VERMICOMPOSTING OF VEGETABLE GARBAGE

By

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THESIS
SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENT FOR THE DEGREE OF
MASTER OF SCIENCE IN AGRICULTURE
(SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)
FACULTY OF AGRICULTURE
KERALA AGRICULTURAL UNIVERSITY

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE
VELLAYANI
THIRUVANANTHAPURAM
1995

DECLARATION

I hereby declare that this thesis entitled "Vermicomposting of vegetable garbage" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Vellayani,
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ACKNOWLEDGEMENT

At the very outset, I wish to place on record my deep sence of gratitude and fervent indebtedness to God Almighty for all the bountiful blessings he has showered upon me at each and every moment without which the study would not have ever seen light.

It is as much my present duty, as it is my previlage to express my sincere gratitude to the Chairman of my advisory committee Dr. (Mrs.) Prabhakumari, P., Assistant professor, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani, for the able guidance and valuable suggestions extended to me during the conduct of this research work and for the co-operation and generous help in the preparation of this thesis.

I express my sincere gratitude to Dr. (Mrs.) P. Padmaja, Professor and Head, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani, for her helpful suggestions and critical scrutiny of the manuscript.

I am extremely thankful to Dr. (Mrs.) Alice Abraham, Professor, Departmen of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani, for her valuable help rendered during the course of the study and for critically reviewing the manuscript.

I earnestly express my sincere thanks to Dr. S.K. Nair, Professor of Microbiology, Department of Plant Pathology, College of Agriculture, Vellayani for his valuable advice, timely assistance during the course of my work and for critical scrutiny of the manuscript.

I am grateful of Sri. C.E. Ajithkumar, Junior Programmer, Department of Agricultural Statistics, College of Agriculture, Vellayani, for rendering his help in computer analysis of the experimental data.

I avail this opportunity to express my profound sense of gratitude to Dr. P. Manikantan Nair, Professor, Department of Plant Breeding, Smt. Sudharmaidevi, C.R., Assistant Professor, Dr. P. Rajendran, Associate Professor, Prof. Abdul Hameed, A. and Smt. Usha Mathew, Assistant Professor, Department of Soil Science and Agricultural

Ann Roshen, Diju, Binila, Roseeta, Lilly, Susan, Sumna, Anna, Anjana, Manjusha, Linu, Ann, Fathima, Sreedevi, Manoj and Sreekumar are a great pleasure to be remembered and recalled.

The awarding of P.G. fellowship by Kerala Agricultural university is gratefully acknowledged.

I am deeply obliged to my parents for being what they really are and my brother and sister for all their affection, inspiration and encouragement which contributed a lot in the completion of my study.

I gratefully acknowldege M/s. Athira Computers, Kesavadasapuram, Thiruvananthapuram for neatly printing this thesis.

My thanks are also due to many others who have been helpful to me sometime or the other during the period of my study.

Vellayani,
13.7.1995.

ANINA SUSAN ZACHARIAH

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INTRODUCTION

INTRODUCTION

After the green revolution was launched in India in the sixties, substantial increase in the production of food grains could be achieved through the use of improved crop varieties which were responsive to high level of fertilizers and plant protection chemicals. But it has now been realised that the increase in production achieved was at the cost of soil health and that sustainable production at higher levels becomes possible only when the factors leading to the continued maintenance of soil health are adequately taken care of. The use of mineral fertilisers is the quickest and surest way of boosting crop production, their cost and other constraints however, frequently deter farmers from using them in recommended quantities and in balanced proportions. As a consequence there appears to be no option but to fully exploit potential alternative sources of plant nutrients. In addition to integrated use of minerals and organics, renewable waste is accepted as the most appropriate strategy for sustaining high crop yields, minimising soil depletion and value added disposal of what are traditionally labelled as "wastes".

variety of situations. The different methods of waste management include land fill, incineration, lagoons, Anaerobic digestion, pyrolysis, composting etc. Among the various methods, composting is more ecofriendly and more important method of recycling from the agricultural point of view. Composting offers several advantages as a waste disposal method including increased availability of plant nutrients, destruction of pathogens, elimination of unfavourable odours and easy handling. The humus material formed influences the physical, chemical and biological characteristics of soil and organic matter status in addition to increasing crop yields.

The role of earthworms as biological agents in the degradation of organic wastes is already recognised. Vermitech is an aspect of biotechnology involving the use of earthworms as versatile natural bio reactors for effective recycling of organic wastes to the soil resulting in waste land development and sustainable agriculture. The most prominent component of vermitechnology is vermicomposting which is the bioconversion of organic waste material to nutritious vermicompost through earthworm consumption.

Vermicastings, the sustainable effective bio fertilizer produced through vermiculture can be applied to the soil to trigger the soil biology so that transition from chemical nutrition to bio nutrition is quick and without a significant loss of yield. In addition, the production of vermicompost right in the field and at low cost makes it very attractive for practical application. In order to increase the fertilizer value and reduce the dose of application, the fortification of the compost by inoculating with beneficial mircobes is suggested.

It is in the light of the above facts, that the present study was taken up with the objective of standardising an economically feasible method of vermicomposting by which the vegetable garbage can be converted to an enriched organic manure and testing its efficiency for a vegetable crop.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Proper soil management without impairing soil health, is the pre requisite for achieving higher productivity from agricultural land. Among the means available to achieve sustainability in agricultural production, organic matter plays a key role because it possesses many desirable properties and exerts beneficial effects on the physical, chemical and biological characteristics of the soil. With the increasing need to conserve natural resources and energy, recycling of organic wastes assumes major importance. In the entire areas of waste recycling, composting emerges as the most widely applicable process for handling diverse wastes. Microbes, which hasten the process of composting and enhancing the manurial value of compost, occupy a special place in making recycling particularly attractive, as do earthworms which hasten the process of composting by their feeding action and produce castings containing balanced plant nutrients, vitamins, enzymes, immobilised microflora etc.

These aspects are new to India and research works are in infant stages and literature on these aspects is limited. Hence the available literature pertaining to the present investigation is reviewed below.

2.1. Effect of organic matter on soil fertility

Addition of organic substances primarily provides nitrogen to the crops. The organically bound form of nitrogen becomes available to the crops after undergoing the processes of decomposition, followed by mineralisation into inorganic forms such as NH_3, NH_4^+, NO_2^- and NO_3^- and immobilisation of inorganic forms into organic forms. The magnitude of these two reactions control the available nitrogen status in the soil. (Jansson, 1963; Tusneem and Patrick, 1971).

Among the secondary nutrients, calcium and magnesium are complexed mainly in the humic and fulvic fractions of organic matter and there by influence the soil reactions and other chemical properties of the soil (Schnitzer and Skinner, 1969). When these two elements released from the minerals are not taken up by crops, they are likely to be adsorbed by humus thereby preventing the loss of these two nutrients by leaching (Allison, 1973).

Organic manures or composts contain a very large population of bacteriae, actinomycetes and fungi, and stimulate those already present in the soil. The application of organics helps microorganisms to produce polysaccharides which build up better soil structure. Nitrogen fixation and phosphorous solubilisation are also increased due to improved microbiological activity in organic amended soils. The beneficial effects of humus on soil characteristics ultimately result in increased crop yields. (Balasubramaniam *et al.*, 1972 and Gaur *et al.*, 1972).

Mayura and Ghosh (1972) observed that inclusion of farm yard manure with inorganic fertilizers increased CEC of soil, where as continuous use of inorganic fertilizers alone decreased CEC.

Humus, by virtue of its chelating properties, increase the availability of nitrogen, phosphorus, sulphur and other nutrients to plants growing in humus rich soils. The humus substances especially increase phosphorus availability as they have a very high cation exchange capacity (Eberhardt and Pipes, 1974 and Gaur, 1994).

The manifold importance of organic matter in soil formation and soil fertility has been demonstrated by the experience of agriculture over many centuries and by numerous investigations in which the role of organic matter in soil processes as well as in supplying plants with nutrients and biologically active substances has been elucidated (Kononova, 1975).

Mukherjee *et al.* (1979) explained the importance of organic matter in providing phosphorus to the soil.

Subbarao (1982) explained the utilization of farm waste and residue in agriculture as manure for composting and biogas production.

Fellaca *et al.* (1983) reported that humified organic matter can significantly reduce the amount of phosphates required, to maintain a solution concentration necessary for crop growth.

Application of farm yard manure increased the availability of both native and applied micronutrient cations. These ions form stable complexes with organic ligands which decrease their susceptibility to adsorption and fixation. (Swarup 1984)

Srivastava (1985) observed that increased use of nitrogenous fertilizers decreased organic carbon content, total N and available P and K status where as, farm yard manure addition increased all these parameters in the soil.

The complexing property of organic matter influences the availability and mobility of micronutrients. The micronutrients and other heavy metals, designated as toxic elements, form water soluble as well as insoluble complexes with the soil organic matter. The stability of micronutrients which determine the availability follow the order : For humic acid $Cu^{2+} > Fe^{2+} > Zn^{2+} > Mn^{2+}$ where as for fulvic acid the stability is $Cu^{2+} > Zn^{2+} > Fe^{2+} > Mn^{2+}$ (Relan *et al.* 1986).

Organic residue incorporation to the soil improves the over all physical, chemical and biological properties of the soil and the regular return of crop residues to the soil contributes to the soil nutrient pool in a gradual manner, besides offering other indirect benefits (Srivastava *et al.*, 1988, Sidhu and Beri, 1989 and Bhat *et al.*, 1991). Similar results were also reported by Palaniappan and Natarajan (1993). They further stressed the role or organic matter in the maintenance of fertility and productivity.

Combination of organic manures with inorganic fertilizers had a moderating effect on soil reaction, particularly under acidic soils, improvement in the sustained availability of N,P,K,S and the micronutrients particularly zinc (Nambiar and Abrol, 1989).

More (1994) reported that addition of farm wastes and organic manures increased the status of organic carbon, available nitrogen, phosphorus and potassium of the soil.

Among nutrients, the most significant role of organic matter is in supplying K (Bharadwaj, 1995).

2.2. Crop response to organic matter addition

The use of organic matter in crop production was discussed by many workers. Gaur and Mukherjee (1979) reported that wheat straw applied at 5 $t.ha^{-1}$ significantly increased pod yield of ground nut by 95.5 per cent.

Enhanced growth and yield of paddy due to organic matter addition was reported by Bharadwaj (1982) and Rengarajan and Muthukrishnan (1976).

Dhillon and Dhillon (1991) obtained significant increase in wheat yield and contents of available P and K of soil due to incorporation of ground nut residue.

In a four year experiment at Ludhiana, incorporation of green gram straw along with the application of 60 kg fertilizer N/ha^{-1} produced rice yield equal to the use of 120 kg N, 60 kg P_2O_5 and 30 kg K_2O/ha^{-1} (Bhandari *et al.*, 1992).

Minhas and Sood (1994) reported that farm yard manure application significantly increased the crop yields. Super imposition of farm yard manure over the inorganic fertilizers had a spectacular effect on crop yields. The effect of farm yard manure application was beneficial in enhancing the uptake of all three major nutrients by potato and maize.

More (1994) found that application of farm waste and organic manures to the soil enhanced significantly the grain and straw yield of rice and wheat.

2.3. Nutrient cycling in farming system-Composting

Recycling refers to the process by which materials once used is again used to substitute for virgin material.

Waste recycling is neither a modern concept nor an eye catching passing fad. The concept is centuries old. Only the urgency, the scale and complexities of recycling have gone up many fold. In addition, more efficient and versatile recycling processess and technologies have become available which, if applied on the required scale, can bring recyclable, wastes into the main stream of farm input management strategies. Among the various methods of waste recycling, composting is more ecofriendly and more important method from the agricultural point of view.

Yawalker and Agarwal (1962) opined that, because of the high organic matter content and due to relatively higher contents of major nutrients compared to the farm yard manure, compost is valuable in crop production.

Compost making is the process of decomposing plant residues in a heap or pit, bringing the plant nutrient elements in a more readily available form and at the same time eliminating the unwanted readily oxidisable constituents of the plant residues. The process of composting is useful in converting harmful waste products like night soil, rubbish and sewage into an innocuous product that is safe to handle and use. Most of the pathogenic organisms present in these wastes are destroyed by the high temperature generated during the process. (Raghavan, 1964). Thus reduces the health hazards (Bollen, 1985) and minimises the risk resulting from their use (Parr and Colacicco, 1988).

He *et al.* (1992) opined that composting has advantages over land filling and incineration because of lower operational costs, less environmental pollution and beneficial use of the end products.

Gaur and Geetha Singh (1995) reported that due to the effect of high temperature and antibiotics produced during bioconversion, end product is free of pathogens. Humus and carbon di oxide are produced and essential nutrients such as nitrate, sulphate and phosphates are released in the process of composting.

2.4. Influence of compost on soil properties and crop response studies with compost

Terman (1970) reported that urban waste compost improved the productivity of agricultural land.

Soil biological components is favourably influenced by the addition of composts (Gaur and Prasad, 1970)

Terman *et al.* (1973), Dalal (1977), Mehta and Daftardar (1984) and Jimenez *et al.*(1992) reported that city refuse compost is an important source of phosphorus to the crops.

Gallardo-Lara and Nogales (1987) reported that domestic composts are valuable liming material for acid soils due to their high content of calcium and provide organic phosphorus and large quantities of organic matter.

Das (1988) found that composting of plant rich garbage showed increase in humic acid and CEC. He recorded a CEC of 70 meq/100g, C:N ratio of 13 and a nitrogen content of more than 2 per cent in composted material.

Giusquiani *et al.* (1988) and Marchesini *et al.* (1988) reported that city refuse compost improves the humus content, pH, buffering capacity, CEC and releases mineral nutrients gradually.

Hernado *et al.* (1989) reported that addition of municipal refuse compost improved soil structure, water holding capacity, alkali soluble substances etc.

Mature compost has been shown to increase plant nutrition and improve crops (Jimenez and Garcia (1989) and Gallardo-Lara and Nogales, 1987).

Piccolo and Mbagwa (1990) and Pagliai *et al.* (1991) observed that city refuse compost, when well matured, exerts a positive influence on some soil physical properties such as porosity, aggregate stability, water holding capacity and bulk density.

Brink (1993) reported that by converting food waste to compost, loss of nutrients can be reduced and nitrogen can be catched.

Thampan (1993) recommended onfarm recycling of organic wastes and the application of bulky organic manures such as farm yard manure and compost as the most popular agronomic measures to sustain good soil health

Gaur (1994) reported that humus enhances the utilization of fertilizer nutrients by plants and helps in reducing leaching losses.

2.5 Crop response studies with compost

Garbage compost can be used in all areas of crop growing and soil ameleoration - in crop farming, grassland farming, horticulture, forestry and landscaping. It not only improves the physical health of soils, but also provides nutrients to the crops resulting in improved crop productivity.

Pain (1961) reported that compost prepared from mulberry leaves was as efficient as cattle manure in increasing the yield of mulberry leaves and their food value.

Terman (1970) reported that garbage compost provided nutrients to the crops, resulting in improved crop productivity, optimizing agricultural production under limited availability of fertilizers.

Terman and Mays (1973) noticed an increased phosphorus content in sorghum plants with increased compost application.

Hartenstine and Rothwell (1973) observed an increase in the uptake of all nutrients except Mn by Sorghum on compost application.

Khan *et al.* (1981) reported that city compost raised the zinc and iron contents of plants from deficiency to sufficiency levels.

Talashilkar and Vimal (1984) reported that increasing levels of garbage compost from 5 to 30 tonnes/ha resulted in significant increase in grain and straw yields of wheat without causing any harmful effect on soil health.

Pelletin *et al.* (1986) reported increase in vegetable production by applying town refuse compost and sewage sludge compost.

Parr and Colacicco (1988) were of the opinion that though organic wastes have low nutrient contents compared to chemical fertilizers, crop yields are higher when organic materials are applied in combination with chemical fertilizers.

Gaur (1990) reported that humic substances increase P availability as they have a very high cation exchange capacity.

Humus by virtue of its chelating properties, increases the availability of nitrogen, phosphorus, sulphur and other nutrients to plants growing in humus rich soils. The humus substances especially increase phosphorus availability as they have a very high cation exchange capacity (Gaur, 1994, Eberhardt and Pipes, 1974).

Incorporation of municipal waste compost at the rate of 10 $t.ha^{-1}$ and 50 per cent of recommended NPK rate saved half the NPK input in case of finger millet (Gowda *et al.* 1992).

A comprehensive review of the effects of organic manures on crop yield (Gaur, 1994) has shown that average response of crops such as rice, wheat (irrigated and rainfed), cotton (irrigated and rainfed) to the application of 12.6 $t.ha^{-1}$ of manure was 168, 202, 85, 56.4 and 16.2 $Kg.ha^{-1}$ respectively.

2.6 Earthworms as biological agents in decomposition of organic matter

Increasing demand for methods of domestic and industrial organic waste disposal to minimise pollution and maximise resources recovery has led to the recognition of earthworms as a composting element. There is great potentiality for earth worm's biodegradation of organic wastes into vermifertilizer, vermifeed and simultaneous achievement of pollution abatement to a large extent.

Bhat *et al.* (1960) opined that the passage of organic wastes through the gut of worms leads to the accelaration of humification process by the gut microflora and the establishment of microflora in their egesta.

Drift (1962) observed that main effect of litter feeding members of lumbricidae is the mechanical breakdown of the litter into macro fragments (uneaten fragments) and micro fragments (excrements). These are attacked by smaller animals and a variety of microorganisms.

Satchel (1967) emphasized the role of earthworms in organic matter transformation and reported most important action of lumbricidae as conditioning plant remains for microbial action and that they increase rate of decomposition of crop residues.

Allison (1973) observed organic matter of plant origin as the primary food of earthworms and found that some species live in decaying vegetable matter such as leaf litter in forests or in manures and compost piles and seldom penetrate the soil to any appreciable depth.

Syres *et al.* (1979) reported that earthworms are able to increase the decomposition of organic matter and availability of nutrients by comminuating residues and incorporating organic matter into the soil and by producing casts enriched with microflora.

Use of earthworms in the decomposition of organic matter was reported by Graff (1981) and Tomati *et al.* (1983) and they found *Eudrillus eugeniae* as a potential candidate for organic waste degradation.

Watanabe *et al.* (1982) in their studies have shown the ability of earthworms in deodorizing the organic matter on which they feed.

Flack and Hartenstein (1984) reported that earthworms have olefactory sense organs and with the help of these, they are led to malodour cousative micro organisms and feed on them. Thus they produce aerobic conditions and destroy the malodour causative agents.

Edward *et al.* (1985) reported that earthworms can breakdown organic wastes produced in intensive agriculture largely which otherwise cause serious disposal problem, into peat like materials, rich in available nutrients and with a good moisture holding capacity and porosity.

Holmin (1986) suggested the use of earthworm beds for processing waste water and sludge as more advantageous over traditional methods in reducing smell and fungi problem.

Bano *et al.* (1987) suggested that earthworms can be successfully employed in the biodegradation/vermicomposting technology and found that wormscasts produced by African night crawler *Eudrillus eugeniae* can replace compost and to some extent the costly chemical fertilizers in the field. They described *Eudrillus eugeniae* as superb effective agents in the operation of vermicomposting technology

Haimi and Huhta (1987) reported that time of composting was reduced very much by using worms and with *Eisenia foetida*, they got homogeneous mass of castings in a period of one month when sufficient potential biomass was provided. They found that vermicompost is superior to ordinary compost with regard to its physical structure.

Kale *et al.* (1987) reported that the material ingested by earthworms undergo biochemical changes and the ejected cast contains the plant nutrients and growth substances in plant assimilate forms. The fertility is contributed by both the enzymatic and microbial activity that is associated with earthworms.

Chan and Griffith (1988) observed that worms grow rapidly on pre treated pigmanure and produce a humus rich worm cast which is odour free.

Albanell *et al.* (1988) observed that earthworms accelarated the mineralisation rate and converted the manures into castings with higher nutritional values and with a greater degree of humification. The castings obtained from manures mixed with cotton waste showed good fertilizing quality suggesting that this kind of industrial residue may also be used in vericomposting.

Kale and Bano (1988) reported that the earthworm *Eudrillus eugeniae* feed on large quantities of organic matter and can be adopted for degradation of organic matter for the production of organic manure viz., vermicast which is a fine granular and odourless product.

Kale and Bano (1988) and Bano and Kale (1988) showed that under the prevailing climatic conditions *Eudrillus eugeniae* is the most suitable for vermi compost production.

Edward (1988) succeeded in converting the animal and other organic wastes into useful materials that could be added to agricultural land to improve soil structure and fertility and which also would have considerable potential in horticulture as a plant growth medium or component of commercial poting composts.

Hartenstein and Bisesi (1989) reported that for the management of organic waste material, epigeic earthworm species seem to be well fitted because of their surface activity, their ability to colonize organic material quickly and in the process convert it into useful compost. Their ability to minimise malodour formation is probably the most attractive ecofriendly advantage.

Bhole (1992) pointed out that vermiculture biotechnology can be used for city garbage recycling, management of effluents from livestock houses, management of sewage, sludge and decomposition of organic wastes from industries.

Again Jambhakar (1992) reported the use of earthworms as a potential source for decomposing any type of organic wastes and are found to hasten the process of decomposition and compost becomes ready within one and a half months period.

Bhawalkar and Bhawalkar (1992) considered the vermicasts produced from wastes as a resource for LEISA (Low External Input Sustainable Agriculture) and indicated that biocycling of these residues through vermi culture biotechnology obviates the use of agrochemicals derived from non-renewable resources.

Curry and Byrne (1992) reported that earthworms could increase the decomposition of straw in the soil by 26-47 per cent, within 8-10 month period.

Clive and Barter (1992) and Kale and Sunitha (1992) found *Eudrillus eugeniae* as a good species for organic waste management under tropical conditions.

Jambakar (1992) explained vermicomposting as an appropriate technique for the disposal of non toxic solid and liquid organic wastes. He also stataed that it is an effective, low cost and efficient recycling technique of animal wastes (poultry, horse, piggery excreta and cattle dung), agricultural residues and industrial wastes using low energy.

Bhawalkar and Bhawalkar (1993) observed that earthworms feed on any organic wastes two to five times their body weight, after using 5-10 percent feed stock for their growth and excrete mucus coated undigested matter as worm casts. These casts consist of organic matter that has undergone both physical and chemical breakdown through the activity of the muscular gizzard which grinds the materials to a particle size of one to two microns.

Senapati (1994) opined that epigeic or manure worms which are found on the surface and are reddish brown in colour do not process the soil but are efficient in composting of organic wastes and enhance the rate of organic manure production through biodegradation or mineralization and nutrient metabolism.

Manindrapal (1994) found that vermi composted cowdung has more nutrient value for crops than cowdung as a composted manure. Prabhakumari *et al.* (1995) found *Eudrillus eugeniae* as the most efficient species in converting biowastes into vermicomposts at shorter time and the results pointed out the superiority of vermi composts to other organic manures.

2.7 Biomass production potential of earthworms

India has about 3000 species of earthworms which are adapted to a range of enviornment and vermiculture needs. Earthworms can be divided into three categories epigeic, endogeic and anacic (Bouche, 1977). Among this epigeic function as efficient agents of comminution and fragmentation of leaf litter which they finally transform into stabilised organic matter. It is generally known that the epigeic species *Eudrillus eugeniae*, *Perionix excavatus* etc are efficient in composting of organic wastes. In order to utilize these species successfully in vermiculture, all aspects of their biology and biomass production potential must be known.

Edward and Lofty (1977) and Shipitalo *et al.* (1988) found many missing worms during their experiment and considered them as having died and decayed during the course of experiment. They found mortality as a function of diet.

Many species of earthworms are known to be reproductively active throughout the year. Seasonal variations are known to affect productivity (Satchal, 1967).

Apart from this, cocoon productivity among earthworms has been related to the ecological type, available nutrients and environmental factors (Bouche, 1977; Senapati and Dash, 1979; Lavelle, 1981; Graff, 1981; Kale *et al.* 1982).

Graff (1981) reported a reproductive potential of 3-5 cocoons/week/ adult in case of *Eudrillus eugeniae*

Kale *et al.* (1982) reported 145 cocoons/individual in case of *Perionyx excavatus* ie. 0.15 worm^{-1} day^{-1} over 210 days.

Kale and Bano (1985) found that while epigeic *Perionyx excavatus* took 8-12 weeks for maturity and cocoon production, *Pontoscolex correthrurus* took 48 weeks and cocoons production also was low for *Pontoscolex* ie 3-4/season while it was 3-4/week in case of *Perionyx*. Knieriemen (1985) obtained a mean number 0.5 worm^{-1} day^{-1} for *Eudrillus* and 0.41 for *Perionyx excavatus* at 27^{o}c.

Rodriguez *et al.* (1986) dertermined a figure of one cocoon worm^{-1} day^{-1} at 30^{o}c for *Eudrillus eugeniae*.

Kale and Bano (1987) calculated the innate reproductive capacity of *Eudrillus* as 0.138/ind and found the reproductive potential as 2.15/ind/week.

Bano and Kale (1988) reported alternate increase and decrease in cocoon production indicating rhythmicity in gondal activity and also observed a variation of 63.0 + 15.8 to 594.41 + 88.0 in productivity of cocoon for the entire life. They further showed that *Eudrillus eugeniae* which posses a high reproductivity capacity and feeding potential is the suitable species for vermicompost production in the prevailing climatic conditions.

Kale and Bano (1988) obtained a higher growth rate when multiplied in cowdung and vegetable waste mixture. The initial 20 worms became 1462 + 178 after 12 weeks.

Viljoen and Reinecke (1989) obtained 1.26 cocoons worm^{-1} day^{-1} over a period of 300 days. A comparison of the three epigeic species in terms of their potential to be utilized in large scale vermiculture in South Africa revealed that the size, growth and reproductive rate, fecundity etc of *Eudrillus eugeniae* make this species an out standing *candidate for vermiculture. They observed a life cycle of ± 60 days, a maturation time of ± 45 days, a relatively high cocoon production rate, a short incubation time (± 17 days) and a mean number of 2-7 hatchlings cocoon^{-1} and a mean body mass close to 2100 mg for these worms.*

Kale (1992) reported that number of young ones in 5 Kg of worm manure in 3 months ranged from 43 to 4721 depending upon feed material when 100 g of worms were introduced into 7 Kg waste mix.

Reinecke *et al.*(1992) found that mean number of cocoons worm^{-1} day^{-1} over a period of 151 days in case of *Eudrillus* was 0.46 and that of *Perionyx* was 0.33 and they found a hatching success of 78 per cent at 25^{o}c for *Eudrillus eugeniae* and 72 per cent for *Perionyx excavatus*.

2.8 Physico chemical properties of vermi-compost

Satchel (1967) reported that earthworm castings are rich in vitamin B_{12} and inorganic phosphorus.

Graff (1971) reported a higher phosphorus content in the cast than in the surrounding soil.

Sharpley and Syres (1977) reported that P availability to plants increased when the casts of anaecic earthworms were used.

Senapati *et al.* (1980) observed a decrease of 13 per cent and 31 per cent in the C:N ratio after 7 and 25 days of earthworm activity respectively in comparison with a decrease of 4 per cent after 25 days in the absence of earthworms.

Kale and Krishnamoorthy (1980) reported that castings of earthworms were rich in soluble forms of calcium and insoluble carbonates. The concentration of soluble Ca of castings was 11.8 times more than the surrounding soil but in the case of total Ca it was only 1.3 times more than the surrounding soil.

Tomati *et al.* (1983) reported that worm casts were rich in available nutrients for plant growth.

Mba (1983) produced a biologically active humified material with good properties from cassava rind with the use of earth worm *Eudrillus eugeniae*. It resulted in availability and an increased rate of cyanide disappearance.

Syres and Springett (1984) opined that earthworms influence the supply of nutrients in several ways. Earthworm tissue and cast material were enriched in certain nutrients relative to the soil matrix.

The worm cast obtained by using earthworm *Eudrillus eugeniae*, a voracious feeder on organic wastes proved beyond doubt as a suitable bio organic fertilizer. The accumulation of mobile substances in casts of earthworms has been reported. (Bano *et al.* 1984).

Bano *et al.* (1987) rated wormcast produced by *Eudrillus eugeniae* as a biofetilizer and found that it can replace compost and to some extent the costly chemical fertilizers and observed 0.75 per cent N, 0.57 per cent P and 0.4 per cent K in them.

Kale and Bano (1988) obtained a nutrient composition of 0.658 ± 0.12, 0.99 ± 0.14, 0.4 ± 0.16 N, P, and K respectively for vee comp 83E UAS, the vermicast commercially prepared in UAS, Bangalore, and found a comparable increase in the phosphorus in the vermicompost over regular farm yard manure.

Hand *et al.* (1988) investigated the suitability of cowdung as a substrate for vermicomposting by *Eisenia foetida* and found that it increased the nitrite N content of the subsrate but had no significant effect on other chemical and microbial constituents.

Christensen (1988) reported that the earthworm out put comprised almost assimilable products of execretion such as Ammonium and Urea and body tissues which can be rapidly mineralized and they were found to be a potentially significant source of readily available nutrients for plant growth.

In the presence of organic refuse the earthworm population increases resulting in better aeration of soil, more available plant nutrients and improved microbial status. It was reported that the concentration of exchangeable cations (Ca, Na, Mg, K) and available P and Mn was higher in wormcast than in the surrounding soils (Shinde *et al.* 1992).

Vermicompost had a total N content of 1.2 per cent and an available K_2o of 0.396 per cent. It was only 1.09 and 0.192 respectively for cowdung composted without worms. Original N and K_2o were 0.53 and 0.104 per cent for cowdung (Jambhakar, 1992).

Shinde *et al.* (1992) reported that the overall nutrient status and the comparative performance of the vermicomposts were similar to conventional farm yard manure. They got a total N,P,K status of 0.56, 1.48 and 0.36 per cent respectively and an available N,P,K of 387, 43.34 and 4060 ppm respectively. Micro nutrient contents of 21.6, 12.7, 19.2 and 5.8 ppm were also obtained for Fe, Zn, Mn and Cu respectively.

Lavelle and Martin (1992) found that due to intense microbial activity in the gut and from their own metabolic activity, earthworm cast contained significant amounts of nutrients in their cast. N up to 100-130 mg g^{-1} soil and assimilable P 15 mg g^{-1} soil in fresh casts.

Bhawalker and Bhawalker (1993) reported that earthworm cast contained balanced plant nutrients and immobilised microflora which continue to function in the soil and found that vermicastings were also rich in vitamins enzymes, antibiotics and growth hormones.

2.9 Effect of Vermicompost/Vermiculture on physico-chemical properties of soil

The concept of soil as a living system is central to alternative farming systems as opposed to chemical farming. Soil must be fed in a way that the activities of beneficial soil organisms, necessary for recycling nutrients and producing humus are not restricted.

Barley and Kleinig (1964) successfully introduced earthworms into newly sown irrigated pastures, on sandy loam soil in New South Wales with corresponding significant improvement in soil structure, loss of organic matter and increased productivity.

Ghilrov and Mamajev (1966) inoculated earthworms into reclaimed irrigated land in Uzbekistan and reported considerable improvement in soil structure and fertility. The role of earthworms in improving the physico-chemical properties of soil is reported by Kale and Krishnamoorthy (1981).

Mackey *et al.* (1982) showed that earthworms stimulate phosphorus uptake from the re-distribution of organic matter and increasing the enzymatic activities of phosphatase.

Kale and Bano (1983) opined that by using the worm cast as a fertilizer in fields it is possible to bring down the usage of chemical fertilizers and found that it is not only economical but also helps in improving the physico-chemical and biological properties of the soil.

Syres and Springett(1984) observed that earthworms redistribute organic material within the soil, increase the soil penetrability and under certain conditions influence ion transport in soils.

Earthworms play an important role in the process of soil formation and in the maintenance of soil fertility. They incorporate organic matter and turn over large amounts of soil by burrowing, feeding and casting. This leads to improved soil structure (Stewart and Scullions, 1988 and Hooger-Kamp *et al.*, 1983).

Increase in number of N-fixing fungi and bacteria in the soil when earthworms were introduced into experimental plots was observed by Kale *et al.* (1989).

Shuxin *et al.* (1991) reported that by introducing earthworms and applying organic manure in the red arid soil, the structure of the soil, fertility and the growth rate of sugar cane improved. They also noted an increased organic matter in the soil from 0.5 to 0.6 per cent, total nitrogen from 0.03 to 0.05 per cent, total P from 0.093 to 0.121 per cent and total K from 0.085 to 0.121 per cent. Ca, Mg and Mn also increased.

Kale *et al.* (1992) found that the vermicompost application has enhanced the activity of selected microbes in the soil system. The count of N fixers were about 3.48×10^3/g increased plot while it was only 2.16×10^3/g in control plots, this in turn increased total N in the experimental plots. Enhanced N mineralization potential on inoculation of earthworm (*peryonyx excavata*) was reported by Pashenasi *et al.* (1992).

Curry and Byrne (1992) estimated N mineralisation of 3.2 g through excretion and tissue turn over and 3.3 g through enhanced mineralization in faeces when a density of 408 individual /m^2 was present.

Logsdon and Linden (1992) while investigating the interaction of earthworms with soil physical conditions especially its influence on plant growth, found that earthworms create channels that allow deeper root penetration through hard pan. Some earthworm species incorporate surface residues and surface applied lime and fertilizers. Earthworm channels can increase infiltration and reduce run off, increasing soil water availability or in other words deep percolation to maintain favourable water status for crop growth.

Bhawalkar and Bhawalkar (1993) opined that earth worms participate in soil forming process by influencing soil pH, by acting as agents of physical decomposition, promoting humus formation, improving soil structure and by enriching the soil. They further observed that in addition to physical mixing of the soil by burrowing activities, soil enrichment is achieved by speeding up mineralization of organic matter 2-5 times by earthworms.

Vijayalakshmi (1993) reported that soil physical properties such as porosity, soil aggregation, soil transmission, conductivity and dispersive power of wormcast fertilized soil were improved when compared with no wormcast amended soil as reflected in the pot experiment of paddy growth.

Kale (1994) reported that the humus feeder type of earthworms physically mix the contents of deeper layers and make the soils loose and porous. Their body exudates into the soil improve the water holding capacity of soil and promote the establishment of microorganisms.

Gaur and Singh (1995) stated that earthworm mediated conservation (Vermiconsveration) system as a mechanism in which vermicastings replenish the organic matter content of soils.

2.10 Influence of vermicompost/vermiculture on nutrient uptake, growth and yield of crops

Yield increase in pasture production caused by earthworms was noted by Stockdill and Cossens(1966).

Van Rhee (1969) found that grass yields in polders increased up to four times and clover yields upto ten times, after inoculation with earthworms.

Sharpley and Syres (1977) found increased P availability to plants when vermicasts were used.

The possibility of replacing the chemical fertilizers by the organic manure was established by the preliminary field trials conducted on the summer crop of paddy Var. IR-20 (Kale and Bano, 1983).

Atlavinyte and Zimkuviene (1985) observed improved growth and yield in barley crops by using worm activated soils.

Grappelli *et al.* (1985) had reported the initiation of rooting of layers and shoots when grown in worm cast.

Lee (1985) reported that temperate climate earthworms are capable of stimulating plant growth.

The application of worm worked compost resulted in higher yields of paddy crop ranging from 95 per cent increase in grain, 128 per cent increase in straw and root production and 38 per cent decrease in weed growth (Senapati *et al.*, 1985).

Sacirage and Dzelilovic (1986) obtained higher drymatter yields for leek by growing in vermicompost than with the application of mineral fertilizers. They also found that by the application of 4,6 and 8 Kg/m^2 of vermicompost, the cabbage dry mater yield increased from 1 to 66 per cent.

Bouche and Ferriere (1986) reported that ^{15}N labelled nitrogen from earthworms was rapidly and almost entirely taken up by plants in the spring in undisturbed soils.

Kale *et al.* (1987) studied the influence of wormcast on the growth and mycorrhizal colonization of two ornamental plants (salvia and aster) and reported that the worm cast when used as a manure in place of farm yard manure significantly influenced both their vegetative and flowering characters and increased mycorrhizal root colonization.

Curry and Boyle (1987) reported enhanced plant growth in the presence of earthworms which was attributed to an increased supply of readily available plant nutrients and to the physical effect of earthworms in improving soil structure and aeration and in providing channels for root growth in undisturbed profiles.

Senapati (1988) reported the effectiveness of earthworm cast as a substitute for gram powder in mushroom production.

Chan and Griffith (1988) observed that worm castings had a stimulatory effect on the growth of Glycinemax (Soyabean).

Considerable scientific data were generated recently to show that produce obtained from organic farming is nutritionally superior with good tastes, good lustre and better keeping qualities. The better storage life of spinach grown with organic manures was found to be associated with lower free amino acid content, lower level of nitrate accumulation and higher protein-nitrogen to nitrate nitrogen. (Lampkin,1990).

Shuxin *et al.* (1991) observed 30 to 50 per cent increase in plant growth and N uptake and a 10 per cent increase in height and effective tillering and diameter of sugar cane. He also reported a 20 to 25 per cent increase in height and 50 per cent increase in weight of soyabean plants when vermicompost was applied.

Reddell and Spain (1991) suggested that part of growth stimulation credited to earthworms may be due to more rapid and intensive infection by mycorrhizal propagules which almost is ubiquitous in earthworm casts in field situations.

Spain *et al.* (1992) found increased plant production related to earthworm biomass due to the addition of earthworms to the field.

Kale *et al.* (1992) found significantly higher levels of uptake of N and P in rice treated with vermicompost.

Gunjal and Nikam (1992) reported earthworm inoculation in combination of heavy mulching of agricultural wastes all the year round as a successful practice of grape production without application of chemical fertilizers further Barve (1993) reported increase in the yield and improved quality both in taste and in attractive luture on application of vermicompost to grape. Reduction in cost of cultivation is also indicated.

Ferriere and Cruz (1992) observed higher dry matter yield in maize plants by the application of vermicompost.

Phule (1993) obtained more sugar cane yield from vermiculture treated plots and also the juice had 3-4 extra brix and lesser salts than chemical fertilizer applied crop.

By applying vermicompost, Khamkar (1993) obtained healthier coccinia plants and better keeping quality of vegetables, reduced cost of cultivation through low labour cost and reduced use of fertilizers and pesticides (Desai, 1993).

Vadiraj *et al.* (1993) reported that use of vermicompost as a component of potting mixture in cardamom nursery helped better seedling growth and dry matter production in a shorter period of time.

2.11 Enrichment of compost

In fact the manurial value of compost is judged mainly by its plant nutrient content. The quality of the compost, besides other factors is determined by the composition of the base material it self. The attempt for improvement of the quality of the compost by the addition of inorganic fertilizers does not appear to be profitable in view of high cost of such fertilizers coupled with losses during composting.

Compost made from municipal rubbish has a low nutrient content. The feasibility of increasing the nutrient content of the compost through the activities of nitrogen fixing micro organisms and P solubilising fungi was investigated and found that it is not possible to enrich the municipal compost with either nitrogen fixing bacteria or P solubilising fungi to release P from rock phosphate unless the pH of the compost was reduced (Balakrishna *et al.*, 1961). But the use of chemical fertilizers, sewage sludges and microbial culture was suggested. (Venkateswarulu and Spatt, 1977 and Gaur, 1980).

2.12 Effect of Microbial inoculation on compost

Shukla and Pathak (1961) observed increased rate of ammonification and nitrification of organic matter on addition of phosphorus.

Poincelot (1975) observed that the addition of phosphorus to plant organic matter increased the rate of decomposition and nitrogen conservation.

Extensive studies at IARI have shown that inoculation with N fixing and phosphate solubilising micro organisms improved the manurial value of compost (Gaur *et al.*, 1978 and Sadasivam *et al.*, 1981).

Mathur *et al.* (1980) reported release of nitrogen and citric acid and water soluble P on incubating compost with rock phosphate.

Sadasivam *et al* (1981) found that inoculating rock phosphate amended composts with cultures of *Azotobacter* and P solubilising strain of *Aspergillus* increased their nitrogen and humus content.

Gaur *et al.* (1982) reported increased total nitrogen content, available phosphorus and humus content of jowar stalk plus wheat straw compost

Kapoor *et al* (1983)observed that inoculation of *Azotobacter* into already decomposed material increased nitrogen content. They also found that composting with rock phosphate significantly increased citrate soluble P and this was further increased on inoculation with *Aspergillus*.

Mathur and Debnath (1983) observed that incorporation of rock phosphate improved the quality of compost by increasing the contents of citrate soluble phosphorus, nitrogen, calcium, magnesium and micro nutrients.

Bharadwaj and Gaur (1985) and Rasal *et al.* (1988) reported that due to increased microbial population, nitrogen fixing and phosphorus solubilizing process get acelarated and the compost became ready for use within four months with low C:N ratio and high N and P content in the enriched and inoculated compost.

Mathur *et al.* (1986) reported that addition of microbial inclulants reduced the composting period by about four weeks and improved the ferlizer value of paddy straw rock phosphate compost.

Shukla and Kundu (1986) observed increased nitrogen concentration in legumes due to bacterial inoculation which may be attributed to enhanced nitrogen fixation or increased nitrogen assimilation by plants.

Hajra (1988) noticed inoculation with microbial cultures and or rock phosphate favourably affected the quality of compost. Total N of the enriched compost varied within the range of 1.18 to 1.82 per cent in comparison of 0.97 per cent in the control. An appreciable amount of N was enriched by *Azotobacter* in all the treatments. The *enrichment increased progressively when* Azotobacter inoculation was supplemented with rock phosphate and P solubilisation culture. An increase of 64 per cent in citrate soluble P over control was observed when compost was treated with P solubilising organisms and an increase of 78 per cent over the control in N content of the final compost was obtained when treated with *Azotobacter*

Rasal *et al.* (1988) obtained compost with low C:N ratio high amount of N and P as compared to uninoculated compost when sugar cane trash and 10 per cent animal dung was composted using celluloytic fungi, nitogen fixing bacteria and phosphorus solubilising fungi with an addition of rock phosphate. As compared to uninoculated compost N content of inoculated compost was doubled due to enrichment treatment. As in case of N, total and citrate soluble P was increased further due to the addition of rock phosphate and phosphorus solubilising micro organism.

An incubation study conducted by Prasad and Singhania (1989) showed that manures enriched with nitrogen or phosphorus maintained higher levels of available N and P in the soil for longer periods than the fertilizers alone.

Sadasivan *et al.* (1981) observed a reduction in C:N ratio to 14 when *Azotobacter* and *Aspergillus* were inoculated in rock phosphate amended compost, where as without inoculation and rock phosphate the C:N ratio attained was only 23. Application of Rock Phosphate and/or inoculation improved the total N status of finished compost as compared to composting done without any amendment.

The manurial value of municipal waste compost was enhanced by enrichment with *Azotobacter*, gypsum and rock phosphate (Gowda *et al.* 1992). They observed an increased citrate soluble P after composting. Amendment with rock phosphate increased the total nitrogen also.

Composts, amended with rock phosphate, when inoculated with cultures of *Azotobacter* and P solubilising strains increased the total N content and the humus content appreciably. There was 25.4 per cent increase over control while microorganisms alone were inoculated and the increase was 31.9 percent over the control when rock phosphate was also used along with microbial culture (Gaur and Sadasivam, 1993).

Verma (1993) reported that the inoculation of P Solublising Organisms like *Aspergillus awamori*, after the thermophilic phase of composting ie after composting for two months when the temperature stabilised around $30^{o}c$, improved the quality of compost.

2.13 Effect of microbial inoculation on plant uptake and plant growth

Bacterization with phosphate solubilizers resulted in significant increase in uptake of phosphorus and nitrogen and yield of crops. A significantly higher amount of P was taken up by wheat with Phosphobacterin application (Sundara Rao, 1968)

Kundu and Gaur (1980) found positive response of wheat to single and combined inoculation with phosphobacterin and *Azotobacter* on nitrogen and phosphorus uptake by wheat crop.

Cohen *et al.* (1980) reported increased nitrogen uptake for a wide range of tropical and temperate crops under a wide range of controlled condition in green house and the laboratory by *Azospirillum* inoculation.

Uptake of phosphorus from rock phosphate and nitrogen by berseem significantly increased due to inoculation of phosphatic biofertilizer in presence of farm yard manure. (Sundararao, 1981).

Subba Rao (1981) reported that savings in fertilizers is possible by *Azospirillum* inoculation in rice, wheat, barley fodder oats and sorghum.

Azospirillum inoculation enhanced uptake of nitrate, phosphorus and potassium by roots of maize, wheat and sorghum (Okon, 1982; Lin *et al.* 1983; and Kapulnik *et al.*, 1985).

Goyal and Mishra (1983) observed that inoculation with P solubilizing microorganisms increased phosphatase activity and release of phosphorus.

Subba Rao (1984) reported that beneficial response of crop plants to inoculation with *Azotobacter* can be attributed to growth substances produced by the organism in addition to nitrogen fixing.

Inoculation of efficient phosphate solubilisers with farm yard manure and Rock Phosphate either alone or together significantly increased the uptake of phosphorous (Banik and Dey 1985).

Singh (1985) found that phospho compost prepared by enrichment with rock phosphate was as good as that of single super phosphate in microplot field experiments taking moong bean and wheat as test crop.

Mishra and Banagar (1986) also emphasized that the phosphorus enriched compost was comparable to single super phosphate in crop response and P uptake.

With the use of nitrogen and phosphorus enriched products of garbage compost it would be possible to substitute 25 per cent nitrogen and 50 per cent phosphorus doses recommended for rice, when applied on nitrogen and phosphorus substitution basis (Talashilkar and Vimal, 1986).

Kumar and Balasubramanian (1986), Muthukrishnan and Purushothaman (1992) and Resmi (1993) observed increased uptake of nitrogen due to *Azospirillum* inoculation by rice.

Singh and Yadav (1990) observed increased germination percentages, P in leaf sheath, P in juice, P uptake and yield in wheat, greengram and rice receiving different doses of phosphatic fertilizers with phosphorus solubilising bacteria.

Gaur (1990) reported that inoculation of seedlings with microphos biofertilizers can provide 30 Kg P_2O_5/ha, by solubilising the soil phosphorus and applied phosphorus.

Resmi (1993) observed increased root proliferation *and there by more uptake of potassium due to* Azospirillum inoculation of rice.

2.14 Effect of microbial inoculation on crop yield

Response of grain crops, vegetables and forages to seed inoculation with P solubilizers along with organic amendments and rock phosphate, bone meal or SSP have been studied. In earlier works carried out in USSR 5-10 per cent yield increase due to inoculation with phosphobacterin was observed (Mishustin and Naumova, 1962). They also found that P solubilisers produce fungistatic and growth promoting substances which influence plant growth.

Significant increase in yield was recorded in rice, cabbage and brinjal and evidence of a positive increase in *yield obtained in wheat, onion and tomato on* Azotobacter inoculation of seed or seeding (Sundar Rao *et al.* 1963; Lehri and Mehrotra, 1968; 1972; Mehrotra and Lehri, 1971 and Shinde *et al.* 1977).

Sundar Rao (1968) obtained significant increase in yields in case of wheat, rice, maize, chick pea, pigeon pea, soyabean, ground nut, berseem and paddy due to inoculation with phosphobacterin.

Subba Rao *et al.* (1979a,1979b) observed significant increase in the yield of straw and grain of barley, rice, fodder oats, wheat, soyabean, pearlmillet etc by *Azospirillum* inoculation.

Kundu and Gaur (1980) found positive response of wheat to single and combined inoculation with phospho bacterin and *Azotobacter* on the yield.

Cohen *et al.* (1980) obtained increased yield for a wide range of tropical and temperate crops by *Azospirillum* inoculation.

Increased yields in berseem and rice obtained due to inoculation of P solubilising organisms with farm yard manure (Sundara Rao, 1981; Banik and Dey 1985)

The field experiments conducted at different locations of India have indicated the positive response of rice to *Azospirillum* inoculation (Rao *et al.* 1983; Jayaram and Ramiah, 1986 and Kumar and Balasubramanian, 1986).

Shukla and Kundu (1986) obtained increased yields in plants by bacterial inoculation.

Plant responses to inoculations with Azotobacter and *Azospirillum* in cereals and non cereals are often reported in terms of increased grain yield, plant biomass yield, nutrient uptake, grain and tissue N content, nitrogenase activity, early flowering, tiller numbers, greater plant height, leaf size, increased enzyme levels in plant parts, increased number of spikes and grains per spike, thousand grain weight, increased root length and volume, reduced insect and disease infection (Okon, 1985; Wani, 1990).

The mechanism by which the plants inoculated with *Azospirillum* and *Azotobacter* derive positive benefits in terms of increased grain yield, plant biomass and N uptake are attributed to small increase in N input from BNF, development and branching of roots, production of plant growth hormones, enhancement in uptake of NO_3, NH_4^+, H_2PO^-, K^+, Rb^+ and Fe^{2+}, improved water status of plants, increased nitrate reductase activity in plants, production of antibacterial and antifungal compounds (Okon, 1985; Pandey and Kumar, 1989; Wani, 1990).

Multilocational trials with Azospirillum brasilense increased the mean grain yields of pearl millet and sorghum significantly. Increase in yield in pearl millet varied from 10 to 17 per cent and in soughum from 7-31 per cent (Subba Rao, 1986).

Singh and Yadav (1990) observed increased germination percentage and yield in treatments receiving P solubilising organisms.

Patel *et al.* (1991) obtained increased grain yield in pearl millet with *Azospirillum* treatment.

In multilocotonal experiments with pearl millet maximum of 20 percent increase in grain yield and 27.2 percent increase in plant nitrogen uptake due to inoculation of *Azospirillum* was observed at zero level of N application (Wani, 1992)

Yadav (1993) obtained increased grain yields over control in maize and cheena cultivars when *Azospirillum* was used.

Azospirillum has been found more effective towards contributing to increased yields in C_4 plants. (Verma, 1993).

Fertilizer Association of India (1994) reported that field trials conducted to study the influence of Azotobacter and *Azospirillum* inoculation on several non leguminous crops experienced 5-15 per cent increase in yield and a nitrogen contribution of about 25 Kg/ha.

MATERIALS AND METHODS

MATERIALS AND METHODS

The present study entitled "Vermicomposting of vegetable garbage" has been carried out in the College of Agriculture, Vellayani during 1993.

Three successive experiments as detailed below were conducted to achieve the objectives envisaged.

1. Comparison of the efficiency of exotic earthworm (*Eudrillus eugeniae*) and local earthworm - a mixture of (*Perionyx sansibaricus*, *Pontosolex corethrurus*, *Megascolex cochinensis* etc. in composting vegetable garbage.

2. Nutrient enrichment of vermicompost by inoculation with beneficial micro organisms.

3. Testing the efficiency of the enriched compost in enhancing yield and nutrient uptake by Chilli.

3.1. Comparison of the efficiency of exotic earth worms and local earthworms in composting Vegetable garbage

The efficiency was assessed in terms of the time taken for composting, nutrient status of the composted material and the potential of earthworms (in terms of biomass) at compost maturity.

3.1.1 Raw materials used for composting

To ensure the use of uniform raw materials, dried banana leaves and dried cowdung of the following chemical composition alone were used for the various replicated experiments.

	%N	%P	%K
Cowdung	0.63	0.18	0.52
Banana leaves	1.69	0.47	1.54

3.1.2 Pre treatment of raw materials for Vermicomposting

The banana leaves were chopped and mixed with cowdung in the ratio of 1:1 on weight basis and moistened to a level of about 40-50 percent and heaped on the floor for two weeks. This is to stabilise the materials and to allow heat generation during the initial stages of decomposition prior to inoculation with earthworms which could be harmful to them otherwise.

3.1.3 Preparation of Compost

Different types of composting was conducted as an experiment in a Completely Randomised Design with three treatments and seven replications. The treatments were as follows.

T_1 - Vermicomposting by local earthworms (a mixture of *Perionyx sansibaricus*, *Megascolex cochinensis*, *Pontoscolex corethrurus* etc).

T_2 - Vermicomposting by exotic earthworms (*Eudrillus eugeniae*)

T_3 - Ordinary composting

3.1.3.1. Preparation of Vermicompost

Composting was carried out in plastic trays of 50 x 30 x 20 cm size. Hundred numbers of adult clitellate earthworms were introduced into five kilograms of pretreated raw material taken in plastic trays covered with moistened gunny bags and kept in thatched sheds. Adequate moisture level (about 45 per cent) was maintained by sprinkling water every alternate day. When the compost was ready by its physical appearance such as the development of a dark brown to black colour with uniformly disintegrated structure, watering was stopped. After three days, the compost was removed from the trays and heaped on a plastic sheet and kept in shade. The compost was removed from the top leaving the earthworms in the form of a bundle at the bottom. The total biomass of earthworms was estimated by taking the total number of adults, juveniles and cocoons from each replication.

3.1.3.2. Preparation of ordinary compost

Raw materials used for vermicomposting was used for ordinary composting also. Here five kilograms of pre treated cow dung waste mixture was taken in plastic trays of same size used for vermicomposting and plastered well with mud to create anaerobic condition. Watered regularly to maintain a moisture level which prevented cracking of mud plaster. Occasionally the mud plaster was removed and the compost maturity was visually observed. After completion of composting the mud plaster was carefully removed.

For both ordinary and vermi compost, the time taken for composting was recorded. Compost recovery was noted by estimating the wet and airdried weight. The airdried samples were gently powdered, passed through a 2 mm sieve, weighed both portions separately and thus the ratio of decomposed to undecomposed was noted. Samples of air dried compost were gently powdered and used for fractionation and chemical analysis.

3.2. Nutrient enrichment of vermicompost by inoculation with beneficial micro organisms

This experiment was also conducted Completely Randomised Design with nine treatments and three replications. The vermiculture composts, with the indigenous earth worms, with exotic earth worms and ordinary composts formed the base materials for the nine treatments. The treatments were as follows.

T_1 - Local earthworm compost (Uninoculated)

T_2 - Local earthworm compost inoculated with *Azospirillum*

T_3 - Local earthworm compost inoculated with P solubilising organisms and 1% rock phosphate

T_4 - Local earthworm compost inoculated with *Azospirillum*, P solubilising organisms and 1% rock phosphate

T_5 - Exotic earthworm compost (Uninoculated)

T_6 - Exotic earthworm compost inoculated with *Azospirillum*

T_7 - Exotic earthworm compost inoculated with P solubilising organisms and 1% rock phosphate

T_8 - Exotic earthworm compost inoculated with *Azospirillum*, P solubilising organisms and 1% rock phosphate

T_9 - Ordinary compost (Uninoculated)

The vermicompost samples obtained from local earthworms and exotic earthworms were inoculated with cultures of *Azospirillum* and P solubilising organisms (obtained from microbiology department, College of Agriculture, Vellayani) at the rate of 25 g per 1 kg of compost. Inoculated compost samples were incubated for a period of two weeks at a moisture level of 25-35 per cent in earthern pots covered with moistened gunnybags and kept in a thatched shed.

After incubation for the prescribed period, compost samples were thoroughly mixed, air dried, sampled and analysed for chemical constituents.

3.3. Efficiency of the enriched compost in enhancing yield and nutrient uptake by Chillie

A pot culture study was conducted using the enriched composts in a Completely Randomised Design with ten treatments and three replications. Treatments were as follows.

T_1 - Uninoculated local earthworm compost

T_2 - Local earthworm compost enriched with *Azospirillum*

T_3 - Local earthworm compost enriched with P solubilising organisms and 1% rock phosphate

T_4 - Local earthworm compost enriched with *Azospirillum*, P solubilising organisms and 1% rock phosphate

T_5 - Uninoculated exotic earthworm compost

T_6 - *Exotic earthworm compost enriched with* Azospirillum

T_7 - Exotic earthworm compost enriched with P solubilising organisms and 1% rock phosphate

T_8 - Exotic earthworm compost enriched with *Azospirillum*, P solubilising organisms and 1% rock phosphate

T_9 - Uninoculated ordinary compost

T_{10} - Farm Yard Manure

Chilli variety Jwalamukhi was the crop used for pot culture study.

Pots were filled with 10 kg of red soil having the following chemical composition.

pH - 5.2, organic carbon 0.46 per cent

Total Nitrogen	0.014 per cent
Total Phosphorous	0.04 per cent
Total Potassium	0.315 per cent

The rate of application of inorganic and organic fertilizers were as per the package of practices recommendation of Kerala Agricultural University (1993). In treatments where 1 per cent rock phosphate was added, it was taken into consideration for fertilizer application when the crop was planted.

30 days old Chilli seedlings were planted at the rate of one plant per pot and watered twice a day. 0.025% Quinolphos was sprayed when the attack of mealy bugs was noticed. Yield of Chillies obtained as well as the total dry matter production of each plant were recorded.

3.4. Chemical analysis

Compost samples were analysed for pH, EC,CEC, total organic carbon, oxidisable organic carbon, total nitrogen, C:N ratio, total phosphorus and total potassium following standard analytical procedures (Jackson, 1973).

Total Ca, Mg, Mn, Zn and Cu were determined in the perchloric acid extract of the sample using Atomic Absorption Spectrophotometer Model PE 3030.

In addition to these the samples were analysed for alkaline extractable carbon, humic acid, fulvic acid etc. in the following manner.

3.4.1.1. Humic acid

Humic acid was determined adopting the process suggested by Stevenson (1965).

The sample was washed with 0.5N HCl and 40 g of the washed sample was taken in a polythene centrifuge bottle. To this 200 ml of 0.5 N sodium hydroxide was added. The mixture was shaken for 12 hours in a mechanical shaker, the sides of the bottle were washed with distilled water and the mixture was centrifuged. Dark coloured supernatent liquid was filtered and the pH of the solution was adjusted to 1.0 with Con. HCl. Additional 200 ml of 0.5 N NaOH was added to the residue, the content was shaken, centrifuged and filtered. The residue was dispersed in 200 ml distilled water, centrifuged and the supernatent liquid was added to the previous extracts. The residue was estimated as non humified organic matter. The pH of the extract was adjusted to 1.0 with Con. HCl and the humic acid was allowed to settle. The supernatent liquid was siphoned out and saved for estimating fulvic acid. The humic acid suspension was transferred to a polythene bottle and the humic acid was separated by centrifuging. Humic acid was redissolved in 0.5 N sodium hydroxide and reprecipitated with Con. HCl. Humic acid was again separated by centrifuging. This purification procedure was repeated. The supernatent liquid in each case was transferred to the original acid filtrate. Humic acid was washed with distilled water until free of chloride. Now humic acid was dried and ground to a fine powder. This was weighed and represented as percentage of humic acid on moisture free basis.

3.4.1.2. Fulvic acid

The acid soluble fraction collected during the separation of humic acid was fulvic acid. A known aliquot of this solution was evaporated and dried in a silica crucible. The weight of residue was estimated and reported as percentage of fulvic acid on moisture free basis. (Stevenson, 1965).

3.4.1.3. Alkaline extractable carbon

Alkali extracted portion of the compost was separated as per the procedures suggested by Stevenson (1965). A known aliquot was taken and organic carbon was determined by Walkley and Black titration method (Jackson, 1973).

3.4.1.4. Humic carbon and fulvic carbon ratio

Humic carbon and fulvic carbon were determined in the extracted humic and fulvic acids by using Walkley and Black titration method (Jackson, 1973) and Humic C : fulvic C ratio was worked out.

3.4.1.5. Degree of compost maturity

From the aforementioned determinations degree of compost maturity and humification indices were worked out. (Jimenez and Gracia, 1992).

$$\text{Humification ratio} \quad HR = \frac{\text{Alkali extractable C}}{\text{Oxidisable carbon of compost}} \times 100$$

$$\text{Humification Index} \quad HI = \frac{\text{Humic carbon of the compost}}{\text{Oxidisable carbon of compost}} \times 100$$

$$\text{Percentage humic acid Pha} = \frac{\text{Humic carbon of the compost}}{\text{Alkali extractable carbon}} \times 100$$

3.4.2. Analysis of enriched compost

Enriched compost wes analysed for total nitrogen, total phosphorus and total potassium (Jackson, 1973) total Ca, Mg, Mn, Zn and Cu (Holmes, 1945).

3.4.3. Plant analysis

Uprooted plants were chopped and dried to constant weight in an electric oven at 70°C, ground and passed through 0.5 mm sieve. The contents of N,P,K, secondary nutrients and micronutrients of the plants coming under each treatments were determined following the procedures given below (Jackson, 1973).

Parameter	Method
Nitrogen	Modified microkjeldhal method
Phosphorous	Vanadomolybdate yellow colour method using klett summerson photo electric colorimeter
Potassium	Flame photometer
Secondary and micro nutrients	Atomic absorption spectrophotometer

3.4.4. Uptake of nutrients

The total uptake of nutrients by the plants were calculated as the product of the percent of these nutrients in the plant samples and the respective dry weights and expressed as g $plant^{-1}$.

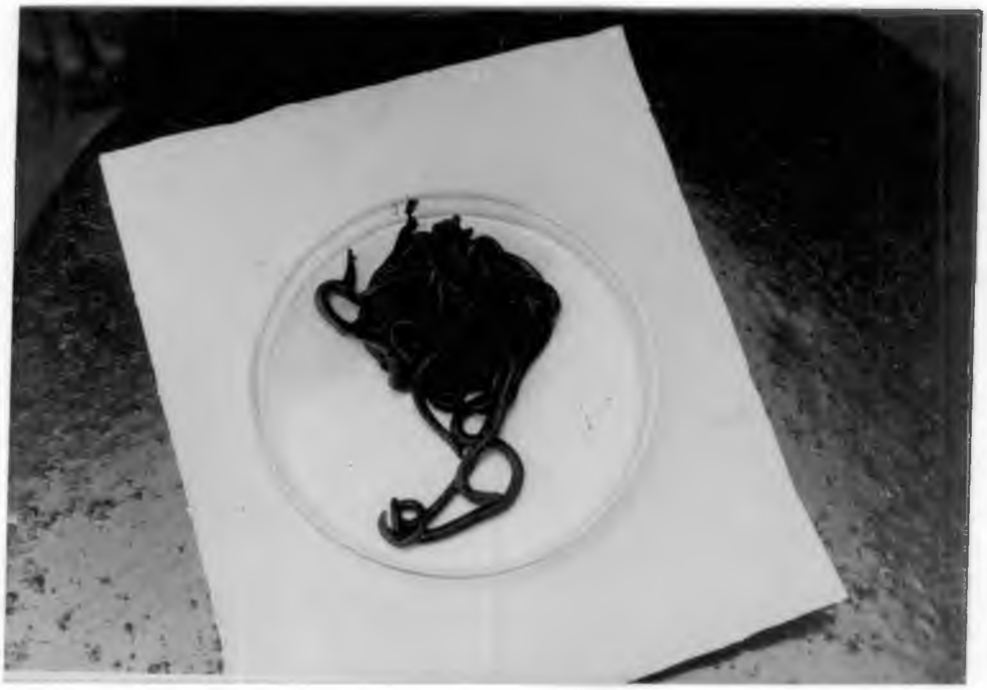
3.5. Statistical analysis

Data obtained from the above experiments were subjected to statistical analysis by applying analysis of variance technique and significance tested by F test (Snedecor and Cochran, 1975).

Simple correlations were worked out between properties of compost, properties of enriched compost, nutrient uptake of plants and yield. Simple linear regression equations were developed to relate yield and nutrient uptake with significant attributes.

1 Epigeic earth worm species Eudrillus eugeniae - Adult worm

2 Cocoon of Eudrillus eugeniae



3 A bundle of earthworms

4 Preparation of compost

5 Enrichment of compost

6 Pot culture experiment with chille as the test crop

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

The results of the present study consisting of three experiments on various aspects of vermicomposting, enhancings its nutrient value by incorporation of beneficial micro organisms and actually testing its validity for a vegetable test crop are presented and discussed.

4.1. Comparison of the efficiency of exotic earthworms and local earthworms in composting vegetable garbage

4.1.1. Mean data on humified fractions of compost, non humified fractions of compost, time taken for composting, ratio of decomposed to undecomposed and loss on ignition are presented in table.1

4.1.1.1 Time taken for composting

The epigeic earthworm species Eudrillus eugeniae took only 41 days for converting 5 kg of wastes to compost, while it took 72 days for compost ripening by the usual method. Local earthworms required 56 days for composting.

From the results obtained it is quite evident that earthworms reduce the time taken for composting significantly. The passage of organic material through the earthworm gut results in the physical decomposition due to the muscular grinding action of the gizzard, aided by ingested silica granules. This comminution provides considerable enhanced surface area for the subsequent microbial decomposition. This may be the reason for the significantly reduced composting time while utilizing earthworms. Similar results have been obtained by Bhawalkar and Bhawalkar (1993). Senapati (1989) observed a 25 per cent reduction in composting time due to earthworm activity. The indigenous earthworms decreased composting time to the extent of 21 per cent compared to oridinary per cent composting.

Among the different worm species used the epigeic exotic earthworm, *Eudrillus eugeniae* reduced the time taken for composting significantly when compared to local worms. It may be due to the higher feeding rate of *Eudrillus eugeniae* which are voracious feeders and prolific breeders Kale and Sunitha, 1992). *Eudrillus eugeniae* has been reported as a potential candidate for organic waste degradation by Tomati *et al.* (1983), Haimi and Huhta (1987), Albanell *et al.* (1988), and Prabhakumari *et al.* (1995).

4.1.1.2 Ratio of decomposed to undecomposed

To determine the rate and degree of decomposition of wastes, the ratio of decomposed to undecomposed fraction was determined at compost maturity. The ratio was significantly higher for *Eudrillus eugeniae* compost (9.43) while for local worm compost it was 2.41 and for ordinary compost it was only 0.31. The higher degradation rate in earthworm compost is thus evident. This higher degradation was due to the fact that the earthworm gizzard is a novel colloidal mill in which the feed is ground into particles smaller than two microns giving thereby an enhanced surface area for microbial processing (Bhawalkar and Bhawalkar, 1993). Increased rate of decomposition on using worms was reported by Satchel (1967), Bano *et al.* (1987) and Albanell *et al.* (1988).

Hartenstein and Bisesi (1989) reported that for management of organic waste material epigeic earthworms were well suited which agreed with the results of the present study. The superiority of *Eudrillus eugeniae* in decomposing organic waste has been reported by Kale and Bano (1988), Bano and Kale (1988), Clive and Barter (1992), Kale and Sunitha (1992) and Prabhakumari *et al.* (1995).

4.1.1.3 Loss on ignition

As recommended by Gallardo-Lara and Nogales (1987) total organic matter was determined by ignition loss at 600^{o}c. Loss on ignition of different composts are presented in table.1. Local worm composts suffered a loss of 63.76 per *cent on ignition. Loss on ignition of* Eudrillus eugeniae compost was 58.07 while that of ordinary compost was 69.05 per cent. Significantly lower levels of loss on ignition or total organic matter was observed for earthworm treated composts which may be due to the higher degradation of the organic material used. Jimenez and Garcia (1989) observed a variation ranging from 32 to 68 with an average of about 50 per cent in the total organic matter content of different city refuse compost depending on the heterogenity of wastes. When *Eudrillus eugeniae* was used as an agent for degradation, total organic matter level was very low which indicated the higher rate of degradation.

4.1.1.4. Humified and non humified fractions of compost

Humified and non humified fractions of different composts were found to be significantly different. Humified and non humified fractions of Eudrillus compost was 39.24 and

60.76 per cent respectively while that of ordinary compost was 30.93 and 69.07 respectively. Local earthworm compost also had a comparatively higher humified fraction (33.83 per cent) when compared to ordinary compost. From the data it can be inferred that vermicompost had a higher content of humified fraction and low non humified fraction when compared to that of ordinary compost. Humic materials are thought to be formed by microbial, enzymatic and chemical transformations of plant and animal residues (Flaig *et al.*, 1975). Because of the increase in relative abundance of the aromatic constituents, it would seem that lignin or lignin like molecules are probably of significance in the formation of humus (Alexander, 1961). Actinomycetes and some other microflora participate in this process. By providing ideal conditions, earth worms promote growth of micro organisms in their gut. Actinomycetes and bacteria which are important in waste degradation increase exponentially along the entire length of the tubular biorector almost 1000 times greater than in the surrounding soils. (Bhawalkar and Bhawalkar, 1993). This may be the reason for the presence of increased humified materials in the vermicompost. Neuhauser *et al.* (1978) emphasized that the peroxidases of invertebrates bring about the polymerization of aromatic compounds and in turn

Table 1. Quality parameters of different composts

	Time taken for composting (days)	Ratio of decomposed to undecomposed	Loss on ignition (%)	Non humified fraction of compost of (%)	Humified fraction of compost (%)
T_1	56	2.41	63.76	66.17	33.83
T_2	41	9.43	58.07	60.76	39.24
T_3	71	0.31	69.05	69.07	30.93
CD	1.34	1.69	2.14	1.42	1.42

Table 2. Biomass potential of worms at compost maturity

	Cocoons/100 g	Young ones/100 g	Total no. of Adult worms
T_1	3.29	9.00	51
T_2	10.14	22.29	81
CD	2.61	3.32	15

T_1 - Vermicomposting by local earthworms
T_2 - Vermicomposting by exotic earthworms
T_3 - Ordinary composting

the humification of organic matter. The passage of organic wastes through the gut of worms leads to the acceleration of humification process by the gut microflora and the establishment of microflora in their egesta (Bhat *et al.*, 1960). Kale *et al.* (1991) emphasized the presence of lignolytic and cellulolytic organisms in the earthworm worked soils and summarised that the symbiotic micro flora of worms are involved in lignin degradation. Businelli *et al.* (1989) also reported the high humifying capacity of worms. This is very much in evidence from the higher humified fractions in the composts made with the help of earth worms in the present experiment.

4.1.2. Biomass potential of earthworms at compost maturity

It is generally known that the epigeic species *Eudrillus eugeniae* and *Perionyx excavatus* have a potential as waste decomposers (Hartenstein *et al.*, 1979; Graff, 1974; Haimi and Huhta, 1986; Kale *et al.*, 1982). In order to utilize these species successfully in vermiculture all aspects of their biology must be known. Table 2. gives the biology of earthworm species used.

There was significant variation in cocoon *production between the species used.* Eudrillus eugeniae showed a higher cocoon production of about 11 per 100 g of compost by 100 worms in 41 days while 100 local earth worms produced only 3.29 cocoons per 100 g compost in 56 days. Kale and Bano (1985) found that while epigeic *Perionyx excavatus* took 8-12 weeks for maturity *Pontoscolex correthrurus* took 48 weeks. Cocoon production also was low for *Pontoscolex* ie., 3-4 cocoons/season while it was 3-4/week in case of *Perionyx.* Bano and Kale (1988) found that there was a 40 fold increase at the end of the year in case of *Eudrillus* while it was only 5-10 fold in *Perionyx excavatus. Eudrillus eugeniae* produced 65 cocoons in 3 months while it was only 27 for *Perionyx excavatus.*

Number of young ones found at compost maturity were also significantly different. When 22 young ones were found in 100 g of Eudrillus compost it was only 9 in 100 g of local earthworm compost.

The results obtained in the present study at Vellayani agrees with that of Kale and Sunitha (1992) *conducted at Bangalore who also found that* Eudrillus eugeniae had higher growth rate than *Perionyx excavatus* and *Eisenia foetida*. They obtained 32000 young ones per 160 kg compost in 60 days when thousand *Eudrillus eugeniae* worms were introduced. Kale (1992) found that number of young ones in 5 kg of worm manure in three months ranged from 34 to 4721 depending upon feed material when 100 g of worms were introduced into seven kilogram waste mix. Number of hatchling/cocoon is 3 for *Eudrillus eugeniae* while it was only one/cocoon in case of *Perionyx*. (Bano and Kale, 1988). It coupled with high fecundity of *Eudrillus* may be the reason for more number of young ones in Eudrillus worked compost. Mean number of cocoons per worm per day over a period of 15 days in case of *Eudrillus* was 0.46 and that of *Perionyx* was 0.33 at 25^{o}C and a hatching success of 78 per cent was observed for *Eudrillus eugeniae* while it was 72 per cent for *P. excavatus* (Reinecke *et al.*, 1992).

In the case of adults also the number was much lower in the local worm compost rather than Eudrillus compost. Out of 100 earthworms introduced only 51 local worms and 81 Eudrillus worms remained in the compost at compost maturity. The missing worms might have died and subsequently decayed during the course of the experiment.

Similar reports were made by Edward and Lofty, 1977 and Shipitalo *et al.*, 1988. They explained the mortality as a function of diet.

4.1.3. Different fractions of compost

Different fractions of compost indicates the humifying levels of compost. To determine compost maturity different indices were worked out using these values. Mean values of different carbon fractions of compost like oxidisable carbon, humic acid, fulvic acid, HA/FA ratio alkali soluble carbon, humic carbon and fulvic carbon are presented in table 3.

4.1.3.1. Oxidisable carbon in the compost

Oxidisable carbon content of local earthworm compost was 14.1 per cent, while that of Eudrillus compost was 13.93 per cent and of ordinary compost was 17.24 per cent. From the data it was found that oxidisable carbon content of vermi composts were significantly lower than that of ordinary compost. Lower levels of oxidisable carbon indicated higher degree of decomposition and higher levels of loss of carbon due to oxidation of organic matter as CO_2. More *et al.* (1987) showed that the oxidation degree depends on the chemical nature of the organic compounds especially the quantity of aromatic molecules, nitrogen, heterocyclic groups and degree of polymerization. The reports by Kale (1992) and Jimenez and Garcia (1992) on the chemical composition of compost agree with the results obtained from the present study.

4.1.3.2. Humic acid

The humic acid content of different composts varied significantly Table (3). Humic acid content of different composts like local earthworm compost, Eudrillus compost and ordinary compost were 20.73, 25.26 and 17.93 per cent respectively. Eudrillus composts had a higher humic acid content. It may be due to the fact that since earthworms decompose materials more rapidly there may be more finer particles, which can react with and retain the humic acid in considerably larger proportion (Anderson *et al.* 1974). Tropical humid condition also favours the accumulation of humic acid (Usha, 1982) resulting in relatively higher values.

4.1.3.3. Fulvic acid

The treatments recorded fulvic acid contents of 13.1, 13.98 and 13 per cent for local earthworm compost, Eudrillus compost and ordinary compost (Table 3). There was not much variation in fulvic acid content of different composts.

4.1.3.4. Humic acid : Fulvic acid ratio

HA:FA ratio was worked out for different composts. (Table 3). Significant difference in HA/FA ratio were observed among different treatments. Local earthworm compost had an HA/FA ratio of 1.58. HA/FA ratio of Eudrillus compost was 1.8 and that of ordinary compost was 1.37. Ordinary compost had significantly lower levels of HA/FA ratio. It may be due to the more acidic nature and weak microbial activity resulting in the formation of more fulvic acid compared to humic acid (Banerjee and Chakraborthy, 1977). But humic acids are reported to be the most abundant of the humic substances in all humus materials (Flaig, 1983).

4.1.3.5. Alkali soluble carbon

Alkali soluble carbon content of the local earthworm compost was 16.38 per cent and that of ordinary compost was 15.89 per cent. Eudrillus compost showed the highest alkali soluble carbon content of 18.86 per cent. Alkali soluble carbon is the carbon content of alkali extractable fraction of humus and expressed as percentage of total humus. Alkali extractable fraction of humus represents the total humified material present in the humus which is the sum of humic acid and fulvic acid. Higher per cent of alkali soluble carbon in the vermicompost shows the higher levels of humification in them. Higher humifying degree of vermicompost is due to the accelerated humification process by the gut microflora and establishment of microflora especially lignolytic microflora in their egesta, while the organic waste passes through the earthworm gut. (Bhat *et al.*, 1960; and Kale *et al.*, 1991). Buisinelli *et al.* (1989) and Bhawalkar and Bhawalkar (1993) also reported higher humifying capacity of worms.

.1.3.6. Humic carbon

Carbon content of humic acid of different composts viz. local earthworm compost, Eudrillus compost and ordinary composts were 56.25, 55.46 and 55.66 per cent respectively (Table 3). From the data it was evident that the method of

Table 3. Fractions of composts

	Oxidisable carbon (%)	Humic acid (%)	Fulvic acid (%)	HA/FA	Alkali soluble carbon (%)	Carbon in humic acid (%)	Carbon in fulvic acid (%)
T_1	14.05	20.73	13.10	1.58	16.38	56.25	56.26
T_2	13.93	25.26	13.98	1.80	18.86	55.46	57.58
T_3	17.24	17.93	13.00	1.37	15.89	55.66	55.69
CD	1.01	0.92	0.60	0.04	0.72	2.07	2.07

Table 4. Humification indices

	C:N ratio	Cha:Cfa	Pha	HI	HR
T_1	11.56	1.59	71.19	83.33	115.98
T_2	8.24	1.74	74.19	100.84	134.73
T_3	17.24	1.38	62.88	58.09	92.53
CD	0.95	0.01	2.80	7.17	9.35

T_1 - Local earth worm compost
T_2 - Eudrillus compost
T_3 - Ordinary compost

conversion of wastes had no effect on carbon content of humic acid. Earlier Shnitzer and Khan (1978) reported a humic carbon content ranging from 52.8 to 58.7 per cent for humic acid. Balagopalan (1992) obtained a humic carbon content of above 57 per cent.

4.1.3.7. Fulvic carbon

Carbon content of fulvic acid of different composts were 56.26 per cent for local earthworm compost, 57.58 for Eudrillus compost and 55.69 per cent for ordinary compost respectively. Similar values were reported by Balagopalan, 1992 and Shnitzer and Khan (1978) reported that carbon content of fulvic acid ranged from 40.7 to 50.6 per cent while Balagopalan (1992) reported that the carbon content of fulvic acid was almost constant ie. about 57 per cent.

4.1.4. Humification indices

To find out degree of compost maturity, humification indices viz. C:N ratio, Cha:Cfa, Pha, HI and HR were worked out. Based on these values the quality of the compost obtained is discussed.

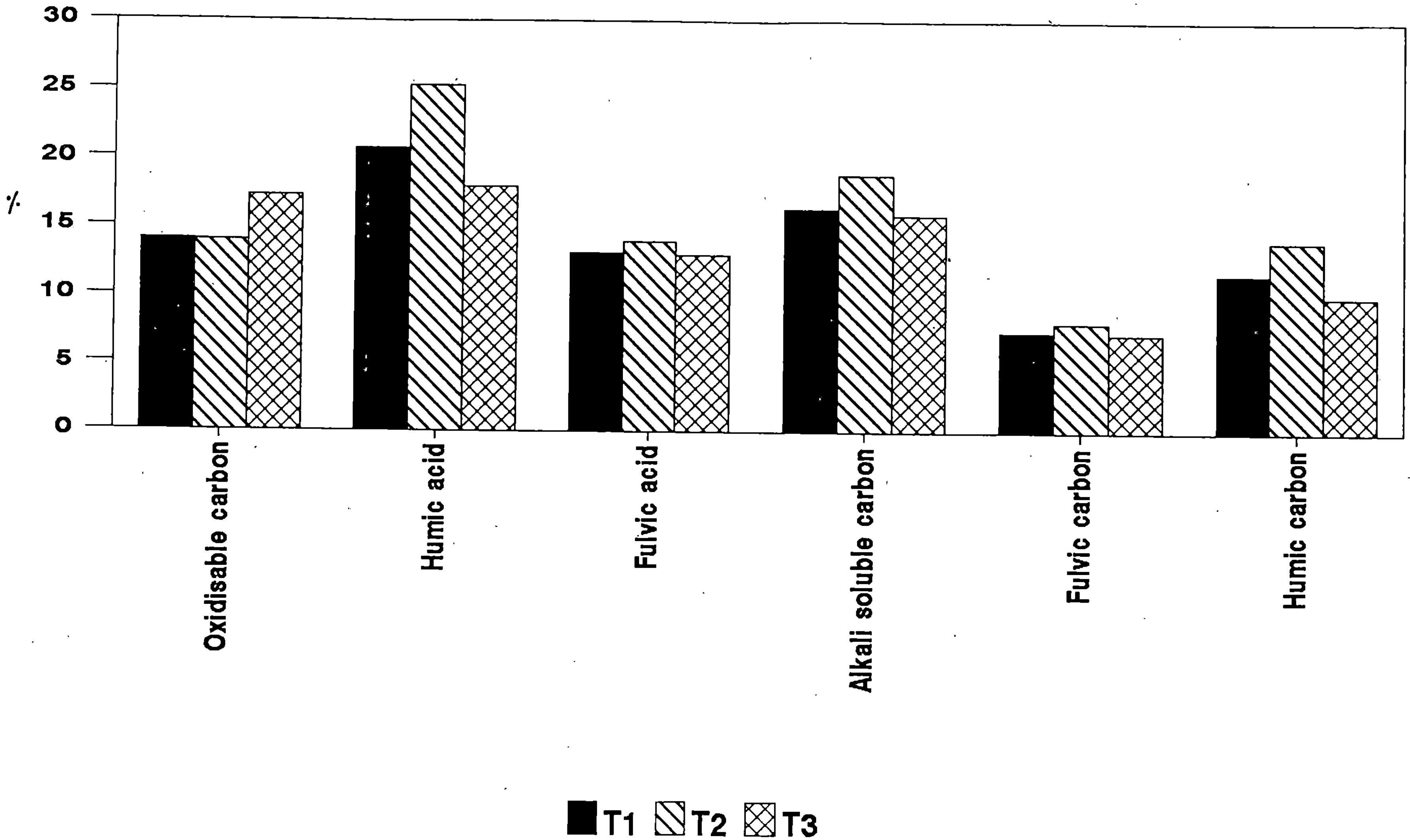


Fig. 1. Humification parameters of different composts

4.1.4.1. C:N ratio

Eudrillus compost had a significantly narrow C:N ratio (8.24). C:N ratio of local earthworm compost was 11.56 and ordinary compost had a C:N ratio of 17.24. The C:N ratio is one of the most important parameters that determines the extent of composting and the degree of compost maturity in newly formed organic materials. A C:N ratio below 20 is indicative of an acceptable maturity in the finished product, ratio of 15 or evenless being preferable. (Inbar *et al.*, 1990). The optimum value of C:N ratio to assure an acceptable degree of maturity of the compost is < 12 (Jimenez and Garcia, 1992). As composting proceeds the microflora use the carbon for energy and the nitrogen for cell building. The C:N ratio narrows down with time since the nitrogen remains in the system while some of the C is released as CO_2 (Gaur and Sadasivan, 1993). Nitrogen fixing bacteria indirectly help in decreasing C:N ratio by making available more nitrogen from added organic matter (Lee, 1985; Jambakar, 1991; Shinde *et al.*, 1992 and Rasal *et al.*, 1988). The increased microflora in the earthworm gut especially nitrogen fixing organisms may be the reason for the narrow C:N ratio in vermicomposts. Jambhakar (1992) obtained C:N ratio of 12 for earthworm worked waste within one and a half month.

From the point of view of application and use of the compost in cropping situations higher value of local compost (17.24) indicates possibility of temporary immobilization of nitrogen in the soil and suggests a need for application of small quantities of nitrogenous fertilizers to get over this temperory immobilization. Such a temporory inmobilisation, however is not likely when the local earthworm compost (C:N ratio 11.56) or (C:N ratio 8.24 are used.

4.1.4.2. Cha : Cfa

From table 4. it could be observed that Cha : Cfa ratio of Eudrillus compost and local worm compost were significantly higher compared to ordinary compost. The ratios were 1.74, 1.58 and 1.38 respectively. Jimenez and Garcia (1992) reported that Cha : Cfa should be more than 1.6 for mature compost. From the result obtained it could be observed that vermicomposts have got a greater degree of compost maturity which could be more acceptable. The wider Cha to Cfa in vermicomposts is related to the mineralisation of more easily hydrolysable humic acids. (Farid *et al.*, 1994).

4.1.4.3. Pha

From the calculated values of Pha it was observed that the Pha of local earthworm compost was 71.19 while it was 74.19 for Eudrillus compost and 62.88 for ordinary compost.

Pha of vermicompost were observed to be significantly greater than that of ordinary compost and so they have got more acceptable degree of compost maturity. Jimenez and Garcia (1992) observed that Pha value should be more than 62 for well matured compost, which more or less agree with the present findings.

4.1.4.4. HI

Humification Index of the different composts were calculated and presented in table 4. The values were 83.33 for local earthworm compost, 100.83 for Eudrillus compost and 58.09 for ordinary compost. HI of all the three composts differ significantly and are above 13 which indicates that all are well humified. Jimenez and Garcia (1992) reported that HI of a compost should be more than 13 for its acceptance.

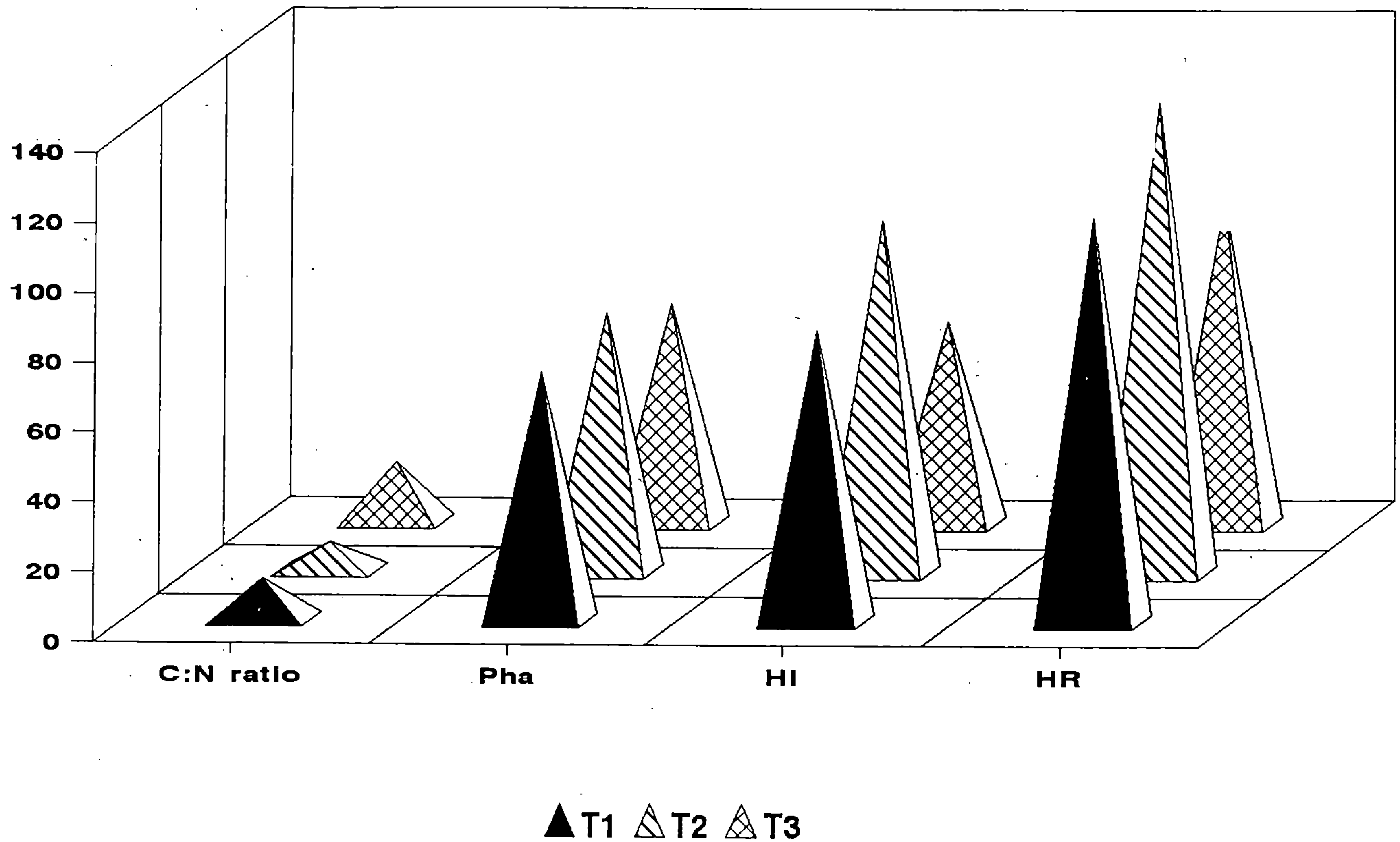


Fig. 2. Humification indices of different composts

4.1.4.5. Humification ratio

The values obtained as HR of different composts viz. local earthworm compost, Eudrillus compost and ordinary composts were 115.98, 134.73 and 92.53 respectively. Eudrillus compost had a significantly higher level of humification ratio, which may be due to the higher degree of humification. Humification ratio of ordinary compost was significantly low compared to vermicomposts due to its lower levels of humification. High humifying capacity of earthworms has been shown by Bhat *et al.*, 1960; Businelli *et al.*, 1984; Neuhauser *et al.*, 1978 and Bhole, 1992.

4.1.5. Physico chemical properties of composts

Different physico chemical properties of composts were determined and have been presented in table 5. The quality of compost is discussed in terms of different physico chemical properties of compost.

4.1.5.1. pH

From table 5. it could be observed that pH of vermicompost ranged from neutral to alkaline while that of ordinary compost was more or less acidic. The pH of the Eudrillus compost was 7.34 while that of local earthworm compost was 6.81 and of ordinary compost was 6.33. These results agree with the observations recorded by Bano *et al.*, (1987), Kale and Bano (1988), Gunjal and Nikam (1992), Shinde *et al.*, (1992) and Bhawalkar (1993). Kale (1992) observed a pH of 6.8 to 7.8 for compost produced by the activity of worms.

Lee (1985) observed that earthworm casts are closer to neutral pH range than those of the surrounding soil and reported that the possible factors that act on pH were NH_4^+ excretion and or excretion from the calciferous glands. Binkly and Richter (1987) reported that conversion of organic N to ammonia and further to NH_4^+, temporarily reduces the pool of H^+ in the soil. Haimi and Huhta (1990) observed that earthworms significantly raised the pH of the humus and opined that, part of the effect of earthworms on soil pH was probably an increase in the concentration of ammoniacal nitrogen. Bhawalkar and Bhawalkar (1993) also reported that pH of the intestinal content of earthworms is remarkably stable around neutral to slightly alkaline. The calciferous glands in them fix $CaCo_3$ and prevent any fall in pH (Robertson, 1936; Wallwork 1983 and Kale and Krishnamoorthy, 1980).

Table 5. Physico-chemical properties of composts

	pH	EC ds/m	CEC Cmol/kg	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Mn (ppm)	Zn (ppm)	Cu (ppm)
T_1	6.81	2.05	82.11	1.22	0.66	1.48	0.47	1.03	1137.14	254.80	64.00
T_2	7.34	1.62	81.55	1.69	0.76	2.71	0.29	1.35	1412.86	345.77	71.69
T_3	6.33	2.38	80.61	1.08	0.46	0.95	0.16	0.60	1389.71	202.89	51.31
CD	0.29	0.19	9.45	0.06	0.02	0.23	0.05	0.15	75.54	36.83	3.67

T_1 - Local earth worm compost

T_2 - Eudrillus compost

T_3 - Ordinary compost

4.1.5.2. CEC

Table 4. showed that there was no significant difference in CEC of different composts. CEC of composts viz. local earthworm compost, Eudrillus compost and ordinary compost were 82.11, 81.55 and 80.61 Cmol kg^{-1} respectively. CEC is an index to assess compost maturity and Jimenez and Garcia (1992) suggested a CEC of more than 67 Cmol kg^{-1} for acceptable compost maturity which agree with the results obtained from the present study. Satchel (1958) reported that worm activity increased base exchange capacity. The large available surfaces of humus particles have many cation exchange sites that adsorb nutrients for eventual plant use (Miller and Donahue, 1992).

4.1.5.3. Nutrient composition of different composts

Table 5 gives the mean values of major and minor nutrients contained in different composts.

4.1.5.3.1. Nitrogen

Significant differences were observed in the nitrogen content of vermicomposts and ordinary compost. The nitrogen content of *Eudrillus eugeniae* worked compost was 1.6

per cent while it was 1.22 per cent for local earthworm compost and 1.08 per cent for ordinary compost. The higher degree of decomposition and mineralisation in vermicompost may be one of the reasons for the high N content in vermicompost. Similar results were reported by Syres and Springett, 1984; Bano *et al.*, 1987; Kale and Bano, 1988; Shuxin, 1991 etc. Increased number of nitrogen fixing bacteria in worm casts can also contribute to the high nitrogen content in worm worked composts (Loquet *et al.*, 1977, Kale *et al.*, 1989). Nitrogenous excretions from the worms also can enrich the composts from organic wastes (Bhawalkar, 1993). Haimi and Huhta (1990) obtained an increased nitrogen content by earthworm activity and opined that it may be due to the earthworm carcasses. But later it was confirmed that microbial activation by the earthworms and or excretion by earthworms are more important in nitrogen cycling than the additional N brought into the soils in the earthworm biomass. Micro organisms in the gut of some earthworm species, using mucus secreated from the gut epithelium as an energy source, may fix atmospheric nitrogen in quantities that are significant for the earthworm's metabolism and as a source of nitrogen for plant growth (Lee, 1992). A significant proportion of carbon assimilated by

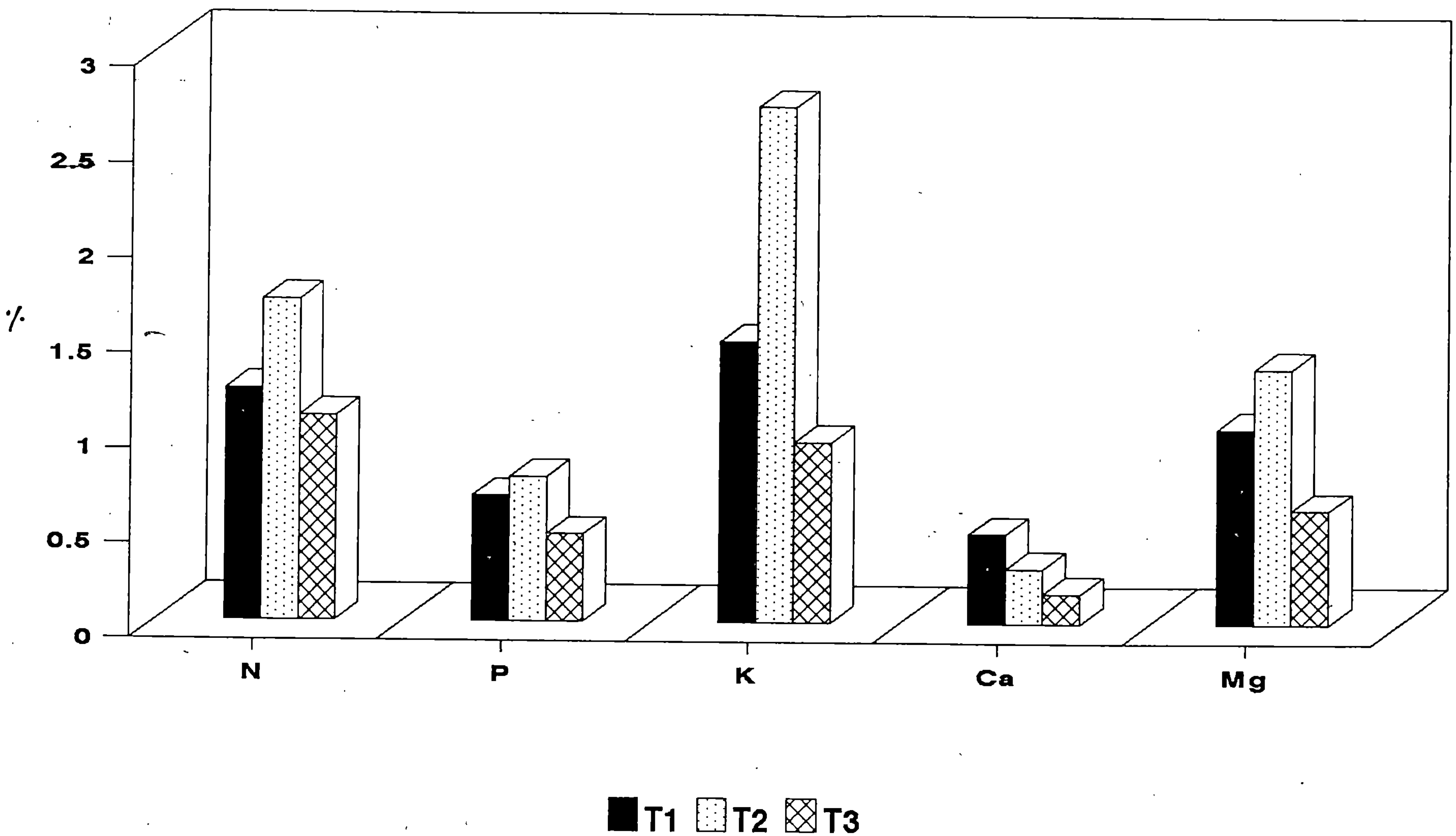


Fig. 3. Nutrient composition of different composts

earthworms is secreted as intestinal and cutaneous mucus with greater C:N ratios than those of the resources used (Lavelle *et al.*, 1983; Cortez and Bouche, 1987). As a result part of the nitrogen assimilated may be in excess and have to be excreted. Another reason for high mineral nitrogen excretion is the rapid turn over of nitrogen in earthworm biomass as shown by Ferriere and Bouche (1985) for temperate earthworm and further confirmed for the pantropical species *Perionyx Corethrurus* (Barois *et al.*, 1987).

Matsumoto (1991) also obtained a higher percentage of total nitrogen in wormcasts which agrees with the result obtained in the present study.

4.1.5.3.2. Phosphorus

Table 5 shows that the phosphorus content of vermi compost was significantly higher than that of ordinary compost. Phosphorus content of the Eudrillus compost was 0.76 per cent while that of local earthworm compost was 0.66 and that of ordinary compost was 0.46 per cent Satchel (1967), Graff (1971), Kale and Bano (1988), etc. reported similar values.

The higher P content in the vermi compost may be due to the greater mineralisation of organic matter with the aid of microflora associated with earth worms. The mechanism behind the effect of earthworms were thought to be partly due to enhanced microbial and phosphatase activity (Sharpley and Syres, 1976; 1977), partly to the physical break down of plant material and trituration of the mineral fraction (Mansell *et al.*, 1981) and partly to intimate mixing of ingested particles with soil in earth worm casts. (Mackey *et al.*, 1982; 1983).

4.1.5.3.3. **Potassium**

Table 5 shows the significant difference in K content of composts obtained from same materials due to earthworm activity. Eudrillus composts had a higher K content of 2.71 per cent while the K content of local earthworm compost was 1.48 per cent and that of ordinary compost was 0.95 per cent.

Puh (1941) and Lunt and Jacobson (1944) reported increased concentrations of available and exchangeable K contents in casts compared to surrounding soils.

Basker *et al.* (1992) inferred that earthworms increase the availability of K by shifting the equilibrium among the forms of K from relatively unavailable forms to more available forms. Venkataramani (1994) obtained a similar value of 2.74 per cent K for vermicompost. Bano *et al.* (1987) observed considerable variation in the K_2O content of compost when earthworms were used as biological agents for degradation of wastes.

4.1.5.3.4. Calcium

Calcium content of vermicompost was significantly higher than that of ordinary compost. Local worm compost had the highest Ca content of about 0.47 per cent and Eudrillus compost had a Ca content of 0.29 per cent while that of ordinary compost had only 0.16 per cent.

High Ca content of vermi composts was reported by earlier workers also (Nijhawan and Kanwar, 1952; Kale and Krishnamoorthy, 1980; Shuxin *et al.*, 1991 etc.). Kale and Krishnamoorthy (1980) found an increase of 1.3 times of total Ca in castings.

According to Pierce (1972) species with active calciferous glands absorb excess Ca from their diet and transfer it to calciferous glands from which it is excreted via the digestive tract. One of the local earthworms used in the experiment, *Pontoscolex corethrurus* has well developed calciferous glands (Kale and Krishnamoorthy, 1980) and that may be the reason for high Ca content in the local earthworm compost. Kale and Krishnamoorthy (1980) opined that considerable amount of total Ca in castings was due to the selective feeding of Ca rich materials by the worm.

4.1.5.3.5. Magnesium

Magnesium content of composts presented in table 5 shows that Eudrillus compost had a significantly higher Mg content of 1.35 per cent. Mg content of local earth worm compost was also high ie., 1.05 per cent while that of ordinary compost was only 0.6 per cent. An available Mg content of 0.38 per cent was reported by Bano *et al.* (1987) and higher nutrient content may be due to accelerated mineralisation.

4.1.5.3.6. Manganese

With a manganese content of 1412.86 ppm, Eudrillus compost had significantly higher Mn content than the other two composts. Compost obtained using local earth worms had lower Mn content ie., 1137.14 ppm while Mn content of ordinary compost was 1387.71 ppm. Lee (1992) reported that possible significance of Mn in earth worm worked soil may be by the same path way as that of calcium.

4.1.5.3.7. Zinc and Copper

Analysis of the data shows significantly higher Zn content in vermi composts. Eudrillus compost had a Zn content of 345.77 ppm and local earthworm compost had a Zn content of 254.8 ppm. The Zn content of ordinary compost was only 202.89 ppm.

Copper content of different composts was significantly different. Eudrillus compost had the highest content of 71.69 ppm followed by local earthworm composts with a copper content of 64.1 ppm and ordinary compost with a copper content of 51.31 ppm. This may be due to the addition of accumulated Cu in the earthworm body to the compost due to its degradation. The earthworms have the capacity to accumulate trace elements in certain parts of the body, there by decreasing the trace element concentration in the compost. But when the worms die the trace elements in their bodies get

Table 6. Coefficient of correlation between physio-chemical properties and humification parameters

	Oxidisable carbon	Humic acid	Fulvic acid	HA/FA ratio	Alkali soluble carbon	Fulvic carbon	Humic carbon
pH	-0.6687**	0.8082**	0.4569*	0.8442**	0.7981**	0.8070**	0.8537**
EC	0.6679**	-0.8732**	-0.5352**	-0.8922**	-0.8065**	-0.7392**	-0.8446**
CEC	0.0906	-0.0170	-0.0655	0.0068	-0.0546	0.0243	0.1415
Oxidisable carbon	1.0000	-0.7021**	-0.2903	-0.7912**	-0.5615**	-0.4830*	-0.7315**
Nitrogen	-0.5766**	0.9413**	0.6464**	0.9295**	0.9212**	0.8740**	0.9543**
Phosphorous	-0.8465**	0.9054**	0.5105**	0.9575**	0.7889**	0.7339**	0.9326**
Potassium	-0.6453**	0.9299**	0.6468**	0.9182**	0.8868**	0.8872**	0.9231**
Calcium	-0.7300**	0.2501	0.1412	0.4139*	0.0776	0.0659	0.3308
Magnesium	-0.7052**	0.4318	0.1639	0.4882**	0.1587	0.1405	0.4523*
Manganese	0.3863	0.1845	0.3257	0.0743	0.3574	0.3299	0.1633
Zinc	-0.6290**	0.8596**	0.5320**	0.8823**	0.8587**	0.8058**	0.8278**
Copper	-0.7626**	0.8684**	0.5389**	0.8940**	0.7837**	0.7331**	0.8930**

* Significant at 5% level

** Significant at 1% level

incorporated into the compost, there by increasing the final concentration of trace elements in the compost.

4.1.6 Correlation Studies

4.1.6.1 Correlation between humification parameters and physico-chemical properties of compost

Coefficient of correlation between physico chemical properties of compost and humification parameters like different carbon fractions ie., humic acid, fulvic acid, HA/FA ratio, alkali soluble carbon, fulvic carbon and humic carbon are presented in table 6.

The pH was negatively and significantly correlated with oxidisable carbon and positively and significantly correlated with all other humification parameters such as organic carbon, HA, FA, HA/FA, alkali soluble carbon, Cha and Cfa respectively).

Oxidisable organic carbon was significantly and negatively correlated with all other humification parameters (r value being -0.7021,-0.7912,and -0.5615 with HA, HA/FA ratio, alkali soluble carbon respectively). The nitrogen of the compost was positively and significantly correlated with humification parameters such as HA, FA and alkali soluble carbon. All nutrients, except Manganese, showed a negative significant correlation with organic carbon and highest negative correlation was for organic carbon with phosphorus (r value being -0.8465). Humic acid was positively correlated with all the nutrients. It was significantly and positively correlated with N,P,K,Zn and Cu (r value being 0.9413, 0.9054, 0.9299, 0.8596 and 0.8684 respectively) Fulvic acid was significantly and positively correlated with N,P,K,Zn and Cu (r value being 0.6464, 0.5105, 0.6468, 0.5320 and 0.5384 respectively). Here the influence of humic and fulvic fractions in nutrient availability is well brought out. The fulvic and humic acid fractions because of their high adsorptive capacities can help in the retention of nutrients, there by making them available to plants. HA/FA ratio showed significant and positive correlation with all the nutrients except Mn. Highest correlation was between HA/FA and P content.

Alkali soluble carbon, fulvic carbon and humic carbon were positively and significantly correlated with N, P,K,Zn and Cu content of the compost.

Table 7. Coefficient at correlation between physico chemical properties of composts and humification indices

	C:N ratio	Cha:Cfa	Pha	HI	HR
pH	-0.8382**	0.7730**	0.7343**	0.8259**	0.8216**
EC	0.8667**	-0.7981**	-0.7111**	-0.8186**	-0.8014**
CEC	-0.0253	0.1768	0.3008	0.0376	-0.0711
Oxidisable carbon	NS	-0.7891**	-0.7780**	-0.8932**	-0.8936**
Nitrogen	-0.8627**	0.8751**	0.7762**	0.8587**	0.8298**
Phosphorous	-0.9753**	0.9352**	0.9021**	0.9504**	0.9106**
Potassium	-0.8793**	0.8271**	0.7635**	0.8713**	0.8515**
Calcium	-0.5386**	0.4637*	0.5707**	0.5083**	0.4666*
Magnesium	-0.6100**	0.5890**	0.7044**	0.5660**	0.4862**
Manganese	0.0833	0.0315	-0.1197	-0.0398	-0.0144
Zinc	-0.8379**	0.7475**	0.6601	0.7998**	0.8111**
Copper	-0.9143**	0.8722**	0.8300**	0.8800**	0.8523**

* Significant at 5% level

** Significant at 1% level

4.1.6.2 Correlation between physico-chemical properties of compost and humification indices

Correlation coefficients were worked out between humification indices and physico-chemical properties of compost and the results are presented in Table 7. pH was significantly and negatively correlated with C:N ratio (r value was -0.8382) and it was positively and significantly correlated with Cha:Cfa, Pha, HI and HR (r values being 0.7730, 0.7343, 0.8259 and 0.8216 respectively). All the humification indices gave significant and negative correlation with oxidisable organic carbon. All the nutrients except Mn were negatively and significantly correlated with C:N ratio. The effect of C:N ratio on nutrient availability is well brought out here. When the C:N ratio increases, immobilization takes place and nutrients become unavailable for plant growth. Only by narrowing down the C:N ratio, mineralisation can take place, there by increasing the nutrient availability. All the nutrients except Mn were positively and significantly correlated with Cha:Cfa, Pha, HI and HR. Mn content of compost was negatively correlated with Pha, HI and HR and was positively correlated with Cha:Cfa and C:N ratio. But none of the correlations were significant.

Table 8. Coefficient of correlation between pH, EC, CEC and nutrient content of composts

	pH	EC	CEC
Nitrogen	0.8123**	-0.8899**	0.0961
Phosphorous	0.8418**	-0.8653**	0.0301
Potash	0.8424**	0.8816**	0.0090
Calcium	0.3236	-0.2893	-0.0408
Magnesium	0.4655*	-0.3486	0.2205
Manganese	0.0052	-0.1302	-0.0327
Zinc	0.7723**	-0.8714**	-0.0422
Copper	0.9292**	-0.8305**	0.0376

* Significant at 5% level

** Significant at 1% level

4.1.6.3 Correlation between pH, EC, CEC and nutrient content of compost

The pH was significantly and positively correlated with almost all the nutrients in the composts revealing the influence of pH on nutrient availability. All the nutrients except trace elements are available to plants at a pH value around neutral to alkaline. But pH and EC had no significant correlation with Ca, Mg and Mn. The CEC was positively correlated with N,P,K, Mg and Cu, while a negative correlation was obtained with Ca, Mn and Zn.

4.2 Nutrient enrichment of vermicompost by inoculation with beneficial microorganisms

The manurial value of a compost is judged mainly by its plant nutrient content. The quality of the compost, on the other hand, is determined, besides other factors, by the composition of the base material itself. The attempt for the improvement of the quality of the compost by addition of inorganic fertilizers does not appear profitable in view of the high cost of such fertilizers, coupled with losses during composting. Therefore an attempt was made to improve the

Table 9. Nutrient composition of enriched composts

	N	P	K	Ca	Mg	Mn	Zn	Cu
	%					ppm		
T_1	1.14	0.65	1.57	0.43	1.04	0.13	232.53	54.07
T_2	1.33	0.67	1.88	0.56	1.03	0.14	219.27	55.60
T_3	1.12	1.35	1.61	1.35	1.10	0.15	232.00	55.13
T_4	1.45	1.36	2.08	1.29	1.09	0.15	231.13	57.07
T_5	1.76	0.72	2.60	0.25	1.30	0.15	336.27	57.40
T_6	1.92	0.77	2.84	0.25	1.30	0.15	316.20	58.07
T_7	1.81	1.75	2.71	0.90	1.34	0.14	315.60	56.00
T_8	2.08	1.76	3.47	0.81	1.33	0.15	328.27	61.60
T_9	1.10	0.51	1.04	0.14	0.58	0.13	195.47	49.20
CD	0.08	0.15	0.08	0.11	0.05	0.01	27.46	11.31

quality of compost by inoculation with effective nitrogen fixing and P solubilizing microorganisms at appropriate stages of decomposition (Hajra, 1988). Extensive studies in this regard at the IARI have shown that inoculation with *Azotobacter chroococcum* and phosphate solubilising microorganisms improved the manurial value of compost (Gaur *et al.*, 1978; Gaur, 1987; Sadasivam *et al.*, 1981 and Gaur and Mathur, 1990).

4.2.1 Nitrogen

Nitrogen content of composts was influenced by enrichment with microorganisms. The earthworm *Eudrillus eugeniae* compost when treated with *Azospirillum*, P solubilising organisms and 1 per cent rock phosphate gave maximum nitrogen content of 2.08 per cent while the uninoculated Eudrillus compost had a nitrogen content of only 1.76 per cent. Eudrillus compost when inoculated with *Azospirillum* gave a nitrogen content of 1.92 per cent and N content was 1.81 per cent when inoculated with P solubilising organisms. Ordinary compost, uninoculated local earthworm compost and local earthworm compost treated with P solubilising organisms were 1.1, 1.14 and 1.12 per cent respectively. No significant difference was observed between these values. Local earthworm compost when inoculated with *Azospirillum* and both *Azospirillum* and P solubilizing organisms also had significantly higher nitrogen content than ordinary compost and the values being 1.33 and 1.45 per cent respectively. An appreciable amount of N was enriched by *Azospirillum*. The enrichment increased progressively when *Azospirillum* inoculation was supplemented with rock phosphate and the phosphate solubilising culture. Hajra (1988) observed a variation within the range of 1.18 to 1.82 per cent in total N of the enriched compost in comparison of 0.97 per cent in the control. This agrees with the results *obtained in the present study. Inoculation with* Azotobacter and phosphate solubilising culture in presence of 1 per cent rock phosphate is a beneficial input to obtain a good quality compost rich in N (Tiwari *et al.*, 1989) Banana leaf compost prepared with similar biotechnology contained 2.8 per cent N against 1.90 per cent N in the control treatment. Increased nitrogen conservation due to rock phosphate addition was reported by several other workers (Dhar *et al.*, 1955; Poincelot, 1975). Inoculating the compost previously amended *with rock phosphate with cultures of* Azotobacter chroococcum and the phosphate solubilising organisms increased the total nitrogen content by 31.9 per cent over control while without rock phosphate increase was 25.4 per cent (Gaur and Sadasivan, 1993). Increase in nitrogen content due to microbial inoculation is also reported by Gaur(1983) and Rasal *et al.* (1988). A nitrogen gain of almost 100 per cent with combined inoculation of Aspergillus, P solubilising organisms and 1 per cent rock phosphate was observed (Gaur 1983).

4.2.2 Phosphorus

The data on P content of enriched compost is given in table 9. The P content of Eudrillus compost inoculated with *Azospirillum* and P solubilising organisms was on par with the P content of Eudrillus compost inoculated with P solubilising organisms. But when compared to uninoculated Eudrillus compost, the P contents were significantly high (1.76 per cent N for Eudrillus compost enriched with *Azospirillum* and P solubilising Organisms and 1.75 per cent for Eudrillus compost enriched with P solublising organisms). When Eudrillus compost was treated with *Azospirillum* alone the P content was only 0.77 per cent. However, when local earthworm compost was inoculated with microorganisms, the P contents were significantly lower than that of enriched Eudrillus compost. Local worm compost inoculated with Azospirillum and P solubilising organisms and one per cent rock phosphate recorded a P content of 1.36 per cent while *the uninoculated local earthworms compost,* Azospirillum inoculated local earthworm compost and ordinary composts had a P content of only 0.65, 0.67 and 0.51 per cent respectively. Hajra (1988) observed similar results while enriching straw compost using nitrogen fixing and P solubilising organisms and rock phosphate. The mechanism of conversion of insoluble P by P solubilising organisms to available forms include altering the solubility of inorganic compounds to the ultimate soluble form through production of acids and/or H_2S under aerobic and anaerobic conditions respectively, and mineralising organic compounds with the release of inorganic phosphate. The phosphate solubilisers also produce the hormones and growth promoting substance (Dey,1988). An increase in total and citrate soluble P due to the addition of rock phosphate and phosphorus solubilising culture was observed by Rasal *et al.* (1988) also. He obtained a P content of 0.76 per cent P_2O_5 for enriched compost while P_2O_5 content of uninoculated compost was only 0.36 per cent. Gaur *et al*, 1982; Gaur 1983 and Tiwari *et al*, 1989 observed increased phosphorus content in compost enriched with N fixing and P solubilizing organisms with 1 per cent rock phosphate. The solubilisation of P by these micro organisms is attributed to excretion of organic acids like citrate, glutamic, succinic, lactic, oxalic, glyoxalic, maleic, fumaric, tartaric and α keto butyric (Subbarao, 1983 and Gaur, 1988 and 1990). The action of organic acids can be attributed to their ability to form stable complexes with Al^{++}, Ca^{++}, Fe^{++} and Mg^{++}. These micro organisms weather rock phosphate and tricalcium phosphate by decreasing the particle size reducing it to nearly amorphous form (Gaur, 1988).

4.2.3. Potassium

Potassium content of different composts inoculated with microorganisms and unioculated are given in table 9. The K content of different composts ranged from 1.04 per cent (for ordinary compost) to 3.47 per cent (Eudrillus composts enriched with *Azospirillum* and P solubilising organisms). When treated with *Azospirillum* alone, Eudrillus compost gave a K content of 2.84 per cent. The K content of local worm compost inoculated with beneficial micro organisms were significantly lower than that of Eudrillus compost. But for the local worm compost also inoculation with *Azospirillum* and P solubilising organisms gave a significantly higher K content than inoculation with *Azospirillum* alone (values being 2.08 per cent and 1.88 per cent respectively). The increase in K content by inoculation with beneficial microbes may be due to accelarated mineralization of organic wastes by microbial activity. Also when the degree of degradation increases, the nutrients get concentrated in the final product obtained.

4.2.4. Calcium

From table 9 it was obvious that calcium content of local earthworm composts enriched with P solubilising organisms and 1 per cent rock phosphate and those enriched with both *Azospirillum* and P solubilising organisms with one per cent rock phosphate were significantly higher than that of other treatments, the values being 1.35 per cent when inoculated with P solubilising organisms and 1.29 per cent when inoculated with *Azospirillum* and P solubilising organisms.

The Ca content of Eudrillus compost also significantly increased by treating with *Azospirillum* and P solubilising organisms. Here it could be observed that a higher content of Ca was found in Eudrillus compost inoculated with P solubilising organisms alone rather than that with both *Azospirillum* and P solubilising organisms (The values being 0.90 per cent and 0.81 per cent respectively). The calcium content of ordinary compost, uninoculated local earth worm compost and Eudrillus composts were 0.14, 0.43 and 0.25 per cent respectively. The enrichment of Ca may be due to the concommitment addition of Ca contained in rock phosphate. The P solubilising microorganisms weather rock phosphate and tricalcium phosphate by decreasing the particle size, reducing it to nearly amorphous form (Gaur, 1988).

4.2.5. Magnesium

In general Mg content of different composts was increased by treating with beneficial microorganisms like *Azospirillum* and P solubilising organisms. But a significant difference could not be observed between the various enriched composts. Here the increase in Mg content may be due to the accelerated mineralization by microbial activity. The indirect addition through rock phosphate may also be one of the reason for the higher content of Mg in enriched composts.

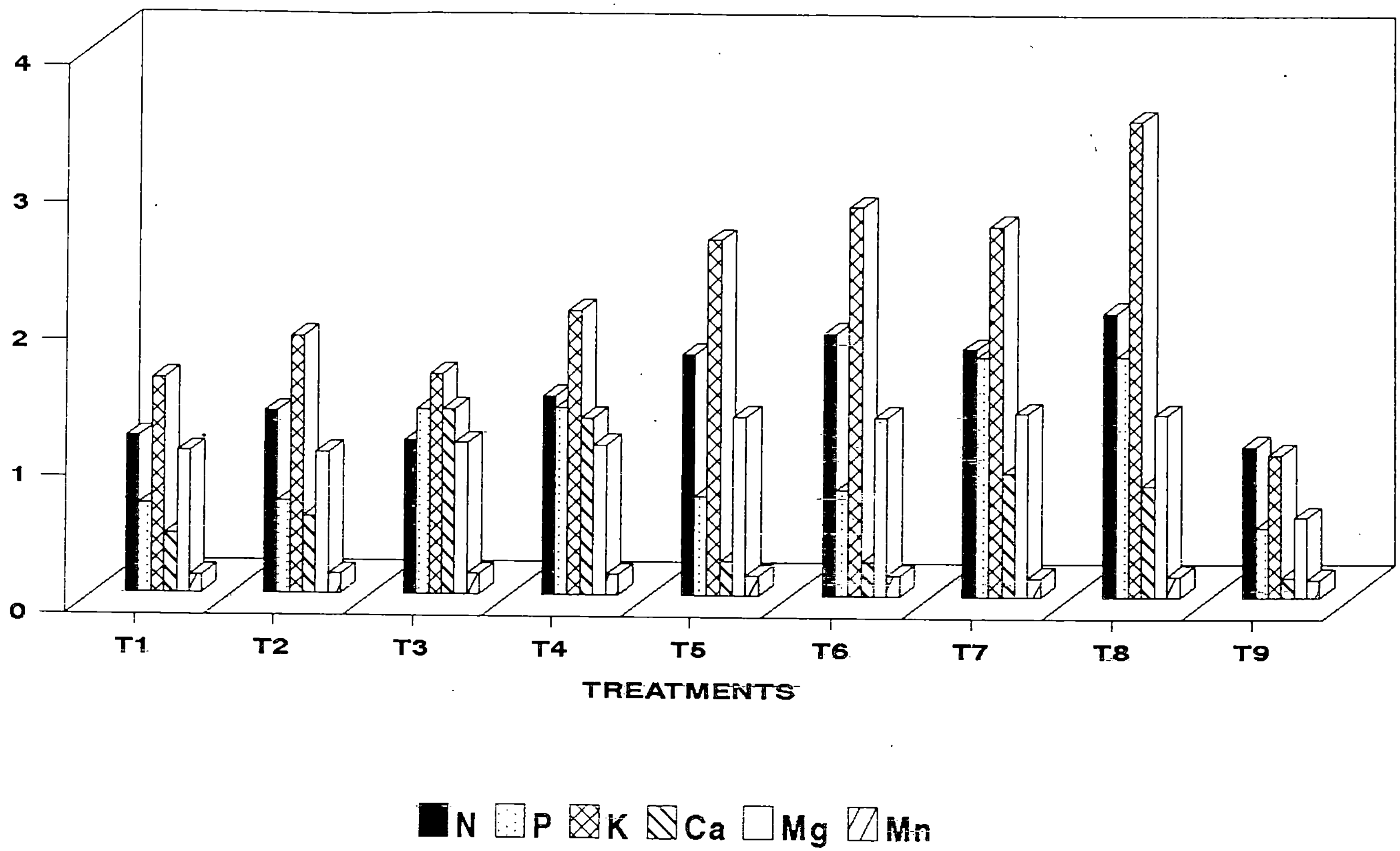


Fig. 4. Nutrient composition of enriched composts

4.2.6. Manganese

No significant difference in the Mn content due to enrichment with microorganisms was observed. The results are presented in table 9. Lowest Mn content was observed for ordinary compost ie. 0.13 per cent. Mn and highest Mn content of 0.15 per cent for Eudrillus compost treated with P solubilising organisms and *Azospirillum*. Eudrillus compost treated with *Azospirillum*, un inoculated Eudrillus compost, local compost treated with *Azospirillum* and P solubilising organisms and local compost treated with P solubilising organisms were on par with regard to their Mn content.

4.2.7. Zinc

The data on zinc content of enriched compost is given in table 9. No significant difference in zinc content could be seen due to enrichment with microorganisms. However here it could be seen that inoculation with microbes have slightly decreased the Zn content in the compost. Zinc content for uninoculated Eudrillus compost was 336.27 ppm while for Eudrillus treated with P solubilising organisms and Azospirillum was 328.27 ppm.

4.2.8. Copper

Table 9 gives the Cu content of different inoculated and uninoculated composts. There was no significant difference among different treatment except for T_8 ie Eudrillus compost inoculated with P solubilising organisms and *Azospirillum* where the Cu content was 61.6 ppm. A slight increase in the Cu content of the enriched composts may be due to the indirect addition of Cu through the culture medium.

4.3. Efficiency of the enriched compost in enhancing yield and nutrient uptake by chilli

Addition of organic manure improves the soil environment which encourages proliferation of roots which in turn draw more water and nutrients from larger areas. Also organic manures after decomposition release macro and micro nutrients which become available to the plants and there by increasing the nutrient uptake.

4.3.1. Biometric observation

Biometric observations are recorded at 5 stages of growth of the crop viz 35 DAP, 50 DAP, 65 DAP, 80 DAP and 90 DAP.

Table 10. Height of plants at different stages of growth

	35 DAP	50 DAP	65 DAP	80 DAP	95 DAP
			cm		
T_1	26.55	37.77	43.80	49.00	52.00
T_2	31.75	45.60	50.85	56.25	59.50
T_3	27.50	38.00	44.90	50.70	53.50
T_4	35.10	48.85	56.05	59.95	61.50
T_5	30.90	39.20	44.95	49.95	54.00
T_6	36.90	45.80	56.15	62.55	66.00
T_7	31.70	38.60	45.50	52.60	56.00
T_8	38.75	57.55	64.60	71.55	75.00
T_9	23.65	34.25	40.40	47.05	51.00
T_{10}	22.25	32.10	37.60	42.25	46.00
CD	5.68	7.34	11.57	11.00	10.44

4.3.1.1. Plant height

Effect of different types of compost on plant height are given in table 10.

Treatments had significant effect on plant height and maximum height (75 cm) was recorded with application of *Eudrillus* compost enriched with *Azospirillum* and P solubilising organisms at the last stage of observation (95 DAP). A significant variation in plant between different treatments was also observed at 50 DAP and 65 DAP. At all the stages plant height was significantly higher for Eudrillus compost inoculated with P solubilising organisms and *Azospirillum*.

Also it was observed that worm cast treated plants attained more height compared to natural compost and farm yard manure treated plants. Worm casts, when used as manure, in place of farm yard manure, significantly influenced the vegetative characters (Kale *et al.*, 1991). Increased plant height in sugarcane and soyabean by addition of vermicompost were also reported by Shuxin *et al.* (1991). *Azospirillum* has been reported to have a growth promoting effect which may be the reason for increased plant height in T_8, T_6, T_4 and T_2. Significant enhancement in the root and shoot development was observed due to *Azospirillum* inoculation in rice (Purushothaman *et al.*, 1988). This more or less agree with the results obtained in the present study.

Increase in plant height is attributed to the rapid meristematic activity due to nitrogen as reported by Crowther (1935). Influence of N in increasing the vegetative growth of plants is a universally accepted fact. Significant increase in plant height due to incremental doses of N by applying N enriched compost (by Azospirillum treatment) is in conformity with the results obtained by Joseph, 1982; Paraminder Singh *et al.*, 1986; Rao and Gulshanlal, 1986 and John, 1989.

Due to the higher rate of metabolic activity coupled with rapid cell division brought about by phosphorus (Bear, 1965) P application at higher rates (by applying P solubilising and organisms rock phosphate treated compost which had higher P content) resulted in uptake of P and this might have resulted in increased utilization of N, leading to increased vegetative growth. James and Harwin, 1967;

Table 11. Number of leaves per plant

	35 DAP	50 DAP	65 DAP	80 DAP	95 DAP
T_1	215.00	302.50	329.50	330.50	307.00
T_2	290.50	380.00	413.50	410.00	385.50
T_3	262.50	306.00	349.50	350.00	341.00
T_4	373.50	483.50	509.00	504.00	493.00
T_5	322.50	376.50	409.00	400.50	392.50
T_6	434.00	505.50	541.00	547.00	539.00
T_7	391.00	490.50	520.50	515.50	502.00
T_8	630.50	707.50	771.50	770.50	743.00
T_9	199.00	267.00	289.00	288.50	259.00
T_{10}	182.50	248.00	278.50	282.50	251.50
CD	214.68	223.24	259.58	260.41	242.60

Table 12. Shoot : root ratio

	Shoot:root ratio
T_1	1.80
T_2	2.89
T_3	1.71
T_4	2.40
T_5	1.88
T_6	3.00
T_7	1.69
T_8	2.58
T_9	1.55
T_{10}	1.50
CD	0.18

Mohammed Kunju, 1968; Joseph, 1982 and John, 1989 obtained increased plant height due to higher levels of P application.

4.3.1.2. Number of leaves per plant

The influence of different composts on number of leaves per plant are given in Table 11. Here it could be noticed that the different types of composts did not influence the number of leaves per plant significantly at different stages of observation. However a slight increase in the number of leaves per plant was observed in the plants which received the enriched Eudrillus composts. Among them, plants treated with both *Azospirillum* and P solublising organisms inoculated Eudrillus composts gave maximum number of leaves per plant. Also it was at 65 DAP that the maximum number of leaves per plant was noticed. Here also the positive influence of enriched composts may be due to the growth promoting effects of beneficial microorganisms.

4.2.1.3. Shoot : root ratio

A significant variation in shoot : root ratio was observed in plants growing in various treatments. However the highest shoot : root ratio was observed in plants where the organic source was Eudrillus compost inoculated with *Azospirillum* (shoot/root ratio is 3). Plants with local worm compost enriched with *Azospirillum* as organic source gave the second highest value for shoot : ratio (2.89) followed by Eudrillus compost inoculated with *Azospirillum* and P solublising organisms (2.58). Here also it could be observed that the performance of farm yard manure and ordinary compost was very much inferior to that of vermicomposts.

The mechanisms by which the plants inoculated with beneficial microbes derive positive benefits in terms of plant biomass is attributed to small increase in N input from biological nitrogen fixation, development and branching of roots, production of plant growth hormones, enhancement in uptake of NO_3^-, NH_4^+, $H_2PO_4^+$, K^+, Rb^+ and Fe^{2+}, improved water status of the plants, increased nitrate reductase activity in plants and production of antibacterial and antifungal compounds (Okon, 1985; Pandey and Kumar, 1989 and Wani, 1990).

Higher levels of N increased shoot weight compared to root weight and so shoot : root ratio increases (James and Harwin, 1967; Mohammed Kunju, 1968 and John, 1989). This

Table 13. Nutrient uptake by plants

	N	P	K	Ca	Mg	Mn	Zn	Cu
	g/plant			mg/plant				
T_1	0.39	0.18	0.86	54.71	141.42	1.96	2.71	2.40
T_2	0.64	0.17	0.98	50.37	139.24	2.46	3.05	2.35
T_3	0.47	0.23	0.89	55.30	162.21	2.27	3.20	2.21
T_4	0.84	0.32	1.24	81.81	207.70	2.83	3.98	2.62
T_5	0.51	0.19	0.84	56.46	179.63	1.88	2.91	2.09
T_6	0.89	0.24	1.16	71.42	289.87	3.14	4.18	3.27
T_7	1.02	0.28	1.49	340.97	260.48	3.18	4.91	4.04
T_8	1.33	0.35	1.37	184.55	312.54	4.44	4.92	4.13
T_9	0.39	0.16	0.86	57.75	137.63	2.68	2.84	2.13
T_{10}	0.29	0.20	0.64	36.65	98.93	1.21	2.03	1.19
CD	0.19	0.024	0.33	109.63	42.12	0.95	1.17	1.04

may be the reason for higher shoot : root ratio in plants meaoured with *Azospirillum* treated compost. But when P is applied, better development of root (Buckman and Brady, 1960) and thereby reduced shoot : root ratio observed (Mohammed Kunju, 1968; John, 1989). It may be the reason for slight decrease in shoot : root ratio when applied P was higher. But Joseph (1982) obtained higher shoot : root ratio with applied P.

4.3.2. Nutrient uptake by plants

The increase in nutrient uptake following organic manure application is probably due to the improvement in soil environment which encourages proliferation of roots which in turn derive more water and nutrients from larger volumes of soil.

4.3.2.1. Nitrogen

The data on uptake of nitrogen by plants under different treatments are given in table 13. In general, the N uptake by the plant was considerably increased when enriched vermicompost were used as the organic source. Here also it could be noticed that maximum N uptake was for plants where the organic source was Eudrillus compost inoculated with *Azospirillum* and P solubilising organisms (1.33 g/plant) which is significantly higher than that of other treatments. This is followed by *Eudrillus* compost inoculated with *Azospirillum*, Eudrillus compost enriched with P solubilising organisms, local compost inoculated with *Azospirillum* and P solubilising organisms (values being 1.02, 0.89 and 0.84 g/plant respectively). Here also it could be seen that the N uptake was much less when farm yard manure and ordinary compost were used as the organic source. The increase in N uptake may be due to the fact that a vast portion of non available N present in organic matter could be made available to plants through vermicomposting and microbial activity. Generally good response to inoculation are obtained at intermediate levels of N fertilizers. In the present study the inorganic fertilizers recommendation was as per the package of practices of KAU. The increase in N uptake may be attributed to small increase in N input from biological nitrogen fixation by *Azospirillum*, increased nitrate reductase activity with the enhancement in uptake of NO_3 and NH_4^+. In multi location experiments with pearl millet higher increase in grain yield, plant biomass and total N uptake were observed with zero N + inoculation and the extent of response declined with increasing levels of applied N (Wani *et al.*, 1988). There are reports of about 30 to 50 per cent increase in plant absorbance of nitrogen by inoculating with N fixing organisms (Shuxin *et al.*, 1991). Increased uptake of N due to *Azospirillum* inoculation was reported by Kumar and Balasubramanian (1986), Muthukrishnan and Purushothaman (1992) and Resmi (1993).

4.3.2.2. Phosphorus

Data on P uptake by plants under different treatments is given in table 13. P uptake was also highest in plant treated with Eudrillus compost enriched with *Azospirillum* and P solubilising organisms (0.35 g/plant). The P uptake by plants treated with *Azospirillum* and P solubilising organisms inoculated local earthworm compost was also found to be high when compared to other treatments (0.32 g/plant). However significantly lower values for P uptake were obtained when farm yard manure and ordinary compost were used as the organic source (0.20 and 0.16 g/plant respectively). The earthworms stimulate P uptake from the redistribution of organic matter and by increasing the enzymatic activation of phosphatase (Mackay *et al.*, 1982). The increased mineralisation of native soil P as a result of production of organic acids during decomposition of organic matter may also be one of the reason for increased P uptake by the plants. The solubilisation of P by these microorganisms is attributed to excretion of organic acids like citric, glutamic, succinic, lactic, oxalic, glyoxalic, maleic, fumaric, tartaric and α keto butyric acids. (Subba Rao, 1983); (Gaur, 1988 and 1990). In addition to P solubilisation, these microorganisms can mineralize organic P into a soluble form. These reactions take place in the rhizosphere and because the organisms render more P into solution than that required for their own growth and metabolism, the surplus is available for plants there by increasing the P uptake. The increased P availability by increase in solubility of P by higher phosphatase activity by vermicompost application was noticed by Syres and Springett (1984). Shuxin *et al.* (1991) observed an increase of 18.2 ppm available P over control by earthworm cast application. Better P uptake in plants inoculated with P solubilising organisms was noticed by Subba Rao (1988).

4.3.2.3. Potassium

The potassium uptake of plants under different treatments are given in table 13. The values ranged from 0.64 g/plant for plants treated with farm yard manure to 1.49 g/plant for plants treated with Eudrillus compost inoculated with P solubilising organisms. However no significant variation in K uptake by plants under different treatments was observed. The increase in K uptake due to vermicompost application may be due to increase in K availability by shifting the equilibrium among the forms of K from relatively unavailable forms to more available forms in the soil (Baskar *et al.*, 1992). Little is known about the effect of vermicompost on K availability and this may be due to the fact that the K content of plant debris is less than that of the soil, and K is not strongly bound in plant material. The increased concentration of K in the cast under field condition could have resulted from the transport of K from K rich horizon of subsoil by earthworm activity or may be due to a change in one or more of the factor affecting fixation *and release of K in soil (Basker* et al., *1992)* Azospirillum inoculation and higher level of P in P enriched composts would have enhanced the root proliferation which helps in

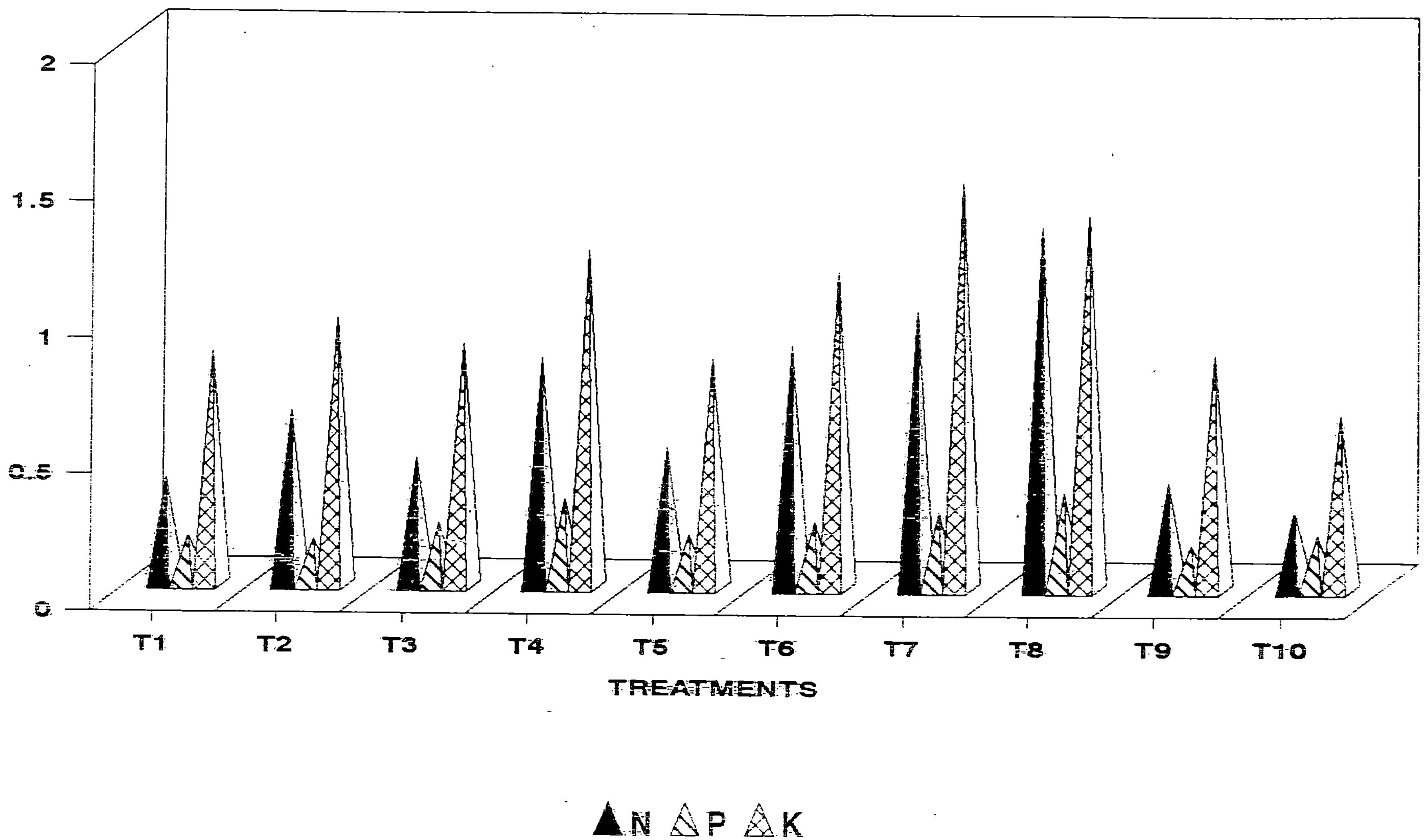


Fig. 5. Macro nutrient uptake by plants

more uptake of potassium. Resmi (1993) showed superiority of *Azospirillum* application in uptake of potassium. Also K uptake linearly increases with N uptake (Biswas, 1987; Salam, 1988; Krishnaprasad and Madhusoodana Rao, 1989 and Resmi, 1993).

4.3.2.4. Calcium and Magnesium

The calcium and magnesium uptake by plants under different treatments is given in table 13. A scan through the data revealed that maximum Ca uptake (340.97 mg/plant was recorded by plants manured with enriched Eudrillus compost (T_1 followed by plants treated with local earthworm compost. While farm yard manure and natural compost treated plants had Ca uptake level of 36.65 and 57.75 mg/plant only. Similarly the Mg uptake by plants under different treatments are significantly different with 98.39 and 137.63 mg/plant for farm yard manure and natural compost treated plants to 312.54 mg/plant for *Azospirillum* and P solubilising organisms inoculated Eudrillus compost treated plants. P solubilising organisms enriched Eudrillus compost treated plants and plants treated with *Azospirillum* enriched Eudrillus compost also had significantly higher Mg uptake viz. 289.87

and 260.68 mg/plant. The increased Ca and Mg availability in vermicomposts may be the reason for the increased uptake (Shuxin *et al.*, 1991). The calciferous glands in earthworms contain carbonic anhydrase which catalyse the fixation of CO_2 as $CaCO_3$. Also the application of vermicomposts enriched with beneficial microbes improve the soil environment helping in better root proliferation thereby increasing the availability of native Ca and Mg.

4.3.2.5. Micronutrients

In the case of micro nutrients no significant variation was observed in the nutrient uptake by plants under different treatments. The highest value for Mn uptake was noticed for T_8 ie Eudrilius compost enriched with both *Azospirillum* and P solubilising organisms treated plants (4.4 mg/plant). This is followed by P solubilising organisms enriched Eudrillus compost treated plants, (3.18 mg/plant) *Azospirillum* enriched Eudrillus compost treated plants (3.14 mg/plant) and both *Azospirillum* and P solubilising organisms enriched local worm compost treated plants (2.83 mg/g). Mn uptake by plants treated with farm yard manure was as low as 1.23 mg/plant. But Hartenstein and Rothwell (1973) when tried pelletized garbage compost as a source of nutrients observed an increase in the uptake of all nutrients except that of manganese. As explained earlier earthworms are reported to have the capacity to accumulate trace elements in some parts of their bodies there by decreasing the final concentration in the composts. Only if the earthworms die and decay these nutrients get fully incorporated into the compost.

The uptake uptake of Zn by plants coming under different treatments ranged from 2.03 mg/plant (farm yard manure treated plants) to 4.92 mg/plant (*Azospirillum* and P solubilising organisms enriched Eudrillus compost treated plants). Table 13. But there was not much significance in Zn uptake by plants under different treatments Khan *et al.* (1981) obtained higher levels of Zn content in plants due to city compost application.

The data for Cu uptake by plants is given in table 13. Different treatments had no significant variation in the Cu uptake by plants. But slightly higher uptake of Cu was shown by plants treated with different enriched Eudrillus composts 4.13, 4.04 and 3.27 mg/plant respectively, while

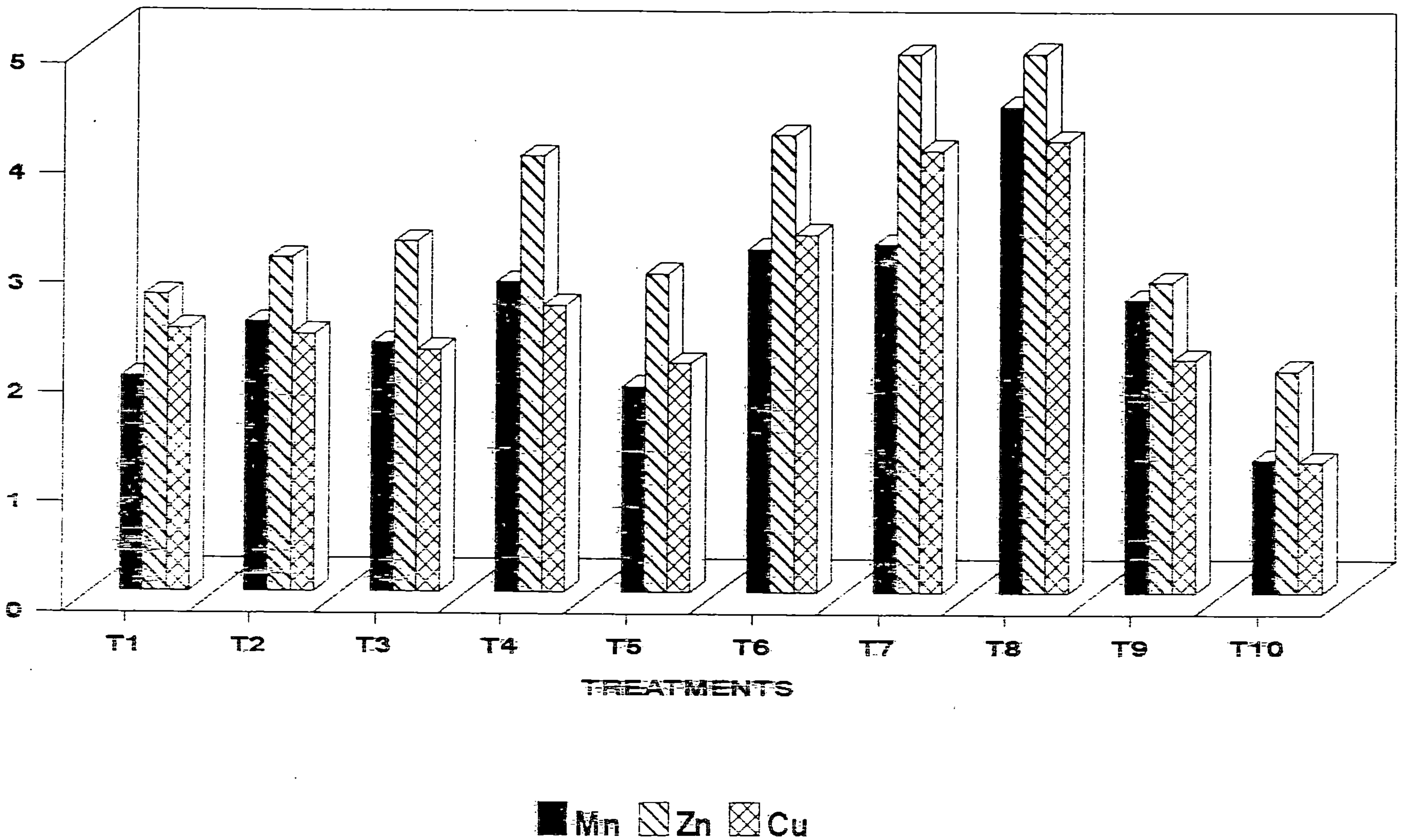


Fig. 6. Micro nutrient uptake by plants

Table 14. Yield of chilli

	Yield g/plant
T_1	131.42
T_2	147.02
T_3	129.23
T_4	217.90
T_5	116.42
T_6	196.23
T_7	178.49
T_8	302.89
T_9	145.25
T_{10}	104.57
CD	39.76

farm yard manure treated plants had a lower uptake level of 1.19 mg/plant. A study for utilizing copper tailings in *agriculture through vermicomposting using* Eudrillus eugeniae showed earthworms as a bio indicator for the copper toxity in the medium (Gangadhar and Kale, 1993).

4.3.3. Yield

Mean fruit yield of plants under different treatments are given in table 14. Total fruit yield was significantly influenced by various treatments. Application of Eudrillus compost enriched with *Azospirillum* and P solubilising organisms (T_8) recorded the highest yield of 302.89 g/plant, which was significantly superior to all other treatments. Control (T_{10}) plants where farm yard manure was applied instead of composts gave the lowest yield of 104.57 g/plant. But it was on par with yield obtained from plants treated with uninoculated composts.

Yield of plants treated with *Azospirillum* and P solubilising organisms enriched local worm compost, *Azospirillum* enriched Eudrillus compost, P solubilising organisms enriched Eudrillus compost were on a par but were significantly superior to all other treatments (except T_8) and recorded the yields of 217.9, 196.23 and 178.49 g/plant respectively.

The higher availability of N and P due to improved physical environment created by worms, N fixing and P solubilising organisms have contributed to highest yields (More, 1994). Similar increase in yields due to application of worm worked composts reported by Senapati *et al.* (1985). Increased yields in soyabean and sugar cane were also reported due to vermicompost application (Shuxin *et al.*, 1991). *Azospirillum* due to its ability to fix elemental N and its growth promoting substances improves the yield of crops (Subba Rao, 1983). Noticeable increases in yields especially in vegetables were also observed due to inoculation of P solubilising organisms. In an evalution of the reported world wide success of *Azotobacter* and *Azospirillum* inoculation, statistically significant yield increases were reported (Wani, 1990). More than the N fixation activity, the ability of producing growth promoting substance may be the reason for increased yields due to *Azospirillum* inoculation. Significant increase in soyabean yield was obtained due to inoculation with P solubilising

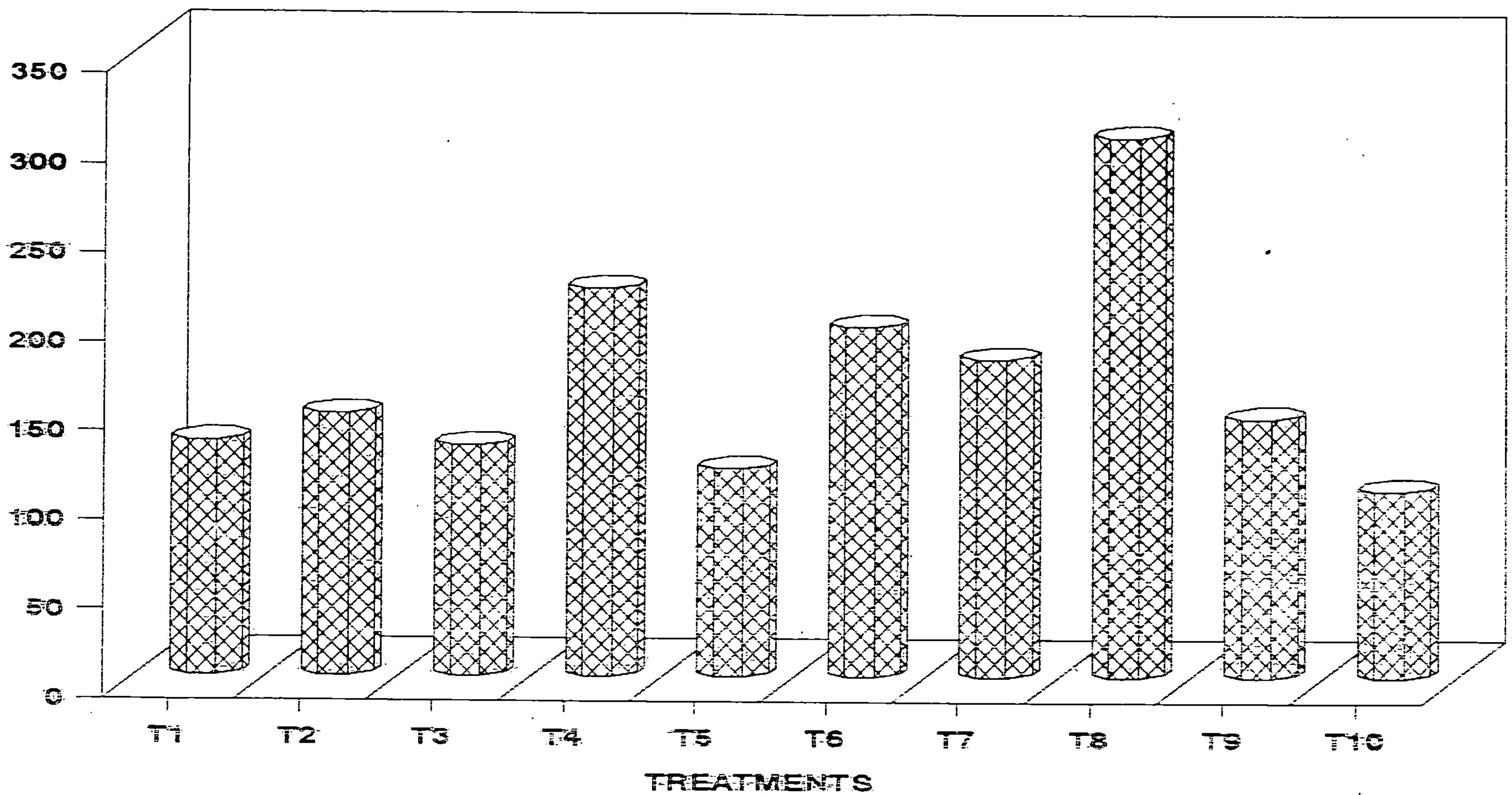


Fig. 7. Yield (g/plant)

Table 15. Coefficient of correlation between humification parameters and nutrient uptake and yield

	N	P	K	Ca	Mg	Mn	Zn	Cu	Yield
Humic acid	0.6469**	0.4817**	0.4931**	0.504**	0.7695**	0.373**	0.5903**	0.6059**	0.3820
Fulvic acid	0.5333**	0.3356	0.4285	0.4496*	0.6727**	0.3901	0.5528**	0.5123*	0.3644
HA/FA ratio	0.6379**	0.4907*	0.4782*	0.4772*	0.7456**	0.3453	0.5841**	0.5864**	0.3716
HI	0.5913**	0.4854*	0.4949*	0.3790	0.6882**	0.3523	0.5466*	0.566**	0.3471

* Significant at 5% level

** Significant at 1% level

bacteria along with rock phosphate application over the control, where as application of 80 kg P_2O_5 per ha through Single Super Phophate did not result in similar increase (Sundara Rao, 1968). In multi locational trials conducted with different crops, increased yields (0-50 per cent) were obtained due to inoculation with P solubilising organisms with or with out rock phosphate addition. Potato tuber yields were increased dramatically (50-60 per cent) due to inoculation with P solublising organisms. Gaur, 1988. In field trials berseem, Maize, wheat and paddy responded to inoculation with P solublising organisms and showed a significant increase in yield (Sundara Rao, 1968).

4.3.3.1 Correlation between humification parameters with nutrient uptake and yield

Humic acid was significantly and positively correlated with all nutrient uptakes except Mn uptake by the plants. Degree of correlation was highest between humic acid and magnesium (r value being 0.7695) followed by correlation between humic acid and nitrogen (r value is 0.6469). No significant correlation was obtained between yield and humic acid.

Table 16. Coefficient correlation between yield and height of plant, number of leaves and shoot:root ratio

	Yield
Ht 35 DAP	0.7482**
Ht 50 DAP	0.8101**
Ht 65 DAP	0.7706**
Ht 80 DAP	0.8138**
Ht 95 DAP	0.8156**
Leaves 35 DAP	0.7758**
Leaves 50 DAP	0.7927**
Leaves 65 DAP	0.7778**
Leaves 80 DAP	0.777**
Leaves 95 DAP	0.7829**
Shoot/root ratio	0.5512

** Significant at 1% level

Fulvic acid was positively and significantly correlated with N, Ca, Mg, Zn and Cu uptake (r values were 0.5333, 0.4406, 0.6727, 0.5528 and 0.5123 respectively). Fulvic acid had no sigificant correlation with yield. Significant positive correlation was observed between HA:FA ratio and N, P, K, Ca, Mg, Zn and Cu uptake of plants. Highest correlation was between HA:FA and Mg followed by HA:FA ratio and N. Uptake of all the nutrients were positively correlated with humification index and significant positive correlations were observed between humification index with Mg, N, Cu, Zn, K and P. (r values being 0.6882, 0.5913, 0.566, 0.5466, 0.4949, 0.4854 respectively).

Effect of humic acid on the availability of Ca and Mg was reported earlier by Pal and Sengupta (1985).

4.3.3.2. Correlation between yield and biometric characters of plant

Yield was significantly and positively correlated with height of plants and number of leaves per plant at all stages of observations. Number of leaves at 50 DAP showed the highest degree of correlation between yield (r value being 0.7927). Even though yield gave a positive correlation with shoot : root ratio the correlation was non significant.

Table 17. Coefficient of correlation between nutrient content of composts nutrient uptake by plants and yield

Nutrient content	N	P	K	Ca	Mg	Mn	Zn	Cu	Yield
N	0.8238**	0.6333**	0.6311**	0.4942*	0.8863**	0.6311**	0.7117**	0.7066**	0.6625**
P	0.7872**	0.8778**	0.7731**	0.7444**	0.6696**	0.6370**	0.7900**	0.7235**	0.6614**
K	0.8374**	0.6916**	0.6396**	0.4888*	0.8786**	0.6125**	0.7064**	0.7193**	0.6624**
Ca	0.7496**	0.8409**	0.7236**	0.7131*	0.7010**	0.5860*	0.7398**	0.6930**	0.5907**
Mg	0.6210**	0.5624**	0.4950*	0.4361*	0.6895**	0.3117	0.5651*	0.5450*	0.3668
Mn	0.3885	0.4484*	0.1704	0.0803	0.4096	0.2329	0.4090	0.1074	0.2989
Zn	0.5872**	0.4340*	0.4626*	0.5000*	0.7186**	0.4001	0.5502*	0.5463*	0.3629
Cu	0.3437	0.5170*	0.4872*	0.2916	0.3244	0.2565	0.4333	0.2214	0.3370
Yield	0.9058**	0.8503**	0.7708**	0.4527*	0.8169**	0.8924**	0.7986**	0.7601**	----

* Significant at 5% level
** Significant at 1% level

4.3.3.3. Coefficient of correlation between nutrient content of composts, nutrient uptake by plants and yield

Results of correlation studies clearly showed that correlation coefficients of yield attributing characters were highly significant.

Nutrient uptake by the plants were positively correlated with nutrient content of compost. Highest correlation was observed between N content of the compost and Mg uptake by plant (r value being 0.8863) which means that the increase in N content enhancing Mg uptake. Correlation between K content of compost and Mg uptake (r value 0.8778), P content of compost and P uptake by plant (r value 0.8778) and Ca content of compost and P uptake (r value of 0.8409) follows. N content of compost and K content of compost were also significantly and positively correlated with N uptake by the plant (r values being 0.8238 and 0.8374 respectively). Here also the nutrient interactions are well explained. As discussed earlier, most of the nutrients have a synergistic effect on the uptake of all the nutrients. Also because of the conducive environment created by the proliferation of roots by vermicompost application, the uptake of nutrients is increased. Yield was positively correlated with the nutrient contents of the compost. Significant positive correlations were observed between yield and N content of compost, yield and P content of compost, yield and K content of compost and yield and Ca content of compost (r values were 0.6625, 0.6614, 0.6624 and 0.5907 respectively). Significant yield increase observed with higher levels of N content in the compost. Yield increase due to increased levels of N application was reported earlier by Subbiah (1983), Srinivas (1983), Narasappa *et al.* (1985), Hegde (1986), Paraminder Singh *et al.* (1986), Prabhakar *et al.* (1987), Shukla *et al.* (1987), Ramarao *et al.* (1988) and John (1989). Increases in yield due to increased P content was reported by Khan and Surya Narayana (1977), Joseph (1982); Prabhakar *et al.* (1987) and John (1989). There was progressive increase in yield with high levels of K. K had its influence on uptake and utilization of N. (Subbiah, 1983; Kadam *et al.*, 1985; Ramarao *et al.*, 1988;, John, 1989).

Uptake of all nutrients were positively and significantly correlated with yield of plants. Among them N uptake was highly correlated to yield (r value is 0.9058).

From the strength of correlation it could be observed that N uptake was influencing the yield to the maximum followed by Mn uptake (r value being 0.8924).

The beneficial effect of higher levels of P in increasing the uptake of nitrogen have been reported by James and Harwin (1967), Joseph (1982) and John (1989). Increase in the uptake of nitrogen by increased K content was reported earlier by Ozaki and Hamilton (1954), Speldon and Ivanic (1968), Ivanic and Strelec (1976), Joseph (1982) and John (1989). Increased uptake of P with increasing levels of applied N and P was reported earlier by James and Harwin (1967), Joseph (1982) and John (1989). Increased uptake of K with increasing levels of applied N has been reported by Ozaki and Hamilton (1954), Joseph (1982) and John (1989). P has got a favourable effect on K uptake. Beneficial effects of higher levels of K application in increasing P uptake was reported earlier by Speldon and Ivanic (1968) Ivanic and Strelec (1976), Joseph (1982) and John (1989).

7 Comparison of different types of enrichment treatments

8 Comparison of different types of enrichment treatments

9 Comparison between T_9 and T_1

10 Comparison between T_9 and T_2

11 Comparison between T_9 and T_3

12 Comparison between T_9 and T_4

13 Comparison between T_9 and T_5

14 Comparison between T_9 and T_6

15 Comparison between T_9 and T_7

16 Comparison between T_9 and T_8

SUMMARY

SUMMARY

The ever increasing garbage, which we throw out pollutes the environment and becomes a health hazard when it is left to rot on streets and roads. The total annual waste biomass of India is about 2500 million tonnes and the disposal of this garbage is a very serious problem today and needs much attention. A major portion of this garbage is bio-degradable and are rich sources of nutrients and can be converted to organic manures, if recycled properly. This assumes more significance in view of the existing energy shortage and consequent escalation in the cost of chemical fertilizers. Due to socio-economic constraints the availability of these manures are restricted. So we have to evolve a socially acceptable technology which will ensure pollution abatement, besides producing organic fertilizers from garbage and crop residues. So an attempt was made to utilize earthworms and micro organisms as biological agents in producing an enriched organic manure from vegetable garbage and its efficiency in increasing production was tested in a vegetable crop chilli. The findings of the study are summarised below.

1. Earthworms reduced the time taken for composting. Among *the different earthworm species used*, Eudrillus eugeniae took only 41 days for converting waste to compost while local worms took 56 days.

2. When *Eudrillus eugeniae* was used as the biological agent for decomposition, rate of degradation was more. This was evidenced from ratio of decomposed to undecomposed and humified matter of the compost.

3. Eudrillus compost showed a lower oxidisable carbon content of 13.93 per cent, higher humic acid content of 25.26 per cent, higher HA/FA ratio of 1.8 and higher alkali soluble carbon of 18.86 per cent.

4. Carbon content of humic acid and fulvic acid were more or less same irrespective of the method used for compost production.

5. Humification indices worked out gave a higher degree of compost maturity for Eudrillus compost. C:N ratio was narrowed down to 8.24 in Eudrillus compost while Cha:Cfa was more (1.74). Pha, HR and HI were also very high for Eudrillus compost, which indicated higher maturity of the compost.

6. Vermicomposts showed a pH ranging from neutral to alkaline. pH of the Eudrillus compost was 7.34 while that of ordinary compost was 6.33.

7. CEC of different composts were more or less same which ranged from 80.61 to 82.11 Cmol kg^{-1}.

8. Nutrient content of vermicomposts were higher when compared to that of ordinary compost. N,P and K content of Eudrillus compost was 1.69, 0.76 and 2.71 per cent respectively, while it was only 1.08, 0.46 and 0.95 per cent for ordinary compost prepared from the same feed materials. Calcium content of vermicomposts were high but local earthworm composts had higher Ca content than other two. Eudrillus composts showed a higher per cent of Mg and micro nutrients like Mn, Zn and Cu.

9. Biomass production potential of different earth worm species showed the potentiality of *Eudrillus eugeniae* in compost production. They had a higher reproductive potential of 11 cocoons and 22 young ones/100 g of compost in 41 days while it was only three cocoons and nine young ones for local worms in 56 days.

10. Correlation studies showed that all the nutrients except Mn had a negative significant correlation with organic carbon. Humic acid and fulvic acid were positively correlated with the nutrients content of the compost and N, P, K, Zn and Cu gave significant correlations with humic acid and fulvic acid.

11. Enrichment of composts with N fixing *Azospirillum* and P solubilising micro organisms along with one per cent rock phosphate had a significant effect on their nutrient content. *Azospirillum* treated composts had a higher N content while both *Azospirillum* and P solubilising organisms inoculated compost had the maximum N and K content. Composts inoculated with P solubilising organisms and one per cent rock phosphate had highest P, Ca and Mg content. Microbial enrichment had no significant effect on the level of micro nutrients in the composts.

12. Application of Eudrillus compost inoculated with both *Azospirillum* and P solubilising organisms had the highest plant height (75 cm), more number of leaves (771.5) and highest shoot : root ratio (3).

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13. Application of Eudrillus compost increased the uptake of nutrients by plants. Application of Eudrillus compost inoculated with both *Azospirillum* and P solubilising organisms increased the uptake of N, P and Mg significantly (1.33, 0.35, 0.31 g/plant respectively) and increased the uptake of micronutrients slightly. K and Ca uptake was more for plants treated with Eudrillus composts enriched with P solubilising organisms. Correlation studies showed that nutrient uptake was significantly and positively correlated with nutrient content of compost.

14. Application of Eudrillus compost enriched with both *Azospirillum* and P solubilising organisms to plants gave maximum per plant yield (302.89 g/plant)

15. Correlation studies showed that yield was positively and significantly correlated with nutrient content of compost, nutrient uptake of the plant, plant height and number of leaves per plant.

From the results it can be concluded that by utilizing earth worms vegetable garbage can be converted to nutrient rich organic manures. Among the different earth worms species *Eudrillus eugeniae* is found to be the superb agents for biodegradation.

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VERMICOMPOSTING OF VEGETABLE GARBAGE

By

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ABSTRACT OF THE THESIS
SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENT FOR THE DEGREE OF
MASTER OF SCIENCE IN AGRICULTURE
(SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)
FACULTY OF AGRICULTURE
KERALA AGRICULTURAL UNIVERSITY

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMIST
COLLEGE OF AGRICULTURE
VELLAYANI
THIRUVANANTHAPURAM
1995

ABSTRACT

An economically feasible method of composting, utilizing earthworms and beneficial micro organisms was standardized to produce an enriched organic manure and its efficiency was tested on a vegetable crop (Chilli). Comparison of the biomass production potential of earthworms and the composts produced by them were carried out in an experiment in CRD with three treatments and seven replications. The efficiency of the epigeic earthworm species, *Eudrillus eugeniae* in composting was well established. They had a greater biomass production potential and produced 11 cocoons and 22 young ones per 100g of compost in 41 days, *Eudrillus eugeniae* reduced the time required for composting and increased the rate of degradation and degree of humification. Eudrillus composts had a reduced oxidisable organic carbon content and increased humic acid and alkali soluble carbon content. HA:FA ratio was increased in Eudrillus compost and C:N ratio was narrowed down to a greater extent. Carbon content of humic acid and fulvic acid fractions of the three composts were found to be the same. Similarly the cation exchange capacity also had comparable values. Vermicomposts showed a pH ranging from neutral to

alkaline. Eudrillus compost showed a higher percentage of N, P, K, Mg, Mn, Zn and Cu in them. But Ca content was more in local earthworm compost.

Inoculation of beneficial micro organisms increased nutrient levels of vermicomposts to a greater extent. Inoculation of both *Azospirillum* and P solubilising organisms along with one per cent rock phosphate gave maximum N, P, K and micro nutrients. Ca and Mg were highest in composts treated with P solubilising micro-organisms and one per cent rock phosphate. Various growth parameters were increased due to the application of Eudrillus compost enriched with both *Azospirillum* and P solubilising organisms. Application of Eudrillus compost increased the uptake of nutrients by plants. Uptake of N, P, Mg, Mn, Zn and Cu were higher for plants treated with Eudrillus compost enriched with both *Azospirillum* and P solubilising organisms. Yield was maximum for plants treated with Eudrillus compost enriched with both *Azospirillum* and P solubilising organisms.

Yield and nutrient uptake of plants were significantly and positively correlated with nutrient content of compost and so vermitechnology using earthworms as biological agents is found to be the best for bio-degradation of organic wastes. Also *Eudrillus eugeniae* was found to be the superb effective agent for the operation of this technology.