere were reported to produce IAA which will release the auxins continuously at low concentrations (Frankenberger and Arshad, 1995). The activity of auxin derivatives depend on microbial population in the proximity of plant rhizosphere. The formation of auxins from L-tryptophan is a biotic reaction. The microbes utilize the auxin precursor (L-Tryptophan) and synthesis auxin. Hence activity of auxin derivatives serve as measure of phenotypic characteristics of microbiota of that soil. Scaglia *et al* (2015) ascribed auxin-like activity associated with the vermicompost to the humic acid fraction (HA) particularly carboxylic acids and amino acids.

The highest microbial count was recorded in the rhizosphere of soils which received vermicompost prepared using native earthworms in silpaulin vermibeds. The sustained supply of nutrients and organic matter in the rhizosphere of vermicompost treated soils provide energy sources to microbes and thereby encourage their proliferation (Khaddar and Yadav, 2006).

Urease enzyme essentially hydrolyze urea into ammonium and carbon dioxide. Concentration of urease enzyme was significantly dependent on the pH and substrate concentration (Tabatabai and Bremner, 1972). From Table 4.26 it was clear that significantly superior urease activity was recorded in compost prepared in banana planting pits. The increased urease activity of *in-situ* compost treated plots may be due to the combined action of favourable pH (5.9) and availability of mineralizable N (310kg $ha^{-1}$of soil) together with microbial activity in the vicinity of rhizosphere (Tiquia, 2002).

L-Asparaginases are enzymes that act on C-N bonds (other than peptide bonds) on respective amino acids releasing NH_3, which are important in N mineralization to provide plant available N. It essentially catalyzes the hydrolysis of L-asparagine with the production of ammonia and aspartic acid. Activity of L-asparaginase had significant correlation with organic carbon and available N (Frankenberger and Arshad, 1995). The activity of L-asparaginase was significantly higher in soils treated with vermicompost prepared using exotic earthworms in banana planting pits. The higher availability of substrate nitrogen (312.58 kg ha^{-1}) in the rhizosphere of vermicompost applied plants might have contributed to the activity of L-asparaginase in the rhizosphere soils.

Dehydrogenase activity is an index of biological activity of soil. The activity of dehydrogenases was the highest in *in-situ* compost treated plots. The greater biological activity coupled with stabilization of extracellular enzymes through complexation with humic substances might be the reason for continuous availability of substrate for enzymes (Adak *et al.,* 2014). The increased dehydrogenase activity in compost amended soil was attributed to the significantly higher organic carbon content (1.26%) and humic acid content in those soils as shown in section 4.1.4.

The different treatments had a significant effect on the activity of alkaline phosphomonoesterases of rhizosphere soils. Significantly superior activity of alkaline phosphates was observed in plots receiving recommended dose of fertilizers and FYM. The balanced supply of nutrients, along with organic matter in the form of FYM might have induced congenial environment for microbial growth and enzyme activity under integrated nutrient management system. Alkaline phosphatases originate from microorganisms and are not produced by plants (Okur *et al.,* 2008). Phosphatase activity plays a key role in organic P mineralization and compost applied soils had significantly higher content of alkaline phosphatase activity.

The activity of acid phosphatases was higher than alkaline phosphatases irrespective of the treatments. The highest activity of acid phosphatase was recorded in soils that received recommended dose of fertilizers and FYM after the harvest of banana. The acid phosphatases are produced both by plants and microorganisms. Mineral fertilization increased the substrate availability to P solubilizing microbes and increased acid phosphatase activity (Masto *et al.*, 2006) which catalyzes the hydrolysis of esters and anhydrides of H_3 PO_4 to release inorganic phosphorus, which is assimilable for plants (Bautista-Cruz and Ortíz-Hernández, 2015). The presence of earthworms helped in faster transformation of organic P by facilitating better environment to microbes and plant roots (Saha *et al.*, 2008).

5.3.4. Addition of nutrients through *in-situ* incorporation of crop residues

After the harvest of banana, the remaining residues (leaves, pseudostem and rhizome) were shredded and added to the respective crop pits. The addition of nutrients through *in-situ* banana residue incorporation were worked out and results are discussed below.

The data on addition of C to soil through *in-situ* incorporation of crop residues revealed that the highest C was added from residues of plots that received recommended dose of fertilizers and FYM. Due to the huge quantity of biomass generated, the nutrient addition to soil was also significantly high from POP treatment. Among the composting treatments, the plots received *in-situ*

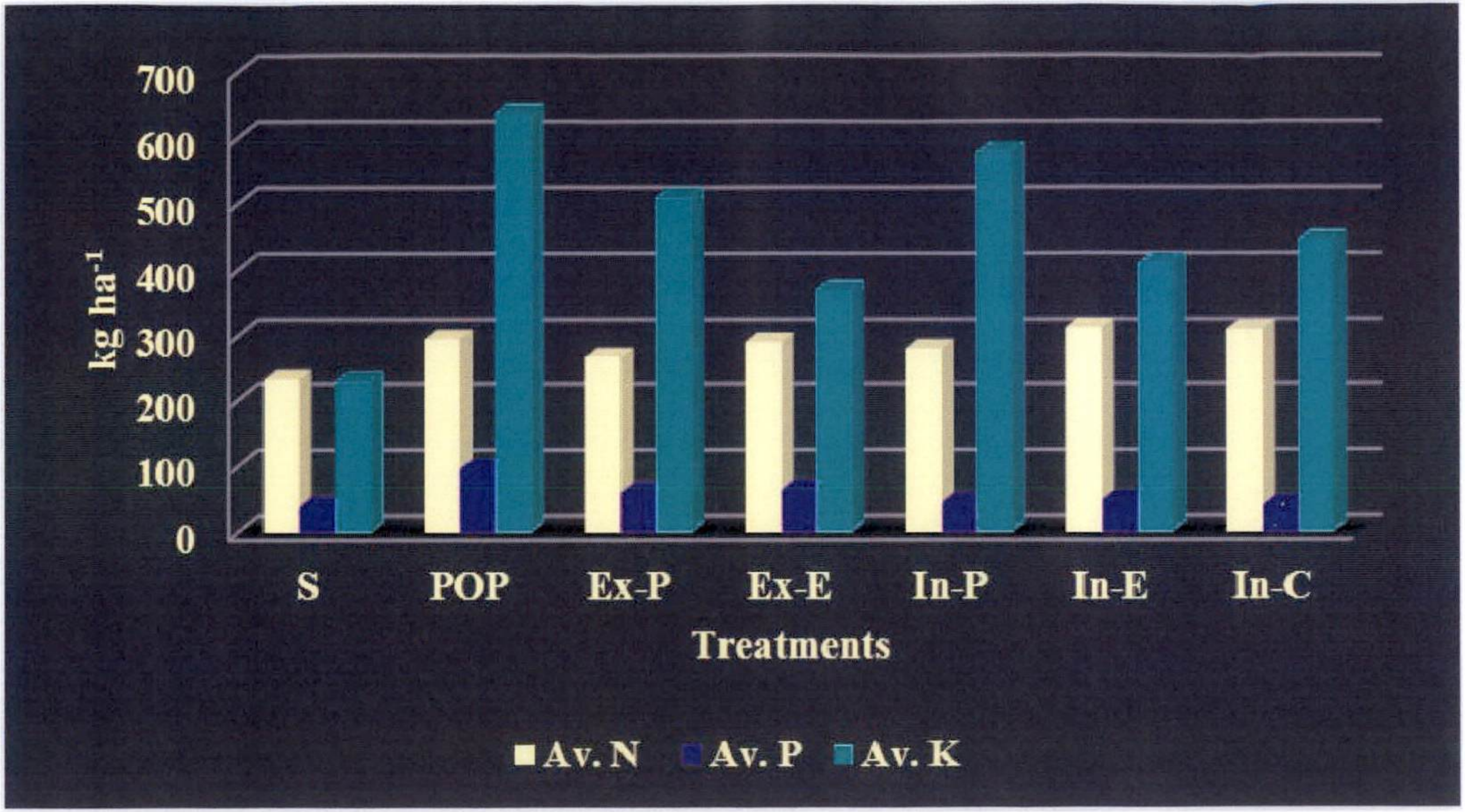


Figure 5.35. Effect of treatments on available nutrients of experimental soil after the harvest of banana

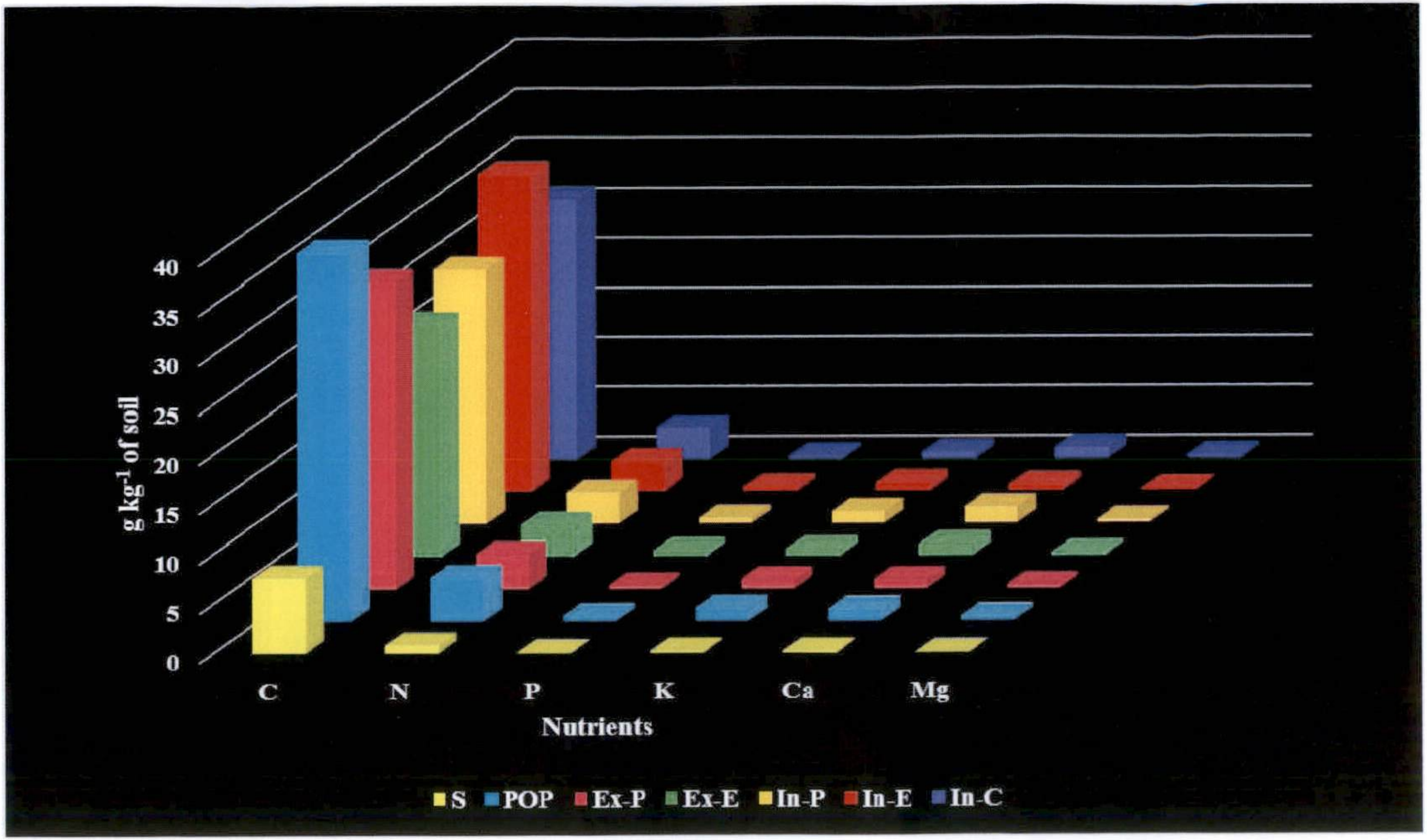


Figure 5.36. Effect of treatments on nutrients added to soil by *in-situ* incorporation of banana residues

vermicompost prepared using exotic earthworms and *ex-situ* vermicompost using native earthworms were significantly superior to other treatments. In the organic treatments, the presence of high content of humic carbon augmented the microbial activity and improved the carbon status of soil by priming action as discussed in section 4.1.4.

The highest addition of N to soil through *in-situ* incorporation of banana residues were obtained from plots that received recommended dose of fertilizers FYM (Figure 5.36). However all organic treatments except vermicompost using exotic earthworms were on par in the addition of N through residue incorporation. Analysis of P addition to soil through *in-situ* incorporation of crop residues showed that both *in-situ* and *ex-situ* modes of composting were on par to POP. The exotic earthworms under *ex-situ* conditions and native earthworms under *in-situ* conditions were significantly superior to other modes of composting in improving the P status of the soil.

The quantity of K added through banana residues were significantly superior in plots receiving recommended dose of fertilizers and FYM (Figure 5.36). The *in-situ* vermicompost prepared using native earthworms were significantly superior to that produced *ex-situ*. Among the species of earthworms, the highest quantity of K was added in plots receiving vermicompost prepared using native earthworms irrespective of the modes of composting. Thus it was established that native earthworms are more efficient in adding K to soil than exotic earthworms.

Among the different treatments, the highest Ca was added to soil through residues from plots receiving *in-situ* vermicompost prepared using native earthworms (Figure 5.36). The quantity of Ca added through recommended dose of fertilizers and FYM was on par with *ex-situ* vermicomposting using exotic earthworms. The native earthworms were significantly superior to exotic earthworms in enriching the soil with Ca through the residues when prepared under *in-situ* conditions.

The highest addition of Mg was obtained from residues of plants treated with recommended dose of fertilizers and FYM (Figure 5.36). Native earthworms under *ex-situ* and *in-situ* conditions were significantly superior in adding Mg to soils through residue addition whereas exotic earthworms were significantly superior in enriching the soil with Mg only under *ex-situ* conditions. However the quantity of Mg added through residues from vermicompost produced *in-situ* and *ex-situ* using native earthworms were significantly superior to exotic earthworms under *in-situ* mode of vermicomposting. The vermicompost prepared using native earthworms were on par with compost prepared *in-situ* when added through *in-situ* mode of composting.

5.3.5 C and N mineralization from banana residues after *in-situ* incorporation

Soil carbon mineralization rate is a key indicator of soil functional capacity (Mutuo *et al.*, 2006). C mineralization rate was observed after addition of residues to the pits till the stabilization of C: N ratio of the residues. The results of the single pool exponential model fits for C and N mineralization revealed that C mineralization was faster from residues of POP up to 30 days of incorporation (Figure 4.9). All the composting amended plant residues had a positive slope up to 90 days of incorporation. Among the modes of composting, the highest C mineralization was from *in-situ* composting treatments. This was proved from the half-life calculations, which indicated that composting treatments have got longer half-lives than that of POP.

Nitrogen mineralization is the conversion of organic N to inorganic available form. The highest N mineralization was observed in residues from *ex-situ* vermicompost prepared using exotic earthworms. Among the modes of composting, the highest N was mineralized from plant residues of *in-situ* composting treatments. However, the N mineralization of all treatments followed a linear fashion.

The most striking difference in pattern of C mineralization between the inorganic and organic nutrition was that the fertilizer input provided nutrients in the easily available form, which promotes the intense microbial activity in the initial phase of residue decomposition. As a result, there will be exhaustion of readily available C sources due to wider C: N ratio of residues. This results in the temporary immobilization of nutrients. As a consequence, the microbes will get starved and die in large numbers to release the C immobilized in their bodies (microbial biomass carbon). At this stage, the microbes which were acclimatized to the mineralization of recalcitrant pool of C will proliferate and continue the mineralization process. Thus the fertilizer addition shifts the C mineralization from labile to recalcitrant pools immediately, which is not occurring in compost treated plots. In compost treated plots, a relatively slower equilibrium occur between labile and recalcitrant pool of C. It in turn helps in the better proliferation and multiplication of microbes which are ultimately the drivers of all nutrient transformations in soil enigma.

5.3.6. Changes in available nutrient content of soil after *in-situ* incorporation of banana residues.

The changes in the available P content of various treatments are shown in Table 4.30. The highest content of available P was recorded from incorporation of residues of *ex-situ* vermicompost treated plants. This is due to the high P content of the plants treated with *ex-situ* vermicompost prepared by exotic earthworms (Appendix 6a. and 6b.). The high P content of plants might be due to the efficient translocation of P through humic acid mediated lateral roots from the sustained release of P from *ex-situ* compost (Section 4.1.3.; Appendix 6a. and 6b.) prepared by exotic earthworms.

The highest K and Ca contents were recorded from residues of plants that received combined application of fertilizers and FYM. This might due to the application of high analysis fertilizers and lime and its translocation by the plants. Among the composting treatments, the highest K and Ca content was recorded from residues treated with *in-situ* mode of vermicomposting and composting respectively. However, the increase in concentration of K after addition of residues was highest from *ex-situ* vermicomposting treatments. However the plants pre-treated with *Eisenia foetida* worked *ex-situ* vermicompost mobilized the highest available Ca in the rhizosphere soil after 160 days of incorporation of residues to the soil.

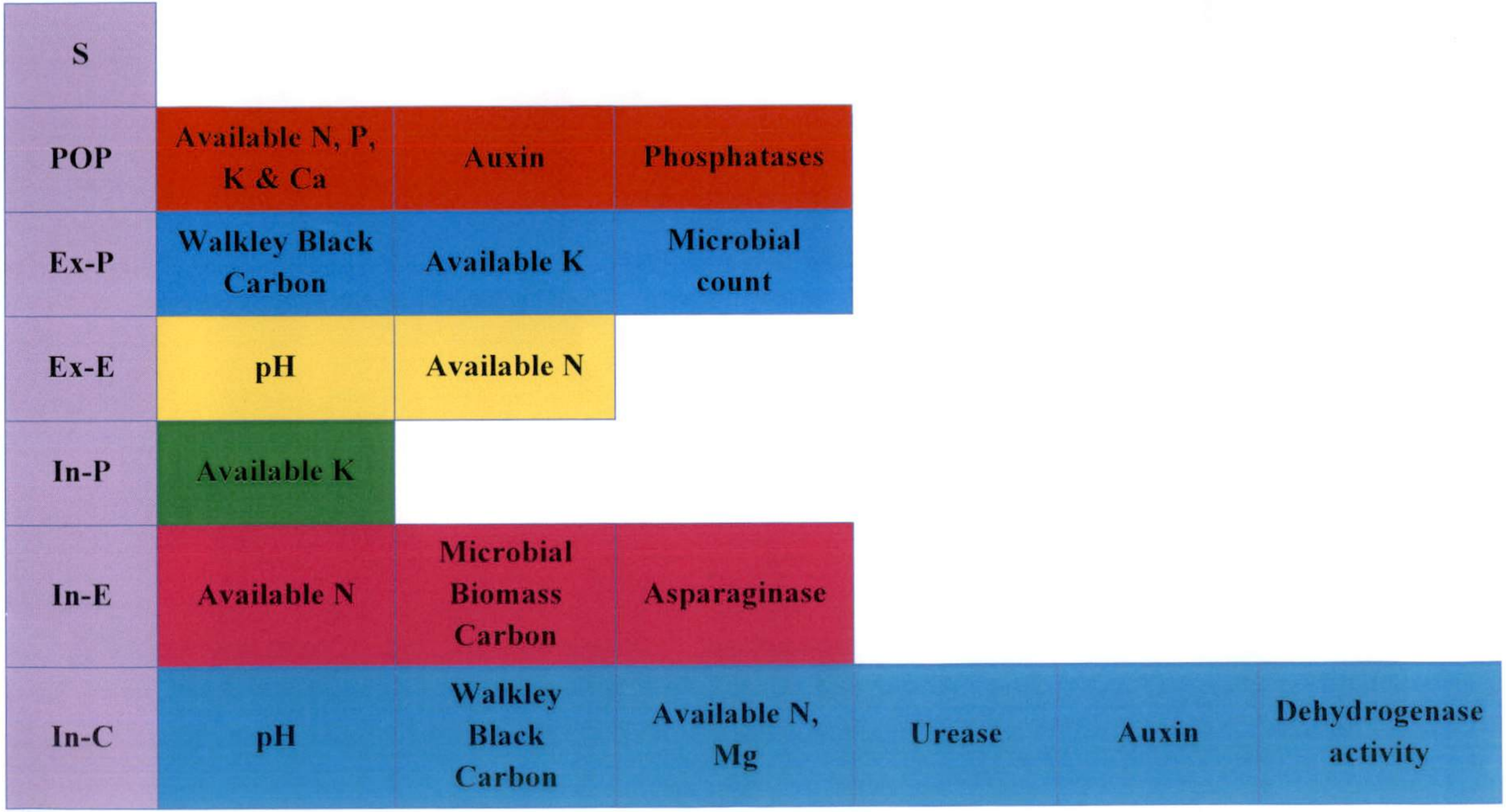
The highest content of available Mg was recorded from soils received nutrition through *in-situ* compost. But addition of magnesium through the crop reside incorporation to soil could not attain the optimum level of available Mg in soils.

5.3.7. Factors contributing to the health of soil

Figure 5.37 discusses the factors affecting the soil health of the experimental field after banana cultivation under different modes of nutrition. The combined use of recommended dose of fertilizers and FYM had significant influence on the available nutrient status of the soil particularly N, P, K and Ca. Since the availability of P is plenty, the activity of phosphatase enzyme was significantly higher under POP treatment. The high concentration of auxins from rhizosphere of banana grown under POP may be due to the root exudation and microbial production. The different modes of organic nutrition had significant influence on the soil fertility. The *ex-situ* mode of composting using native earthworm *Perionyx excavatus* had improved the soil with more content of Walkley Black Carbon, available K and microbial count. The *ex-situ* mode of vermicomposting using *Eisenia foetida* had significant influence in regulating the pH and available N content of soil. The *in-situ* vermicomposting using native earthworms on the other hand had significant influence on available K content of the soil. Significant effect of available N, microbial biomass carbon and asparaginase activity was pronounced under *in-situ* mode of vermicomposting using *Eisenia foetida*. However, the *in-situ* composting was found to have significant influence on rhizosphere pH, WBC, available nutrients like N and Mg, activity of urease and dehydrogenases. The effect of *in-situ* mode of composting also had pronounced influence on the auxin content of soil.

5.3.8. Practical /scientific utility of the study

Vermitechnology is widely accepted as a means of converting bio wastes/ crop residues to humic manures for amending the cultivated soils. Worm biology as well as conversion efficiency of exotic earthworms are well documented and hence they are utilized in vermiculture on a commercial scale. Considering the diversity of earthworm species with varied soil types /agro-climatic conditions,



S						
POP	Available N, P, K & Ca	Auxin	Phosphatases			
Ex-P	Walkley Black Carbon	Available K	Microbial count			
Ex-E	pH	Available N				
In-P	Available K					
In-E	Available N	Microbial Biomass Carbon	Asparaginase			
In-C	pH	Walkley Black Carbon	Available N, Mg	Urease	Auxin	Dehydrogenase activity

Figure 5.37. Factors contributing to soil health due to *in-situ* incorporation of banana residues

the species most suited to a particular region must be made use of. The potential of native earthworms under *ex-situ* and *in-situ* modes of composting was exploited in the present study.

The results proved the conservation of nitrate in the humic substances produced by *Perionyx excavatus* collected and reared from the experimental soil. Another interesting finding was the liming effect of vermicompost due to the presence of $CaCO_3$ nodules in the casts of *Eisenia foetida* suggesting its application for the reclamation of acidic soils of Kerala.

Though the integrated management practices resulted in better yields of banana, the benefit: cost ratio was more for the crop under compost nutrition. Of course, this is primarily due to the less cost involved in the farming practices and the premium price for the organic fruits in the market. Hence, the nutrient economy through *in-situ* vermicomposting is highlighted in this study.

By harnessing the nutrients, phytohormones and enzymes either through *in-situ* vermicomposting or decomposition, there will be considerable bio nutrition to the land without affecting the ecological balance of nature. Decomposition kinetics is interpreted with the use of models developed for each treatment under investigation. All the modes satisfactorily describe the carbon mineralization – immobilization phases. Ultimately the research results helped to conclude that there is a gradual carbon mineralization pattern from composting treatments in contrast to spontaneous loss of carbon under the combined nutrition of organic and inorganics which makes it more sustainable in the long run.

5.3.9. Future lines of work

a) Native worms adapted for each soil type must be identified through studies involving metagenomics and their vermiconversion efficiency must be monitored.

b) Impact of exotic earthworm proliferation on the indigenous earthworm species needs to be critically assessed.

c) Molecular level characterization of humic acids produced by lignin polyphenol rich crop residues and their impact on the build-up of soil health must be thoroughly investigated.

Summary

6. SUMMARY

An investigation entitled "Efficiency of vermiconversion and decomposition of farm residues on soil health, yield and quality of banana (*Musa spp.*)" was undertaken at College of Horticulture and Banana Research Station, Kannara during 2013-2015. The salient research findings are summarized experiment wise as follows

Experiment I

- The pH, electrical conductivity, content of C, N, P and K of the composts prepared under *ex-situ* mode of composting using silpaulin sheets was significantly superior to that prepared under *in-situ* mode of composting in banana planting pits.
- Sum of N, P_2O_5 and K_2O (4.47 to 4.82 %) was significantly higher in *ex-situ* composting as against minimum tolerance limit (2.5 %) prescribed by the Fertilizer (control) order (GOI, 1985).
- Content of micronutrients and heavy metals, Cr and Ni were significantly higher in compost prepared under *in-situ* mode of composting as compared to that under *ex-situ.*
- Compost yield was more in *ex-situ* mode of composting and *Eisenia foetida* was found to be more efficient (40-50days) as compared to *Perionyx excavatus* (50-60 days).
- The highest auxin content of 26.02 $\mu g\ g^{-1}$ of compost was recorded in vermicompost prepared by *Eisenia foetida* whereas the highest dehydrogenase activity of 1798.63 $\mu g\ g^{-1}$ of compost was recorded by vermicompost prepared using *Perionyx excavatus.*
- Total viable microbial count was significantly higher in compost prepared both under *ex-situ* and *in-situ* modes as against their vermicomposting counter parts.

- ❖ Humic acid content was recorded as the highest for *in-situ* compost (42.15 %) which was on par with vermicompost prepared by *Eisenia foetida* (32.79 %) under *ex-situ* mode of composting.
- ❖ Humic acid characterization by Fourier Transform Infra-Red spectroscopy revealed the following
- ✓ Presence of aromatic rings and triple bond skeleton
- ✓ Presence of long linear aliphatic side chains
- ✓ Relatively higher presence of polysaccharide like substances in *ex-situ* mode of composting
- ❖ Quantification of degree of decomposition in terms of ratio of intensity of bands at 2930 cm^{-1} to 1034 cm^{-1} testified that intense degree of decomposition was brought out by *Perionyx excavatus* with humic acids of high aromaticity
- ❖ Scanning Electron Microscope imagery revealed neo-formed $CaCO_3$ nodules embedded in humic acids produced by *Eisenia foetida*
- ❖ Transmission Electron Microscopy of humic acids revealed the following
  - ✓ Globular structure of humic acids produced by *Perionyx excavatus* due to H bond aided coiling
  - ✓ Lamellar structure with voids for *Eisenia foetida* worked vermicompost due to de-protonation and reduction in H bond

Experiment II

- ❖ Higher bunch yield of 10.81 kg $plant^{-1}$ was obtained from the treatment based on POP (300:115:450g N: P_2O_5:K_2O $plant^{-1}$ +FYM at the rate of 20kg $plant^{-1}$).
- ❖ Composting treatments recorded yields ranging from 6.77 – 7.24 kg $plant^{-1}$.
- ❖ Number of fingers per hand and number of functional leaves contributed to bunch yield irrespective of treatments.
- ❖ Weight of one finger was significantly influenced by the modes of nutrition and ranged from 101.67 to 178.67g.

- Time taken for bunching as well as harvesting was considerably reduced for plants grown under *in-situ* mode of vermicomposting.
- The highest benefit cost ratio of 1.26 was recorded for cultivation of plants under compost prepared *in-situ*.
- Plants grown under composting recorded significantly higher contents of P and Mg in the index tissues at four months after planting than that of plants grown under POP.
- Analysis of quality parameters of the fruits revealed the following
  - ✓ Highest titratable acidity of 0.97 g of citric acid $100g^{-1}$ of fruit was recorded for absolute control followed by POP (0.69 g of citric acid $100g^{-1}$ of fruit).
  - ✓ Total sugars, reducing sugars and non-reducing sugars were higher in *in-situ* composting treatments.
  - ✓ Sensory evaluation of ripened fruits of banana from various treatments was more favourable for POP treatment.

Experiment III

- Analysis of crop residues from various treatments revealed that C content was 22.5 - 32.47 percent in leaf and pseudostem residues and 21.55 - 33.43 percent in rhizome residues; N content varied from 2.61 - 3.99 percent in leaf and pseudostem residues and 2.77 - 3.58 percent in rhizome residues; P content ranged from 0.41 to 0.58 percent in leaf and pseudostem residues and 0.19 to 0.59 percent in rhizome residues; K content was 0.47 to 1.37 percent in leaf and pseudostem residues and 0.53 to 1.06 percent in rhizome residues. The calcium content varied from 0.64 to 1.91 percent in leaf and pseudostem residues and 0.45 to 1.44 percent in rhizome residues. The Mg content recorded values from 0.14 to 0.29 percent in leaf and pseudostem residues and from 0.23 to 0.36 percent in rhizome residues.

- Residue decomposition by *in-situ* incorporation of residues registered the following
  - ✓ The *in-situ* compost treated plots recorded the highest quantity of potentially mineralizable C (61.79mg kg^{-1} of soil) whereas *ex-situ* vermicompost prepared by *Eisenia foetida* recorded the highest amount of potentially mineralizable N (91.0 mg kg^{-1} of soil).
  - ✓ Rate of C mineralization was the highest for POP treatment with 0.044 mg C day^{-1} kg^{-1} of soil and that of N was 0.0003 mg N day^{-1} kg^{-1} of soil.
  - ✓ Half-life ($t_{1/2}$) of C mineralization was the highest for *in-situ* compost (6.6 days) and lowest for POP (3.8 days).
  - ✓ Potentially mineralizable N and rate of N mineralization highest for *Eisenia foetida* worked *ex-situ* vermicompost with 91mg of N kg^{-1} of soil and 0.015 mg N day^{-1} kg^{-1} of soil respectively.

References

REFERENCES

A.O.A.C [Association of Official Analytical Chemists]. 2000. *Official and tentative methods of analysis*, Washington, D.C., US. 757p.

Abraham, R. 1998. Indole acetic acid oxidase activity in brinjal as influenced by fertilizers treatments. M.Sc. (Ag) thesis, Kerala Agricultural University, Vellanikkara. 155p.

Achsah, R. S. and Prabha, M. L. 2013..Potential of vermicompost produced from banana waste (*Musa paradisiaca*) on the growth parameters of *Solanum lycopersicum*. *Int. J. Chem. Tech. Res.* 5 (5): 2141-2153.

Acuña, J. J., Jorquera, M. A., Martínez, O. A., Menezes–Blackburn, D., Fernández, M.T., Marschner, P., Greiner, R., and Mora, M. L. 2011. Indole acetic acid and phytase activity produced by rhizosphere bacilli as affected by pH and metals *J. Soil Sci. Plant Nutr.* 11 (3):1-12.

Adak, T., Singha, A., Kumar, K., Shukla, S.K., Singh, A., and Singh K.V. 2014. Soil organic carbon, dehydrogenase activity, nutrient availability and leaf nutrient content as affected by organic and inorganic source of nutrient in mango orchard soil. *J. Soil Sci. Plant Nutr.* 394-406.

Adhikary, S. 2012. Vermicompost, the story of organic gold: A review. *Agri. Sci.* 3(7): 905-917.

Agyeman, K., Berchie, J. N., Gaisie, E., and Adomako, J. 2013. Synchronization of nutrient release from *Gliricidia sepium* with nutrient uptake by Maize through biomass decomposition. *Int. J. Sci. Adv.Techn.* 3 (3): 49 – 57.

Al-Barakah, F. N., Radwan, S. M. A., and Abdel-Aziz, R. A. 2013. Using Biotechnology in recycling agricultural waste for sustainable agriculture and environmental protection. *Int. J. Curr. Microbiol. Appl. Sci.* 2(12):446-459.

Al-Harthi, K., and Al-Yahyai, R. 2009. Effect of NPK fertilizer on growth and yield of banana in Northern Oman. *J Hort. For.* 1(8):160-167.

Allison, S. D., Wallenstein, M. D., and Bradford, M. A. 2010. Soil carbon response to warming dependent on microbial physiology. *Nature Geosci.* 3(5): 336-340.

Amaravathi, G. and Reddy, R. M. 2015. Environmental factors affecting vermicomposting of municipal solid waste. *Int. J. Pharm. Biol. Sci.* 81-93.

Amerine, M. A., Pangborn, R. M., and Roessler, E. B. 1965. Principles of sensory evaluation of food. *In: Food Science and Technology Monographs.* Academic Press, New York, pp. 38-339.

Amir, S., Hafidi, M., Bailly, J. R., and Revel, J. C., 2003. Characterization of humic acids extracted from sewage sludge during composting and of their Sephadex gel fractions. *Agron.* 23:269–275.

Anand, C. K. and Apul, D. S. 2014. Composting toilets as a sustainable alternative to urban sanitation-a review. *Waste Manage.* 34(2):329-343.

Appiah, F., Kumah, P., and Idun, I. 2011. Effect of ripening stage on composition, sensory qualities and acceptability of keitt mango (*Mangifera indica* l.) chips. *African J. Food Agric. Nutr. Dev.* 11(5):5096-5109.

Arancon, N. Q., Edwards, C. A., Bierman, P., Metzger, J. D., and Lucht, C. 2005. Effects of vermicomposts produced from cattle manure, food waste and paper waste on the growth and yield of peppers in the field. *Pedobiol.* 49:297-306.

Arancon, N. Q., Edwards, C. A., Bierman, P., Welch, C., and Metzger, J. D. 2004. Influences of vermicomposts on field strawberries: 1. Effects on growth and yields. *Bioresour. Technol.* 93:145–153

Arancon, N. Q., Lee, S., Edwards, C. A., and Atiyeh, R. M., 2003. Effects of humic acids and aqueous extracts derived from cattle, food and paper-waste vermicomposts on growth of greenhouse plants. *Pedobiol.* 47: 741–744.

Aremu, A. O., Kulkarni, M. G., Bairu, M. W., Finnie, J. F., and Staden, J. V. 2012. Growth stimulation effects of smoke-water and vermicompost leachate on greenhouse grown-tissue-cultured 'Williams' bananas. *Plant Growth Regul.*66:111–118.

Athani, S. I., and Hulamani, N. C. 2000. Effect of vermicompost on fruit yield and quality of Banana *cv. Rajapuri* (*Musa* AAB). *Karnataka J. Agril. Sci.* 13(4): 942-946.

Atiyeh, R. M., Domínguez, J., Subler, S., and Edwards, C. A. 2000. Changes in biochemical properties of cow manure during processing by earthworms (*Eisenia andrei*, Bouché) and the effects on seedling growth. *Pedobiologia* 44: 709–724

Banerjee, G. 2010. Economics of banana plantation under organic and in-organic farming systems. Working paper, NABARD, Mumbai, pp.1-10.

Barrett, D. M., Beaulieu, J. C., and Shewfelt, R. 2010. Color, favor, texture, and nutritional quality of fresh-cut fruits and vegetables: desirable levels, instrumental and sensory measurement, and the effects of processing. *Crit. Rev. Food Sci. Nutr.*, 50:369–389.

Bautista-Cruz, A., and Ortiz-Hernández, Y. D. 2015. Hydrolytic soil enzymes and their response to fertilization: A short review. *Comunicata. Scientiae* 6(3): 255-262.

Bernal, M. P., Navarro, A. F., Sanchez-Monedero, M. A., Roig, A., and Cegarra, J., 1998. Influence of sewage sludge compost stability and maturity on carbon and nitrogen mineralization in soil. *Soil Biol. Biochem.* 30 (3):305–313.

Bhalerao, V. P., Pujari, C. V., and Patil, N. M. 2010. Effect of organics by substituting inorganic N fertilizer on soil properties, nematode population and yield. *Asian J. Soil Sci.* 4 (2): 236-240.

Bhargava, B. S., and Reddy, B. M. C.1991. Selection of index tissue in banana *cv.* Robusta (*Musa* AAA Cavendish) for nutritional diagnosis and yield. *Indian J. Hort.* 49(2): 120-126.

Bhat, S. A., Singh, J. and Vig, A. P. 2015. Potential utilization of bagasse as feed material for earthworm *Eisenia fetida* and production of vermicompost. *SpringerPlus*, 4 (1): 1-9.

Bijulal, B. I. 1997. Effect of vermicompost on the electrochemical properties and nutritional characteristics of varied soils. M.Sc. (Ag) thesis, Kerala Agricultural University, Vellanikkara, 143p.

Bindhu, C. J., 2010. Calcium dynamics in substrate – wormcast- mushroom- plant continuum. Ph. D thesis, Kerala Agricultural University, Vellanikkara, 104p.

Bisen, J. S., Singh, A. K., Kumar, R., Bora, D. K., and Bera, B. 2011. Vermicompost quality as influenced by different species of earthworm and bedding material. *Two Bud.* 58:137-140

Bradford, M. A., Davies, C. A., Frey, S. D., Maddox, T. R., Melillo, J. M., Mohan, J. E., Reynolds, J. F., Treseder, K. K. and Wallenstein, M. D. 2008. Thermal adaptation of soil microbial respiration to elevated temperature. *Ecol. Lett.,* 11:1316–1327.

Bray, R. H. and Kurtz, L. T. 1945, Determination of total, organic, and available forms of phosphorus in soils. *Soil Sci.* 59: 39-45.

Busato, J. G., Lima, L., Aguiar, N. O., Canellas, L. P., and Olivares, F. L. 2012. Changes in labile phosphorus forms during maturation of vermicompost enriched with phosphorus-solubilizing and diazotrophic bacteria. *Bioresour. Technol.* 110:390-395.

Butani, A. M. and Chovatia, R. S. 2014. Effect of chemical fertilizer and vermicompost on days to flowering, harvesting and maturity of banana (*Musa paradisiaca* L.) *cv. Grand Naine. Asian J. Hort.*, 9(2): 305-308.

Cabanas-Echevarría, M., Torres–García, A., Díaz-Rodríguez, B., Ardisana, E. F. H., and Creme-Ramos, Y. 2005. Influence of three bioproducts of organic origin on the production of two banana clones (*Musa* spp. AAB.) obtained by tissue cultures. *Alimentaria* 369:111–16.

Campitelli P., and Ceppi, S. Effects of composting technologies on the chemical and physicochemical properties of humic acids. *Geoderma* 144: 325–333

Canellas, L. P., and Olivares, F. L. 2014. Physiological responses to humic substances as plant growth promoter. *Chem. Biol. Technol. Agric.*1 (3): 1-11.

Canellas, L. P., Olivares, F. L., Okorokova, A. L., and Facanha, A. R., 2000. Humic acids isolated from earthworm compost enhance root elongation, lateral root emergence, and plasma H^+-ATPase activity in maize roots. *Plant Physiol.* 130: 1951-1957.

Carvalho, C. S.M., Aguiar, L. V. B., Sales-Campos, C., Minhoni, M. T. A., and Andrade, M. C. N. 2012. Applicability of the use of waste from different banana cultivars for the cultivation of the oyster mushroom. *Braz. J. Microbiol:* 819-826

Casida L. E., Klein, D. A., and Santaro, T. 1964. Soil dehydrogenase activity. *Soil Sci.* 98:371–376.

Černý, J., Balík, J., Kulhánek, M., and Nedvěd, V. 2008. The changes in microbial biomass C and N in long-term field experiments. *J. Plant Soil Environ.* 54 (5): 212–218.

Chan, Y.C., Sinha, R. K., and Wang, W. 2010. Emission of greenhouse gases from home aerobic composting, anaerobic digestion and vermicomposting of household wastes in Brisbane (Australia). *Waste Manage. Res.* 29(5):540–548.

Chandna, P., Nain, L., Singh, S., and Kuhad, R. C. 2013. Assessment of bacterial diversity during composting of agricultural by-products. *BMC Microbiol.* 13:99.

Chaoui, H. I., Zibilske, L. M., and Ohno, T. 2003. Effects of earthworm casts and compost on soil microbial activity and plant nutrient availability. *Soil Biol. Biochem.* 35: 295–302.

Chaves, B., Cayón G., and Jones, J. W. 2009. Modeling potential plantain (*Musa* AAB Simmonds) potential yield. *Agron. Colomb.* 27(3): 359- 366.

Chhonkar, P. K. Bhadraray, S., Patra, A. K., and Purakayastha, T. J. 2007. *Experiments in Soil Biology and Biochemistry*, Westville Publishing House, New Delhi. 182p.

Chowdhury, A., Hazra, A. K., Mahajan, S., and Choudhury, J. 2007. Microbial communities of earthworm *(Perionyx excavatus* Perrier) gut, cast and adjacent soil in two different fields of West Bengal. *Rec. Zool. Surv. India.* 107(IV):101-113.

Dakora, F. D. and Phillips, D. A. 2002. Root exudates as mediators of mineral acquisition in low-nutrient environments. *Plant Soil* 245:35–47.

Darwin, C. 1881.*The formation of vegetable mould through the action of worms with some observations on their habits*. John Murray, London. 326p.

Das, M. N. and Giri, N. C. 1986. *Design and analysis of experiments*, (2nd Ed.), New Age International (P) Limited Publishers, New Delhi. 364p.

Doran, J.W. and Safely, M. 1997. Defining and assessing soil health and sustainable productivity. *In:* Pankhurst, C. E., Doube, B. M., and Gupta, V. V. S. R. (eds.), *Biological Indicators of Soil Health.* CABI Publishing. UK, pp.1-28.

Edwards, C. A., and Fletcher, K. E. 1988. Interaction between earthworms and microorganisms in organic matter breakdown. *Agric Ecosyst Environ.* 20: 235-249.

El Harti, A., Saghi, M., Molina, J.A.E., and Téller, G. 2001a. Production d'une substance rhizogène à effet similaire à celui de l'acide indole acètique par le ver de terre *Lumbricus terrestris*. *Can. J. Zool.* 79:1911-1920.

El-Harti, A., Saghi, M., Molina, J. A. E. and Teller, G. 2001b. Production des composes indoliques rhizogénes par le ver de terre *Lumbricus terrestris. Canadian J. Zool.* 79:1921-1932.

Ellerbrock, R. H., Hohn, A., and Gerke, H. H., 2001. FTIR studies on soil organic matter from long-term field experiments. *In:* Rees, R.M., Ball, B.C., Campbell, C.D., Watson, C.A. (Eds.), *Sustainable management of soil organic matter*. CABI Publishing, Wallingford, pp.34– 41.

Ellerbrock, R.H., Hohn, A., and Rogasik, J., 1999. Functional analysis of soil organic matter as affected by long-term manorial treatment. *Eur. J. Soil Sci.* 50:65– 71.

Elvira, C., Sampedro, L., Benítez, E., and Nogales, R. 1998. Vermicomposting of sludges from paper mill and dairy industries with *Eisenia andrei*: A pilot-scale study. *Bioresour. Technol.* 63 (3):205-211.

Emperor, G. N. and Kumar, K. Microbial population and activity on vermicompost of *Eudrilus eugeniae* and *Eisenia fetida* in different concentrations of tea waste with cow dung and kitchen waste mixture. *Int. J. Curr. Microbiol. App. Sci* 4(10): 496-507.

Esakkiammal, B., Esaivani, C., Vasanthi, K., Bai, L. L., and Preya, N. S. 2015. Microbial diversity of vermicompost and vermiwash prepared from *Eudrilus euginae Int. J. Curr. Microbiol. App. Sci.*4 (9): 873-883.

Fernandes, E.R. K., Marangoni, C., Medeiros, S. H. W., Souza, O., and Sellin, N. 2012. Slow pyrolysis of banana culture waste: leaves and pseudostem. Paper presented at 3rd International Conference on Industrial and hazardous waste management. 1-8.

Flavel, T. C., Murphy, D. V., Lalor, B. M., and Fillery, I. R. P. 2005. Gross N mineralization rates after application of composted grape marc of soil. *Soil Biol. Biochem.*, 37(7): 1397–1400.

Fornes, F., Mendoza-Hernández, D., García-de-la-Fuente, R., Abad, M., and Belda, R. M. 2012. Composting versus vermicomposting: a comparative study of organic matter evolution through straight and combined processes. *Bioresour. Technol.* 118: 296-305.

Frankenberger Jr., W. T. and Arshad, M. 1995. *Phytohormones in Soils: Microbial Production and Function.* Marcel and Deckker, New York, 503p.

Frankenberger, W. T. Jr., and Tabatabai, M. A. 1991. L-Asparaginase activity of soils. *Biol. Fertil. Soils* 11: 6-12.

Gajalakshmi, S. and Abbasi, S. A. 2004. Earthworms and vermicomposting. *Ind. J. Biotechnol.* 3:486 – 494.

Ganeshamurthy, A. N., Satisha, G. C., and Patil, P. Potassium nutrition on yield and quality of fruit crops with special emphasis on banana and grapes. *Karnataka J. Agric. Sci.*, 24 (1): 29-38.

Garcia-Gil, J. C., Plaza, C., Soler-Rovira, P., and Polo, A. 2000. Long-term effects of municipal solid waste compost application on soil enzyme activities and microbial biomass. *Soil Biol. Biochem.* 32 (13):1907-1913.

Garg, A. K., and Mudgal, V. 2007. Organic and mineral composition of Gomeya (cow dung) from desi and crossbred cows—a comparative study. *Int. J. Cow Sci.* 3:1–2

Garg, V. K., Kaushik, P., and Dilbagi, N. 2006. Vermiconversion of wastewater sludge from textile mill mixed with an aerobically digested biogas plant slurry employing *Eisenia foetida. Ecotoxicol. Environ. Safety* 65: 412-419.

Gaur, A. C. 2009. Methods of analysis of organic manures. *In*: Tandon, H. L.S. (Ed.) *Methods of Analysis of Soils, Plants, Waters, Fertilizers and Organic manures.* Fertilizer Development and Consultation Organization, New Delhi, India, pp.184-201.

Geense, P., Pattison, A. B., Kukulies, T. L., Scholberg, J. M. S., and Molina, A. B. 2015. Can changes in soil properties in organic banana production suppress *Fusarium* Wilt? *Nat. Resour.* 6: 181-195

GOI [Government of India]. 1985. *The Fertilizer (Control) Order*, Department of Agriculture and Cooperation, Ministry of Agriculture and Rural Development, New Delhi. 91p.

Gonzalez, C. R., Salinas, D. G. C. and Castillo, J. J. M. 2012. Effect of number of functional leaves at flowering on yield of banana Grand Naine (*Musa* AAA Simmonds) *Rev. Fac. Nal. Agr. Medellín* 65(2): 6585-6591.

Gore, N. S. and Sreenivasa, M. N. Influence of liquid organic manures on growth, nutrient content and yield of tomato (*Lycopersicon esculentum* Mill.) in the sterilized soil *Karnataka J. Agric. Sci.,* 24(2): 153-157.

Groenigen, J. W., Lubbers, I. M., Hannah, M. J. V, Brown, G. B., Deyn, G. B. D and Groenigen, K. J. 2014. Earthworms increase plant production: a meta-analysis. *Sci. rep.* 4 (6365): 1-7.

Guillou, C. L., Angers, D. A., Maron, P. A., Leterme, P. and Menasseri-Aubry, S. 2012. Linking microbial community to soil water-stable aggregation during crop residue decomposition. *Soil Biol. and Biochem.* 50:126-133.

Günzler, H., and Böck, H., 1990. IR-Spectroskopie. Verlag Chemie, Weinheim

Guo, L., Wu, G., Li, C., Liu, W., Yu, X., Cheng, D. and Jiang, G. 2015. Vermicomposting with maize increases agricultural benefits by 304 %. *Agron. Sustain. Dev.* 35: 1149–1155.

Hashemimajd, K., Kalbasi, M., Golchin, A., and Shariatmadari, H., 2004. Comparison of vermicompost and composts as potting media for growth of tomatoes. *J Plant Nutr.* 27(6): 1107–1123.

Hassan, S. A., Mijin, S., Yusoff, U. K., Ding, P., and Wahab, P. E. M. 2012. Nitrate, ascorbic Acid, mineral and antioxidant activities of *Cosmos caudatus* in response to organic and mineral-based fertilizer rates. *Molecules.* 17:7843-7853.

Haynes, R. J. and Zhou, Y. F. 2016. Comparison of the chemical, physical and microbial properties of composts produced by conventional composting or vermicomposting using the same feedstocks. *Environ. Sci. Pollut. Res.* 23(11):10763-10772.

Hazarika,T. K., Bhattacharyya, R. K., and Nautiyal, B. P. 2015 Growth parameters, leaf characteristics and nutrient status of banana as influenced by organics, biofertilizers and bioagents. *J. Plant Nutr.* 38(8):1275-1288.

Hesse, P. R.1994. *A textbook of Soil Chemical Analysis.* CBS Publishers and distributors, New Delhi. 200p.

Hewitt, C.W. 1955. Leaf analysis as a guide to the nutrition of banana. *Exp. J. Expt. Agric.* 23: 11-16.

Huang, K., Li, F., Wei, Y., Fu, X., and Chen, X. 2014. Effects of earthworms on physicochemical properties and microbial profiles during vermicomposting of fresh fruit and vegetable wastes. *Bioresour. Technol.* 170: 45–52

Hunt, J. F., Ohno, T., He, Z., Honeycutt, C.W., and Dail, D. B. 2007. Inhibition of phosphorus sorption to goethite, gibbsite, and kaolin by fresh and decomposed organic matter. *Biol. Fert. Soil* 44: 277-288.

IARI [Indian Agricultural Research Institute] 2012. Crop residues management with conservation agriculture: Potential, constraints and policy needs. Indian Agricultural Research Institute, New Delhi, 32p.

Jackson, M. L. 1958. *Soil chemical analysis.* Prentice Hall Inc., Englewood Cliffs, New Jersey, 110p.

Jenkinson D. S. and Powlson D. S. 1976. The effects of biocidal treatments on metabolism in soil-V. A method for measuring soil biomass. *Soil Biol. Biochem.* 8:209-213.

Jones, R. L. and Kaufman, P. B. The role of gibbrellins in plant cell elongation. *Crit. Rev. Plant Sci.* 1(1): 23-47.

Juárez, P. D. A., de la Fuente, J. L. and Paulín, R. V. 2011. Vermicomposting as a process to stabilize organic waste and sewage sludge as an application for soil. *Trop. Subtrop. Agroecosyst.* 14: 949-963.

Kaiser M., and Ellerbrock R. H. 2005. Functional characterization of soil organic matter fractions different in solubility originating from a long-term field experiment. *Geoderma.*127:196– 206.

Kale, R. D. 1995. Vermicomposting has a bright scope. *Ind. Silk* 34*: 6-9*

Kalemelawa, F., Nishihara, E., Endo, T., Ahmand, Z., Yeasmin, R., and Tenywa, M. M. 2012. An evaluation of aerobic and anaerobic composting of banana peels treated with different inoculums for soil nutrient replenishment. *Bioresour. Technol.* 126:375-382.

Kathirvel, D. 2007. Cost and Returns of Banana Cultivation in Tamil Nadu with Special Reference to Karur District. *J. Contemp. Res. Manage*, North America. 2(1): 11-19.

Katyal, J. C. 1989. Fertilizer use and impact on environment. *In:* FAI Seminar, fertilizer, agriculture and national economy VI/2, Fertilizer Association of India, New Delhi, pp. 1-8.

Kerala Agricultural University (KAU). 2011. *Package of Practices Recommendations: Crops.* (14th Ed). Kerala Agricultural University, Thrissur. 360p.

Khaddar, V. K. and Yadav, S. 2006. Effect of integrated nutrient management practices on soil microbial population in a soybean-wheat cropping sequence. *J. Environ. Res. Develop.* 1(2): 159 – 164.

Khan, A. and Ishaq, F. 2011.Chemical nutrient analysis of different composts (vermicompost and pit compost) and their effect on the growth of a vegetative crop *Pisum sativum. Asian J. Plant Sci. Res.*1 (1):116-130.

Kojima, K. 1995. Simultaneous measurement of ABA, IAA and GA's in citrus– Role of BA in relation to sink ability. *J. Agric. Res.* 29: 179-185.

Kramer, A. 1965. Evaluation of quality of fruits and vegetables *In:*, Irving, Jr. G.W. and Hoover, S. R. (eds.), *Food Quality* American Association for the Advancement of Science, Washington, DC, pp. 9–18.

Kumari, M. S. S. and Ushakumari, K. 2002. Effect of vermicompost enriched with rock phosphate on the yield and uptake of nutrients in cowpea *(Vigna unguiculata* l. Walp) *J. Trop. Agric.* 40: 27-30.

Lal, R. 2005. World crop residues production and implication of its use as a biofuel. *Env. Intl.* 31: 575-586.

Lalitha, R., Fathima, K. and Ismail, S.A. 2000. The impact of bio-pesticide and microbial fertilizers on productivity and growth of *Abelmoschus esculentus. Vasundhara: The Earth.* 1–2:4–9

Lazcano, C. and Dominguez, J. 2011. The Use of Vermicompost in Sustainable Agriculture: Impact on Plant Growth and Soil Fertility. *Soil Nutr.* 10:1–23.

Lee, K. E. 1985. *Earthworms: Their Ecology and Relationships with soils and Land Use.* Academic Press, Sydney, 411p.

Lee, S. K. and Kader, A. A. 2000. Pre harvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biol. Technol.* 20: 207–220.

Leifeld, J., Siebert, S., and Kogel-Knabner, I. 2002. Changes in the chemical composition of soil organic matter after application of compost. *Eur. J. Soil Sci.* 53:299-309.

Lekasi, J. K., Bekunda, M. A., Woomer, P. L., and Tenywa, J. S. 1999. Decomposition of Crop Residues in Banana-Based Cropping Systems of Uganda. *Biol Agri. Hort.*, 17(1):1-10.

Li, K., Fu, S., Zhan, H., Zhan, Y., and Lucia, L. A. 2010. Analysis of the chemical composition and morphological structure of banana pseudostem. *Bio-Resour.* 5(2):576-585.

Lim, S. L., Lee, L. H., and Wu, T. Y. 2016. Sustainability of using composting and vermicomposting technologies for organic solid waste biotransformation: recent overview, greenhouse gases emissions and economic analysis. *J. Clean Prod.* 111 (Part A): 262–278.

Logah, V., Safo, E.Y., Quansah, C., and Danso, I. 2010. Soil microbial biomass carbon, nitrogen and phosphorus dynamics under different amendments and cropping systems in the semi – deciduous forest zone of Ghana. *West African J. Ecol.*, 17: 121 – 133.

Lowe, L. E. 1978 Carbohydrates in Soil. *In:* Schnitzer, M. and Khan, S. U. (eds.) *Soil Organic Matter.* Elsevier Science Publishers B. V. Amsterdam, the Netherlands, pp.65-91

Luo, Y. Q., Wan, S. Q., Hui, D. F., and Wallace, L. L. 2001. Acclimatization of soil respiration to warming in a tall grass prairie. *Nature*, 413: 622–625.

Ma, L., and Xu, R. 2010. Effects of regulation of pH and application of organic material adsorption and desorption of phosphorus in three types of acid soils. *J. Ecol. Rural Environ.* 26:596-599.

Manna, M. C., Rao, S., Sahu, A., and Singh, U. B. 2012. *Compost Handbook: Research-Production–Application, Fertiliser Development and Consultation Organisation*, New Delhi. 132p.

Martin, O. and Dewes, T. 1992. Loss of nitrogenous compounds during composting of animal wastes. *Bioresour. Technol.* 42:103–111.

Masciandaro, G., Ceccanti, B., and Garcia, C. 2000. "*In situ*" vermicomposting of biological sludges and impacts on soil quality. *Soil Biol. Biochem.* 32 (7): 1015–1024.

Masto, E. R., Chhonkar, P.K., Singh, D. and Patra, A. K. 2006. Changes in soil biological and biochemical characteristics in a long-term field trial on a sub-tropical inceptisol. *Soil Biol. Biochem.* 38 (7): 1577–1582.

Mathew, S. K., Mary, G.C.F., and Varghese, R. 2015. Efficacy of ligno-phenolic composts in the growth promotion of vegetables. *Int. J. Sci. Nature.* 6(3):338 -340.

Meera, A. V. 1998. Nutrient economy through seed coating with vermicompost in cowpea. M.Sc. (Ag) thesis. Kerala Agricultural University, Thrissur. 140p.

Memon, N., Memon, K. S., Anwar, R., Ahmad, S., and Nafees, M. 2010. Status and response to improved NPK fertilization practices in banana. *Pak. J. Bot.*, 42(4): 2369-2381.

Miezah, K., Ofosu-Anim, J., Budu, G. K. O., Enu-Kwesi, L., and Cofie, O. 2008. Isolation and identification of some plant growth promoting substances in compost and Co-Compost. *Int. J. Virol.* 4(2):30-40.

Misra, R. V., Roy, R. N., and Hiraoka, H. 2003. On-farm composting methods. Land and water discussion paper 2. Food and Agricultural Organization, Rome, Italy.pp.1-26.

Moldes A., Cendon, Y., and Barral, M. T. 2007. Evaluation of municipal solid waste compost as a plant growing media component by applying mixture design. *Bioresour. Technol.* 98: 3069-3075.

Murbach, M. R., Boaretto, A. E., Muraoka T., and Souza, E. C. A. 2003. Nutrient cycling in a RRIM 600 clone rubber plantation. *Sci. Agric.* 60: 353-357.

Murthy, S. V. K., Iyengar, B. R. V., and Kaeker, N. K. 1995. Comparative absorption and utilization of fertilizer nitrogen applied to Robusta banana (*Musa paradisiaca*) at different growth stages. *Indian J. Agric. Sci.* 65:655-658.

Mutuo, P. K., Shepherd, K. D., Albrecht, A., and Cadisch, G. 2006. Prediction of carbon mineralization rates from different soil physical fractions using diffuse reflectance spectroscopy. *Soil Biol. Biochem.* 38:1658–1664.

Nair, R. V. R., and Sushama, P. K., 2014. Environmentally sustainable composting technique of elephant dung. *Green Farming. J.* *5*(2):230-234.

Nambiar, I. P. S., Marykutty, K. C., Balakrishnan, S., Pillai, M. R. C., and Nayar, M. N. C. 1979. Effect of split application of N and K on banana var. '*Nendran*'. *Agric. Res. J. Kerala.* 17:275-277.

Nannipieri, P., Giagnoni, L., Landi, L., and Renella, G. 2011. Role of phosphatase enzymes in soil. *In:* Bunemann, E., Oberson, A., and Frossard, E. (eds), *Phosphorus in action: Biological processes in soil phosphorus cycling.* Soil biology, 26. Heidelberg: *Springer* pp. 251–244.

NHB [National Horticultural Board]. 2014. *Annual report 2014 – 15.* Ministry of Agriculture & Farmers Welfare, Govt. of India, 124p.

Nattudurai, G., Vendan, S. E., Ramachandran, P. V., and Lingathurai, S. 2014. Vermicomposting of coirpith with cowdung by *Eudrilus eugeniae* Kinberg and its efficacy on the growth of *Cyamopsis tetragonaloba* (L) Taub. *J. Saudi Soc. Agric. Sci.* 13:23–27.

Ngo, P., Rumpel, C., Doan. T., and Jouquet, P. 2012. The effect of earthworms on carbon storage and soil organic matter composition in tropical soil amended with compost and vermicompost. *Soil Biol. Biochem.* 50: 214 – 220.

Nielson, R. L. 1965. Presence of plant growth substances in earthworms demonstrated by paper chromatography and the Went Pea test. *Nature.* 208:1113-1114.

Nisha, J. 2007. Role of microflora in the quality of vermin-products in improving plant growth. M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur, 156p.

O'Brien, T. A. and Barker, A.V. 1996. Growth of peppermint in compost. *J. Herbs Spices Med. Plants* 4: 19-27.

Ojedokun, A. T. and Bello, O. S. 2016. Sequestering heavy metals from wastewater using cow dung. *Water Resourc. Ind.* 13: 7-13.

Okur, N., Kayikçioglu, H. H., Okur, B., and Delibcak, S. 2008 Organic amendments based on tabacco waste compost and farmyard manure: influence on soil biological properties and butter-head lettuce yield. *Turk J Agric For* 32: 91-99.

Padmavathiamma, P. K., Li, L. Y., and Kumari, U. R. 2008. An experimental study of vermibiowaste composting for agricultural soil improvement. *Bioresour. Technol.* 99 (6): 1672–1681.

Pant, A. P., Radovich, T. J. K., Hue, N. V., Talcott, S. T., and Krenek, K. A. 2009. Vermicompost extracts influence growth, mineral nutrients, phytonutrients and antioxidant activity in pak choi (*Brassica rapa cv. Bonsai*, Chinensis group) grown under vermicompost and chemical fertilizer. *J. Sci. Food. Agr.* 89(14): 2383–2392.

Parthasarathi, K. 2007. Influence of moisture on the activity of *Perionyx excavatus* (Perrier) and microbial—nutrient dynamics of pressmud vermicompost. *Iran J. Environ. Health Sci. Eng.* 4(3):147–156.

Parthasarathi, K., Balamurugan, M. Prashija, K. V., Jayanthi, L., and Basha, S. A. 2016. Potential of *Perionyx excavatus* (Perrier) in lignocellulosic solid waste management and quality vermifertilizer production for soil health. *Int. J Recycl. Org. Waste Agric.*5: 65–86.

Parthasarathy, K., Balu, D. R. C., and Rao, P. S. 1970. Studies on sandal spur. VII. Polyphenol oxidase activity and metabolism of sandal (*Santalum album*) in healthy and diseased. *Proc. Indian Acad. Sci.* 72: 277-284.

Pathma, J. and Sakthivel, N. 2012. Microbial diversity of vermicompost bacteria that exhibit useful agricultural trait and waste management potential. *Springer Plus*, 1: 26.

Pattnaik, S. and Reddy, M. V. 2010. Nutrient status of vermicompost of urban green waste processed by three earthworm species—*Eisenia fetida, Eudrilus eugeniae*, and *Perionyx excavatus*. *Appl. Environ. Soil Sci.* 13p.

Pattnaik, S. and Reddy, M. V. 2009. Bioconversion of municipal (organic) solid waste into nutrient rich vermicompost by earthworm *Eudrilus eugeniae, Eisenia fetida* and *perionyx excavatus. Dyn. Soil Dyn. Plant*, 3: 122 - 128.

Pettit, R. E. 2004. Organic matter, humus, humate, humic acid, fulvic acid and humin: Their importance in soil fertility and plant health [Online]. Available: http://static1.squarespace.com/static.pdf [22Jun 2016]

Piper, C. S.1966. *Soil and Plant Analysis*. Hans Publishers, Bombay, India.368p.

Preetha, D. 2003. Biotic enrichment of organic wastes from ayurvedic preparations. M.Sc (Ag) thesis, Kerala Agricultural University, Thrissur. 94p.

Rahman, M. M., Islam, A. K. M. S., Salehin, S., and Al-Matin, M. A. 2016. Development of a model for techno-economic assessment of a stand-alone off-grid solar photovoltaic system in Bangladesh. *Int. J. Renew. Energy Res.* 6(1):140 – 149.

Rajalakshmi, D., and Narasimhan, S. 1996. Food antioxidants: Sources and methods of evaluation. *In:* Madhavi, D. L., Deshpande, S. S., and Salunkhe, D. K. (eds), *Food Antioxidants: Technological, Toxicological, and Health Perspectives.* Marcel Dekker Inc., New York, pp. 65-158

Rajalekshmi, K. 1996. Effects of vermicompost/ vermiculture on physicochemical properties of soil. M.Sc. (Ag) thesis, Kerala Agricultural University, Vellanikkara, 126p.

Rajput, A., Memon, M., Memon, K. S., and Tunio, S. 2015. Integrated nutrient management for better growth and yield of banana under Southern Sindh climate of Pakistan. *Soil Environ.* 34(2):126-135.

Rao, Ch. S., Venkateswarlu, B., Babu, D. D., Wani, M., Dixit, S., Sahrawat, K. L. S., and Kundu, S. 2011. *Soil Health Improvement with Gliricidia Green Leaf Manuring in Rainfed Agriculture, On Farm Experiences*. Central Research Institute for Dryland Agriculture, Santoshnagar, P.O. Saidabad, Hyderabad 500 059, Andhra Pradesh, p16.

Raphael, L., Sierra, J., Recous, S., Ozier-Lafontaine, H., and Desfontaines, L. 2012. Soil turnover of crop residues from the banana (*Musa* AAA cv. Petite-Naine) mother plant and simultaneous uptake by the daughter plant of released nitrogen. *Eur. J. Agron.* 38:117– 123

Robinson, J. C., and Sauco, V. G., 2010. *Bananas and Plantains* (2nd Ed.). CAB International., Oxfordshire, U.K, 273p.

Robinson, J.C. 1996. *Bananas and Plantains.* CAB International, Wallingford. 238p

Robison, W. L., Brown, P. H., Stone E. L., Hamilton, T. F., Conrado, C. L., and Kehla, S. 2008. Distribution and ratios of ^{137}Cs and K in control and K-treated coconut trees at Bikini Island where nuclear test fallout occurred: Effects and implications. *J. environ. radioact.* pp. 1-20.

Ross D. J. 1987. Soil microbial biomass estimated by the fumigation-incubation procedures: seasonal fluctuation and influence of soil moisture content. *Soil Biol. Biochem.* 19: 397–404.

Ross, M., Klammer, S., Knapp, B., Aichberger, K., and Insam, H. 2006. Long-term effects of compost amendment of soil on functional and structural diversity and microbial activity. *Soil Use Manage.* 22:209-218.

Sabrina, D.T., Hanafi, M. M., Gandahi, A. W., Mohamed, M. T.M., and Aziz, N. A. A. 2013. Effect of mixed organic-inorganic fertilizer on growth and phosphorus uptake of setaria grass (*Setaria splendida*). *Aust. J. Crop Sci.* 7(1):75-83.

Saha, S., Mina, K. A., Gopinath, B. L., and Kundu, S., and Gupta, H. S. 2008. Relative changes in phosphatase activities as influenced by source and application rate of organic composts in field crops. *Bioresour. Technol.* 99:1750–1757.

Sarnklong, C., Cone, J.W., Pellikaan, W., and Hendriks, W.H. 2010. Utilization of rice straw and different treatments to improve its feed value for ruminants: A Review. *Asian Australas J Anim Sci.* 23: 680–692.

Sarwar, M., Arshad, M., Martens, D. A., and Frankenberger, W.T. 1992.Tryptophan-dependent biosynthesis of auxins in soil. *Plant Soil* 147: 207-215.

Scaglia, B., Pognani, M., and Adani, F. 2015. Evaluation of hormone-like activity of the dissolved organic matter fraction (DOM) of compost and digestate *Sci. Total Environ.* 514:314–321.

Schnitzer, M. 1982. Organic matter characterization. *In:* Page, A. L., Miller, R. H., and Keeney, D. R., (eds), *Methods of Soil Analysis Part 2, Chemical and Microbiological Properties'. Agronomy No. 9.* (2nd Ed.). Madison, Wisconsin, USA. pp. 581-594.

Selvamani, P. and Manivannan, K. 2009. Effect of organic manures, inorganic fertilizers and biofertilizers on the nutrient concentration in leaves at different growth stages of banana *cv. Poovan. J. Phytol.* 1(6): 381-387.

Shariatmadari H., Shirvani M., and Jafari, A. 2006. Phosphorus release kinetics and availability in calcareous soils of selected arid and semiarid toposequence. *Geoderma.* 132, 261-272.

Sheela, V.L. and Nair, R. S. 2001. Growth, flowering and yield potential of tissue culture banana. *J Trop Agr.* 39: 1-4.

Siddique, J., Khan, A. A., Hussain, I., and Akhter, S. 2005. Growth and Reproduction of Earthworm *(Eisenia fetida)* in Different Organic Media. *Pakistan J. Zool.,* 37(3): 211-214.

Sierra, J., Desfontaines, L., Faverial, J., Loranger-Merciris, G., and Boval, M. 2013. Composting and vermicomposting of cattle manure and green wastes under tropical conditions: carbon and nutrient balances and end-product quality. *Soil Res.* 51(2): 142-151.

Simon, T. 2007. Quantitative and qualitative characterization of soil organic matter in the long-term fallow experiment with different fertilization and tillage. *Arch. Agron. Soil Sci.* 53:241-251

Sims, J. T. 1990. Nitrogen mineralization and elemental availability in soils amended with cocomposted sewage sludge. *J Environ. Qual.* 19: 669-675.

Singh, A., Singh, R.V., Saxena, A. K., Shivay, Y. S., and Nain, L. 2014. Comparative studies on composting efficiency of *Eisenia foetida* (Savigny) and *Perionyx excavatus* (Perrier). *J Exp. Biol. Agric. Sci.* 2(5): 508-517.

Singh, H. P., and Mustaffa, M. M. M. 2009. *Banana: New Innovations*. Westville Publishing House, New Delhi. 212p.

Singh, J. S., Pandey, V. C., and Singh, D. P. 2011. Efficient soil microorganisms: A new dimension for sustainable agriculture and environmental development. *Agric. Ecosyst. Environ.* 140: 339–353.

Singh, S. and Nain, L. 2014. Microorganisms in the conversion of agricultural wastes to compost. *Proc. Indian Natl. Sci. Acad.* 80 (2): 473-481.

Sinha, R. K. 2009. The concept of sustainable sgriculture: An issue of food safety and security for people, economic prosperity for the farmers and ecological security for the nations. *American-Eurasian J. Agric. Environ. Sci.*, 5 (S):1-55.

Sivananthi, T and Paul, J. A. J., 2014. Effect of Humic acid of vermicompost on *Zea mays* root growth *Scrut. Int. Res. J. Agri., Plant Biotechnol. Bio Prod.* 1(2):7-16

Sommer, S. G. 2001. Effect of composting on nutrient loss and nitrogen availability of cattle deep litter. *Euro. J. Agron.*14:123–133.

Sreedevi, L. and Suma, D. A. 2015. Comparative Quality analysis of Banana (var *palayamkodan*). *Int. Res. J. Biological Sci.* 4(4): 6-11.

Srikanth, K., Srinivasmurthy, C. A., and Parama, V. R. R. 2000. Direct and residual effect of chemical compost, cowdung, vermicompost and fertilizers on properties of an alfisol. *J. Indian Soc. Soil Sci.* 48(3): 496-499.

Steniford, E. 1987. Recent developments in composting. In: de Bertoldi, M., Ferranti, M., and Zucconi, F. (eds), *Compost, Production, Quality and Use*. Elsevier, London, pp. 52-60.

Stevenson, F.J., 1994. *Humus chemistry: genesis, composition, reactions.* John Wiley and Sons, New York.

Stott, D. E. and Martin, J. P., 1990. Synthesis and degradation of natural and synthetic humic material in soils. *In:* MacCarthy, P., Clapp, C.E., Malcolm, R.L., and Bloom, P.R. (eds), *Humic substances in soil and crop sciences: selected readings.* American Society of Agronomy, Soil Science of America, Madison, pp. 37–63.

Strayer, R. F. and Atkinson, C. F. 1997. An overview: Recycling nutrients from crop residues for space applications. *Compost Sci. Utilis.* 5(3):25 -31.

Subbiah B.V. and Asija G. L. 1956. A rapid procedure for estimation of available nitrogen in soils. *Curr. Sci.,* 25: 259–260.

Sundberg, B. 1990. Influence of extraction solvent (buffer, methanol, acetone) and time on the quantification of indole-3-acetic acid in plants. *Plant Physiol.* 78: 293-297.

Sureshkumar, P. and Sandeep, S. 2015. Secondary nutrients and their management. *In:* Rattan, R. K., Katyal, J. C., Dwivedi, B. S., Sarkar, A. K., Bhattacharyya, T., Tarafdar, J. C., and Kulal, S. S. (eds), *Soil Science: An Introduction.* Indian Society of Soil Science, New Delhi. pp. 601-622.

Sushama P. K., John, S. K., and Gopinathan, R 2010. *Chemistry of composting,* Director of Extension, Kerala Agricultural University, Mannuthy, Thrissur. 78p.

Suthar, S. 2009. Impact of vermicompost and composted farmyard manure on growth and yield of garlic (*Allium stivum* L.) field crop. *Int. J. Plant Prod.* 3 (1): 27-38.

Suthar, S. and Gairola, S. 2014. Nutrient recovery from urban forest leaf litter waste solids using *Eisenia fetida. Ecol. Eng.* 71, 660–666.

Swarnam, T.P., Velmurugan, A., Pandey, S. K., and Roy, D. S. 2016. Enhancing nutrient recovery and compost maturity of coconut husk by vermicomposting technology. *Bioresour. Technol.* 207:76-84.

Szajdak, L., and Maryganova, V. 2009. Impact of age and composition of shelterbelts plants on IAA content as allelochemical in soils. *Allelopathy J.* 23(2): 461-468.

Tabatabai, M. A. and Bremner, J. M. 1969. Use of *p*-nitrophenyl phosphate for assay of soil phosphatase activity. *Soil Biol. Biochem.* 1:301–307.

Tabatabai, M. A., and Bremner, J. M. 1972. Assay of urease activity in soils. *Soil Biol. Biochem.* 4:479-487.

Thangaselvabai, T., Suresh, S., Joshua, J. P., and Sudha, K. R. 2009. Banana nutrition – A Review. *Agric. Rev.,* 30 (1): 24 – 31.

Tiquia, S. M. 2002. Evolution of extracellular enzyme activities during manure composting. *J. Appl. Microbiol.,* 92(4): 764–775

Trevisan, S., Francioso, O., Quaggiotti, S., and Nardi, S. 2010. Humic substances biological activity at the plant-soil interface – From environmental aspects to molecular factors. *Plant Signal Behav.* 5:6, 635-643.

Tripathi, G. and Bhardwaj, P. 2004. Earthworm diversity and habitat preferences in arid regions of Rajasthan. *Zoo's Print J.* 19: 1515-1519.

Vanilarasu, K. and Balakrishnamurthy, G. 2014. Influences of organic manures and amendments in soil physiochemical properties and their impact on growth, yield and nutrient uptake of banana. *The Bioscan.* 9(2): 525-529.

Vijayan, V.D. 2015. Heavy metal contamination of laterites by accumulation of solid wastes. PhD thesis. Kerala Agricultural University, Thrissur, Kerala. 146p.

Walkley, A., and Black, I. A. 1935. An examination of the Degtareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* 37: 29-38.

Wang, J., Hu, Z., Xu, X., Jiang, X., Zheng, B., Liu, X., Pan, X. and Kardol, P. 2014. Emissions of ammonia and greenhouse gases during combined pre-composting and vermicomposting of duck manure. *Waste Manage.* 34(8):1546-1552.

Watanabe, F. S. and Olsen, S. R. 1965. Test of an ascorbic acid method for determining phosphorus in water and NaHC03 extracts from soil. *Soil S ci. Soc. Am. Proc.* 29:677-678.

Werner, M. and Cuevas, R., 1996. *Vermiculture in Cuba. Biocycle.* Emmaus, PA., JG Press. 37: 61-62.

Wieder, W. R., Bonan, G. B. and Allison, S. D. 2013. Global soil carbon projections are improved by modelling microbial processes, *Nature Clim. Change*, 3: 909–912.

Wlodarczyk, T. 2000. Some of aspects of dehydrogenase activity in soils. *Int. Agrophysics, 14: 365-376.*

Wobiwo, F. A., Mercy, A. B. L. and Emaga, H. T. 2015. Nutritive Value of three varieties of banana and plantain blossoms from Cameroon. *Greener J. Agri. Sci.* 5(2): 52-61.

Wohler I. 1997. Auxin-indole derivatives in soils determined by a colorimetric method and by high performance liquid chromatography. *Microbiol. Res.*152:399-405.

Wollum, A. G., 1982. *Methods of Soil Analysis*. Madison, Wisconsin, USA, pp.781-801.

Wu, D., Liu, P., Luo, Y., Tian, G., and Mahmood, Q. 2010. Nitrogen transformations during co-composting of herbal residues, spent mushrooms, and sludge. *J Zhejiang Univ Sci B*. 11(7), 497-505.

Zandonadi, D. B., and Busato, J. G. 2012. Vermicompost humic substances: technology for converting pollution into plant growth regulators. *Int. J. Environ. Sci. Eng. Technol.* 3:73-84.

Zandonadi, D. B., Santos, M. P., Busato, J. G., Peres, L. E. P., and Facanha, A. R. 2013. Plant physiology as affected by humified organic matter. *Theor. Exp. Plant Physiol.* 25(1): 12-25

Zhang, B. G., Li, G. T., Shen, T. S., Wang, J. K., and Sun, Z. 2000. Changes in microbial biomass C, N and P and enzyme activities in soil incubated with the earthworm *Metaphire guillelmi* or *Eisenia fetida*. *Soil Biol. Biochem.* 32: 2055-2062.

Zomo, S. A., Ismail, S. M., Jahan, M. S., Kabir, K., and Kabir, M. H. 2014. Chemical properties and shelf life of banana (*Musa sapientum* L.) as influenced by different postharvest treatments. *The Agriculturists.* 12(2): 6-17.

Zorpas, A. A., Arapoglou, D., and Panagiotis, K. 2003. Waste paper and clinoptilolite as a bulking material with Dewatered Anaerobically Stabilized Primary Sewage Sludge (DASPSS) for compost production. *Waste Manage.* 23:27–35.

Zsolnay, A., 1996. Dissolved humus in soil waters. In: Piccolo, A. (ed.), *Humic substances in terrestrial ecosystems.* Elsevier, Amsterdam, pp. 171–223.

Appendix I. Correlation between compost quality with its chemical and biochemical parameters

	Moisture	pH	EC	TC	TN	TP	TK	TCa	TMg	TS	TFe	TZn	TMn	TCu	TNi	TCr	Auxin	Dehy	Ash
Moisture	1																		
pH	.931**	1																	
EC	.686**	.754**	1																
TC	.803**	.898**	.764**	1															
TN	.810**	.909**	.758**	.994**	1														
TP	.687**	.754**	1.000**	.765**	.759**	1													
TK	.688**	.755**	1.000**	.765**	.759**	1.000**	1												
TCa	.545*	.744**	0.431	.710**	.733**	0.431	0.431	1											
TMg	0.255	0.312	-0.083	0.132	0.162	-0.084	-0.083	.655**	1										
TS	.776**	.886**	.784**	.980**	.978**	.785**	.785**	.705**	0.144	1									
TFe	-0.427	-.565**	-.772**	-.766**	-.748**	-.773**	-.772**	-0.381	0.369	-.767**	1								
TZn	.580**	.787**	.480*	.775**	.800**	.480*	.481*	.963**	.535*	.770**	-.506*	1							
TMn	0.095	0.03	-.453*	-0.25	-0.212	-.454*	-.453*	0.219	.763**	-0.277	.770**	0.093	1						
TCu	-0.094	-0.189	-.566**	-.440*	-0.411	-.567**	-.566**	0.039	.699**	-.452*	.895**	-0.115	.956**	1					
TNi	-0.258	-0.363	-.622**	-.605**	-.582**	-.622**	-.623**	-0.265	0.292	-.630**	.853**	-0.356	.702**	.799**	1				
TCr	-0.235	-0.343	-.535*	-.543*	-.528*	-.536*	-.536*	-0.276	0.198	-.584**	.727**	-0.364	.536*	.660**	.948**	1			
Auxin	.531*	.590**	.713**	.696**	.674**	.712**	.713**	0.207	-0.164	.718**	-.706**	0.362	-.486*	-.602**	-.597**	-.533*	1		
Dehy	.522*	.598**	.643**	.702**	.700**	.643**	.644**	0.327	-0.019	.740**	-.592**	.436*	-0.282	-.441*	-.567**	-.611**	.806**	1	
Ash	-.775**	-.877**	-.801**	-.911**	-.909**	-.801**	-.802**	-.702**	-0.106	-.879**	.802**	-.776**	0.287	.485*	.613**	.534*	-.652**	-.600**	1

Appendix II. Quality standards for city/ urban composts and vermicomposts as per Fertilizer (Control) Order, 1985

Parameters	**City compost**	**Vermicompost**
Total organic carbon (% by weight, minimum)	12	18
Total N (as N % by weight, minimum)	0.8	1
Total phosphates as P_2O_5 (% by weight, minimum)	0.4	0.8
Total potashs as K_2O (% by weight, minimum)	0.4	--
C:N ratio	<20	--
pH	6.5 - 7.5	--
Conductivity (as dS m^{-1}) not more than	4	--
Heavy metal content (as mg kg^{-1}) maximum		
As (asAs_2O_3)	10	--
Cd (as Cd)	5	5
Cr (as Cr)	50	50
Cu (as Cu)	300	--
Ni (as Ni)	50	50
Pb (as Pb)	100	100
Zn (as Zn)	500	--

Appendix III. Benefit – cost analysis of banana cultivation under different treatments

Treatments	B:C ratio
S	-
POP	1.11
Ex-P	1.01
Ex-E	1.21
In-P	1.13
In-E	1.17
In-C	1.26

Appendix IV. Correlation between yield, growth and bunch characterstics of banana

	Functional Leaf (No.)	Pseudostem height	Pseudostem girth	Bunch yield	No. of hands /Bunch	Wt. of fingers	No. of fingers/hand
Functional Leaf (No.)	1						
Pseudostem height	0.407	1					
Pseudostem girth	.619**	.696**	1				
Bunch yield	.704**	.638**	.820**	1			
No. of hands /Bunch	.638**	.711**	.668**	.694**	1		
Wt. of fingers	.816**	.543*	.761**	.877**	.669**	1	
No. of fingers/hand	.746**	.622**	.613**	.751**	.603**	.728**	1

Appendix Va. Sensory evaluation chart

Sensory evaluation

Name of scorer: RINCY ROSE T JOHN
Date: 18-3-2015

Please score the given banana fruit chops using the 9 point Hedonic scale

Score	Inference
9	Like extremely
8	Like very much
7	Like moderately
6	Like slightly
5	Neither like not dislike
4	Dislike slightly
3	Dislike moderately
2	Dislike very much
1	Dislike extremely

Treatments	Colour	Taste	Texture	Flavor	Appearance	Sweetness	Overall acceptability
T6	6	7	7	7	7	7	7
T3	6	6	6	7	6	6	6
T2	9	8	8	8	8	9	~~8~~9
T7	8	8	9	8	9	8	8
T5	8	8	7	7	8	8	8
T4	7	6	7	7	8	6	7
T1	6	5	7	7	6	4	5

Remarks:

Signature R. Rose

Appendix V b. Sensory evaluation chart

Sensory evaluation

Name of scorer: Vaisakhi K.C.
Date: 18/8/2015

Please score the given banana fruit chops using the 9 point Hedonic scale

Score	Inference
9	Like extremely
8	Like very much
7	Like moderately
6	Like slightly
5	Neither like not dislike
4	Dislike slightly
3	Dislike moderately
2	Dislike very much
1	Dislike extremely

Treatments	Colour	Taste	Texture	Flavor	Appearance	Sweetness	Overall acceptability
✓ T_6	6	6	7	7	6	7	6
T_3	5	6	7	6	5	8	7
T_2	9	7	6	7	9	9	9
T_7	8	8	6	8	7	9	8
T_5	7	8	8	8	8	8	8
T_4	6	7	8	7	5	5	7
T_1	6	5	6	6	4	6	6

Remarks:

Signature Vaisakhi

Appendix Vc. Sensory evaluation chart

Sensory evaluation

Name of scorer: Aswathy Gopinadhan
Date: 18/3/2015

Please score the given banana fruit chops using the 9 point Hedonic scale

Score	Inference
9	Like extremely
8	Like very much
7	Like moderately
6	Like slightly
5	Neither like not dislike
4	Dislike slightly
3	Dislike moderately
2	Dislike very much
1	Dislike extremely

Treatments	Colour	Taste	Texture	Flavor	Appearance	Sweetness	Overall acceptability
T6	6	6	5	6	5	5	5
T3	5	5	5	5	6	5	5
T2	8	8	8	7	8	7	8
T7	7	8	7	8	8	7	7
T5	7	7	6	6	7	6	6
T1	6	5	5	6	7	4	5
T4	7	6	6	7	8	7	7

Remarks:

Signature Aswathy Gopinadhan

Appendix Vd. Sensory evaluation chart

Sensory evaluation

Name of scorer: R.V. RAMANA
Date: 18|3|15

Please score the given banana fruit chops using the 9 point Hedonic scale

Score	Inference
9	Like extremely
8	Like very much
7	Like moderately
6	Like slightly
5	Neither like not dislike
4	Dislike slightly
3	Dislike moderately
2	Dislike very much
1	Dislike extremely

Treatments	Colour	Taste	Texture	Flavor	Appearance	Sweetness	Overall acceptability
T6	9	7	6	7	8	7	7
T3	7	8	6	7	7	6	6
T2	9	9	8	8	9	9	9
T7	8	8	7	8	8	8	8
T5	7	8	6	7	8	8	7
T4	7	8	7	7	8	7	7
T1	6	5	5	6	7	4	5

Remarks:

Signature

Appendix Ve. Sensory evaluation chart

Sensory evaluation

Name of scorer: BHAVYASREE K T
Date: 18·03·15

Please score the given banana fruit chops using the 9 point Hedonic scale

Score	Inference
9	Like extremely
8	Like very much
7	Like moderately
6	Like slightly
5	Neither like not dislike
4	Dislike slightly
3	Dislike moderately
2	Dislike very much
1	Dislike extremely

Treatments	Colour	Taste	Texture	Flavor	Appearance	Sweetness	Overall acceptability
1 T_5	8	8	7	7	7	7	8
2 T_4	7	8	7	6	7	7	7
3· T_3	7	8	6	7	7	6	6
4 T2	9	9	8	8	9	9	9
5 T_1	7	6	7	7	6	4	6
6· T6	4	6	4	7	9	7	6
7 ·T7·	8	8	7	8	8	8	8

Remarks:

Signature Bhavya

Appendix Vg. Sensory evaluation chart

Sensory evaluation

Name of scorer: M. Surya
Date: 18/03/2015

Please score the given banana fruit chops using the 9 point Hedonic scale

Score	Inference
9	Like extremely
8	Like very much
7	Like moderately
6	Like slightly
5	Neither like not dislike
4	Dislike slightly
3	Dislike moderately
2	Dislike very much
1	Dislike extremely

Treatments	Colour	Taste	Texture	Flavor	Appearance	Sweetness	Overall acceptability
① T5	7	8	8	7	6	7	7
② T4	8	7	7	7	8	6	6
③ T3	5	6	6	7	8	7	6
④ T6	7	9	8	7	8	7	8
⑤ T1	6	5	5	6	7	4	5
⑥ T7	8	8	6	6	7	7	7
⑦ T2	8	9	9	7	7	8	9

Remarks:

Signature

Appendix Vh. Sensory evaluation chart

Sensory evaluation

Name of scorer: Sreenath. P.V

Date: 18/03/15

Please score the given banana fruit chops using the 9 point Hedonic scale

Score	Inference
9	Like extremely
8	Like very much
7	Like moderately
6	Like slightly
5	Neither like not dislike
4	Dislike slightly
3	Dislike moderately
2	Dislike very much
1	Dislike extremely

Treatments	Colour	Taste	Texture	Flavor	Appearance	Sweetness	Overall acceptability
T1	7	8	8	5	7	8	8
T2	8	8	8	7	7	7	9
T4	7	6	6	7	8	7	7
T5	7	7	7	5	6	6	6
T3	4	6	4	6	9	7	6
T6	6	6	7	7	6	7	6
T7	7	8	8	7	8	8	8

Remarks:

Signature 18/03/15

Appendix Vi. Sensory evaluation chart

Sensory evaluation

Name of scorer: ARUN. G
Date: 18/03/2015,

Please score the given banana fruit chops using the 9 point Hedonic scale

Score	Inference
9	Like extremely
8	Like very much
7	Like moderately
6	Like slightly
5	Neither like not dislike
4	Dislike slightly
3	Dislike moderately
2	Dislike very much
1	Dislike extremely

Treatments	Colour	Taste	Texture	Flavor	Appearance	Sweetness	Overall acceptability
T6	7.0	7.0	6.0	6.0	6.0	7.0	7.0
T3	6.5	7.0	6.5	6.5	7.0	7.0	6.5
T2	8.0	8.0	7.5	8.0	8.0	8.0	8.0
T7✓	7.5	7.0	8.0	7.5	7.5	7.0	7.5
T5	7.0	8.0	8.0	8.0	8.0	7.0	7.5
T4	7.0	6.0	6.5	6.5	6.5	6.0	6.0
T1	7.0	6.0	7.0	7.0	6.0	4.0	6.0

Remarks:

18/03/2015

Signature

Appendix Vj. Sensory evaluation chart

Sensory evaluation

Name of scorer: Nithya Jose
Date: 18|3|2015

Please score the given banana fruit chops using the 9 point Hedonic scale

Score	Inference
9	Like extremely
8	Like very much
7	Like moderately
6	Like slightly
5	Neither like not dislike
4	Dislike slightly
3	Dislike moderately
2	Dislike very much
1	Dislike extremely

Treatments	Colour	Taste	Texture	Flavor	Appearance	Sweetness	Overall acceptability
T6	6	7	8	8	8	7	8
T3	6	7	7	7	6	7	7
T2	9	9	9	9	9	9	9
T7	8	8	8	7	8	8	8
T5	7	7	7	7	8	7	7
T4	7	7	6	7	6	5	6
T1	6	5	6	6	4	6	6

Remarks:

Signature Nithya Jose

Appendix VIb. Effect of treatments on content of nutrients in rhizome residues of banana

Nutrients	Treatments							CD (p=0.05)
	S	POP	Ex-P	Ex-E	In-P	In-E	In-C	
C	21.55	23.75	32.83	26.72	24.28	33.43	30.69	1.39
N	2.77	2.97	3.2	3.58	3.13	2.77	3.1	0.19
P	0.22	0.37	0.19	0.59	0.48	0.3	0.24	0.1
K	0.53	1.06	0.88	0.55	1	0.95	0.79	0.05
Ca	0.45	0.74	0.69	1.23	1.44	0.46	0.73	0.02
Mg	0.23	0.35	0.28	0.33	0.36	0.27	0.3	0.02

EFFICIENCY OF VERMICONVERSION AND DECOMPOSITION OF FARM RESIDUES ON SOIL HEALTH, YIELD AND QUALITY OF BANANA (*Musa spp.*)

by

MAYADEVI, M. R.

(2012 – 21 - 126)

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the
Requirement for the degree of

DOCTOR OF PHILOSOPHY IN AGRICULTURE

Faculty of Agriculture
Kerala Agricultural University

Department of Soil Science and Agricultural Chemistry

COLLEGE OF HORTICULTURE

KERALA AGRICULTURAL UNIVERSITY

THRISSUR 680656

KERALA, INDIA

2016

ABSTRACT

An investigation entitled "Efficiency of vermiconversion and decomposition of farm residues on soil health, yield and quality of banana (*Musa spp.*)" was undertaken at College of Horticulture and Banana Research Station, Kannara during 2013-2015. The objectives of the study were to compare the efficiency of native and exotic earthworms on vermiconversion of farm residues and the effects of different modes of vermicomposting on soil health, yield and quality of banana and to evaluate the *in situ* decomposition of banana crop residues

An experiment with seven treatments and three replications was laid out in randomized block design to assess the composting efficiency of native and exotic earthworms. Seven treatments included absolute control as soil (S), *ex-situ* compost in silpaulin vermibed without earthworms (Ex-C), *ex-situ* vermicompost in silpaulin vermibed using *Perionyx excavatus* (Ex-P), *ex-situ* vermicompost in silpaulin vermibed using *Eisenia foetida* (Ex-E), *in-situ* vermicompost in banana planting pits using *Perionyx excavatus* (In-P), *in-situ* vermicompost in banana planting pits using *Eisenia foetida* (In-E), *in-situ* compost in banana planting pits without earthworms (In-C). In the next study, the prepared composts were tested along with recommended doses of fertilizers and FYM to assess their effects on growth, yield and crop quality of banana var. *Nendran* in RBD with seven treatments replicated thrice. The treatments were absolute control (S), 300:115:450g $N:P_2O_5:K_2O$ plant^{-1} + FYM at the rate of 20 kg plant^{-1} (POP), *ex-situ* vermicompost in silpaulin vermibeds with *Perionyx excavatus* at the rate of 20 kg plant $^{-1}$ (Ex–P), *ex-situ* vermicompost in silpaulin vermibeds with *Eisenia foetida* at the rate of 20 kg plant $^{-1}$ (Ex–E), *in-situ* vermicompost in crop pits with *Perionyx excavatus* at the rate of 20 kg plant $^{-1}$ (In-P), *in-situ* vermicompost in crop pits with *Eisenia foetida* at the rate of 20 kg plant $^{-1}$ (In-E), *in -situ* compost at the rate of 20 kg plant $^{-1}$ (In-C). After the harvest of the crop, the entire residues from each plant was incorporated in the respective crop pits and the *in-situ* degradation of the banana residues was monitored. The salient findings are summarized as follows

In the first trial, the composting efficiency of native and exotic earthworms under different modes of composting was compared. Chemical properties of compost like pH, electrical conductivity, and content of primary nutrients were significantly affected by modes of composting. Exotic earthworms like *Eisenia foetida* produced higher auxin content in the compost whereas *Perionyx excavatus* registered higher dehydrogenase activity under ex-situ mode of composting. The total microbial load was recorded in the compost prepared without earthworms under both modes of composting. Compost yield was more in *ex-situ* composting methods and *Eisenia foetida* was more efficient in composting as compared to *Perionyx excavatus*. Humic acid characterization by Fourier Transform Infra-Red spectroscopy revealed a similar spectra from different treatments and were found to be characterized by aromatic rings and triple bonded skeleton. Presence of relatively higher quantity of polysaccharide like substances was observed in *in-situ* mode of composting. The spectra of humic acids for *ex-situ* composts prepared using *Perionyx excavatus* revealed a nitrate band of characteristic shape appearing prominently. *Perionyx excavatus* produced humic acids with high aromaticity both under *ex-situ* and *in-situ* mode of composting. Scanning electron microscopy revealed neo-formed $CaCO_3$ nodules embedded in humic acids in the ex-situ vermicompost produced by *Eisenia foetida*. Transmission Electron Microscopy of humic acids indicated a globular structure for vermicompost prepared by *Perionyx excavatus* and a lamellar structure with voids for vermicompost prepared using *Eisenia foetida*.

On field experimentation with different treatments using Nendran banana as the test crop, the highest yield was obtained for combined application of fertilizers and farm yard manure as per POP. Number of fingers per hand and number of functional leaves were found to influence the yield, irrespective of treatments. The number of days to bunching and harvest was significantly reduced for banana under *in-situ* composting. Higher content of total, reducing and non-reducing sugars were observed for *in-situ* composting treatments. On the contrary, higher titratable acidity was recorded for the control treatment. Both vitamin C content and sensory parameters were complimentary for POP treatment. Increased absorption and translocation of nutrients such as N, P, K and Mg in fruits were observed under organic nutrition using *Perionyx excavatus*.

For the next study, the residues of banana were added to the respective pits for monitoring the carbon and nitrogen mineralization. The carbon mineralization with respect to time was fitted to single pool exponential model to derive the rate of mineralization and half-life. It revealed crop residues pre-treated with vermicompost using exotic earthworms had a higher rate of cumulative C mineralization. Nitrogen addition by both exotic and native species of earthworms were almost similar under *in-situ* conditions. The banana residue decomposition by *Eisenia foetida* was about 3.5 times higher than that of *Perionyx excavatus*. *Perionyx excavatus* pre-treated residues added the maximum calcium to the soil.