

**DYNAMICS OF EARTHWORM - SOIL - PLANT -  
RELATIONSHIP IN SEMIARID TROPICS**

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# DYNAMICS OF EARTHWORM - SOIL - PLANT - RELATIONSHIP IN SEMIARID TROPICS

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*By*

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This is to certify that the thesis entitled "DYNAMICS OF EARTHWORM-SOIL-PLANT RELATIONSHIP IN SEMIARID TROPICS" submitted by Mr. R. B. PAWAR in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY in SOIL SCIENCE, to the University of Agricultural Sciences, Dharwad, is a record of research work carried out by him during the period of his study in this University under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.


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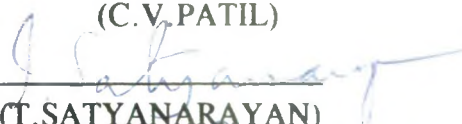
  
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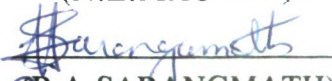
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**AFFECTIONATELY DEDICATED**

**TO MY**

**BELOVED PARENTS**

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## CONTENTS

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Chapter	Title	Page No.
I	Introduction	1-3
II	Review of Literature	4-47
III	Materials and Methods	48-66
IV	Experimental Results	67-135
V	Discussion	136-179
VI	Summary	180-183
VII	References	184-214
	Appendices	215-227

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## LIST OF TABLES

Table No.	Title	Page No.
1.	Mean monthly meteorological data for the year 1994-95 and 63 years recorded at the meteorological observatory, Regional Research Station, Raichur.	54
2.	Physico-chemical properties of soils of experimental site.	56
3.	Nutrient content of vermicompost and FYM	57
4.	Effect of soil moisture levels on growth and biomass of earthworm	68
5.	Effect of soil pH on growth and biomass of earthworm	68
6.	Effect of soil salinity on growth and biomass of earthworm	70
7.	Effect of soil temperature on growth and biomass of earthworm	70
8.	Decomposition of different crop residues by earthworms	73
9.	Population and biomass of earthworm as influenced by different crop residues used as mulch	75
10.	Enzyme activity in soil as influenced by earthworm and different crop residues	77
11.	pH, organic carbon and available nutrient content of soil as influenced by earthworm and crop residues	80
12.	Available nutrient content ( $\text{mg kg}^{-1}$ ) of soil as influenced by earthworm and crop residues at different days of incubation	84

Table No.	Title	Page No.
13.	Effect of organic manures and fertilizer levels on growth and yield of maize	91
14.	Total cost of cultivation ('000' Rs ha <sup>-1</sup> ) of maize cultivation with organic manures and fertilizer levels	94
15.	Net returns ('000'Rs ha <sup>-1</sup> ) realized due to application of organic manures and fertilizer levels	94
16.	Effect of organic manures and fertilizer levels on the uptake of nutrients by maize	96
17.	Effect of organic manures and fertilizer levels on pH, E.C., organic carbon and available nutrient status of soil after the harvest of maize	104
18.	Effect of <i>in situ</i> vermiculture and fertilizer levels on growth yield of maize	110
19.	Total cost of cultivation ('000' Rs ha <sup>-1</sup> ) of maize cultivation with <i>in situ</i> vermiculture and fertilizer levels.	115
20.	Net returns ('000' Rs ha <sup>-1</sup> ) realised due to <i>in situ</i> vermiculture and fertilizer levels	115
21.	Effect of <i>in situ</i> vermiculture and fertilizer levels on uptake of nutrients by maize	117
22.	Effect of <i>in situ</i> vermiculture and fertilizer levels on pH, E.C., organic carbon and available nutrient status of soil after the harvest of maize	126
23.	Infiltration rate (cm hr <sup>-1</sup> ) of soil as affected by <i>in situ</i> vermiculture and fertilizer levels	133
24.	Population and biomass of introduced and native worms as affected by mulch and fertilizer levels	133

## LIST OF FIGURES

Figure No.	Title	Between Pages
1.	Mean monthly meteorological data for the year 1994-95 and for 63 years recorded at the meteorological observatory, Regional Research Station, Raichur.	54-55
2.	Plan of layout of field experiments.	58-59
3.	Effect of soil moisture level on growth and biomass of earthworm.	137-138
4.	Effect of soil pH on growth and biomass of earthworm.	137-138
5.	Effect of soil salinity on growth and biomass of earthworm.	137-138
6.	Effect of soil temperature on growth and biomass of earthworm.	137-138
7.	Decomposition of different crop residues by earthworm.	140-141
8.	Effect of organic manures and fertilizer levels on the yield of maize.	151-152
9.	Net returns ('000' Rs ha <sup>-1</sup> ) from maize cultivation as realized due to application of organic manures and fertilizer levels.	154-155
10.	Effect of <i>in situ</i> vermiculture and fertilizer levels on the yield of maize.	162-163
11.	Net returns ('000' Rs ha <sup>-1</sup> ) from maize cultivation as realized due to <i>in situ</i> vermiculture and fertilizer levels.	165-166

## LIST OF APPENDICES

Appendix No.	Title	Page No.
1.	Chemical composition of crop residues	215
2.	Quantity and cost of different inputs used for maize cultivation for one hectare.	216
3.	Gross returns ('000' Rs ha <sup>-1</sup> ) of maize realized due to application of organic manures and fertilizer levels.	217
4.	Gross returns ('000' Rs ha <sup>-1</sup> ) realized due to <i>in situ</i> vermiculture and fertilizer levels.	218
5.	Effect of organic manures and fertilizer levels on nutrients content of maize grain	219
6.	Effect of organic manures and fertilizer levels on nutrients content of maize stover	219
7.	Effect of Organic manures and fertilizer levels on the uptake of N, P and K (kg ha <sup>-1</sup> ) by maize	220
8.	Effect of organic manures and fertilizer levels on uptake of Ca, Mg and S (kg ha <sup>-1</sup> ) by maize.	221
9.	Effect of organic manures and fertilizer levels on uptake of micronutrients (g ha <sup>-1</sup> ) by maize	222
10.	Effect of <i>in situ</i> vermiculture and fertilizer levels on nutrients content of maize grain	223
11.	Effect of <i>in situ</i> vermiculture and fertilizer levels on nutrients content of maize stover	224
12.	Effect of <i>in situ</i> vermiculture and fertilizer levels on uptake of N,P and K (kg ha <sup>-1</sup> ) by maize	225
13.	Effect of <i>in situ</i> vermiculture and fertilizer levels on uptake of Ca, Mg and S (kg ha <sup>-1</sup> ) by maize.	226
14.	Effect of <i>in situ</i> vermiculture and fertilizer levels on uptake of micronutrients by maize (g ha <sup>-1</sup> )	227

# Introduction

## I. INTRODUCTION

There is an increasing awareness worldwide about alternative/natural/biological/organic/sustainable farming in view of energy shortages, food safety and soil and environmental pollution arising out of chemical farming. Whatever be the name, this alternative farming system largely excludes the use of inorganic fertilizers, pesticides, growth regulators, etc. This system relies upon efficient recycling of crop residues, animal manures, green manures etc, minimum mechanical cultivation, increase in pest resistance through balanced nutrition of plants, biological pest control and crop rotation. The government of India is also giving more thrust to balanced and integrated nutrient management as a part of overall plan to promote organic farming in order to meet the international demand for organic farm produce and thus boost export opportunities.

The present hike in the price of chemical fertilizers has compelled the Indian farmers to resort to less fertilizers for crops and thus reduction in crop yields. At this critical juncture, there is an urgent need to optimize nutrient recycling to sustain crop production without affecting soil health and protection of environment from pollution.

However, the change-over from chemical to organic farming is difficult under Indian condition. Farmers have to forgo yields, till the soil productivity is built-up by recycling of organic matter. Very few farmers can bear this loss, but our planners cannot accept lesser food production to feed the growing population. However, it is possible to effect a quick changeover to sustainable agriculture by harnessing vermiculture biotechnology to the soil (Bhawalkar and

Bhawalkar, 1992). Vermiculture biotechnology involves the use of earthworms as a dynamic natural bioreactor which can help in nutrient cycling efficiently.

As early as 1881, Darwin recognised the significant role of earthworms as the biotic component of soil process and maintaining soil fertility. Since then, the scientists all over the world have recognised the ability of earthworm in recycling of organic wastes. They feed on animal and plant residues and most deciduous leaves. They do not prefer waxy and resinous plant residues. The ingested organic matter and the fine textured soils are excreted as small granular aggregates, which can resist rupture by raindrop impact and provide abundant and readily available plant nutrients. Earthworms are most active in humid and subhumid tropics which influence the rate of soil turnover, mineralization, humification of soil organic matter, soil texture, porosity, infiltration rate and soil water retention characteristics.

Scientists all over the world have recognised the potential of earthworm in recycling of organic wastes and production of vermicompost. It is rich in all plant nutrients, beneficial microorganisms like N-fixers, biologically active metabolites, particularly, gibberlins, cytokinins, auxins and group B vitamins and several enzymes like lipase, cellulase, chitinase, urease, dehydrogenase and nitrogenase. The vermicompost can be applied alone or in combination with organic or inorganic fertilizers to get better yield and quality of diverse crops. The species of earthworms employed for recycling of organic wastes are *Eiseniae fetida* and *Eudrilus eugeniae* by the researchers and farmers in countries like USA, Japan and Mexico. In India, for the first time, the culturing techniques of the exotic species of

earthworm *Eudrilus eugeniae* obtained from Germany were developed by Radha Kale at UAS, Bangalore and proved its efficiency under tropical conditions. At present, this species is widely utilized for vermicomposting of organic residues and *in situ* vermiculture. Farmers from different agroclimatic regions of India have successfully and profitably adopted this technology by using different species of earthworm on diverse crops and they are getting better quality of produce than conventional farming.

There is an increasing awareness about sustainable agricultural system. In view of this, a new generation of scientists are concentrating their research in understanding the relationship between earthworms, pedogenesis, sustainable soil fertility, crop yield and protection of the environment (Lee, 1992). Keeping this in view, the present study on the "Dynamics of earthworm (*Eudrilus eugeniae*)-soil-plant relationship in semi-arid tropics" has been undertaken with the following objectives :

1. To assess the optimum and potentially deleterious physico-chemical conditions in the soil environment on survival and growth of earthworm.
2. To understand the role of earthworm in soil biotechnology.
3. To assess the fertilizer quality of vermicompost and its effect on the growth and yield of hybrid maize (Cv. Deccan-103) and soil properties.
4. To suggest the management strategies that will enable to promote earthworm activity and increase the productivity of maize crop and improve the soil properties.
5. To work out the economics of vermicompost and vermiculture biotechnology.

# Reviews of Literature

## II. REVIEW OF LITERATURE

In this chapter, growth and fecundity of earthworm in relation to soil environment, their role in soil biotechnology, effect of earthworms and vermicompost on growth, yield of crops and soil properties and benefits of vermiculture biotechnology in agriculture has been reviewed as under.

### 2.1 Effect of soil environment on earthworms

Earthworms are invertebrate which form an important group of phylum annelida, class chaetopoda and order oligochaeta, found in moist terrestrial environment. Oligochaeta, have been divided into various families, the most important are megascolecid and lumbricid and both are valuable to agriculture. Earthworms are most active in humid and subhumid tropics and manifold advantages in maintaining soil fertility. The major factors that influence the distribution and abundance of earthworms in soil profile are soil pH, salinity, moisture, temperature and organic matter.

#### 2.1.1 Soil moisture

Burrow formation of *Aporrectodea caliginosa*, a substrate feeding earthworm in relation to three soil moisture contents (48, 60 and 73 per cent of dry weight) was determined by Scheu (1987b). He observed that soil moisture content affected burrowing activity only below a distinct threshold moisture content (60%). At sufficient moisture, an increase in temperature by 5°C approximately doubled the amount of egesta produced. On the nutrient rich mull site of beech forest, Staff (1987) observed higher earthworm activity due to the combined effect of more favourable soil moisture and higher litter quality compared to moor site. Mishra and

Ramkrishnan (1988) related monthly fluctuations of earthworm population to soil moisture in different jhum fallows developed after slash and burn agriculture in north-eastern India.

Moisture preference for growth and reproduction of the African nightcrawler, *Eudrilus eugeniae* was studied by Viljoen and Reinecke (1990) with the aid of cylindrical moisture towers filled with cattle manure at temperature of 25°C. They observed that clitellate worm showed a wider preference range than the juveniles and the preference range of the juveniles coincided with the moisture levels at which cocoons were deposited. The highest frequency of occurrence for clitellate worms was between moisture levels of 80 and 82 per cent. For cocoon deposition the highest frequency was at moisture levels between 79 and 80.5 per cent and most juvenile worms showed a preference for moisture range between 77.5 and 79.0 per cent. It was concluded that this earthworm species could be utilized in biodegradation of organic waste material with a relatively high moisture content. Kale and Bano (1992) reported somewhat lower range (20-40%) of moisture tolerance by *Eudrilus eugeniae*. Similarly, the compost worm *Eisenia fetida* can survive at low moisture levels (50%) (Reinecke and Venter, 1985).

Generally earthworms were more active during the monsoon season and its population size was significantly correlated with soil moisture (Bhadauria and Ramkrishnan, 1991). Similarly, significant correlation between earthworm population size and soil moisture was reported by Makulec (1991). He also found that both drying as well as prolonged flooding of soil entailed a reduction in the species number, density and biomass of earthworm.

The weight loss by *Allolobophora longa* when placed in soils with different water potentials was examined by Kretzschmar and Bruchou (1991). The results indicated that the earthworms had no physiological mechanism to cope with variations in soil water potential. At soil water potential of 620 KPa, no earthworm activity was possible and diapause was observed. At soil water potential of 167 KPa, the exchange of water between earthworms and the soil was at maximum and they proposed this level of soil moisture at which diapause in the earthworm was induced. Daniel (1991) reported that soil water potential of 7 KPa was optimum for food consumption of juveniles of *Lumbricus terrestris*, whereas zero consumption occurred at 40 KPa soil water potential. Interaction of soil moisture and food on growth and aerobic metabolism in *Eisenia fetida* was reported by Diehl and Williams (1992). They indicated that moisture had a significant positive effect on growth, respiration and burrowing rate of earthworm. Low soil moisture caused a general reduction in aerobic metabolism and growth, possibly because of lower oxygen diffusion across a dry cuticle. Fragoso and Lozano (1992) reported that amputated juveniles of *Pontoscolex corethrurus* entered diapause and regenerated regardless of soil moisture. Biomass increase was correlated with soil moisture, the correlation being higher in controls than amputees. Diapause, mortality and regeneration of adult amputated worms were higher at low soil moisture contents but the fecundity increased with increase in soil moisture.

Optimum cocoon production of earthworm *Eisenia andrei* was found at moisture content of 85 per cent in the soil. This moisture content exceeded field capacity (Gestel *et al.*, 1992). Hallatt *et al.* (1992) studied the moisture

requirements in the life cycle of *Perionyx excavatus* in cattle manure. The results showed that the worms grew and reproduced best between moisture levels of 75.2 and 83.2 per cent. The juveniles and clitellate worms preferred a moisture content of 81 per cent although cocoon deposition by clitellate worms was highest at a moisture level of 78.5 per cent. Baker *et al.* (1993a) reported that the highest number of earthworms were found in winter and early spring when the soil were wettest (Soil water potential less than 150 kPa). Makulec (1993) reported that the development of earthworm communities depended on current soil moisture content and the peat type. Both drying as well as prolonged flooding of soil entailed a reduction in the species number, density and biomass of earthworm communities. Baker *et al.* (1993b) observed that all the three species of introduced earthworms in pasture soils of South Australia occurred predominantly in the top 10 cm of soil for four to five months in a year when the soil were wet. During other seasons, they were found at lower depth in soil profile. Simpson *et al.* (1993) noticed that the population density of aquatic earthworm in different farmers rice fields in the Philippines was positively correlated with soil moisture.

Moisture requirements of *Dendrobaena veneta*, a candidate for vermicomposting was studied by Muyima *et al.* (1994) in the glass flasks filled with cattle manure. They reported that the highest frequency of clitellate worms was between 77.9 and 78.7 per cent, while the moisture preference ranged between 67.4 and 84.3 per cent. For cocoon production the highest frequency was between 73.1 and 79.9 per cent. The optimum moisture content for growth and maturation of juvenile worm was 75.0 per cent.

### 2.1.2 Soil reaction

In a laboratory study, Laverac (1961) observed that the distribution of different species of earthworm was related to soil pH in their natural habitat. He showed that the threshold value for stimulation of *Allolobophora longa* was between pH 4.6 and 4.4, for *Lumbricus terrestris* was between pH 4.3 and 4.1 and for *Lumbricus rubellus* was pH 3.8. In another laboratory experiment, he confirmed that when *Allolobophora longa* and *Lumbricus rubellus* were placed in pots of soil acidities ranging from pH 4.9 to 4.0, *Lumbricus rubellus* burrowed into all the soils, but *Allolobophora longa* only burrowed into the soils of pH 4.6 and above. On soils having pH 4.4 to 4.0, *Allolobophora longa* searched actively for a time and then became quiescent on the surface, where they eventually died, suggesting their sensory response to soil acidity and not nutrition deficiency.

Staff (1987) reported that soil chemical conditions, notably pH, were probably the main factors determining inter-site differences in abundance and species composition of earthworm. Similarly, Reddy and Pasha (1993) observed that seasonal population structure of earthworm was significantly influenced by the seasonal pattern of soil reaction and other physical factors in semi-arid tropical grassland soil.

Reddy and Alfred (1978) observed comparatively small earthworm population in sub-tropical pine forest soil of shillong, North-Eastern India due to lower soil pH (5.80 to 6.25). Similarly, Bhadauria and Ramkrishnan (1991) found significant correlation between soil pH and earthworm population in forest ecosystem of North-Eastern India.

Robinson *et al.* (1991) noticed that earthworms of six species burrowed rapidly into limed soil than unlimed soils from *Picea sitchensis* plantation. Similarly, Robinson *et al.* (1992b) reported that liming increased earthworm density in long-established plots of *Picea abies* on an acid brown soil in northern France. Similarly, in northern Ireland, addition of lime permitted a substantial community of earthworms to develop in deep peat soil under *Picea sitchensis* including acid intolerant species rare in coniferous soils. Further, Robinson *et al.* (1992a) found that liming of peat taken from a *Picea sitchensis* stand reduced mortality and weight loss of five earthworm species, measured over eight weeks. Total earthworm biomass was sustained over twelve months of experimentation in limed treatments, whereas only four per cent remained in the treatment without lime. Earthworm cocoons were produced in limed treatments only.

Makeschin (1991) reported that liming and gypsum fertilization in acid forest soil increased the earthworm activity due to increased pH and Ca and Mg saturation in soil. Similar favourable effect of liming on survival of earthworm was found by Haimi and Enbrok (1992).

Briones *et al.* (1992) observed that some species of earthworm (*Dendrobaena madeirensis*, *Dendrobaena octaedra*, *Dendrobaena pygmaea*, *Eisenia eiseniane* and *Allolobophora oliveirae*) preferred acid organic soils with low calcium and magnesium contents and a high aluminum content. On the other hand, Sosa (1992) reported that alkaline soils of the south-west slopes of Tenerife harboured a considerably poorer earthworm fauna. Similarly, Gestel *et al.* (1992) found that cocoon production of earthworm (*Eisenia andrei*) was reduced at high soil pH (9.0).

Ammer and Makeschin (1994) observed that seven years of simulated acid rain (pH 2.7-2.8) in an old Norway spruce stand reduced the worm population (*Dendrobaena octaedra* and *Lumbricus rubellus*) to about five individuals per sq.m. and complete disappearance of *Dendrobaena rubidus*. But liming increased the worm population significantly. Judd and Mason (1995) recorded only small number of earthworms on the newest soil which had a low pH. They observed that *Lumbricus terrestris* could survive but not reproduce in soils of pH 3.0.

From the literature, it appears that the growth and survival of earthworms was adversely affected in extreme acidic or alkaline soil reaction. Although some species do survive in acidic/alkaline condition, majority of the species preferred neutral soil reaction.

### 2.1.3 Soil salinity

Seasonal population structure of earthworm was significantly influenced by seasonal pattern in soil salinity and other chemical and physical factors in semi-arid tropical grassland soils (Reddy and Pasha, 1993). Earlier, Kale and Krishnamoorthy (1978) reported that soil moisture, salinity and organic matter concentration were the principal factors controlling the distribution and bionomic of earthworm population around Bangalore.

Inoculation of earthworm with organic manures and heavy mulching of organic wastes can be used successfully for improving saline soils. Bhawalkar and Bhawalkar (1992) reported a case study of vegetable farmer who grew successfully, tondali - a vegetable crop on saline soil with saline irrigation water by

adopting *in situ* vermiculture biotechnology. They also reported good results in sugarcane grown on saline soil with saline ground water irrigation and *in situ* vermiculture.

Fly ash toxicity declined with time and once a surface organic mat developed, epigeic earthworm species colonized in it. High salinity was probably the main reason for the toxicity of fresh fly ash to earthworms (Townsend and Hodgson, 1973).

#### 2.1.4 Soil temperature

The earthworm can maintain a lower body temperature than that of its surroundings by evaporating body water. Nevertheless, soil temperature is of fundamental importance in earthworm ecology because of its effects on motor activity and metabolic rate.

Miles (1963) recorded an upper lethal temperature of 33.3°C for *Eisenia fetida* and 27.5°C for *Allolobophora terrestris*, which were acclimatised to 15°C for several weeks. Kale and Rao (1973) reported that the temperature that could be tolerated by *Perionyx excavatus* collected from Bangalore ranged from 8 to 30°C. Whereas, Nagabhushanam and Hanumante (1978) observed that the same species of earthworm (*Perionyx excavatus*) collected from Nagpur had a 24-hour median heat and cold tolerance of 39.5° and 16.3°C, respectively. They accounted this discrepancy due to the ecological variations of the two populations.

Scheu (1987b) reported that at sufficient soil moisture an increase in temperature from 10 to 15°C approximately doubled the amount of egesta produced by *Apporrectodea caliginosa* in a beechwood soil. Mishra and Ramkrishnan (1988)

related monthly fluctuation of earthworm population to soil temperature and other factors in jhum fallows of north-eastern India. Similarly, the effect of soil temperature on earthworm population in the forest ecosystems of north-east India was reported by Bhadauria and Ramkrishnan (1991). Butt (1991) concluded that a temperature between 15 and 20 °C was most satisfactory for overall growth and reproduction of *Lumbricus terrestris*. Gestel *et al.* (1992) reported that cocoon production of earthworm *Eisenia andrei* in an artificial soil substrate was optimum at 20°C. Viljoen and Reinecke (1992) subjected juveniles of *Eudrilus eugeniae* to different constant temperature in a temperature gradient trough, keeping other environmental factors and food availability at a constant optimal level. They found that no worms survived at temperature below 12°C and all succumbed after 50 days at temperatures of 30°C and above. A steady increase in growth rate was observed with higher temperatures and the highest mean biomass per worm was attained at 29°C. The highest maturation rate was obtained at 22 and 25°C and it was found to be the optimal temperature for cocoon production. It was concluded that the earthworm species (*Eudrilus eugeniae*) would be a better candidate for vermiculture in tropical region as it exhibited a high degree of intolerance for temperature below 16°C. Kale and Bano (1992) studied the temperature requirement of *Eudrilus eugeniae* in the laboratory under controlled conditions. They reported that the temperature tolerance of same species ranged from 18 to 35°C.

The best survival of earthworm (*Apporrectodea caliginosa*) was found at temperature between 12 and 32°C with relative humidity of 55 to 75 per cent. The highest survival rate was obtained at 22°C and 75 per cent relative humidity in the light loam soil (Yousuf and Shoreit, 1992).

Reinecke *et al.* (1992) showed that *Eisenia fetida* had a wider tolerance for temperature than *Eudrilus eugeniae* and *Perionyx excavatus* often as high as 43°C and as low as 5°C. Viljoen *et al.* (1992) studied the influence of temperature on the life cycle of *Dendrobaena veneta*. It was observed that the life cycle was complete in 100 days at 15°C and it took 150 days to complete the life cycle at 25°C. At 25°C maturation was quicker, worms started to produce cocoons at younger age and more cocoons were produced than at 15°C. The incubation period of cocoons was also shorter at higher temperature. However, the number of hatchling (juvenile) per cocoon was more at lower temperature.

## **2.2 Role of earthworm in soil biotechnology**

### **2.2.1 Rate of decomposition of crop residues**

Decomposition is a multi-step process involving the break-down of complex material into carbon dioxide, water and mineral compounds. The dynamics of decomposition of organic materials in soils are strongly influenced by the physico-chemical microenvironment of the soil biota. Earthworms affect the dynamics of decomposition process both directly and indirectly. Direct effects include the metabolism of organic materials with the help of several enzymes (protease, lipase, amylase, cellulase, lichenase and chitinase) and microflora in the gut of earthworm which subsequently affects microbial activity after the gut contents have been excreted (Tracey, 1951). Indirect effects include the modification of environmental condition for decomposition by changing physical condition at given substrate location in soil or relocating the materials to sites where physical conditions are different. Scientists all over the world have recognised the ability of

earthworms in recycling of organic waste and production of organic manure. The research on biodegradation of organic matter by earthworms suggested that only a few selected species of worms are efficient in conversion of organic wastes into organic manure. The endogeic worms feeding on soil rich in humic substances fail to live for long time under semi-natural conditions.

Darwin (1881) was the first to draw attention to the way in which earthworms mixed plant residues and dung with underlying soil and help in the formation of vegetable moulds. In addition to this, comminution of organic matter by earthworms exposes fresh surface to microbial attack. The interaction between earthworms and microorganisms in break-down of organic matter progressively and finally incorporating it into water-stable aggregates was shown by many workers (Edward and Fletcher, 1988 and Cortez *et al.*, 1989).

The influence of abiotic and biotic factors on the biodegradation of organic substances under laboratory conditions was studied by Ziegler and Zech (1989). They incubated beech litter at 20°C and 70 per cent of maximum water holding capacity in the presence and absence of a mixture of clay, silt, sand and lime and litter feeding earthworms (*Eisenia fetida*). Beech litter biodegradation was intensified by earthworm activity only in early stages of the decomposition process. During later stages, organic matter seems to be stabilized in micro-aggregates of biogenic origin. Application of mineral substrate led to the formation of organo-mineral complexes with progressive decomposition. Similarly, introduction of *Lumbricus terrestris* into reclaimed mine spoil enhanced the litter decomposition (Vimmerstedt and Finney, 1973). Zachman and Linden (1989) reported that corn residue mulch with worms (*Lumbricus rubellus*) degraded 30 per cent faster than in

no worm control. Haimi and Huhta (1990) reported that both the species of earthworm increased the decomposition of substrate litter in laboratory condition. The earthworm species (*Lumbricus rubellus*) stimulated microbial respiration by 15-18 per cent, whereas *Dendrobaena octaedra* stimulated it only slightly. Martin (1991) reported that a tropical geophagus earthworm (*Miliosonia anomala*) common in the humid savanas of Ivory coast ingested soil particles without selection. The coarse organic fraction (250-2000  $\mu\text{m}$ ) was depleted by 25-30 per cent in fresh casts compared to the control non-ingested soil indicating its role in break-down of coarse organic fraction. Similarly, Hendriksen (1991) observed disappearance of organic particle from cattle dung pats in the field through earthworm mediated transport. The decomposition rate of straw which was accessible to earthworms in the soil was increased by 26-47 per cent within 8-10 months period compared with that of straw without earthworms (Curry and Byrne, 1992).

Epigeic species are efficient feeders on nitrogen rich organic matter and are fast breeders (Kale and Bano, 1992). The epigeic earthworm (*Eudrilus eugeniae*) was best adopted for degradation of organic matter for the production of organic manure (Kale and Bano, 1988). Similarly, Bano *et al.* (1987) suggested that the earthworm (*Eudrilus eugeniae*) can be successfully employed in the biodegradation of organic matter and vermicomposting technology.

Use of earthworms as a potential source to decompose organic waste was found by Jambhekar (1992). The results revealed that introduction of earthworms to the organic waste hastened the process of decomposition and compost became ready within one and half months period. Kale *et al.* (1992) introduced two

species of earthworms (*Eudrilus eugeniae* and *Perionyx excavatus*) into culture pots containing agricultural wastes and sugarcane trash as culture beds. They found that the earthworm activity enhanced the degradation of cellulose and lignin components of organic wastes. *Eudrilus eugeniae* utilized cellulose better than *Perionyx excavatus* when sugarcane trash was used as bedding material, whereas *Perionyx excavatus* utilized lignin better than cellulose in both the bedding materials. Engelstad (1991) reported that the earthworms (*Eiseniae andrei* and *Lumbricus rubellus*) enhanced decomposition of cellulose and hemicellulose of garden refuse. Similarly, Springett *et al.* (1992) observed that cellulose decomposition rates were increased upto 30 per cent due to earthworms.

Spain and Hodgen (1994) studied the decomposition of sugarcane trash used as a surface mulch or incorporated into soil. They observed that the decomposition occurred in two phases, an initial phase of rapid leaching followed by a period of soil mixing resulting from earthworm casting into the decomposing residues. Kretschmar and Ladd (1993) studied the influence of substrate location, soil compaction and earthworm numbers on decomposition of  $^{14}\text{C}$ -labelled mature leaves of *Trifolium subterraneum* in soil. The results revealed that the influence of earthworm in decomposition of plant material appeared to be indirect, through the interaction of their activities and substrate location.

Hendriksen (1990) conducted litter bag experiment with different kinds of leaf litter. He observed that detritivorous (*Lumbricus* sp.) and geophagous (*Apporrectodea* sp.) earthworms prefer certain litter type over others. Detritivores feed selection depended upon the palatability and the polyphenol concentration of

litter, whereas geophagus did not react to litter palatability. Litter disappearance was significantly correlated with detritivore numbers indicating that they used the litter as food and hence influenced the composition of the litter layer. Similarly, Slapokas and Granhall (1991) reported that the decomposition of litter by earthworm was faster from the large mesh bags than from small mesh bags. During first year, the rate of decomposition of litter from both types of bags and under the nets was much higher for *Salix daphnoides* than for *Salix viminalis* and *Salix fragilis*. They attributed this difference due to lower tannin content of *Salix daphnoides* litter. Martin and Lavelle (1992) reported that assimilation of fresh organic matter and leaf material by geophagus earthworm (*Millsonia anomala*) was higher than root material due to high content of water soluble compounds and the high N availability in fresh organic matter.

Zou (1993) found that the 'N' content of litterfall in tropical tree plantation was positively correlated with earthworm density. Greater earthworm density was observed on the forest floor under albizia stands compared to eucalyptus stands. This suggested that litter quality rather than litter quantity was primarily responsible for the greater density and activity of earthworm.

The reproduction and growth of earthworms (*Eisenia fetida*) on various substrates was compared in the laboratory by Zajonc (1991). The results indicated that addition of compost, soil and rabbit dung had a positive effect but substrates with added sand or sawdust had a negative effect on number of cocoons and hatchlings. Nuutinen (1992) reported that the epigeic earthworms (*Dendrobaena rubidus*) present in sandy loam soil, increased under reduced tillage and straw residue chopped and left on the surface.

Tian *et al.* (1993) compared the effect of different plant residues (acacia, gliricidia and leucaena prunings, maize stover and rice straw) applied as mulch on soil fauna under field condition in the humid tropics. They found that the mean population of earthworms over two years was greater under any type of plant residue by 41 per cent compared to control. Leucaena prunings supported the highest earthworm population and it was negatively correlated with lignin:N ratio of plant residues. The results further indicated that the chemical composition of plant residues, particularly, N and lignin contents, played a critical role in fauna abundance in the soil through their effect on palatability and decomposability and indirect effect of mulching on soil microclimate.

### 2.2.2 Nutrient recycling

Nutrient cycling is one of the important basic processes which regulate soil fertility through weathering of soil minerals and decomposition of plant residues by microorganisms, fungi and soil animals. Earthworms are one of the important contributors to soil fertility. Earthworms contribute to N mineralization directly, through consumption, digestion, respiration/excretion and indirectly by influencing population dynamics of other soil biota through predation or through affecting their environmental conditions (Marinissen and Rüter, 1993). It is now well established that phosphorus bound in organic matter is converted to available form when it passes through the gut of earthworm. The bacteria and fungi takes phosphorus fixed by soil minerals, subsequent ingestion of these microorganisms by earthworm release it in plant available form which is mediated by phosphates produced within the earthworm gut, while further release of phosphorus may be induced by microorganisms in casts after their excretion (Lee, 1992). Ionic

regulatory mechanism in earthworms involve uptake of  $Ca^{++}$  from ingesta and its excretion via calciferous glands as  $CaCO_3$  (Lee, 1985). Similar results were reported by Kale and Krishnamoorthy (1980). They observed that in *Pontoscolex corethrurus*, calcium is concentrated and excreted as concretions formed in the calciferous glands. The cast contained 1.3 times more total calcium than in surrounding soil and it had 11.8 times more ionic calcium than the soil.

Barois *et al.* (1987) studied the effect of geophagus earthworm (*Pontoscolex corethrurus*) on nitrogen transmission in the soil. They reported that the earthworm mucus contained large quantities of water-soluble carbon compounds which triggers mineralization of organic compounds ingested with soil due to increased microbial activity. They found that the cast had 2.7 times more  $NH_4^+$ -N than the surrounding soil. Similarly, Parkin and Berry (1994) observed that earthworms were intimately involved in the cycling of C and N in soil. They also reported that the earthworm casts were enriched in mineral N relative to surrounding soil and that the amount of N accumulated in cast was a reflection of the N content of the organic matter used as a food source by the earthworms.

Cortez *et al.* (1989) studied the C and N transformation in soil with or without earthworms fed with  $^{14}C$  and  $^{15}N$  labelled wheat straw. They found that the ingestion of C and N originating from the soil native organic matter was 66 and 11 times larger than the ingested litter C and N, respectively. Incorporation of  $^{14}C$  and  $^{15}N$  - labelled litter into earthworm reached 1.6 and 9.4 per cent, respectively after 31 days. This increase of C and N from litter showed that the litter from wheat straw became more palatable after contamination by soil microorganisms.

Jambhekar (1992) suggested that the nutrients from crop residues can be recycled through composting with the use of earthworms. He observed significant increase in N, P and K availabilities in earthworm treated compost.

Binet and Trehen (1992) studied the nitrogen dynamics of earthworm (*Lumbricus terrestris*) in cultivated soils fed on  $^{15}\text{N}$ -labelled ryegrass litter for 85 days. They observed that  $^{15}\text{N}$  released from the litter into the soil was three times larger with than without worms which gave a daily output flux of 0.13 mg N per live worm per day. The rate of incorporation of  $^{15}\text{N}$ -labelled litter into the earthworm was 0.14 mg N per live worm per day which indicated a nitrogen renewal of 10 per cent in earthworm biomass in 85 days. The whole N input from earthworm into the soil reached 76  $\mu\text{gN}$  per live worm per day.

Curry and Byrne (1992) reported that the earthworm population of 408 per sq.m. of aerable land mineralised 3.2 g N per sq.m. through excretion and tissue turnover and further 3.3 g N per sq.m. through enhanced mineralization in faeces, annually. The contribution of earthworms to nutrient recycling in alley cropping was reported by Hauser (1993). In alley cropping, three times more N, P, Ca and Mg were recycled to the surface than in no tree control plots. The relative contribution of casts to nutrient cycling in alley cropping was 33 per cent N, 16 per cent P, 6 per cent Ca and 34 per cent Mg. Permanent shading in the vicinity of hedge rows was identified as the most important factor enhancing casting activity. James (1991) studied the soil nitrogen, phosphorus and organic matter processing by earthworms in tall prairie grass. He reported that organic matter equivalent to 10 per cent of total soil organic matter in the top 15 cm soil is passed through the

earthworm each year. Mineral N processed was 10-12 per cent of annual plant N uptake while, the P processed was equivalent to 50 per cent of annual plant uptake. Knight *et al.* (1992) reported that the moderate population densities of surface active species had detectable effect on the mineral N fluxes in intensively managed pastures.

Vimmerstedt and Finney (1973) studied the impact of earthworm introduction on litter burial and nutrient distribution in Ohio strip-mine spoil banks. The amount of exchangeable cations and available P increased (K from 0.17 to 0.19, Ca from 1.7 to 2.7 and Mg from 1.8 to 2.5 meg 100g<sup>-1</sup> of spoil and available P increased from 1.7 to 4.2 ppm) due to earthworm activity. Scheu (1987a) observed additional mineralization of N caused by burrowing activity of the substrate feeding *Apporrectodea caliginosa* in a beechwood forest with the application of limestone.

Haimi and Huhta (1990) reported that the earthworms (*Lumbricus rubellus* and *Dendrobaena octaedra*) increased N mineralization, considerably and the level of PO<sub>4</sub>-P was increased slightly in coniferous forest floor. Similar effects of earthworm on N and P mineralization in coniferous forest were reported by Huhta *et al.* (1991); Haimi and Boucelham (1991) and Haimi and Enbrok (1992).

Edwards and Lofty (1982) estimated that nitrogen mineralized due to earthworm activity was as high as 100 kg N per ha in agricultural soils. Similarly, Bhadauria and Ramkrishnan (1989) showed the importance of earthworms in nutrient cycling through by rapid mineralization of detritus and concentrating nutrients in the surface wormcasts, where a large biomass of the root system was located during the early cropping and fallow phases under shifting agricultural

system of north-east India. Robinson *et al.* (1992a) also reported increased N mineralization due to earthworm activity in limed peat soils under *Picea sitchensis* plantation.

### 2.2.3 Microbial activity

Earthworms play a key role in soil biology as a versatile natural bioreactor. They effectively harness the beneficial soil microflora, destroy soil pathogens and convert organic wastes into valuable products such as biofertilizers, biopesticides, vitamins, enzymes, antibiotics, growth hormones and proteinous soil biomass. There is dramatic increase in microbial population upto 1000 times in the gut of earthworm. These microorganisms provide food for earthworms. Bacteria are of minor importance in the diet, algae are of moderate importance, protozoa and fungi are major sources of nutrients. Symbiotic interaction between earthworms and microorganisms exist in breaking down and fragmentation of organic matter progressively (Bhawalkar and Bhawalkar, 1992).

Khambata and Bhat (1957) made observations on the intestinal microflora from 60 earthworms of *Pheretima* species in 343 isolates. With the restricted nutritive media provided, they isolated *Pseudomonas*, *Nocardia*, *Streptomyces* and *Bacillus* from the intestinal tract. The association of microflora and earthworms also depend on the experimental diet provided to earthworms. A steady increase in the *Azotobacter* population and stable establishment of worm population was observed when cow dung was used as food medium (Bhat, 1974). The increase in total-N and nitrate-N in the soils was observed due to earthworm activity by many workers (Shrikande and Pathak, 1948; Nijhawan and Kanwar,

1952 and Senapati *et al.*, 1980). Such increase in total-N and nitrate-N was attributed to increase in *Azotobacter* counts in soils activated by earthworms (Bhat *et al.*, 1960). In a French pasture having 12 species of earthworms, Bhatnagar (1975) found that the drilosphere of earthworm consisted of 40 per cent of aerobic nitrogen-fixing bacteria, 13 per cent of anaerobic nitrogen-fixers and 16 per cent denitrifiers. Loquet *et al.* (1977) reported that the earthworm burrows lined with their casts were excellent media for harbouring N-fixing bacteria. Further, they observed increased microbial load in the ejected material of earthworm and it was attributed due to the conducive environment in earthworm body for microorganisms.

Dash *et al.* (1979) found that *Fusarium species* was present only in the anterior regions of the gut of earthworm (*Drawide calebi*). Freshly produced cast did not contain *Fusarium* suggesting that colonies of *Fusarium* were digested in the gut of worms and thus reducing the population of these plant pathogens. But on the contrary, Edwards and Fletcher (1988) reported that earthworms can disperse pathogenic microorganisms and influence the viability of fungal spores.

Smick and Pizl (1989) noticed the presence of N<sub>2</sub>-fixing bacteria on the body surface and in the gut of earthworm. Similarly, Kale *et al.* (1989) reported that the number of bacteria in paddy field increased by earthworm activity although the total microbial population was unaffected. Further, Kale *et al.* (1992) observed higher number of N-fixers in vermicompost treatment in summer paddy field.

Bano *et al.* (1987) reported that the vermicompost obtained from culturing of *Eudrilus eugeniae* harbours large number of humus forming microbes (bacteria, actinomycetes and fungi) and N-fixers. Similarly, Tiwari *et al.* (1989)

observed higher microbial population in wormcast than the surrounding soil. Eiler *et al.* (1991) studied the influence of long term application of pig slurry on earthworm and microbial population of soil. They found that increasing slurry application raised the earthworm population and microbial biomass in the soil. Yousuf and Shoreit (1992) reported that introduction of earthworms (*Apporrectodea caliginosa*) significantly increased the total number of bacteria and fungi in all the four soils studied (light loam, clay loam, sandy clay lom and sand). Scheu (1992) determined the active and total microbial biomass in the soil and earthworm (*Apporrectodea caliginosa*) faecal particles. He found that active microbial biomass increased in earthworm faeces by 17 per cent but the percentage of active microorganisms were similar in faeces (5.0%) and soil (4.5%). Pashanasi *et al.* (1992) studied the effect of inoculation of endogeic earthworm (*Pontoscolex corethrurus*) on soil microbial biomass in a pot experiment. The results showed significant effect of earthworm in increasing microbial biomass accumulation in soil. Similarly, Mulongoy and Bedoret (1989) reported that the earthworm cast collected under leucaena plantation had higher microbial biomass ( $807 \mu\text{g g}^{-1}$ ) than the corresponding soil ( $289 \mu\text{g g}^{-1}$ ) but the number of denitrifying microorganisms or cowpea *Rhizobia* were the same.

Daniel and Anderson (1992) studied the microbial biomass and activity in different of soil materials after passage through the gut of earthworm (*Lumbricus rubellus*). Earthworms were fed on four different soils with light fraction organic material contents ranging from 3.7 to 76.1 per cent of the soil dry weight and soil water potentials standardized at 8 KPa. The results revealed that the microbial biomass-C in soils, as measured with a modified fumigation-extraction

method, ranged from 0.4 to 7.5 mg C g<sup>-1</sup> soil. After gut passage (6-8 hr) microbial biomass-C did not change significantly but rates of CO<sub>2</sub> production and bacterial plate counts were higher in casts compared to initial standardized soils ingested by earthworms. Chimielewski and Makulec (1993) reported that the earthworm casts on variously decomposed sedgemoor and older peat soils increased the development of fungi and cellulolytic microflora. Harinikumar *et al.* (1991) noticed the presence of infective *Vesicular arbuscular* mycorrhizal (VAM) propagules in worm cast which were found to survive upto 11 months, suggesting the role of earthworms in dissemination of VAM fungi.

Tiunov (1993) reported higher microbial activity in the drilosphere of earthworm (*Apporrectodea caliginosa*). Stephens *et al.* (1994) studied the influence of the earthworm (*Apporrectodea trapezoides*) on the colonization of alfa-alfa roots by *Rhizobium meliloti*. The results demonstrated that *Apporrectodea trapezoides* increased root colonization of alfa-alfa by *Rhizobium meliloti*.

#### 2.2.4 Enzyme activity

The digestive system of earthworm consists of pharynx, oesophagus and gizzard followed by an anterior intestine that secretes enzymes and posterior intestine that absorbs nutrients. The digestive enzymes of earthworms include protease, amylase, lipase, cellulase and chitinase. These enzymes are probably produced by the earthworms themselves, but cellulase and chitinase may possibly be produced by microorganisms living in the intestine (Tracey, 1951). Ross and Cairn, (1982) also reported that the worm cast contained active enzymes such as protease, amylase, lipase, cellulase, chitinase etc. which continued to disintegrate organic

matter long after they had been excreted. Zhang *et al.* (1993) studied the activity and origin of digestive enzymes in the gut of tropical earthworm (*Pontoscolex corethrurus*). They reported that the earthworm possesses a weak but quite complete enzyme system. In the gut, the enzymes were capable of degrading heteroside (N-acetyl glucosamine), oligosaccharides (Maltose, L-amino ribose and polysaccharides). The strongest enzymatic activities were located in the fore gut and mid gut. Among the main enzymes found in the gut, cellulase and mannanase were not detected in the cultured tissues nor in the cultured medium which indicated that these two enzymes were produced by microorganisms ingested with soil.

Tiwari *et al.* (1989) reported that the earthworm cast contained higher enzyme activities than surrounding soil of a pineapple plantation. They attributed this due to selective feeding habit of earthworms on organically rich substrates which break down during passage through the gut.

Smick and Pizl (1989) found an increase in nitrogenase activity in field deposited casts of earthworm (*Apporrectodea caliginosa*) in comparison with surrounding soil. They also observed that nitrogenase activity in the casts of *Lumbricus rubellus* was higher than in unmodified soil and it increased significantly by burrowing and feeding activity of these worms indicating the presence of active N<sub>2</sub>-fixing bacteria on the body surface and or in the gut of earthworm. Weiss and Tresendorfer (1993) studied the influence of earthworms on enzymatic activity of the soil. The results indicated that earthworm activity increased the phosphatase, dehydrogenase, protease and nitrogenase enzyme activity in soil.

Tiunov (1993) compared urease activity in soil and earthworm faeces. They observed that urease activity was 30-40 per cent higher in earthworm (*Aporrectodea caliginosa*) coprolites as compared with just ingested soil. The increased enzymatic activity remained in the coprolites for long periods after their release. The urease activity on the surface of living galleries was several times higher than that of surrounding soil, due to general increase in microbial activity and the rate of organic matter mineralization. Similar results were reported by Chmielewski and Makulec (1993). They noticed that the presence of earthworms increased urease activity in soil.

Singaram and Kamalkumari (1995) reported favourable effect of FYM in increasing dehydrogenase, urease, catalase and several other enzyme activities in soil and it was more pronounced due to combined application of FYM and NPK fertilizers. They attributed this to increased mineralization of nutrients from microbial decomposition of organic matter.

### **2.3 Impact of tillage and cultivation practices on earthworms**

Healthy earthworm population can be maintained by following reduced tillage, limiting the use of pesticides, increasing the return of organic matter to soil and by using fertilizers, manures and crop residues appropriately (Fraser, 1994).

Deibert *et al.* (1991) reported that the cultivated soil had lower population and biomass of earthworms (*Apporrectodea caliginosa*) than the grassland site. Decreasing tillage over time increased the earthworm population in the cultivated sites to levels approaching grassland site. Similarly, Nuutinen (1992)

observed that the epigeic *Dendrodrilus rubidus* present in sandy loam soil of Southern Finland increased under reduced tillage and straw residue mulch. In a cropping experiment with maize, Wyss and Glasstetter (1992) found that tillage caused 50 per cent reduction of population and 30 per cent reduction in biomass of earthworms. Similarly, Pfiffner (1993) observed significantly higher densities and biomass of anecic species of earthworms in the biological plots than the conventional and no fertilizer control plots.

Cluzeau *et al.* (1992) reported that trampling by cattle induced 70 to 86 per cent decrease in earthworm density and biomass of small size species and juveniles of earthworms due to destruction of large portion of stems and roots with the removal of some of the vegetative cover in grassland. Similarly, Pizl (1992) reported that high traffic intensity of farm machinery considerably reduced the population and biomass of juveniles and epigeic species of earthworms in apple orchard. Springett *et al.* (1992) also reported significant reduction in population and activity of introduced earthworms with increased intensity of cultivation in horticultural land previously denuded of earthworms.

The effect of inorganic fertilizers on earthworm population depends on whether they increase or decrease soil acidity. Thus lime, nitrochalk, nitrate of soda and basic slag tend to increase earthworm populations and sulphate of ammonia and sulphate of potash have the opposite tendency (Escritt and Arthur, 1948). Reduction of earthworm population from this cause was however, negligible unless the soil reaction fell below 4.5-5.0 (Jefferson, 1955) and this did not occur when normal amounts of fertilizers and lime were applied (Ogg and Nicol, 1945). Jacob

and Wiegand (1952) reported that the arable land receiving dressings of mineral fertilizers had more worms than the unfertilized plots, probably due to increased root residues. Tiwari (1993) reported that application of NPK fertilizers caused significant increase in population, biomass and activities of earthworm in cultivated Oxisol which was further increased due to combined application of NPK fertilizers with organic manures.

Cuendet and Ducommun (1990) observed that spreading of sewage sludge associated with FYM had positive effect on earthworm population than mineral fertilizers. Simpson *et al.* (1993) also reported increase in earthworm population due to addition of urea and green manuring of *Sesbania rostrata* in irrigated rice field in the Philippines. Haraldsen *et al.* (1994) reported that application of cattle slurry stimulated the earthworm (*Apporrectodea caliginosa*) activity but application of NPK fertilizers caused the least biomass and number of earthworms in silty clay loam soil in central Norway. Sarthchandra *et al.* (1993) reported that there was no long-term effect of phosphatic fertilizers on earthworms (*Apporrectodea caliginosa* and *Lumbricus rubellus*) in pastoral soils.

## **2.4 Effect of vermicompost on crop yield and soil properties**

### **2.4.1 Growth, yield and quality of crops**

Vermicompost contains significant quantities of available nutrients, a large beneficial microbial population and biologically active metabolites, particularly gibberellins, cytokinins, auxins and group B vitamins, which can be applied alone or in combination with organic or inorganic fertilizers so as to get better yield and quality of diverse crops (Gavrilov, 1962, Tomati *et al.*, 1983; Bano *et al.*, 1987).

Khan (1966) reported that the growth of maize on loamy soil was better in plots applied with casts of *Metaphire posthuma* than in plots that received FYM. Dacayo (1985) reported that sucker production in African daisy was significantly higher with 25 per cent worm cast but the growth was almost ceased at 75 and 100 per cent cast. The yield of lettuce with 50 per cent cast was six times better than soil alone. Peachy was best at 75 per cent cast but drastically declined at 100 per cent cast. *Oleracea* responded dramatically upto 75 per cent cast. On the other hand, onion and peanut did not respond to cast addition and with 100 per cent cast the bulb/pod formation did not occur. Similarly, Evangelista (1986) found that application of pure earthworm cast showed significant effect on the weight of roots, nitrogen, phosphorus, calcium and magnesium contents of the lettuce leaves. Plants treated with 50 per cent earthworm cast and 50 per cent soil showed highly significant effect on the fresh weight of whole plant and the dry weight of leaves. Libunao (1986) observed no significant effect on all growth parameters tested when earthworm cast was used as soil medium for onion cultivation.

Kale and Bano (1986) reported that application of vermicompost as a source of manure increased the growth and yield of paddy. Rivera (1986) observed that amargosa (ampalaya) plants grown in the soil medium containing 75 per cent earthworm cast produced higher bi-weekly growth increment, longer and more fruits than those in other treatments. However, application of cast beyond this level resulted in significant decrease in yield.

Huang and Zhao (1991) found that application of worm cast @ 1.3 t per ha increased the cucumber and tomato yields by 42 and 61 per cent, respectively. Kale *et al.* (1987) observed that the pots having worm cast recorded

significant increase in number of inflorescences per plant and early flowering in salvia, whereas in aster, stem girth, leaf area index and diameter of flowers were increased. Incorporation of vermicompost increased protein synthesis in lettuce and radish by 24 and 32 per cent, respectively (Tomati *et al.*, 1990).

Lui Shuxin *et al.* (1991) found that application of worm cast increased the dry weight of soyabean plants by 40 to 70 per cent and N uptake by 30 to 50 per cent. The phosphorus and potassium contents in the plant were twice more than the control. Zhao and Huang (1991) observed that mixing of worm cast with  $^{15}\text{N}$  labelled chemical fertilizer increased the height, weight of stalk, effective tillering, thousand grain weight and yield of wheat. The N content of stalk and seed and total N uptake by wheat were also increased. Kale *et al.* (1992) observed that application of vermicompost in combination with inorganic fertilizers, increased the N and P uptake by paddy. Application of vermicompost along with oil cake to sapota resulted in increased yield and better quality of fruits. Similarly, Puranik (1992) observed improved quality and size of fruits in custard apple due to application of vermicompost. So also, rose, marigold, sonataka, ixora showed good response to vermicompost application and sonataka continued to bloom even after the season was over, whereas the performance of lawn grass was not good.

Stolyarenko *et al.* (1992) reported that application of vermicompost stimulated the root and shoot growth of maize plantlets. Similarly, Vadiraj *et al.* (1992) observed significant increase in height, number of leaves per plant, number of roots per plant, length of root and fresh and dry weight of cardamom seedlings when vermicompost was used as potting mixture.

Balaji (1994) observed that application of vermicompost @ 2.5 or 5.0 t per ha or FYM @ 20 t per ha or different levels of recommended dose of inorganic fertilizers alone or in combination resulted in increase in growth and dry weight of plants and improved the yield and quality of flowers in China aster.

Stolyarenko *et al.* (1994) studied the effect of application of vermiculture products to three self-pollinated maize lines differing in the ripeness rate in phytotron green-house cultivation. They reported that vermiculture products increased the productivity of maize with reduction in vegetative period and decreased the nitrate content in grains.

Venkatesh (1995) reported that application of vermicompost @ 5 t per ha alone or in combination with recommended doses of FYM and different levels of inorganic fertilizers increased the nutrient content of petioles and improved the yield and quality of Thompson seedless grapes.

#### 2.4.2 Soil properties

Lui Shuxin *et al.* (1991) reported that the amount of organic matter, total nitrogen, phosphorus and potassium and available phosphorus and potassium content of soil after the harvest of soyabean increased due to application of earthworm cast.

Kale *et al.* (1992) observed high level of total N in paddy plots applied with vermicompost and comparatively less quantity of fertilizers. They attributed this due to higher count of N fixers in the treated plot than that of the control plot.

Balaji (1994) also recorded higher levels of total nitrogen, available phosphorus and potassium in the treatments which received either vermicompost alone or in combination with FYM or chemical fertilizers than control.

Venkatesh (1995) found that application of vermicompost in combination with inorganic fertilizers in grapes decreased the pH of soil and increased the organic carbon and available N,  $P_2O_5$ ,  $K_2O$  and DTPA extractable Fe, Mn, Zn and Cu content of soil.

## **2.5 Effect of earthworms on crop yield and soil properties/health**

### **2.5.1 Growth, yield and quality of crops**

The importance of earthworms was first stressed by Charles Darwin (1881) in his book 'The Formation of Vegetable Mould through the Action of Worms' one of the milestones in the understanding of soil biology and soil productivity. Since Darwin's period several workers have demonstrated the beneficial effect of earthworms in increasing crop yields. Dreidax (1931) obtained 7.4 per cent increase in yield of winter wheat from plots into which 84 g live worms per sq.m. had been introduced. On plots to which 54 g per sq.m. of dead worms had been added, the yield was 15.3 per cent higher than those plots to which no worms had been added. The N content of the crop from the plots into which live worms had been introduced was 21 per cent higher than that of control plots and about equal to that from plots treated with dead worms. About half of the 21 per cent increase was ascribed to the effect of live worm activity and half to the manurial effect of dead worms during the experiment.

Uhlen (1953) found that in heavily manured plots the highest yield of barley was obtained in soil containing large number of earthworms (*Lumbricus terrestris* and *Lumbricus rubellus*) which was attributed to the decomposition of the manure by earthworms. However, in unfertilized soils the highest yields were obtained where most of the worms died. In another study, 5 per cent more yield of barley was recorded in frames stocked with mixed populations of earthworms in numbers equal to high field populations than unstocked frames. Hopp and Slater (1949) recorded higher yield of various crops due to earthworm activity and it was attributed to increased level of readily available nitrogen in the presence of either dead or live worms. On the contrary, Agrawal *et al.* (1958) observed that earthworms had adverse effect on plant growth. Similarly, Patel and Patel (1959) reported that earthworms retarded the germination, growth and root development of tobacco plants in Gujarat.

Nelson (1965) observed improved growth of pastures and other crops due to abundance of earthworm fauna, chemical exudates and microbes associated with them. He also demonstrated the presence of allied compounds of IAA in earthworm tissues. Increased yield of barley was observed in the presence of worms (Altanvinyte *et al.*, 1968). Similar increase in growth and yield of grasses was reported by Ross and Cairns (1982) due to release of worms into fields.

*In situ* vermiculture with deep burrowing species of earthworms (*Lumbricus rubellus* and *Lumbricus terrestris*) significantly increased plant population, weight of plant, depth of root penetration, height of plant and yield of barley (Edward and Lofty, 1978 and Altanvinyte and Zim-kuviene, 1985).

Similarly, Springett and Syers (1979) observed increased herbage production in rye grass seedlings in presence of worms due to increased availability of nutrients in soil.

Increased dry matter production in pastures due to earthworm activity was reported by Hoogerkamp *et al.* (1983). Similarly, Buse (1990) noticed enhanced growth of grasses in the presence of worms in cores taken from upland pastures due to improved nutrient availability. James (1991) reported that mineral 'N' processed by earthworms was 10-12 per cent of annual plant N uptake while the P processed was equivalent to 50 per cent of annual uptake in tall grass prairie. In small scale experiments, the activity of introduced earthworm species adapted to the existing conditions and greatly increased the yields and N and P contents of *Panicum maximum* (Lavelle *et al.*, 1991). The yield and sucrose content of sugarcane were increased in red-arid soil of China due to earthworms (Lui Shuxin *et al.*, 1991). Spain *et al.* (1992) also observed the stimulation of plant growth by tropical earthworms. They recorded increased growth of maize and guinea grass in an infertile granite derived soil with the introduction of earthworms. But Zachmann and Linden (1989) reported that the growth and N content of corn plant were not affected by the presence of worms in growth chamber.

Sharma (1994) studied the effect of various organic wastes alone or in combination with earthworm on dry matter yield and nutrient uptake by wheat (*Triticum sativum*) and maize (*Zea mays*). The results indicated that the yield of both the crops increased with the application of organic wastes and the effects of organic wastes were enhanced due to introduction of earthworms. Introduction of

earthworms increased nutrient uptake significantly over the control and treatments with organic wastes alone. Radford *et al.* (1995) reported that conservation tillage practices (Stubble mulch, reduced tillage and no tillage) increased the earthworm population thereby increasing grain yield and protein content of sorghum and wheat due to increase in storage of soil water and efficiency of crop water use under rainfed condition on an alluvial soil in Australia.

Increase in the yield of fruits due to release of worms into orchards was reported by Raw (1962). Jari *et al.* (1992) studied the effect of earthworm (*Lumbricus rubellus*) on net production and nitrogen content of birch seedlings in laboratory microcosmos. Higher concentration of N and biomass of birch seedlings was observed with earthworm treatment than control which indicated the role of earthworm in nutrient mineralization and plant growth. Similarly, Huhta *et al.* (1991) also reported the beneficial role of earthworms in the mineralization of N and P from soil and litter which increased considerably the biomass production and N content of birch seedlings. The trees grown (*Picea abies*) on limed plots of acid brown soil in northern France recorded greater height and growth than the trees in unlimed plots (Robinson *et al.*, 1992a). They attributed this to the beneficial effect of earthworms in limed plots by increasing nutrient turnover. The studies on the effect of inoculating earthworms (*Lumbricus terrestris*, *Allolobophora longa*, *Apporrectodea caliginosa* and *Allolobophora chlorotica*) into intact soil profiles in the laboratory, arable land in the field and newly capped waste disposal sites that had few or no earthworms were carried out by Edward and Bater (1992). The results indicated that in all these studies the rate of growth and yield of plants increased significantly on the inoculated sites. Pashanasi *et al.* (1992) studied the

effect of inoculation of endogeic earthworms (*Pontoscolex corethrurus*) at four different biomass levels (0, 100, 400 and 800 mg per 1.5 kg dry soils) in pots containing seedlings of three tropical fruit trees (*Bactris gasipaes*, *Bixa orellana* and *Eugeniae stipitata*) for 120 days. Significant increase in seedling growth was observed in *Bixa* (14-24 times) and *Eugeniae* (1.6-2.5 times) over control. But an inverse effect (-1.8 to -2.7 times) was observed with the seedlings of *Bactris*. They attributed this differential response of earthworms due to different conditions in the rhizosphere of tree species which affected mineralization of nitrogen and accumulation of microbial biomass in the rhizosphere. Similarly, Beto *et al.* (1992) observed increase in biomass of fruit tree *Bixa orellana* with inoculation of earthworms (*Pontoscolex corethrurus*). Huang and Zhao (1991) showed that *in situ* vermiculture of *Eiseniae fetida* increased the yield of grape, tangerine, and orange by 32, 34 and 13 per cent, respectively. Baphana (1992) reported that *in situ* vermiculture with mulching and 2 lakh earthworms per acre gave 15 tones of best manure that was sufficient for improving quantity, sweetness, keeping quality and harvesting period in sapota. Similarly, Barve (1992) noticed good quality, good taste, firm attachment and attractive lusture in grape berries with the *in situ* vermiculture with mulching treatment.

Gunjal and Nikam (1992) opined that grape cultivation through *in situ* vermiculture at the rate of 100 worms per vine in combination with heavy mulching of agricultural waste proved successful without application of chemical fertilizers. The increase in yield was to the tune of 40 and 36 per cent due to application of chemical fertilizers and vermiculture, respectively over the control. Inoculation of worms with organic mulching without chemical fertilizers recorded the highest TSS

of grape. Similarly, Khamkar (1992) observed better quality of *Coccinea cardifolia* with the application of vermiculture technology. Bhawalkar and Bhawalkar (1992) reported a case study of vegetable farmer who planted *tondali* (cucurbit) on saline soil with saline irrigation. Eventhough the farmer got somewhat lesser yield in vermiculture plot than chemical plot, the vermiculture produce being better in quality, fetched 30 per cent higher price than chemical produce. In another case study of grape grower, he observed better quality of grapes due to *in situ* vermiculture with mulching treatment and the petiole analysis on 45th day from the date of October pruning showed increased concentration of K, Ca, Mg, Fe and Cu. Similar results of *in situ* vermiculture with mulching in improving the yield and quality of Thompson seedless grapes were reported by Venkatesh (1995). He also found higher concentration of N, P, K, Ca, Mg, S, Fe, Mn, Zn and Cu in petioles of grape vine in *in situ* vermiculture with mulching treatment.

Balaji (1994) reported that *in situ* vermiculture with mulching increased the growth, yield and improved the quality of flowers in china aster than control. The yield of flowers obtained was at par with that obtained in recommended dose of fertilizer treatment.

## 2.5.2 Effect of earthworms on soil properties

### 2.5.2.1 Physical

Earthworm activity influences the physical structure of soil by increasing the proportion of waterstable aggregates and formation of burrows. Evans (1948) found that the amount of coarse sand relative to silt and clay in two old pastures with high earthworm populations increased with depth and this might be

due to reduction of the amount of sand in the upper layers by its comminution in the gizzard of earthworms. It was further evident by the presence of a smaller fraction of coarse sand in wormcasts than in soil nearby (Teotia *et al.*, 1950; Shrikhande and Pathak, 1951; Joshi and Kelkar, 1952; Vleeschauwer and Lal, 1981; Mulongy and Bedoret, 1989; Trigo and Diaz, 1992; Zhang and Schrader, 1993; Chan and Heena, 1995). But in some analyses more coarse sand was found in the casts (Lindquist, 1941; Nijhawan and Kanwar, 1952). The first could arise if the wormcast contained more organic matter than the soil or if the worms were selectively ingesting the finer particles, and the second could arise if the wormcast contained material from a sandier horizon than that from which the soil samples were taken.

One of the most important effects of earthworm activity is its influence on the crumb structure of fertile mull soils. In several studies, wormcasts were found to contain more water-stable aggregates than non-cast soil (Teotia *et al.*, 1950; Nijhawan and Kanwar, 1952; Kaldivko *et al.*, 1986; Mulongoy and Bedoret, 1989; Hamilton and Dindal, 1989a; Brais *et al.*, 1989; Chan and Heena, 1995).

Shipitalo and Protz (1988) reported that fresh moist casts were 26 to 41 per cent more dispersible than uningested moist soil. Ageing reduced the dispersibility of moist casts to 49 per cent than uningested soil. Further, Shipitalo and Protz (1989) studied the chemistry and micromorphology of aggregates in earthworm casts. The results showed that the passage of soil through worms disrupted pre-existing micro-aggregates due to breakage of some bonds of water and cation bridge type. However, incorporated fragments of organic debris became plasma encrusted and served as nuclei for new aggregates. Ageing and drying of excreted pellets facilitated bonding of plant and microbial polysaccharides and other

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organic compounds associated with clay, thereby stabilizing the new micro-aggregates. These bonds consisted predominantly of clay-polyvalent cation-organic matter linkages involving calcium. Zhang and Schrader (1993) compared the effect of earthworms (*Lumbricus terrestris*, *Allolobophora longa* and *Apporrectodea caliginosa*) on stabilization of soil aggregates from casts and burrow-wall with those of the natural soil. The results revealed that the total content of polysaccharides increased by 35 to 87 per cent for casts and by 33 to 46 per cent for the burrow wall material which had the strongest effect on the interparticle bonding of the reformed aggregates in terms of tensile strength and water stability. Similarly, the role of earthworms in increasing the mean weight diameter and macroporosity of water-stable aggregates was shown by many workers (Lal and Akinremi, 1983; Kladivoko *et al.*, 1986; Hamilton and Dindal, 1989b; Brais *et al.*, 1989; Hulugalle and Ezumah, 1991; Eiler *et al.*, 1991).

Earthworms have been credited for their burrowing habit. The burrows can increase infiltration and reduce runoff thus increase soil water availability or possibly deep percolation to maintain favourable water status for plant growth (Logsdon and Linden, 1992). *Lumbricus terrestris* burrowed into soil which was artificially compacted to a pore volume as low as 40 per cent (Joschko *et al.*, 1989). Many workers have shown that, in general, earthworm burrows and structural aggregates promote infiltration rate of soil and thus reduce surface runoff (Ehlers, 1975; Kladivko *et al.*, 1986; Zachmann and Linden, 1989; Lal, 1988; Zachmann *et al.*, 1987; Edwards *et al.*, 1990; Hulugalle and Ezumah, 1991; AL-Addan *et al.*, 1991; Hardin and Comis, 1991; Clements *et al.*, 1991; Springett *et al.*, 1992).

However, the adverse effect of earthworm activity on soil physical properties were reported by few workers. Agarwal *et al* (1958) reported that the fertile soil in Himachal Pradesh turned into cement like hard clods and became unproductive due to earthworm activity. The hard aggregates formed by *Pontoscolex corethrurus* was found to be unfavourable for the growth of carrot, raddish and beet root in pot culture which obstructed the penetration of roots resulting in stunted growth (Puttarudraiah and Sastri, 1961). Shipitalo and Protz (1988) reported that the surface casting activity of earthworm, when exposed to raindrop impact may contribute to soil erosion and crusting due to high dispersibility of fresh worm casts.

#### 2.5.2.2 Chemical property

The wormcasts are usually near neutral than soil from their vicinity (Vleeschauwer and Lal, 1981). This was attributed to the calcite crystals excreted by the calciferous glands of earthworm and the secretions of intestine as a whole. Some workers also found that the casts were slightly alkaline with more soluble salts (Joshi and Kelkar, 1952; Nijhawan and Kanwar, 1952; Hulugalle and Ezumah, 1991; Bhaduria and Ramkrishnan, 1991).

Wormcasts and soil from the same neighbourhood have been compared chemically by several workers (Shrikhande and Pathak, 1948; Joshi and Kelkar, 1952; Nijhawan and Kanwar, 1952; Gupta and Sakal, 1967; Dash and Patra, 1979; Vleeschauwer and Lal, 1981; Reddy, 1983; Mulongoy and Bedoret, 1989; Tiwari *et al.*, 1989; Elliot *et al.*, 1991; Bhaduria and Ramkrishnan, 1991; Hulugalle and Ezumah, 1991; Lavelle *et al.*, 1992; Basker *et al.*, 1993; Hendrix *et al.*, 1994; Parkin and Berry, 1994). The results showed that the casts were

generally richer in some or all of the following; total and exchangeable calcium, total and available nitrogen, total and extractable phosphorus, total and exchangeable potassium and magnesium, total exchangeable bases and total organic matter. The differences that were observed in organic matter and other minerals in the castings were mostly due to selective feeding habit of worms on the decomposing particulate matter, break down of soil mineral particles, excretion of mucous and resinous substances which create congenial atmosphere for growth of beneficial microorganisms like free living N fixers and increased enzymatic activity in casts.

Vimmerstedt (1969) analysed soil on a barren rocky, infertile mine spoil bank six months after introduction of worms. He found 165 per cent increase in available phosphorus and 19 per cent increase in available potassium due to earthworm activity. Vimmerstedt and Finney (1973) studied the impact of earthworm introduction on litter burial and nutrient distribution in strip-mine spoil banks of Ohio. It was observed that the exchangeable cations and available P in mineral spoil increased as follows; K from 0.17 to 0.19, Ca from 1.7 to 2.7 and Mg from 1.8 to 2.5 meq per 100 g spoil and P increased from 1.7 to 4.2 ppm. Basak *et al.* (1990) showed that earthworm activity increased the soil fertility with respect to nitrogen, phosphorus and organic matter but not potassium.

Influence of soil ingestion by earthworms (*Apporrectodea caliginosa*) on the availability of potassium in soil was studied by Basker *et al.* (1992). The results indicated that the exchangeable K content increased significantly due to earthworm activity but nitric acid-extractable K did not change significantly. It was inferred that earthworms increased the availability of K by shifting the equilibrium among the forms of K from relatively unavailable forms to more available forms in

silt loam soil. Yousuf and Shoreit (1992) reported increased availability of microelements in soil due to introduction of earthworms (*Apporrectodea caliginosa*). *In situ* vermiculture with heavy mulching of agricultural waste in grape cultivation under drip irrigation increased the total N, available  $P_2O_5$  and water soluble  $K_2O$  content of soil (Gunjal and Nikam, 1992). Similarly, Bhawalkar and Bhawalkar (1992) also reported decrease in soil pH from 8.3 to 6.9 and increase in available potassium from 62.5 to 800 kg per ha due to *in situ* vermiculture with mulching in grape plantation. In another case study of sugarcane grower, they observed 37, 66 and 10 per cent increase in available N  $P_2O_5$  and  $K_2O$ , respectively due to *in situ* vermiculture with mulching. Makulec (1993) reported that the total N and C and exchangeable Ca, Mg and K increased in hydrogenous soil under various degree of mucking due to earthworm activity.

Balaji (1994) reported that *in situ* vermiculture with mulching either alone or in combination with chemical fertilizer in cultivation of china aster increased the available N,  $P_2O_5$  and  $K_2O$  content of soil. Similarly, Venkatesh (1995) reported that *in situ* vermiculture with mulching either alone or in combination with chemical fertilizers in grape cultivation decreased the soil pH and significantly increased the organic carbon and availability of N,  $P_2O_5$ ,  $K_2O$ ,  $SO_4$  and DTPA extractable micronutrients (Zn, Mn, Cu and Fe).

## 2.6 Vermiculture biotechnology

In modern agriculture, the use of chemical fertilizers is inevitable. The present hike in the cost of fertilizers has compelled the farmers to resort to imbalanced nutrition of crops and thus reduction in crop yield. At this juncture, organic recycling through biogenic agencies like earthworm is gaining importance

which not only help to reduce the cost on chemical fertilizers but also improve the physical, chemical and biological properties of soil, besides improving the yield and quality of crops.

Kale *et al.* (1991) reported that application of vermicompost without any chemical fertilizers to six ornamental plants, namely, balsam, zinnia, celotia, marigold and lady's lace showed the performance on par with the treatment that received normal dose of FYM and fertilizers. Similarly, the quantity of chemical fertilizers for vegetable crops such as radish, tomato, carrot, brinjal could be reduced by 25 to 50 per cent when applied with vermicompost.

Baphana (1992) observed that *in situ* vermiculture with earthworm population of two lakhs per acre and without chemical fertilizers improved the yield and quality of sapota. Barve (1992) opined that the input cost in grapes could be reduced from rupees one lakh to Rs. 40,000 per ha by application of vermicompost @ 5 t ha<sup>-1</sup> without reduction in yield level as compared to fertilizer applied plot, besides, the former produce was superior in quality with respect to taste and attractive lusture. Similar results were observed with banana plantation.

Bhawalkar and Bhawalkar (1992) reported a case study of sugarcane grown on saline soil with saline water irrigation. The farmer obtained a net profit of Rs. 1,23,500 per ha from vermiculture plot compared to Rs. 45,000 per ha from chemical plot (FYM + Fertilizers). It was possible to raise two ratoons in vermiculture plot, whereas only one ratoon was possible on chemical plot. The sugarcane grown on vermiculture plot gave 3-4 per cent extra brix with lesser salts.

In another case study of *tondali* (cucurbit) planted on saline soil with saline water irrigation for two years, though the farmer got somewhat lesser average yield in vermiculture plot (22, 710 kg acre<sup>-1</sup> year<sup>-1</sup>) than chemical plot (23,800 kg acre<sup>-1</sup> year<sup>-1</sup>), the former produce was better in quality and fetched 30 per cent higher price than chemical produce. Further, the soil physical properties were improved in vermiculture plot.

Similarly, Desai (1992) reported that application of vermicompost at the rate of one tonne per ha to capsicum resulted in little less yield compared to chemical plot but the net profit was more due to less total input cost.

Gunjal and Nikam (1992) compared the yield and quality of grape grown with *in situ* vermiculture and chemical fertilizer with control plot. They found that the increase in yield over control was 40 per cent and 36 per cent due to chemical fertilizers and *in situ* vermiculture, respectively, but they noticed higher T.S.S. in grapes grown with *in situ* vermiculture.

Balaji (1994) found that application of vermicompost either @ 2.5 t per ha + 50 per cent RDF or 5.0 t per ha vermicompost + 25 per cent RDF or *in situ* vermiculture with 2 lakh worms per ha gave equivalent saleable flower yield of china aster to that obtained with the application of FYM @ 20 t per ha + 100 per cent RDF.

Venkatesh (1995) observed that either *in situ* vermiculture (two lakh worms ha<sup>-1</sup>) or application of vermicompost @ 5.0 t per ha + 75 per cent RDF to grapes can replace the conventional practice of applying FYM @ 20 t per ha + 100

per cent RDF. Further, the produce obtained with the former treatment was better in quality and selflife.

## 2.7 Effect of fertilizer application on growth and yield of maize

Several reports indicate positive response of maize to NPK fertilizer application in terms of growth, dry matter production and yield. The response of maize to applied fertilizers was in the order of N < NP < NPK (Kanwar, 1972).

Singh (1964) reported that the combined application of N and P increased the plant height and other yield attributing characters of maize than application of N alone. Prithviraj *et al.* (1971) found that Deccan Hybrid maize recorded significantly higher grain yield with 135 kg N, 67 kg P<sub>2</sub>O<sub>5</sub> and 45 kg K<sub>2</sub>O per hectare. Similar increase in the yield of maize due to applied fertilizers have been reported by several workers (Gupta *et al.*, 1972; Sinha and Umar, 1972; Iyer and Sardana, 1973; Tiwari *et al.*, 1973).

Krantz and Chandler (1951) observed that N application to maize increased its concentration in leaves and grain and increased the uptake of P and K especially on soils which were high in these nutrients. Shukla (1972) studied the effect of five levels of N and three levels of P on the yield of maize. The results indicated that N rates significantly increased N and K and decreased P content of the leaves. Phosphorus levels had a nonsignificant effect on the uptake of nutrients.

Gupta and Das (1962) reported that the Ca content of maize grains increased by NPK application. Thompson (1962) found that N fertilization generally tended to raise the level of Mg content of maize leaves. Dobrolyubski and

Matyushenko (1970) reported that application of NPK on slightly eroded chernozem soils increased the Mg content of maize leaves in addition to major elements. Blanchar and Hossner (1968) observed that fertilizing with  $\text{NH}_4\text{-N}$  increased sulphur content of maize. Rehm and Caldwell (1970) found that application of labelled N and S significantly increased the uptake of S by maize grown on S deficient sandy loam soil.

Applied N usually showed beneficial effect on Zn uptake and the ultimate yield of maize (Nelson *et al.*, 1959; Lagnin *et al.*, 1962). On the contrary, high soil P or fertilizer P usually had deleterious effect on Zn uptake by corn (Burlison *et al.*, 1961; Lagnin *et al.*, 1962). Prohaszka *et al.* (1971) observed that increasing the dose of N had no effect on Fe content of grain and stem.

Shukla (1972) reported that application of nitrogen to corn invariably resulted in increasing the N content of soil. Similar results were reported in respect of P and K nutrients availability in soil (Indira *et al.*, 1964; Kanwar and Grewal, 1966; Anderson, 1970; Shukla, 1972). Application of organic manures alone or with inorganic fertilizers invariably have resulted in increasing the organic matter content of soil (Kanwar and Prihar, 1962; Jaiyebo and Bouldin, 1967). Similarly, Maurya and Ghosh (1972) observed that continuous application of NPK fertilizers increased the organic matter content of soil.

# Materials and Methods

### III. MATERIALS AND METHODS

The materials used and the experimental techniques adopted in the present investigations are presented in this chapter.

#### 3.1 Laboratory incubation studies

Laboratory incubation studies were conducted to assess the effect of various physico-chemical conditions in the soil environment on the survival and growth of earthworm, *Eudrilus eugeniae*.

##### 3.1.1 Effect of soil moisture on the survival and growth of earthworm

A mixture of air dried and 2 mm sieved soil and well decomposed FYM in the ratio of 9:1 was used as a growth medium for earthworm. The purpose of adding FYM was to provide starter food for earthworms. The moisture content of soil-FYM mix at 0, 30, 500, 1000 and 1500 kPa potential was determined using pressure plate and pressure membrane apparatus (Richards, 1954). One kg of soil-FYM mix was taken in plastic bread box (24x12.5x10cm). The calculated quantity of deionized water was added to soil so as to attain the required water potential. Each treatment was replicated four times. Ten preweighed juveniles of earthworm (*Eudrilus eugeniae*) were released in each box and incubated in shade at room temperature. During the incubation period, the moisture content in each treatment was maintained at predetermined level by frequent addition of deionized water. The soil temperature during the incubation period was maintained at  $26 \pm 2^{\circ}\text{C}$ . After 20 days of incubation, the worms in each treatment were counted and weighed separately. The survival/mortality and growth rate of worms were calculated.

### 3.1.2 Effect of soil pH on survival and growth of earthworm

Bulk surface soil samples having different pH value were collected, air dried and processed to pass through 2mm sieve. A mixture of processed soil and well decomposed FYM in the ratio of 9:1 was prepared. The pH of the soil-FYM mix was determined in 1:2.5 soil: water suspension. The pH of the soils selected for the present study was 5.50, 6.50, 7.00, 7.50, 7.80, 8.00 and 9.00. The maximum water holding capacity of each soil-FYM mix was determined using keen-Raczowski cup method. One kg of soil-FYM mix was added to each plastic bread box (24 x 12.5 x 10 cm). Ten preweighed juveniles of earthworm (*Eudrilus eugeniae*) were released to each bread box. The required quantity of deionized water was added to each treatment so as to maintain moisture content at saturation and it was maintained at saturation throughout the incubation period by adding deionized water daily. The soil temperature during the incubation period was maintained at  $26 \pm 2^\circ\text{C}$ . After 20 days of incubation, the population count and live weight of worms were recorded separately in each treatment and survival percentage and growth rate were calculated.

### 3.1.3 Effect of soil salinity on survival and growth of earthworm

Bulk surface soil samples having graded level of salinity were collected from A.R.S., Gangavati Farm. The soils were air dried and processed to pass through 2 mm sieve. A mixture of processed soil and well decomposed FYM in the ratio of 9:1 was prepared. The electrical conductivity of soil-FYM mix was measured in 1:2.5 soil-water suspension using conductivity meter. The electrical conductivity of soils selected for the present study was 1.75, 2.00, 3.00, 3.50, 4.00, 6.00, 7.00 and 9.00  $\text{dSm}^{-1}$ . The maximum water holding capacity of each soil-

FYM mix was determined using Keen-Raczowski cup method. One kg of soil-FYM mix was taken in plastic bread box (24x12.5x10cm). Ten preweighed juveniles of earthworm (*Eudrilus eugeniae*) were released to each bread box. The required quantity of deionized water was added to each treatment so as to maintain moisture content at saturation and it was maintained at saturation throughout the incubation period by adding deionized water daily. The soil temperature during the incubation period was maintained at  $26\pm 2^{\circ}\text{C}$ . After 20 days of incubation, the population count and live weight of worms were recorded separately in each treatment and survival percentage and growth rate were calculated.

#### **3.1.4 Effect of soil temperature on survival and growth of earthworm**

Bulk surface soil sample from R.R.S., Raichur Farm was collected, air dried and processed to pass through 2mm sieve. A mixture of processed soil and well decomposed FYM in the ratio of 9:1 was prepared. The pH and electrical conductivity of the soil-FYM mix was determined in 1:2.5 soil water suspension. The maximum water holding capacity of soil-FYM mix was determined using Keen-Raczowski cup method. One kg of soil-FYM mix was added to each plastic bread box (24x12.5x10cm). Ten preweighed juveniles were released in each bread box. The required quantity of deionized water was added to each treatment so as to maintain moisture content at saturation and it was maintained at saturation throughout the incubation period by adding deionized water daily. The soil temperature selected for the study was 10, 14, 15, 20, 25, 30, 35, 40, 41 and  $45^{\circ}\text{C}$ . Each treatment was replicated four times. The containers were placed in the BOD incubator and the required ambient soil temperature for each treatment was maintained throughout the incubation period. Each treatment was incubated for 20

days and at the end of incubation period, the population and biomass of worms were recorded. Mortality of all worms within 24 hours of incubation was observed in treatments having soil temperature of 10, 14, 41 and 45°C.

### 3.2 Role of earthworms in soil biotechnology

Bulk surface soil sample from RRS Raichur Farm was collected, air dried and processed to pass through 2mm sieve. A mixture of processed soil and well decomposed FYM in the ratio of 9:1 was prepared. The maximum water holding capacity of soil-FYM mix was determined using Keen-Raczkowski cup method.

One kg of soil-FYM mix was added to each plastic bread box (24x12.5x10cm). The required quantity of deionized water was added to each treatment so as to maintain moisture content at saturation. The crop residues selected for the study were sunflower stalks, maize stover, cotton stalks, sunnhemp stalks and paddy straw. The crop residues were analysed for different nutrients by adopting standard methods and the data are presented in Appendix 1. The crop residues were air dried and chopped into small pieces of 4-5 cms. Seventy five grams of each crop residue (@ 5 t ha<sup>-1</sup>) was applied as surface mulch. One treatment without crop residue served as control. These six treatments were again combined either with or without worms. In all 12 treatment combinations were obtained which were replicated thrice. Ten preweighed juveniles of earthworm (*Eudrilus eugeniae*) were released to each bread box having with worms treatment. The soil moisture was maintained at saturation throughout the incubation period by adding deionized water daily.

Wet soil samples were drawn at 0, 30, 60 and 90 days of incubation (DAI) using tube auger and used for estimation of pH, organic carbon, available nitrogen, phosphorous, potassium and sulphur, DTPA extractable zinc, manganese, copper and iron by adopting standard methods. All the values were expressed on oven-dry weight basis. At 90 DAI, the population and biomass of earthworms and weight of undecomposed crop residues were recorded.

Similarly moist soil samples were drawn at 90 DAI and used for biochemical study of enzyme assays and the results were expressed on oven-dry weight basis.

### **3.2.1 Enzyme assays**

#### **3.2.1.1 Dehydrogenase ( $H_2$ -Oxidoreductase) :**

Five grams of soil was taken in a test tube with rubber stopper and 2.5 mL distilled water and one mL of 2,3,5-triphenyl tetrazolium chloride (3%) were added to it and incubated at 37°C for 24 hours. The soil solution was filtered through Whatman filter paper and washed with methanol to remove the red colour and diluted to 100 mL. The colour intensity was measured at 485 nm (Casida *et al.*, 1964).

#### **3.2.1.2 Urease (Urea amidohydrolase) :**

The reaction mixture consisting of 10 g of soil, 20mL of 0.2 M citrate buffer (pH 6.7) and 10 mL 2 per cent of urea solution in distilled water was incubated at 37°C for 8 hours and filtered. One mL of aliquot of the filtrate was mixed with phenol-sodium reagent and the intensity of colour was read in spectrophotometer after 20 minutes at 630 nm (McGarity and Myers, 1967).

### 3.2.1.3 Catalase ( $H_2O_2$ : $H_2O$ Oxidoreductase) :

The reaction mixture consisting of 2.0 g of soil, 40 mL of distilled water and 5 mL of hydrogen peroxide (30 per cent diluted to 1:100) was placed over a horizontal shaker ( $110 \text{ strokes min}^{-1}$ ) for 20 minutes. After adding 5 mL of 3N  $H_2SO_4$ , the contents of the flask were filtered and a 25mL aliquot was titrated against 0.05 M  $KMnO_4$  (Johnson and Temple, 1964)).

## 3.3 Field experiments

### 3.3.1 Location

The field experiments were conducted at Agriculture College Farm, Raichur during *rabi* 1994-95. Raichur is situated in the North Eastern dry Zone (Zone-2) of Karnataka between  $16^{\circ}15'N$  latitude and  $77^{\circ}20'E$  longitude at an altitude of 389 meters above mean sea level.

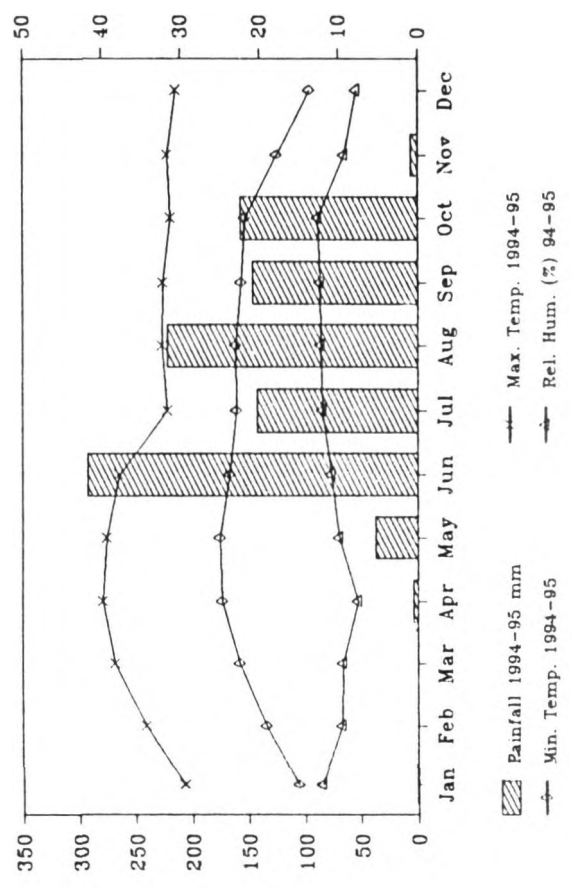
### 3.3.2 Climate

The data on climatic parameters, namely, rainfall, maximum and minimum temperature and relative humidity recorded during the period of experimentation and average values of rainfall of 63 years and mean maximum and minimum temperature and relative humidity of 33 years recorded at the meteorological observatory, Regional Research Station, Raichur are presented in Table 1 and depicted in Figure 1.

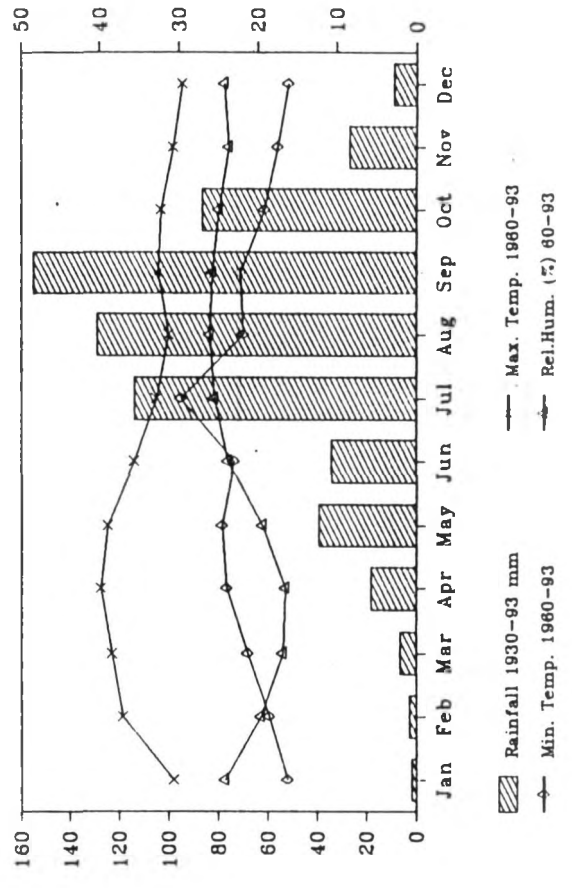
The average annual rainfall at Raichur is 621.32 mm. During the year of experimentation (1994-95) a total rainfall of 1005.3 mm was received in 51 rainy days, but only 19.4 mm rainfall was received during the crop growth period

**Table 1.** Mean monthly meteorological data for the year 1994-95 and 63 years average recorded at the meteorological observatory, Regional Research Station, Raichur.

Month	Rainfall (mm)			Temperature (°C)				Relative Humidity (%)	
	1930-93	1994-95	1960-93	Maximum		Minimum		1960-93	1994-95
				1994-95	1960-93	1994-95	1960-93		
January	1.87	0.8	30.53	29.50	16.20	15.1	77.05	74.4	
February	2.56	-	37.00	34.30	18.51	14.1	62.65	66.8	
March	6.40	-	38.38	38.30	21.22	22.5	53.92	66.0	
April	18.09	4.2	39.85	39.80	23.47	24.7	52.96	52.0	
May	39.18	36.6	38.94	39.30	24.52	25.0	61.99	69.0	
June	34.08	292.0	35.60	37.70	22.94	23.7	75.96	76.0	
July	113.85	141.6	32.77	31.60	22.74	22.9	81.39	84.0	
August	128.79	221.6	31.20	32.30	21.84	23.0	83.36	85.0	
September	154.77	146.0	32.56	32.20	22.20	22.3	82.33	86.0	
October	86.35	156.8	32.20	31.20	19.07	21.8	79.70	88.2	
November	26.59	5.7	30.68	31.60	17.46	17.8	75.76	64.5	
December	8.79	0.0	29.47	30.60	16.16	13.6	77.46	53.5	



a. Mean monthly meteorological data for 1994-95.



b. Mean monthly meteorological data for 63 years (1930-93).

Fig 1. Mean monthly meteorological data for the year 1994-95 and 63 years average of Regional Research Station, Raichur.

i.e. from November 1994 to March 1995. The highest monthly mean maximum temperature of 39.85°C and the lowest monthly minimum temperature of 16.16°C were recorded in the month of April and December, respectively. The mean relative humidity fluctuated between 52.96 per cent in April and 83.36 per cent in August. The corresponding values of relative humidity during 1994-95 were 52.00 and 88.20 per cent recorded in the month of April and October, 1994.

### 3.3.3 Soils

The soils of experimental site belong to Rampur series of Typic Haplustalf. The texture of the soil is sandy clay loam. The soils are medium in organic carbon content, low in available nitrogen, medium in available phosphorus and high in available potassium content. The detailed properties of soils are presented in Table 2.

### 3.3.4 Nutrient composition of vermicompost and FYM

The air dried and sieved vermicompost was obtained from the Department of Agricultural Entomology, College of Agriculture, Raichur. Similarly, well decomposed FYM collected from the compost pit of College Farm was air dried and sieved to pass through 2mm sieve. Both the vermicompost and FYM samples were analysed for total and available nutrients content. The data are presented in Table 3. The pH of both vermicompost and FYM was near neutral but the electrical conductivity of vermicompost was higher ( $1.32 \text{ dSm}^{-1}$ ) as compared to FYM ( $0.22 \text{ dSm}^{-1}$ ). The vermicompost was superior to FYM in N and P contents but low in total K content.

Table 2. Physical and Chemical Properties of soils of experimental site.

Particulars	Expt. - I	Expt. - II
Particle size distribution (%)		
Sand	52.9	51.7
Silt	22.6	22.7
Clay	23.8	24.9
Texture	Sandy clay loam	Sandy clay loam
Maximum water holding capacity (%)	43.6	43.9
pH (1:2.5)	8.55	8.53
EC ( $\text{dSm}^{-1}$ )	0.19	0.21
Organic carbon (%)	0.64	0.66
CEC ( $\text{C mol (p+) kg}^{-1}$ )	13.5	13.7
Available nutrient ( $\text{kg ha}^{-1}$ )		
N	234.83	246.54
$\text{P}_2\text{O}_5$	38.99	35.18
$\text{K}_2\text{O}$	441.33	449.00
$\text{SO}_4$ S	17.39	18.30
DTPA extractable micronutrient ( $\text{mg kg}^{-1}$ )		
Zn	1.02	1.06
Mn	13.77	13.48
Cu	0.31	0.28
Fe	8.49	8.42

Table 3. Composition of vermicompost and FYM

Particulars	Vermicompost	FYM
pH (1:2.5)	7.18	7.20
EC (dSm <sup>-1</sup> )	1.32	0.22
Total nutrients (%)		
N	0.85	0.42
P	0.62	0.12
K	0.45	0.56
Ca	0.53	0.18
Mg	0.21	0.15
S	0.35	0.23
Total micronutrients (mg kg <sup>-1</sup> )		
Zn	467.00	132.00
Mn	250.00	175.00
Cu	26.00	22.00
Fe	380.00	250.00
Available nutrients (mg kg <sup>-1</sup> )		
N	650.00	310.00
P	195.00	48.00
K	1355.00	1024.00
DTPA extractable micronutrients (mg kg <sup>-1</sup> )		
Zn	120.00	25.00
Mn	140.00	110.00
Cu	0.88	0.45
Fe	38.00	35.00

### 3.3.5 Experiment I : Effect of organic manures and fertilizer levels on maize

The experiment was laid out in split-plot design with three replications. The layout plan of the experiment is given in Fig. 2. A combination of four main plot treatments (organic manures) and three sub plot treatments (Fertilizer levels) was followed. The treatment details are furnished below.

#### Main plot treatments

C <sub>1</sub>	-	Control
C <sub>2</sub>	-	FYM @ 20 t ha <sup>-1</sup>
C <sub>3</sub>	-	Vermicompost @ 2.5 t ha <sup>-1</sup>
C <sub>4</sub>	-	Vermicompost @ 5.0 t ha <sup>-1</sup>

#### Sub plot treatments

F <sub>1</sub>	-	25 per cent RDF
F <sub>2</sub>	-	50 per cent RDF
F <sub>3</sub>	-	100 per cent RDF

### 3.3.6 Application of vermicompost and FYM

The quantity of vermicompost and FYM required for each plot was calculated as per treatment details and applied uniformly on the soil surface and mixed into soil upto a depth of 15 cms.

### 3.3.7 Experiment II : Effect of *in situ* vermiculture and fertilizer levels on maize

The experiment was laid out in split-plot design with three replications. The layout plan of the experiment is given in Figure 2. A combination

EXPERIMENT - I

C <sub>1</sub> F <sub>1</sub>	C <sub>1</sub> F <sub>2</sub>	C <sub>1</sub> F <sub>3</sub>
C <sub>3</sub> F <sub>3</sub>	C <sub>3</sub> F <sub>1</sub>	C <sub>3</sub> F <sub>2</sub>
C <sub>2</sub> F <sub>3</sub>	C <sub>2</sub> F <sub>2</sub>	C <sub>2</sub> F <sub>1</sub>
C <sub>4</sub> F <sub>2</sub>	C <sub>4</sub> F <sub>1</sub>	C <sub>4</sub> F <sub>3</sub>
C <sub>3</sub> F <sub>1</sub>	C <sub>3</sub> F <sub>3</sub>	C <sub>3</sub> F <sub>2</sub>
C <sub>4</sub> F <sub>1</sub>	C <sub>4</sub> F <sub>2</sub>	C <sub>4</sub> F <sub>3</sub>
C <sub>1</sub> F <sub>3</sub>	C <sub>1</sub> F <sub>1</sub>	C <sub>1</sub> F <sub>2</sub>
C <sub>2</sub> F <sub>2</sub>	C <sub>2</sub> F <sub>3</sub>	C <sub>2</sub> F <sub>1</sub>
C <sub>4</sub> F <sub>1</sub>	C <sub>4</sub> F <sub>3</sub>	C <sub>4</sub> F <sub>2</sub>
C <sub>3</sub> F <sub>1</sub>	C <sub>3</sub> F <sub>3</sub>	C <sub>3</sub> F <sub>2</sub>
C <sub>2</sub> F <sub>3</sub>	C <sub>2</sub> F <sub>1</sub>	C <sub>2</sub> F <sub>2</sub>
C <sub>1</sub> F <sub>1</sub>	C <sub>1</sub> F <sub>2</sub>	C <sub>1</sub> F <sub>3</sub>

EXPERIMENT - II

W <sub>4</sub> F <sub>2</sub>	W <sub>4</sub> F <sub>1</sub>	W <sub>4</sub> F <sub>3</sub>
W <sub>3</sub> F <sub>1</sub>	W <sub>3</sub> F <sub>3</sub>	W <sub>3</sub> F <sub>2</sub>
W <sub>1</sub> F <sub>2</sub>	W <sub>1</sub> F <sub>3</sub>	W <sub>1</sub> F <sub>1</sub>
W <sub>2</sub> F <sub>1</sub>	W <sub>2</sub> F <sub>2</sub>	W <sub>2</sub> F <sub>3</sub>
W <sub>4</sub> F <sub>1</sub>	W <sub>4</sub> F <sub>2</sub>	W <sub>4</sub> F <sub>3</sub>
W <sub>3</sub> F <sub>2</sub>	W <sub>3</sub> F <sub>3</sub>	W <sub>3</sub> F <sub>1</sub>
W <sub>2</sub> F <sub>1</sub>	W <sub>2</sub> F <sub>3</sub>	W <sub>2</sub> F <sub>2</sub>
W <sub>1</sub> F <sub>2</sub>	W <sub>1</sub> F <sub>1</sub>	W <sub>1</sub> F <sub>3</sub>
W <sub>3</sub> F <sub>3</sub>	W <sub>3</sub> F <sub>2</sub>	W <sub>3</sub> F <sub>1</sub>
W <sub>2</sub> F <sub>2</sub>	W <sub>2</sub> F <sub>1</sub>	W <sub>2</sub> F <sub>3</sub>
W <sub>1</sub> F <sub>3</sub>	W <sub>1</sub> F <sub>1</sub>	W <sub>1</sub> F <sub>2</sub>
W <sub>4</sub> F <sub>2</sub>	W <sub>4</sub> F <sub>3</sub>	W <sub>4</sub> F <sub>1</sub>

N ↑

← RIII →

← RII →

← RI →

Design : Split - Plot

Replications : Three

Main Plot Treatments

- C<sub>1</sub> - Control
- C<sub>2</sub> - FYM @ 20 t ha<sup>-1</sup>
- C<sub>3</sub> - Vermicompost @ 2.5 t ha<sup>-1</sup>
- C<sub>4</sub> - Vermicompost @ 5.0 t ha<sup>-1</sup>

Sub Plot Treatments

- F<sub>1</sub> - 25 per cent RDF
- F<sub>2</sub> - 50 per cent RDF
- F<sub>3</sub> - 100 per cent RDF

Gross Plot size = 4.8 x 3.0 m  
 = 14.4 m<sup>2</sup>  
 Net plot size = 3.6 x 2.4 m  
 = 8.64 m<sup>2</sup>

- W<sub>1</sub> - No mulch no worms
- W<sub>2</sub> - Mulch without worms
- W<sub>3</sub> - Worms without mulch
- W<sub>4</sub> - Worms with mulch

- F<sub>1</sub> - 25 per cent RDF
- F<sub>2</sub> - 50 per cent RDF
- F<sub>3</sub> - 100 per cent RDF

Fig 2. Plan of layout of field experiments.

of four main plot treatments (*in situ* vermiculture) and three sub plot treatments (fertilizer levels) was followed. The treatment details are furnished below.

#### **Main plot treatments**

W<sub>1</sub> - No mulch no worms

W<sub>2</sub> - Mulch without worms

W<sub>3</sub> - Worms @ 2.5 lakh ha<sup>-1</sup> without mulch

W<sub>4</sub> - Worms @ 2.5 lakh ha<sup>-1</sup> with mulch

#### **Sub plot treatments**

F<sub>1</sub> - 25 per cent RDF

F<sub>2</sub> - 50 per cent RDF

F<sub>3</sub> - 100 per cent RDF

#### **3.3.8 Application of FYM**

A basal dose of FYM @ 20 t ha<sup>-1</sup> was applied uniformly on the soil surface and mixed into soil upto a depth of 15 cms.

#### **3.3.9 Mulching**

Chopped sunnhemp stalks were used for surface mulching. One week after germination of maize seeds, the sunnhemp stalks @ 5 t ha<sup>-1</sup> were spread uniformly on the soil surface between the seed lines.

#### **3.3.10 *In situ* vermiculture**

Adult earthworms (*Eudrilus eugeniae*) obtained from vermaries of the Department of Agricultural Entomology, College of Agriculture, Raichur were used for *in situ* vermiculture @ 2.5 lakh worms per ha. The population of earthworm

required for each plot was calculated and released equally and uniformly in each furrow as per treatment details. Sufficient soil moisture was maintained throughout the period of experimentation by providing irrigation at weekly interval.

#### **3.3.11 Sampling of earthworm population**

After the harvest of maize crop, sampling for worms was done at random with the help of an iron ring of 60 cm dia. The earthworm population in the soil was counted by hand sorting and expressed as number of worms per square meter. The population of introduced (epigeic) and native (endogeic) worms were segregated on the basis of colour, size, activity and vertical distribution and their number and biomass were recorded.

#### **3.3.12 Fertilizer application**

The recommended dose of fertilizers for irrigated hybrid maize is 150 kg N, 75 kg  $P_2O_5$  and 40 kg  $K_2O$  per hectare. One third quantity of N and full dose of  $P_2O_5$  and  $K_2O$  were applied basally at the time of sowing through urea, single super phosphate and muriate of potash, respectively. The amount of fertilizers required for each plot in each experiment was calculated as per treatment details. The fertilizer mixture was placed uniformly in bands at 10 cms away and 5 cms below the seed line. The first top dressing of N (one-third quantity) was done at four weeks after sowing and the second top dressing of N (one-third quantity) was done at seven weeks after sowing.

#### **3.3.13 Sowing**

Sowing was done on 26-11-1994. Certified seeds of hybrid maize (Cv. Deccan-103) were hand dibbled at 60 cm x 30 cm spacing.

### **3.3.14 Cultural practices and plant protection measures**

The recommended cultural practices and necessary plant protection measures were followed as per the package of practices for Region-I of UAS, Dharwad.

### **3.3.15 Biometrical observations**

Biometrical observations were recorded on five randomly selected plants in each treatment for the following parameters.

### **3.3.16 Plant Height**

The plant height was measured at harvest. The height from the base of the plant to the base of tassel was measured and expressed as the average plant height in centimeters.

### **3.3.17 Grain weight per plant**

The cobs of five randomly selected plants were removed, air dried and grains were separated and its weight was recorded and expressed as grain weight per plant.

### **3.3.18 Grain yield**

Harvesting of maize was done after complete maturity (27-3-1995). The cobs from the net plot area were removed, air dried and grains were separated and yield per plot was recorded and expressed as grain yield in quintals per hectare.

### **3.3.19 Stover Yield**

The stalks were cut close to the ground level and left in the field for drying. The weight of stover per plot was recorded after complete sun drying and expressed as stover yield in quintals per hectare.

### **3.3.20 Cost of cultivation and net profit**

The cost of cultivation for each treatment was worked out by taking into consideration the price of inputs prevailing in the market. The grain and stover yield of crop was considered to work out the gross income from each treatment. Net profit in each treatment was calculated by deducting the cost of cultivation from the gross income.

### **3.3.21 Thousand grain weight**

One thousand grains were counted randomly, dried in shade and its weight was recorded in grams.

## **3.4 Plant analysis**

### **3.4.1 Preparation of plant sample**

Grain and stover samples of individual treatment were dried in shade and ground to fine powder in Willey mill with stainless steel blades. The powdered plant samples were used for nutrient analyses.

### **3.4.2 Nitrogen**

Nitrogen content of plant sample was estimated by adopting the modified Microkjeldahls method (Jackson, 1973).

### **3.4.3 Digestion of plant sample**

A known quantity of powdered plant sample was predigested with concentrated nitric acid for overnight. Further digestion was done with 5 ml of diacid mixture ( $\text{HNO}_3$  :  $\text{HClO}_4$ ) until white residue was developed. Then the residue was dissolved in 6N HCl and the volume was made upto 50 ml. A blank was prepared in the same way without the plant material.

#### **3.4.4 Phosphorus**

The phosphorus content in the digested plant sample was determined by vanadomolybdophosphoric acid yellow colour method using spectrophotometer at 420 nm wave length (Jackson, 1973).

#### **3.4.5 Potassium**

The potassium content in the digested plant sample was determined by flame photometer after making proper dilutions (Jackson, 1973).

#### **3.4.6 Calcium and Magnesium**

The calcium and magnesium contents in the digested plant sample was determined by EDTA-titration (Jackson, 1973).

#### **3.4.7 Sulphur**

The sulphur content in the digested plant sample was determined by turbidometry method using spectrophotometer at 420 nm wave length (Jackson, 1973).

#### **3.4.8 Micronutrients**

The concentration of zinc, manganese, copper and iron in the digested plant sample was determined after proper dilution using atomic absorption spectrophotometer (Model, Shimadzu, AA-670).

### **3.5 Soil analysis**

#### **3.5.1 Soil sampling and analyses**

Before the start of experiment, composite soil samples (0-15 cm depth) from both the experimental sites were collected, processed to pass through

2mm sieve and preserved for further analyses. Similarly, representative soil samples from each plot were collected after the harvest of maize crop. The soil samples were dried in shade, processed to pass through 2mm sieve and used for further analyses.

### **3.5.2 Particle size distribution**

Particle size distribution of soil was done by adopting the International pipette method (Piper, 1966).

### **3.5.3 Maximum water holding capacity**

Maximum water holding capacity of soil was determined by using Keen-Raczowski cup method (Piper, 1966).

### **3.5.4 Infiltration rate**

Infiltration rate of soil was determined after the harvest of maize crop using double ring infiltrometer (Richards, 1954).

### **3.5.5 pH and Electrical conductivity**

Soil pH was measured in 1:2.5 soil: water suspension by pH meter (Model, LT. 12T). The clear supernatant solution of the above soil water suspension was taken and EC was measured using conductivity meter (Systronics - 304).

### **3.5.6 Organic carbon**

The organic carbon content of soil was estimated by Walkely and Black's wet oxidation method (Jackson, 1973).

### **3.5.7 Cation exchange capacity**

The cation exchange capacity of soil was determined by sodium saturation method (Jackson, 1973).

### **3.5.8 Available nitrogen**

The available nitrogen content of soil was estimated by alkaline permanganate method as described by Subbiah and Asija (1959).

### **3.5.9 Available phosphorus**

The available phosphorus in soil was extracted with 0.5 N  $\text{NaHCO}_3$  (pH 8.5) (Olsen's method). The content of phosphorus in the extract was determined by chlorostannous reduced molybdophosphoric blue colour method using spectronic-20 spectrophotometer at 660 nm wavelength (Jackson, 1973).

### **3.5.10 Available potassium**

The soil was extracted with neutral normal ammonium acetate and the content of potassium in the extract was estimated by flame photometer (Elico D-22) (Jackson, 1973).

### **3.5.11 Available sulphur**

The available sulphur content of soil was extracted by Morgan's reagent. The sulphur content in the leachate was estimated by adopting barium sulphate turbidometry method using spectronic-20 spectrophotometer at 420 nm wavelength (Black, 1965).

### **3.5.12 DTPA — extractable micronutrients**

Ten grams of air dried soil was shaken with 20 ml of extracting solution (0.005 M DTPA + 0.01 M calcium chloride + 0.1 M TEA, pH-7.3) for

two hours. The soil suspension was filtered and the contents of zinc, manganese, copper and iron in it were measured by atomic absorption spectrophotometer (Model, Perkin Elmer, 2380) (Lindsay and Norvell, 1978).

### **3.6 Statistical analysis**

Fishers method of analysis of variance was applied for the analysis and interpretation of data as given by Panse and Sukhatme (1967). The level of significance used in 'F' and 't' test was 0.05. Critical difference was calculated wherever 'F' test was significant.

# Experimental Results

## IV. EXPERIMENTAL RESULTS

The results of laboratory incubation studies and field experiments are presented in this chapter under the following headings.

1. The effect of different physico-chemical conditions in the soil environment on the survival and growth of earthworm.
2. Role of earthworm in soil biotechnology.
3. Effect of application of organic manures and fertilizer levels on the growth, yield and uptake of nutrients by maize and soil properties.
4. Effect of *in situ* vermiculture in combination with different levels of fertilizers on growth, yield and uptake of nutrients by maize and soil properties.

### 4.1 Effect of different physico-chemical conditions in the soil environment on the survival and growth of earthworm

#### 4.1.1 Moisture

The data on the effect of different soil moisture levels on growth and biomass of earthworm are presented in Table 4.

The biomass and growth rate of earthworm differed significantly due to moisture level in the soil. The maximum biomass of 881 mg per worm was recorded at zero KPa soil water potential (saturation). There was significant reduction in biomass with increase in soil water potential. The biomass of earthworm recorded at 30, 500 and 1000 KPa was 217, 97 and 73 mg per worm, respectively. At 1500 KPa soil water potential (wilting point), the earthworms did not survive. Similarly, the growth rate of earthworm was maximum at zero KPa ( $42.1 \text{ mg worm}^{-1} \text{ day}^{-1}$ ), which reduced significantly to 8.8, 3.1 and 1.8 mg per worm per day at 30, 500 and 1000 KPa soil water potential, respectively.

Table 4. Effect of soil moisture levels on growth and biomass of earthworm

Soil water potential (KPa)	Soil moisture content (%)	Initial biomass (mg worm <sup>-1</sup> )	Biomass after 20 DAI (mg worm <sup>-1</sup> )	Gain in biomass (mg worm <sup>-1</sup> )	Growth rate (mg worm day <sup>-1</sup> )
0	79.59	39	881	842	42.1
30	39.48	42	217	175	8.8
500	27.94	36	97	61	3.1
1000	22.54	38	73	35	1.8
1500	18.67	39	—	—	—
SEm ±	—	1.84	4.9	5.1	0.25
CD at 5%	—	NS	15.1	15.7	0.77

Table 5. Effect of soil pH on growth and biomass of earthworm

Soil pH	Initial biomass (mg worm <sup>-1</sup> )	Biomass after 20 DAI (mg worm <sup>-1</sup> )	Gain in biomass (mg worm <sup>-1</sup> )	Growth rate (mg worm <sup>-1</sup> day <sup>-1</sup> )
5.50	37	—	—	—
6.50	35	710	675	33.8
7.00	35	768	733	36.6
7.50	37	728	691	34.6
7.80	35	657	622	31.1
8.10	36	647	611	30.6
9.00	38	486	448	22.3
SEm ±	1.14	6.8	7.5	0.37
CD at 5%	NS	21.0	23.1	1.14

The survival, biomass and growth of earthworm was maximum at zero KPa soil water potential (saturation), it decreased significantly with increase in soil water potential and was zero at 1500 KPa.

#### 4.1.2 pH

The data on the effect of soil pH on growth and biomass of earthworm are presented in Table 5.

The biomass and growth rate of earthworm affected significantly due to soil pH. The highest biomass of 768 mg per worm was recorded at soil pH 7.0 followed by 728 and 710 mg per worm at soil pH 7.5 and 6.5, respectively and were significantly higher than other treatments. Reducing the soil pH to 5.5, mortality of all worms was observed. Similarly, increasing the soil pH above 7.5, significantly reduced the biomass of earthworm. Thus, significantly the lowest biomass of earthworm (486 mg worm<sup>-1</sup>) was observed at soil pH 9.0. Similarly, the growth rate of earthworm was maximum at soil pH 7.0 (36.6 mg worm<sup>-1</sup> day<sup>-1</sup>) followed by pH 7.5 (34.6 mg worm<sup>-1</sup> day<sup>-1</sup>) and pH 6.5 (33.8 mg worm<sup>-1</sup> day<sup>-1</sup>). Increasing the soil pH above 7.5, significantly reduced the growth rate of earthworm. It was 31.1, 30.6 and 22.3 mg per worm per day soil at pH 7.8, 8.1 and 9.0, respectively.

The results indicated that maximum biomass and growth rate of earthworm is achieved between soil pH 6.5 and 7.5.

#### 4.1.3 Salinity

The data on growth and biomass of earthworm as influenced by different levels of soil salinity are presented in Table 6.

Table 6. Effect of soil salinity on growth and biomass of earthworm

Soil salinity (dS m <sup>-1</sup> )	Initial biomass (mg worm <sup>-1</sup> )	Biomass after 20 DAI (mg worm <sup>-1</sup> )	Gain in biomass (mg worm <sup>-1</sup> )	Growth rate (mg worm <sup>-1</sup> day <sup>-1</sup> )
1.75	34	653	619	30.9
2.00	32	795	764	38.2
3.00	31	658	627	31.4
3.50	34	382	348	17.4
4.00	31	378	347	17.3
6.00	30	320	290	14.5
7.00	32	287	256	12.8
9.00	34	255	221	11.1
<b>SEm ±</b>	1.6	9.9	10.0	0.5
<b>CD at 5%</b>	NS	29.7	30.0	1.5

Table 7. Effect of soil temperature on growth and biomass of earthworm

Soil Temp. (°C)	Initial biomass (mg worm <sup>-1</sup> )	Survival of worms (%)	Biomass after 20 DAI (mg worm <sup>-1</sup> )	Gain in biomass (mg worm <sup>-1</sup> )	Growth rate (mg worm <sup>-1</sup> day <sup>-1</sup> )
10	28	-	-	-	-
14	31	-	-	-	-
15	29	30	43	14	0.7
20	32	100	256	224	11.2
25	26	100	274	248	12.4
30	27	100	220	192	9.6
35	30	100	171	141	7.1
40	28	45	69	41	2.1
41	27	-	-	-	-
45	32	-	-	-	-
<b>SEm ±</b>	1.41	2.0	4.6	4.8	0.22
<b>CD at 5%</b>	NS	6.1	13.7	14.3	0.65

Soil salinity levels had significant influence on the biomass and growth rate of earthworm. The highest biomass of earthworm (795 mg worm<sup>-1</sup>) was observed at EC 2.0 dSm<sup>-1</sup> and was significantly superior to other treatments. The biomass of earthworm recorded at EC 3.0 and 1.75 dSm<sup>-1</sup> was 658 and 653 mg per worm, respectively, which were at par with each other but significantly lower than that recorded at EC 2.00 dSm<sup>-1</sup>. Increasing the level of soil salinity above 3.0 dSm<sup>-1</sup>, significantly reduced the biomass of earthworm. The biomass recorded at EC 6.00, 7.00 and 9.00 dSm<sup>-1</sup> was 320, 287 and 255 mg per worm, respectively. Similarly, the growth rate of earthworm was significantly the highest at EC 2.00 dSm<sup>-1</sup> (38.2 mg worm<sup>-1</sup> day<sup>-1</sup>), followed by EC 1.75 dSm<sup>-1</sup> (30.9 mg worm<sup>-1</sup> day<sup>-1</sup>), and 3.0 dSm<sup>-1</sup> (31.4 mg worm<sup>-1</sup> day<sup>-1</sup>). Increasing the level of soil salinity above 3.00 dSm<sup>-1</sup>, significantly reduced the growth rate of earthworm. It was 17.4, 17.3, 14.5, 12.8 and 11.1 mg per worm per day at EC 3.50, 4.00, 6.00, 7.00 and 9.00 dSm<sup>-1</sup>, respectively.

The results indicated that the electrical conductivity of soil between 1.75 and 3.00 dSm<sup>-1</sup> is optimum for higher growth and biomass production of earthworm.

#### 4.1.4 Temperature

The data on the effect of soil temperature on survival, growth and biomass of earthworm are presented in Table 7.

The survival, biomass and growth rate of earthworm were significantly affected by soil temperature. Earthworms did not survive at soil

temperature below 15°C and above 40°C. The survival of worms at 15° and 40°C soil temperature was 30 and 45 per cent, respectively. Soil temperature ranging from 20°C to 35°C recorded 100 per cent survival of released earthworms. The highest biomass of earthworm (274 mg worm<sup>-1</sup>) was recorded at 25°C soil temperature and it decreased significantly either by increasing or decreasing the soil temperature from 25°C. The biomass of earthworm recorded at 15, 20, 30, 35 and 40°C was 43, 256, 220, 171 and 69 mg per worm, respectively. Similarly, the growth rate of earthworm was maximum at soil temperature of 25°C (12.4 mg worm<sup>-1</sup> day<sup>-1</sup>) which reduced significantly to 0.7, 11.2, 9.6, 7.1 and 2.1 mg per worm per day at soil temperature of 15, 20, 30, 35 and 40°C, respectively.

The soil temperature ranging from 20 to 25°C is optimum for maximum survival, growth and biomass production of earthworm.

## **4.2 Role of earthworm in soil biotechnology**

### **4.2.1 Decomposition of crop residues**

The data on decomposition of different crop residues in soil by earthworms are presented in Table 8.

Among the different crop residues tested, the amount of decomposition was highest with sunnhemp stalks (39.1%) followed by paddy straw (38.1%) and both were significantly superior to sunflower stalks (26.1%), maize stover (29.1%) and cotton stalks (27.4%). Introducing earthworms into soil enhanced the decomposition of all the crop residues significantly. The highest decomposition was again recorded with sunnhemp stalks (91.5%) followed by paddy straw (88.4%) and both were significantly superior to sunflower stalks (44.1%), maize stover (50.8%) and cotton stalks (49.3%).

Table 8. Decomposition of different crop residues by earthworm

Treatment	Wt. of residue		Per cent decomposition	Rate of decomposition (mg day <sup>-1</sup> )
	undecomposed (g)	decomposed (g)		
W <sub>0</sub> M <sub>1</sub>	55.43	19.57	26.1	217.41
W <sub>1</sub> M <sub>1</sub>	42.20	32.80	44.1	364.44
W <sub>0</sub> M <sub>2</sub>	53.20	21.80	29.1	242.22
W <sub>1</sub> M <sub>2</sub>	36.90	38.10	50.8	423.33
W <sub>0</sub> M <sub>3</sub>	54.47	20.53	27.4	228.15
W <sub>1</sub> M <sub>3</sub>	38.00	37.00	49.3	411.11
W <sub>0</sub> M <sub>4</sub>	45.67	29.33	39.1	325.93
W <sub>1</sub> M <sub>4</sub>	6.33	68.67	91.5	762.96
W <sub>0</sub> M <sub>5</sub>	46.43	28.57	38.1	317.40
W <sub>1</sub> M <sub>5</sub>	8.70	66.30	88.4	736.66
SEM ±	1.25	1.25	—	13.87
CDt 5%	3.68	3.68	—	40.91

Initial weight of mulch = 75 g

W<sub>0</sub> - No worms and W<sub>1</sub> - Worms  
M<sub>1</sub> - Sunflower stalks, M<sub>2</sub> - Maize stover,  
M<sub>3</sub> - Cotton stalks, M<sub>4</sub> - Sunnhemp stalks and  
M<sub>5</sub> - Paddy stover.

The rate of decomposition of different crop residues in soil followed similar trend. It was highest with sunnhemp stalks with worms ( $762.96 \text{ mg day}^{-1}$ ) followed by paddy straw ( $736.66 \text{ mg day}^{-1}$ ) and both were significantly superior to sunflower stalks ( $364.44 \text{ mg day}^{-1}$ ), maize stover ( $423.33 \text{ mg day}^{-1}$ ) and cotton stalks ( $411.11 \text{ mg day}^{-1}$ ).

The results indicated that both sunnhemp stalks and paddy straw serve as better source of energy for earthworm as compared to sunflower, maize and cotton residues.

#### 4.2.2 Population and biomass of earthworms

The population and biomass of earthworms as influenced by different crop residues are presented in Table 9.

Both the population and biomass of earthworm in soil differed significantly due to addition of different crop residues. In no residue control treatment the juvenile population was nil but its population was significantly the highest with sunnhemp stalks (67.3) followed by paddy straw (40.3) and both were significantly superior to sunflower stalks, maize stover and cotton stalks. The mean population of subadults in no residue control was 2.3 which increased significantly with different crop residues, however, its population did not differ significantly among crop residues. Similarly, the mean population of adults in no residue control was 5.7 which increased significantly to 11.7 with sunnhemp but it was at par with other crop residues except sunflower stalks (8.7). The mean total population of earthworms in no residue control treatment was the least (8.0). Significant increase

Table 9. Population and biomass of earthworm as influenced by different crop residues used as mulch

Treatments	Initial Biomass (g)	Juveniles		Subadults		Adults		Total	
		Population	Biomass (mg)	Population	Biomass (g)	Population	Biomass (g)	Population	Biomass (g)
Control (no mulch)	13.12	-	-	2.3	0.73	5.7	5.84	8.0	6.57
Sunflower stalks	12.78	2.30	71	5.0	1.65	8.7	11.73	16.0	13.45
Maize stover	13.16	4.70	122	6.0	2.34	10.0	15.07	20.3	17.53
Cotton stalks	13.15	3.00	85	5.3	2.01	9.7	12.92	18.0	15.02
Sunn hemp stalks	12.99	67.30	2179	6.0	3.03	11.7	18.22	85.0	23.43
Paddy straw	13.04	40.30	1254	6.3	2.67	10.3	15.84	57.0	19.62
SEm ±	0.14	2.07	46.7	0.47	0.10	0.65	0.51	2.24	0.56
CD at 5%	NS	6.52	147.1	1.45	0.30	2.00	1.56	6.90	1.71

in the total population of worms was observed with sunflower stalks (16.0), maize stover (20.3), cotton stalks (18.0), sunnhemp stalks (85.0) and paddy straw (57.0).

The biomass of juveniles in different treatments followed the same trend as that of population. The highest biomass of juveniles was recorded with sunnhemp stalks (2179 mg) followed by paddy straw (1254 mg) and both were significantly superior to other crop residues. Similarly, the biomass of subadults was significantly higher with sunnhemp stalks (3.03 g) compared to paddy straw (2.67 g), sunflower stalks (1.65 g) and no residue control (0.73g). So also, the biomass of adults was maximum with sunnhemp stalks (18.22 g) followed by paddy straw (15.84 g) and no residue control (5.84 g). Mean total biomass of worms in no residue control was (6.57 g) and it increased significantly to 13.45, 15.02, 17.53, 19.62 and 23.43 g with sunflower stalks, cotton stalks, maize stover, paddy straw and sunnhemp stalks, respectively.

Both the population and biomass of earthworm in soil increased significantly due to addition of different crop residues as mulch. The sunnhemp stalks and paddy straw were superior to other crop residues in increasing the population and biomass of earthworms.

#### 4.2.3 Enzyme activity

The activity of different enzymes in soil differed significantly due to addition of different crop residues and earthworm activity (Table 10). The dehydrogenase activity was significantly low in absolute control soil ( $3.17 \mu\text{g TPF g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ ). Addition of different crop residues increased the dehydrogenase activity significantly and the highest enzyme activity was recorded with sunnhemp

Table 10. Enzyme activity in soil as influenced by earthworm and different crop residues

Treatments	Dehydrogenase activity ( $\mu\text{g TPF g}^{-1}\text{soil } 24\text{hr}^{-1}$ )	Catalase activity ( $\text{mg O}_2 \text{ consumed g}^{-1} \text{soil hr}^{-1}$ )	Urease activity ( $\text{mg NH}_4\text{-N } 100 \text{ g}^{-1} \text{soil hr}^{-1}$ )
W <sub>0</sub> M <sub>0</sub>	3.17	7.40	15.51
W <sub>1</sub> M <sub>0</sub>	9.82	8.15	25.85
W <sub>0</sub> M <sub>1</sub>	3.79	7.52	17.39
W <sub>1</sub> M <sub>1</sub>	11.24	8.03	29.52
W <sub>0</sub> M <sub>2</sub>	4.29	7.73	18.42
W <sub>1</sub> M <sub>2</sub>	12.92	8.26	36.38
W <sub>0</sub> M <sub>3</sub>	4.05	7.55	17.58
W <sub>1</sub> M <sub>3</sub>	12.40	8.16	31.02
W <sub>0</sub> M <sub>4</sub>	5.29	7.71	22.00
W <sub>1</sub> M <sub>4</sub>	26.39	9.76	63.83
W <sub>0</sub> M <sub>5</sub>	4.96	7.74	19.83
W <sub>1</sub> M <sub>5</sub>	24.43	9.05	58.19
SEM $\pm$	0.16	0.12	0.78
CD at 5%	0.48	0.34	2.27

W<sub>0</sub> - No worms and W<sub>1</sub> - Worms

M<sub>0</sub> - No mulch, M<sub>1</sub> - Sunflower stalks, M<sub>2</sub> - Maize stover, M<sub>3</sub> - Cotton stalks,

M<sub>4</sub> - Sunnhemp stalks and M<sub>5</sub> - Paddy stover.

stalks ( $5.29 \mu\text{g TPF g}^{-1}\text{soil } 24 \text{ hr}^{-1}$ ). Introducing earthworms into soil, significantly increased the dehydrogenase activity in all the treatments. The enzyme activity was  $9.82 \mu\text{g TPF per g soil per } 24 \text{ hr}^{-1}$  with maize stover and  $12.40 \mu\text{g TPF per soil per } 24 \text{ hr}^{-1}$  with cotton stalks. The highest enzyme activity was recorded with sunnhemp stalks ( $26.39 \mu\text{g TPF g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ ) and paddy straw ( $24.43 \mu\text{g TPF g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ ) and both were significantly superior to other treatments.

The urease activity in soil followed the same trend as that of dehydrogenase activity. The urease activity in absolute control soil was  $15.51 \text{ mg NH}_4\text{-N per } 100 \text{ g soil per hr}$ . Addition of either sunflower stalks or cotton stalks did not influence the urease activity significantly over control. Whereas it increased significantly due to addition of maize stover ( $18.42 \text{ mg NH}_4\text{-N } 100 \text{ g}^{-1}\text{soil hr}^{-1}$ ), paddy straw ( $19.83 \text{ mg NH}_4\text{-N } 100 \text{ g}^{-1}\text{soil hr}^{-1}$ ) and sunnhemp stalks ( $22.00 \text{ mg NH}_4\text{-N } 100 \text{ g}^{-1} \text{ soil hr}^{-1}$ ). The urease activity in soil increased significantly due to earthworm activity in all the treatments. The urease activity in control was  $25.85 \text{ mg NH}_4\text{-N per } 100 \text{ g soil per hr}$ , which increased significantly to 29.52, 36.38, 31.02, 58.19 and 63.83  $\text{mg NH}_4\text{-N per } 100 \text{ g soil per hr}$  due to addition of sunflower stalks, maize stover, cotton stalks, paddy straw and sunnhemp stalks, respectively.

The catalase enzyme activity in absolute control soil was  $7.40 \text{ mg O}_2$  consumed per g soil per hr. Addition of different crop residues did not influence the catalase activity significantly, but the enzyme activity in soil increased significantly due to earthworm activity ( $8.15 \text{ mg O}_2$  consumed  $\text{g}^{-1}\text{soil hr}^{-1}$ ). The highest

catalase activity in soil ( $9.76 \text{ mg O}_2 \text{ consumed g}^{-1} \text{ soil hr}^{-1}$ ) was recorded in soil treated with sunnhemp stalks followed by paddy straw ( $9.05 \text{ mg O}_2 \text{ consumed g}^{-1} \text{ soil hr}^{-1}$ ) and both were significantly superior to other treatments. While the differences in catalase activity with other crop residues were not significant.

#### **4.2.4 Effect of earthworm activity on pH, organic carbon and available nutrient content of soil**

The data on pH, organic carbon and available nutrients content of soil as influenced by earthworms and crop residues are presented in Table 11 and 12.

##### **4.2.4.1 Soil pH**

The initial pH of the soil ranged from 8.31 to 8.35. The soil pH after 90 days of incubation ranged from 7.44 to 8.28 and it was significantly different between treatments. Addition of different crop residues to soil reduced the soil pH significantly except the sunflower stalks. Though the earthworm activity slightly increased the soil pH in no residue control treatment, it significantly reduced the soil pH in residue treated soil except in sunflower stalks. The lowest soil pH (7.44) was recorded with sunnhemp stalks followed by paddy straw (7.57), maize stover (7.72) and cotton stalks (7.81).

##### **4.2.4.2 Organic carbon**

The organic carbon content of soil before incubation ranged from 1.26 to 1.32 per cent and after 90 days incubation it ranged from 1.14 to 2.10 per cent and was significantly different between treatments. Addition of crop residues significantly increased the organic carbon content of soil. Similarly, introduction of worms significantly increased the organic carbon content of soil except in sunflower

Table 11. pH, organic carbon and available nutrients content of soil as influenced by earthworm and crop residues

Treatments	DAYS AFTER INCUBATION													
	0 DAS						90 DAS							
	pH (1.25)	Organic C (%)	K <sub>2</sub> O	Zn	Mn	Cu	Fe	pH (1:2.5)	Organic C (%)	K <sub>2</sub> O	Zn	Mn	Cu	Fe
W <sub>0</sub> M <sub>0</sub>	8.35	1.32	213.85	1.08	10.24	0.44	6.90	8.28	1.22	370.98	1.22	12.19	0.62	7.09
W <sub>1</sub> M <sub>0</sub>	8.31	1.28	214.43	1.06	10.24	0.42	6.92	8.32	1.14	418.92	1.60	16.35	0.86	12.26
W <sub>0</sub> M <sub>1</sub>	8.32	1.26	214.43	1.06	10.18	0.42	6.90	8.24	1.35	420.97	1.24	14.27	0.68	7.42
W <sub>1</sub> M <sub>1</sub>	8.34	1.32	214.43	1.06	10.22	0.42	6.94	8.25	1.36	528.14	1.66	17.67	0.98	18.39
W <sub>0</sub> M <sub>2</sub>	8.35	1.28	213.85	1.10	10.22	0.44	6.94	8.12	1.42	433.13	1.31	14.48	0.67	7.58
W <sub>1</sub> M <sub>2</sub>	8.32	1.28	213.85	1.10	10.18	0.42	6.94	7.72	1.57	543.96	1.68	21.08	1.17	22.19
W <sub>0</sub> M <sub>3</sub>	8.35	1.32	212.55	1.10	10.18	0.40	6.84	8.18	1.36	398.52	1.37	13.15	0.76	8.22
W <sub>1</sub> M <sub>3</sub>	8.31	1.28	214.43	1.08	10.24	0.40	6.84	7.81	1.49	526.53	1.72	19.09	1.07	17.96
W <sub>0</sub> M <sub>4</sub>	8.32	1.26	213.85	1.08	10.24	0.40	6.88	8.02	1.48	449.48	1.41	14.93	0.78	9.91
W <sub>1</sub> M <sub>4</sub>	8.35	1.32	214.43	1.12	10.22	0.42	6.88	7.44	2.10	624.42	2.72	27.33	1.93	48.61
W <sub>0</sub> M <sub>5</sub>	8.34	1.32	213.85	1.12	10.18	0.44	6.90	8.05	1.45	436.02	1.45	13.84	0.77	8.70
W <sub>1</sub> M <sub>5</sub>	8.34	1.28	213.85	1.10	10.18	0.44	6.88	7.57	1.86	593.59	2.43	25.49	1.35	42.10
SEM ±	-	-	-	-	-	-	-	0.02	0.03	5.25	0.04	0.53	0.03	0.85
CD at 5%	-	-	-	-	-	-	-	0.06	0.10	15.32	0.12	1.54	0.10	2.47

stalks (1.36%). The highest organic carbon content was recorded with sunnhemp stalks (2.10%) followed by paddy straw (1.86%), maize stover (1.57%) and cotton stalks (1.49%).

#### 4.2.4.3 Available $K_2O$

The available  $K_2O$  content of soil before incubation ranged from 212.55 to 214.43 mg per kg and after 90 days of incubation it ranged from 370.98 to 624.42 mg per kg soil. The available  $K_2O$  in soil increased significantly due to addition of either crop residues or earthworm activity. The highest available  $K_2O$  in soil was recorded with sunnhemp stalks (624.42 mg  $kg^{-1}$ ) followed by paddy straw (593.59 mg  $kg^{-1}$ ), maize stover (543.96 mg  $kg^{-1}$ ), sunflower stalks (528.14 mg  $kg^{-1}$ ), cotton stalks (526.53 mg  $kg^{-1}$ ) and no residue control (418.92 mg  $kg^{-1}$ ).

#### 4.2.4.4 DTPA extractable micronutrients

##### Zinc

The content of DTPA extractable zinc of soil ranged from 1.06 to 1.12 mg per kg before incubation which increased to 1.22 mg per kg in absolute control treatment after 90 days incubation. Addition of different crop residues increased the DTPA extractable zinc in soil significantly except the sunflower stalks (1.24 mg  $kg^{-1}$ ) and maize stover (1.31 mg  $kg^{-1}$ ). Introduction of earthworms significantly increased the DTPA extractable Zn content of soil in all the treatments. It was maximum with sunnhemp stalks (2.72 mg  $kg^{-1}$ ) followed by paddy straw (2.43 mg  $kg^{-1}$ ) and both were significantly superior to other treatments.

##### Manganese

The DTPA extractable Mn content of soil before incubation ranged from 10.18 to 10.24 mg per kg. At the end of incubation period, it increased

significantly due to addition of different crop residues over no residue control ( $12.19 \text{ mg kg}^{-1}$ ) except cotton stalks. Earthworm activity also increased the DTPA extractable Mn content of soil significantly. Its content in no residue control was  $16.35 \text{ mg per kg}$ . While the treatment receiving sunnhemp stalks with earthworms recorded the highest amount of DTPA extractable Mn ( $27.33 \text{ mg kg}^{-1}$ ) followed by paddy straw ( $25.49 \text{ mg kg}^{-1}$ ), maize stover ( $21.08 \text{ mg kg}^{-1}$ ), cotton stalks ( $19.09 \text{ mg kg}^{-1}$ ) and sunflower stalks ( $17.67 \text{ mg kg}^{-1}$ ).

### **Copper**

The amount of DTPA extractable Cu in soil before incubation ranged from  $0.40$  to  $0.44 \text{ mg per kg}$ . At the end of incubation period its content increased significantly due to addition of sunnhemp stalks ( $0.78 \text{ mg kg}^{-1}$ ), paddy straw ( $0.77 \text{ mg kg}^{-1}$ ) and cotton stalks ( $0.76 \text{ mg kg}^{-1}$ ). Earthworm activity increased the DTPA extractable Cu content of soil significantly in all the treatments but it was maximum with sunnhemp stalks ( $1.93 \text{ mg kg}^{-1}$ ) followed by paddy straw ( $1.35 \text{ mg kg}^{-1}$ ), maize stover ( $1.17 \text{ mg kg}^{-1}$ ), cotton stalks ( $1.07 \text{ mg kg}^{-1}$ ) and sunflower stalks ( $0.98 \text{ mg kg}^{-1}$ ).

### **Iron**

The DTPA extractable Fe content of soil varied from  $6.88$  to  $6.94 \text{ mg per kg}$  before incubation and from  $7.09$  to  $48.61 \text{ mg per kg}$  after 90 days incubation. Addition of different crop residues to soil did not affect the DTPA extractable Fe content of soil significantly except in sunnhemp treatment ( $9.91 \text{ mg kg}^{-1}$ ). On the other hand, the earthworm activity has significantly increased its content in soil. The highest content of DTPA extractable Fe was recorded with sunnhemp stocks

(48.61 mg kg<sup>-1</sup>) followed by paddy straw (42.10 mg kg<sup>-1</sup>), maize stover (22.19 mg kg<sup>-1</sup>), sunflower stalks (18.39 mg kg<sup>-1</sup>) and cotton stalks (17.96 mg kg<sup>-1</sup>).

#### 4.2.4.5 Available nitrogen

The data presented in Table 12. showed that the available N content of soil at zero day of incubation varied from 112.45 to 118.12 mg per kg. The available N content of soil at 30 days after incubation varied from 84.18 to 167.69 mg per kg and it differed significantly between treatments. It was 129.54 mg per kg in absolute control. Addition of different crop residues significantly reduced the available N content of soil, whereas the earthworm activity increased it significantly. The available N content in soil was significantly the highest in the treatment receiving sunnhemp stalks with earthworms (167.69 mg kg<sup>-1</sup>) followed by no residue control (151.41 mg kg<sup>-1</sup>) and paddy straw (150.46 mg kg<sup>-1</sup>) and they were significantly superior to sunflower stalks (141.18 mg kg<sup>-1</sup>), maize stover (145.16 mg kg<sup>-1</sup>) and cotton stalks (141.18 mg kg<sup>-1</sup>).

The available N content of soil at 60 days after incubation varied from 156.43 to 316.84 mg per kg and differed significantly between treatments. The available N content of soil in absolute control was 156.43 mg per kg which increased significantly due to addition of different crop residues except in cotton stalks (159.74 mg kg<sup>-1</sup>). Similarly, the available N content of soil increased significantly due to earthworm activity. The treatments having combination of earthworms and sunnhemp stalks or paddy straw recorded significantly higher amount of available nitrogen compared to other treatment combinations.

Table 12. Available nutrients content ( $\text{mg kg}^{-1}$ ) of soil as influenced by earthworms and crop residues at different days of incubation

Treatments	DAYS AFTER INCUBATION																			
	0					30					60					90				
	N	P <sub>2</sub> O <sub>5</sub>	SO <sub>4</sub>	N:P:S	N	P <sub>2</sub> O <sub>5</sub>	SO <sub>4</sub>	N:P:S	N	P <sub>2</sub> O <sub>5</sub>	SO <sub>4</sub>	N:P:S	N	P <sub>2</sub> O <sub>5</sub>	SO <sub>4</sub>	N:P:S	N	P <sub>2</sub> O <sub>5</sub>	SO <sub>4</sub>	N:P:S
W <sub>0</sub> M <sub>0</sub>	112.25	16.48	9.41	36.09:2.33:1	129.54	18.06	11.91	32.96:2.02:1	156.43	21.42	12.25	38.72:1.95:1	160.73	29.17	14.72	33.07:2.62				
W <sub>1</sub> M <sub>0</sub>	114.38	16.18	9.75	35.52:2.21:1	151.41	21.43	17.28	26.56:1.65:1	194.87	31.99	17.55	33.66:2.41:1	211.10	39.18	22.74	28.15:2.28				
W <sub>0</sub> M <sub>1</sub>	116.46	17.36	9.75	36:17:2.37:1	84.18	19.45	13.26	19.22:1.95:1	165.71	26.65	16.79	29.91:2.10:1	163.06	31.58	19.78	24.97:2.11				
W <sub>1</sub> M <sub>1</sub>	112.25	17.31	9.25	36.80:2.50:1	141.18	23.02	16.76	25.53:1.83:1	197.96	37.69	21.16	28.36:2.36:1	214.76	47.40	25.29	25.72:2.48				
W <sub>0</sub> M <sub>2</sub>	112.25	16.62	9.41	36.09:2.35:1	97.43	19.78	13.67	21.60:1.93:1	163.05	29.22	16.72	29.54:2.31:1	169.68	32.88	19.42	26.47:2.24				
W <sub>1</sub> M <sub>2</sub>	114.38	16.94	9.75	35.52:2.31:1	145.16	25.16	19.21	22.90:1.75:1	209.45	36.09	23.91	26.55:2.00:1	228.02	50.02	28.63	24.13:2.31				
W <sub>0</sub> M <sub>3</sub>	118.12	16.71	9.54	37.14:2.31:1	96.11	18.73	12.92	22.56:1.93:1	159.74	27.84	17.40	27.83:2.12:1	165.70	30.69	19.77	25.41:2.05				
W <sub>1</sub> M <sub>3</sub>	118.12	18.81	9.41	37.62:2.64:1	141.18	23.48	17.77	24.09:1.76:1	202.50	33.72	22.27	27.55:2.00:1	218.74	49.22	26.32	25.17:2.47				
W <sub>0</sub> M <sub>4</sub>	116.46	18.62	9.75	35.83:2.52:1	103.40	19.25	15.27	20.52:1.68:1	167.69	33.43	20.13	25.25:2.20:1	206.81	34.94	21.80	28.76:2.12				
W <sub>1</sub> M <sub>4</sub>	116.46	16.54	9.54	36.62:2.29:1	167.69	37.98	23.83	21.33:2.11:1	316.84	48.19	32.02	29.98:1.99:1	417.58	64.11	39.49	32.05:2.15				
W <sub>0</sub> M <sub>5</sub>	116.46	16.32	9.41	37.44:2.31:1	102.75	19.81	13.83	22.53:1.91:1	165.04	32.54	18.00	27.78:2.39:1	198.85	34.93	21.50	28.01:2.15				
W <sub>1</sub> M <sub>5</sub>	118.12	17.62	9.75	36.68:2.41:1	150.46	34.79	19.67	23.18:2.36:1	269.11	43.37	25.45	32.04:2.25:1	316.84	56.81	31.01	30.97:2.42				
SEM ±	-	-	-	----	1.78	0.63	0.75	----	2.57	1.42	0.94	----	5.16	1.14	0.68	----				
CD at 5%	-	-	-	----	5.18	1.84	2.19	----	7.51	4.15	2.74	----	15.06	3.34	2.69	----				

The available N content of soil at 90 days after incubation ranged from 160.73 to 417.84 mg per kg and differed significantly between the treatments. The available N content in absolute control was 160.73 mg per kg which increased significantly due to the addition of sunnhemp stalks (206.81 mg kg<sup>-1</sup>) followed by paddy straw (198.85 mg kg<sup>-1</sup>). Similarly, the earthworm activity increased the available N status of soil significantly. The available N content of soil was maximum with sunnhemp stalks (417.58 mg kg<sup>-1</sup>) followed by paddy straw (316.84 mg kg<sup>-1</sup>) and they were significantly superior to other treatments.

#### 4.2.4.6 Available phosphorus

The available P<sub>2</sub>O<sub>5</sub> content of soil before incubation ranged from 16.32 to 18.62 mg per kg. At the 30th day of incubation it varied from 18.06 to 37.98 mg per kg and differed significantly between treatments. The available P<sub>2</sub>O<sub>5</sub> content in absolute control was 18.06 mg per kg which did not increase significantly due to addition of different crop residues, but increased significantly due to earthworm activity. The available P<sub>2</sub>O<sub>5</sub> content of soil was maximum with sunnhemp stalks (37.98 mg kg<sup>-1</sup>) followed by paddy straw (34.79 mg kg<sup>-1</sup>) and both were significantly superior to other treatment combinations.

The available P<sub>2</sub>O<sub>5</sub> content of soil at 60 days after incubation ranged from 21.42 mg per kg to 48.19 mg per kg and differed significantly between the treatments. The available P<sub>2</sub>O<sub>5</sub> content of soil in absolute control was 21.42 mg per kg which increased significantly due to addition of different crop residues. Similarly, the earthworm activity increased its content in soil significantly. The available P<sub>2</sub>O<sub>5</sub> status of soil was significantly the highest with sunnhemp stalks

(48.19 mg kg<sup>-1</sup>) followed by paddy straw (43.37 mg kg<sup>-1</sup>) and both were significantly superior to other treatment combinations.

At 90th day of incubation, the available P<sub>2</sub>O<sub>5</sub> content of soil varied from 29.17 mg per kg to 64.11 mg per kg and differed significantly between treatments. The available P<sub>2</sub>O<sub>5</sub> content in absolute control was 29.17 mg per kg which increased significantly due to addition of sunnhemp stalks (34.94 mg kg<sup>-1</sup>), followed by paddy straw (34.93 mg kg<sup>-1</sup>) and maize stover (32.88 mg kg<sup>-1</sup>). Further, it increased significantly due to earthworm activity. The treatments having combination of earthworms and sunnhemp stalks or paddy straw recorded significantly higher amount of available P<sub>2</sub>O<sub>5</sub> compared to other treatment combinations.

#### 4.2.4.7 Available sulphur

At the beginning of incubation, the available sulphur content of soil ranged from 9.25 to 9.75 mg per kg. Its content varied from 11.91 to 23.83 mg per kg at 30 days after incubation and differed significantly between treatments. The available sulphur content in absolute control was 11.91 mg per kg which increased significantly only with the addition of sunnhemp stalks (15.27 mg kg<sup>-1</sup>). The available sulphur content in soil increased significantly due to earthworm activity. It was highest in treatment having combination of earthworm and sunnhemp (23.83 mg kg<sup>-1</sup>) followed by paddy straw (19.67 mg kg<sup>-1</sup>) and both were significantly superior to other treatments.

The available sulphur content of soil at 60 days after incubation ranged from 12.25 to 32.02 mg per kg and differed significantly between

treatments. Its content in soil was the lowest in absolute control ( $12.25 \text{ mg kg}^{-1}$ ) but increased significantly due to addition of different crop residues and it was maximum with sunnhemp stalks ( $20.13 \text{ mg kg}^{-1}$ ) followed by paddy straw ( $18.00 \text{ mg kg}^{-1}$ ). The available sulphur content in soil increased significantly due to earthworm activity. The treatment receiving sunnhemp stalks with earthworms recorded the highest amount of available sulphur ( $32.02 \text{ mg kg}^{-1}$ ) followed by paddy straw ( $25.45 \text{ mg kg}^{-1}$ ) and maize stover ( $23.91 \text{ mg kg}^{-1}$ ).

At 90th day of incubation, the available sulphur content of soil varied from 14.72 to 39.49 mg per kg and differed significantly between treatments. The available sulphur content in absolute control was 14.72 mg per kg which increased significantly due to addition of different crop residues, however the differences between crop residues were not significant. The available sulphur content of soil increased significantly due to earthworm activity and its content in soil was in the order of sunnhemp stalks ( $39.49 \text{ mg kg}^{-1}$ ) > paddy straw ( $31.01 \text{ mg kg}^{-1}$ ) > maize stover ( $28.63 \text{ mg kg}^{-1}$ ) > cotton stalks ( $26.32 \text{ mg kg}^{-1}$ ) > sunflower stalks ( $25.29 \text{ mg kg}^{-1}$ ) > no residue control ( $22.74 \text{ mg kg}^{-1}$ ).

#### 4.2.4.8 N:P:S ratio

The N:P:S ratio in soil at zero day of incubation ranged from 35.52:2.21:1 to 37.62:2.64:1. At the 30th day of incubation, its value declined in all the treatments ranging from 19.22:1.95:1 to 32.96:2.02:1. While the addition of different crop residues lowered the values of N:P:S ratio in soil, the earthworm activity increased the value of N:P:S ratio in soil. The highest value of N:P:S ratio was recorded in no residue control treatment (26.56:1.65:1) followed by sunflower stalks (25.13:1.83:1).

At 60th day of incubation, the N:P:S ratio in soil ranged from 25.25:2.20:1 to 38.72:1.95:1 and they were higher in all the treatments compared to those at 30th day. Addition of different crop residues lowered the values of N:P:S ratio. Earthworm activity has further lowered the values of N:P:S ratio except with sunnhemp stalks (29.98:1.99:1) and paddy straw (32.04:2.25:1).

At the 90th day of incubation, the N:P:S ratio in soil decreased in all the treatments except in sunnhemp stalks with or without earthworm and paddy straw with worm treatment. The N:P:S ratio in soil ranged from 24.13:2.13:1 to 33.07:2.62:1. While the addition of different crop residues lowered the N:P:S ratio in soil, the earthworm activity increased its value in soil. The N:P:S ratio in soil was the highest in treatment having combination of earthworm and sunnhemp stalks (32.05:2.15:1) followed by paddy straw (30.97:2.42:1) and sunflower stalks (25.72:2.11:1).

#### **4.3 Effect of organic manures and fertilizer levels on growth, yield and uptake of nutrients by maize and soil properties.**

##### **4.3.1 Growth and yield of maize**

The data on the growth and yield of maize as influenced by the application of organic manures and fertilizer levels are presented in Table 13.

##### **4.3.1.1 Plant height**

The plant height of maize in control was 181.9 cm which increased significantly to 192.6 cm due to application of FYM. Similarly, application of vermicompost @ 2.5 and 5.0 t per ha increased the plant height to 199.6 and 207.8 cm, respectively and both were significantly superior to control and FYM treatments.

Table 13. Effect of organic manures and fertilizer levels on growth and yield of maize

Treatments	Plant height (cms)	1000 grain wt. (g)	Grain wt. plant <sup>-1</sup> (g)	Grain yield (q ha <sup>-1</sup> )	Stover yield (q ha <sup>-1</sup> )
C <sub>1</sub> F <sub>1</sub>	165.80	195.80	51.40	29.27	42.74
C <sub>1</sub> F <sub>2</sub>	179.90	223.70	76.20	43.78	52.84
C <sub>1</sub> F <sub>3</sub>	199.90	243.90	91.80	53.15	63.09
<b>C<sub>1</sub> mean</b>	<b>181.90</b>	<b>221.20</b>	<b>73.10</b>	<b>42.07</b>	<b>52.89</b>
C <sub>2</sub> F <sub>1</sub>	177.30	201.70	56.80	32.81	45.93
C <sub>2</sub> F <sub>2</sub>	195.70	232.90	81.50	47.16	57.77
C <sub>2</sub> F <sub>3</sub>	24.70	246.50	94.80	54.87	68.45
<b>C<sub>2</sub> mean</b>	<b>192.60</b>	<b>227.00</b>	<b>77.70</b>	<b>44.94</b>	<b>57.39</b>
C <sub>3</sub> F <sub>1</sub>	185.80	212.50	62.10	35.91	47.77
C <sub>3</sub> F <sub>2</sub>	200.40	249.30	96.10	55.65	68.23
C <sub>3</sub> F <sub>3</sub>	212.70	261.40	110.70	65.58	79.87
<b>C<sub>3</sub> mean</b>	<b>199.60</b>	<b>241.10</b>	<b>89.60</b>	<b>52.38</b>	<b>65.29</b>
C <sub>4</sub> F <sub>1</sub>	197.90	227.20	67.40	37.16	53.27
C <sub>4</sub> F <sub>2</sub>	210.30	253.90	119.70	69.04	76.96
C <sub>4</sub> F <sub>3</sub>	215.40	266.80	125.00	72.50	81.89
<b>C<sub>4</sub> mean</b>	<b>207.80</b>	<b>249.30</b>	<b>104.00</b>	<b>61.53</b>	<b>70.71</b>
<b>F mean</b>					
F <sub>1</sub>	181.70	209.30	59.40	33.79	47.43
F <sub>2</sub>	196.60	240.00	93.40	53.91	63.95
F <sub>3</sub>	208.20	254.70	10.60	61.53	73.33
<b>CD at 5%</b>					
C	5.87	12.10	5.60	4.95	3.95
F	6.20	10.70	3.20	2.45	3.86
F x C	NS	NS	6.30	4.90	7.72
C x F	NS	NS	7.10	5.86	7.17

C<sub>1</sub> - Control, C<sub>2</sub> - FYM @ 20 t ha<sup>-1</sup>, C<sub>3</sub> - Vermicompost @ 2.5 t ha<sup>-1</sup> and

C<sub>4</sub> - Vermicompost @ 5.0 t ha<sup>-1</sup>

F<sub>1</sub> - 25 per cent RDF, F<sub>2</sub> - 50 per cent RDF and F<sub>3</sub> - 100 per cent RDF

The plant height differed significantly due to fertilizer levels. The plant height at 25 per cent RDF was 181.7 cm which increased significantly to 196.6 cm at 50 per cent RDF and to 208.2 cm at 100 per cent RDF.

The interaction effect of manures x fertilizer levels on plant height was not significant.

#### **4.3.1.2 Thousand grains weight**

The weight of thousand grains in control was 221.2 g which increased to 227.0 g due to application of FYM but the differences were not significant. Application of vermicompost @ 2.5 and 5.0 t per ha increased the weight of thousand grains to 241.1 and 249.3 g, respectively and both were significantly superior to control and FYM treatments.

The thousand grain weight increased significantly with increase in fertilizer levels. It was 209.3 g at 25 per cent RDF level which increased significantly to 240.0 g at 50 per cent RDF and to 254.7 g at 100 per cent RDF.

The interaction effect of manures x fertilizer levels on thousand grains weight was not significant.

#### **4.3.1.3 Grain weight per plant**

The grain weight per plant in control was 73.1 g which increased to 77.7 g due to application of FYM but the differences were not significant. Whereas application of vermicompost either at 2.5 or 5.0 t per ha produced significantly higher grain weight of 89.6 and 104.0 g per plant, respectively.

The grain weight per plant differed significantly due to fertilizer levels. The grain weight per plant at 25 per cent RDF was 59.4 g which increased significantly to 93.4 g at 50 per cent RDF and to 105.6 g at 100 per cent RDF.

The interaction effect of manure x fertilizer levels on grain weight per plant was significant. Combined application of FYM and fertilizers did not increase the grain weight per plant significantly. Whereas, the combined application of vermicompost either at 2.5 or 5.0 t per ha and fertilizers significantly increased the grain weight per plant at any given level of fertilizer. The highest grain weight per plant (125.0 g) was recorded due to combined application of vermicompost @ 5.0 t per ha and 100 per cent RDF followed by 50 per cent RDF (119.7 g) and both were significantly superior to all other treatment combinations.

#### **4.3.1.4 Grain yield**

The grain yield of maize in control was 42.07 q per ha which increased to 44.94 q per ha due to application of FYM but the difference in grain yield was not significant. Application of vermicompost to soil @ 2.5 and 5.0 t per ha increased the grain yield to 52.38 and 61.53 q per ha, respectively and both were significantly superior to control and FYM treatments and it has accounted for 24.51 and 42.46 per cent increase in grain yield over control and 16.56 and 36.92 per cent increase in grain yield over FYM treatment.

The grain yield of maize differed significantly due to fertilizer levels. The grain yield of maize at 25 per cent RDF was 33.79 q per ha which increased significantly to 52.91 q per ha at 50 per cent RDF and to 62.53 q per ha at 100 per cent RDF.

The interaction effect of manures x fertilizer levels on grain yield of maize was significant. Combined application of FYM and fertilizers did not increase the grain yield significantly. On the other hand, the combined application of vermicompost either @ 2.5 t per ha or 5.0 t per ha and fertilizers has significantly increased the grain yield of maize at any given level of fertilizer. The highest grain yield of maize (72.50 q ha<sup>-1</sup>) was recorded due to combined application of vermicompost @ 5.0 t per ha and 100 per cent RDF and it was significantly superior to all other treatment combinations except C<sub>4</sub>F<sub>2</sub> treatment. The increase in yield due to above treatment over 100 per cent RDF alone accounted for 36.41 per cent. Further, the grain yield obtained due to application of vermicompost @ 2.5 t per ha alongwith only 50 per cent RDF (55.65 q ha<sup>-1</sup>) was equivalent to that obtained with 100 per cent RDF alone (53.15 q ha<sup>-1</sup>).

#### 4.3.1.5 Stover yield

The stover yield of maize in control was 52.89 q per ha which increased significantly to 57.39 q per ha due to application of FYM. Application of vermicompost @ 2.5 and 5.0 t per ha has further increased the stover yield to 65.29 and 70.71 q per ha, respectively and both were significantly superior to control and FYM treatment and it has accounted for 23.44 and 33.69 per cent increase in yield over control and 13.77 and 23.21 per cent increase in yield over FYM treatment.

The stover yield of maize at 25 per cent RDF was 47.43 q per ha which increased significantly to 63.95 and 73.33 q per ha at 50 and 100 per cent RDF, respectively.

The interaction effect of manures x fertilizer levels on stover yield was significant. The combined application of FYM and fertilizers did not increase the stover yield significantly. On the other hand, the combined application of vermicompost @ 5.0 t per ha and fertilizers significantly increased the stover yield at any given level of fertilizers. The highest stover yield (81.89 q ha<sup>-1</sup>) was recorded due to combined application of vermicompost @ 5.0 t per ha and 100 per cent RDF and it was significantly superior to all other treatment combinations except C<sub>4</sub>F<sub>2</sub> (76.96 q ha<sup>-1</sup>) and C<sub>3</sub>F<sub>3</sub> (79.87 q ha<sup>-1</sup>). The stover yield obtained due to combined application of vermicompost @ 2.5 t per ha and 50 per cent RDF (68.23 q ha<sup>-1</sup>) was equivalent to that obtained in C<sub>1</sub>F<sub>3</sub> (63.09 q ha<sup>-1</sup>) and C<sub>2</sub>F<sub>3</sub> (68.45 q ha<sup>-1</sup>) treatments.

#### 4.3.1.6 Economics

The data on total cost of cultivation and net returns from maize due to application of organic manures and fertilizer levels are presented in Table 14 and Table 15, respectively.

The total cost of cultivation of maize in control was Rs. 4.59 thousand per ha which increased to Rs. 6.09 thousand per ha due to application of vermicompost @ 2.5 t per ha. Further, it increased to Rs. 7.59 thousand per ha due to either application of FYM @ 20.0 t per ha or vermicompost @ 5.0 t per ha. The total cost of cultivation of maize with 25 per cent RDF was Rs. 5.56 thousand per ha which increased to Rs. 6.24 and 7.60 thousand per ha at 50 and 100 per cent RDF, respectively.

Table 14. Total cost of cultivation ( $\text{'000' Rs ha}^{-1}$ ) of maize due to application of different manures and fertilizer levels.

Treatments	F <sub>1</sub>	F <sub>2</sub>	F <sub>3</sub>	C mean
C <sub>1</sub>	3.69	4.37	5.72	4.59
C <sub>2</sub>	6.69	7.37	8.72	7.59
C <sub>3</sub>	5.19	5.87	7.22	6.09
C <sub>4</sub>	6.69	7.37	8.72	7.59
<b>F mean</b>	<b>5.56</b>	<b>6.24</b>	<b>7.60</b>	-

Table 15. Net returns ( $\text{'000'Rs ha}^{-1}$ ) as realized due to application of organic manures and fertilizer levels

Treatments	F <sub>1</sub>	F <sub>2</sub>	F <sub>3</sub>	C mean
C <sub>1</sub>	7.76	12.54	14.78	11.69
C <sub>2</sub>	6.11	10.86	12.51	9.82
C <sub>3</sub>	8.77	15.64	18.12	14.17
C <sub>4</sub>	7.83	19.16	19.16	15.38
<b>F mean</b>	<b>7.62</b>	<b>14.55</b>	<b>16.14</b>	-

SEm ±	CD at 5%
C - 0.52	1.81
F - 0.30	0.90
FxC - 0.60	1.79
CxF - 0.72	2.15

The net returns realised from maize in control was Rs. 11.69 thousand per ha which increased significantly to Rs. 14.17 and Rs. 15.38 thousand per ha due to application of vermicompost @ 2.5 and 5.0 t per ha, respectively, but the difference between two levels of vermicompost was not significant. Whereas application of FYM @ 20 t per ha caused significant reduction in net returns (Rs. 9.82 thousand ha<sup>-1</sup>) over control. The increase in net returns were by 21.22 and 31.56 per cent over control due to application of vermicompost @ 2.5 and 5.0 t per ha, respectively.

The net returns at 25 per cent RDF was Rs. 7.62 thousand per ha which increased significantly to Rs. 14.55 and 16.14 thousand per ha at 50 and 100 per cent RDF, respectively. The net profit increased by 90.94 per cent with 50 per cent RDF and by 111.81 per cent with 100 per cent RDF over 25 per cent RDF.

The interaction effect of manures x fertilizer levels was significant.

The application of vermicompost @ 5.0 t per ha with 50 per cent RDF gave significantly the highest net returns (Rs. 19.56 thousand ha<sup>-1</sup>) but it was at par with C<sub>4</sub>F<sub>3</sub> and C<sub>3</sub>F<sub>3</sub> treatments.

#### **4.3.2 Effect of organic manures and fertilizer levels on uptake of nutrients by maize**

The data on uptake of nutrients by maize as influenced by application of organic manures and fertilizer levels are presented in Table 16.

##### **4.3.2.1 Nitrogen**

The uptake of N by maize in control was 85.01 kg per ha which increased significantly to 98.11 kg per ha due to application of FYM. Application

Table 16. Effect of organic manures and fertilizer levels on the uptake of nutrients by maize

Treatment	N	P	K	Ca	Mg	S	Zn	Mn	Cu	Fe
	←————— Kg ha <sup>-1</sup> —————→						←————— g ha <sup>-1</sup> —————→			
C <sub>1</sub> F <sub>1</sub>	58.79	11.23	43.88	8.67	10.87	5.38	94	190	42	914
C <sub>1</sub> F <sub>2</sub>	89.94	18.08	66.92	12.50	15.78	7.96	132	255	57	1184
C <sub>1</sub> F <sub>3</sub>	106.29	24.50	85.25	15.20	19.70	10.40	168	311	73	1482
<b>C<sub>1</sub> mean</b>	<b>85.01</b>	<b>17.93</b>	<b>65.35</b>	<b>12.13</b>	<b>15.45</b>	<b>7.91</b>	<b>132</b>	<b>252</b>	<b>57</b>	<b>1193</b>
C <sub>2</sub> F <sub>1</sub>	68.33	13.45	50.61	9.68	12.68	6.09	107	211	48	1012
C <sub>2</sub> F <sub>2</sub>	101.11	20.83	75.24	14.31	18.20	9.05	150	282	66	1318
C <sub>2</sub> F <sub>3</sub>	124.88	27.76	89.45	17.10	21.75	11.67	183	347	81	1610
<b>C<sub>2</sub> mean</b>	<b>98.11</b>	<b>20.68</b>	<b>71.77</b>	<b>13.70</b>	<b>17.54</b>	<b>8.94</b>	<b>148</b>	<b>280</b>	<b>65</b>	<b>1313</b>
C <sub>3</sub> F <sub>1</sub>	78.79	15.85	55.86	10.43	13.26	6.93	114	224	52	1086
C <sub>3</sub> F <sub>2</sub>	125.87	26.69	89.24	16.87	21.84	11.92	182	340	82	1621
C <sub>3</sub> F <sub>3</sub>	156.06	34.03	108.87	20.06	25.85	14.21	227	415	101	1959
<b>C<sub>3</sub> mean</b>	<b>120.23</b>	<b>25.52</b>	<b>84.66</b>	<b>15.79</b>	<b>20.32</b>	<b>11.02</b>	<b>174</b>	<b>326</b>	<b>78</b>	<b>1556</b>
C <sub>4</sub> F <sub>1</sub>	85.51	17.76	58.49	12.18	14.71	7.90	138	249	60	1210
C <sub>4</sub> F <sub>2</sub>	159.78	33.65	114.08	20.83	26.14	14.51	231	402	98	1875
C <sub>4</sub> F <sub>3</sub>	169.41	37.87	121.31	22.28	28.43	15.76	253	441	108	2068
<b>C<sub>4</sub> mean</b>	<b>138.24</b>	<b>29.76</b>	<b>97.96</b>	<b>18.43</b>	<b>23.09</b>	<b>12.75</b>	<b>207</b>	<b>364</b>	<b>88</b>	<b>1717</b>
<b>F mean</b>										
F <sub>1</sub>	72.86	14.57	52.21	10.24	12.88	6.58	113	219	50	1055
F <sub>2</sub>	119.18	24.81	86.37	16.13	20.49	10.86	174	320	76	1500
F <sub>3</sub>	139.15	31.04	101.22	18.66	23.93	13.01	208	378	91	1780
<b>CD at 5%</b>										
C	8.96	2.01	8.51	1.00	1.21	0.96	8.4	17.2	4.2	84
F	5.80	1.12	3.80	0.84	1.02	0.67	6.8	16.0	4.0	86
F x C	11.50	2.25	7.60	1.68	2.05	1.35	13.6	32.1	8.0	172
C x F	12.24	2.53	9.64	1.62	1.97	1.38	13.3	30.1	7.5	158

C<sub>1</sub> = Control, C<sub>2</sub> = FYM @ 20 t ha<sup>-1</sup>, C<sub>3</sub> = Vermicompost @ 2.5 t ha<sup>-1</sup> and C<sub>4</sub> = Vermicompost @ 5.0 t ha<sup>-1</sup>  
 F<sub>1</sub> = 25 per cent RDF, F<sub>2</sub> = 50 per cent RDF and F<sub>3</sub> = 100 per cent RDF

of vermicompost @ 2.5 and 5.0 t per ha increased the N uptake by maize significantly to 120.23 and 138.24 kg per ha, respectively and both were significantly superior to control and FYM treatment.

Nitrogen uptake by maize at 25 per cent RDF was 72.86 kg per ha and it increased to 119.18 kg per ha at 50 per cent RDF and to 139.15 kg per ha at 100 per cent RDF and they differed significantly with each other.

The interaction of manures x fertilizer levels on N uptake by maize was significant. Combined application of vermicompost and fertilizers recorded significantly higher N uptake by maize compared to FYM at any given level of fertilizers. The highest N uptake by maize ( $169.41 \text{ kg ha}^{-1}$ ) was recorded due to application of vermicompost @ 5.0 t per ha along with 100 per cent RDF and it was at par with  $C_4F_2$  ( $159.78 \text{ kg ha}^{-1}$ ) and  $C_3F_3$  ( $156.03 \text{ kg ha}^{-1}$ ) but significantly superior to other treatments.

#### 4.3.2.2 Phosphorus

The P uptake of maize in control was 17.93 kg per ha which increased significantly to 20.68 kg per ha due to application of FYM. Application of vermicompost @ 2.5 and 5.0 t per ha further increased the uptake of P by maize significantly to 25.52 and 29.76 kg per ha, respectively and both differed significantly with each other.

The uptake of P by maize at 25 per cent RDF was 14.57 kg per ha which increased significantly to 24.81 kg per ha at 50 per cent RDF and to 31.04 Kg per ha at 100 per cent RDF.

The interaction of manures x fertilizer levels on P uptake by maize was significant. Combined application of organic manures and fertilizers increased the P uptake by maize significantly. The highest uptake of P by maize was recorded due to application of vermicompost @ 5.0 t per ha with 100 per cent RDF (37.87 kg ha<sup>-1</sup>) followed by C<sub>3</sub>F<sub>3</sub> (34.03 kg ha<sup>-1</sup>) and it was at par with C<sub>4</sub>F<sub>2</sub> treatment (33.65 kg ha<sup>-1</sup>) but significantly superior to other treatments.

#### 4.3.2.3 Potassium

The uptake of K by maize in control was 65.35 kg per ha which increased to 71.77 kg per ha due to application of FYM but the difference was not significant. Application of vermicompost @ 2.5 and 5.0 t per ha increased the K uptake significantly to 84.66 and 97.96 kg per ha, respectively.

The uptake of K by maize at 25 per cent RDF was 52.21 kg per ha which increased significantly to 86.37 and to 101.22 kg per ha at 50 and 100 per cent RDF, respectively.

The interaction of manures x fertilizer levels on uptake of K by maize was significant. Combined application of vermicompost and fertilizers recorded significantly higher uptake of K by maize at any given level of fertilizers. The highest K uptake by maize was recorded due to combined application of vermicompost @ 5.0 t per ha with 100 per cent RDF (121.31 kg ha<sup>-1</sup>) and it was at par with C<sub>4</sub>F<sub>2</sub> treatment (114.08 kg ha<sup>-1</sup>) but significantly superior to other treatments.

#### 4.3.2.4 Calcium

The uptake of Ca by maize in control was 12.13 kg per ha which increased significantly to 13.70 kg per ha due to addition of FYM. Application of

vermicompost @ 2.5 and 5.0 t per ha increased the Ca uptake significantly to 15.79 and to 18.43 kg per ha, respectively and both were significantly superior to control and FYM treatment.

The uptake of Ca at 25 per cent RDF was 10.24 kg per ha which increased significantly to 16.13 kg per ha at 50 per cent RDF and to 18.66 kg per ha at 100 per cent RDF.

The interaction of manures x fertilizer levels on uptake of Ca by maize was significant. Combined application of organic manures and fertilizers increased the Ca uptake significantly. The highest Ca uptake ( $22.28 \text{ kg ha}^{-1}$ ) was recorded with the combined application of vermicompost @ 5.0 t per ha and 100 per cent RDF and it was significantly superior to all other treatment combinations except  $C_4F_2$  ( $20.83 \text{ kg ha}^{-1}$ ).

#### 4.3.2.5 Magnesium

The uptake of Mg by maize in control was 15.45 kg per ha which increased significantly to 17.54 kg per ha due to application of FYM. Further, the application of vermicompost @ 2.5 and 5.0 t per ha increased the Mg uptake significantly to 20.32 and 23.09 kg per ha, respectively.

The Mg uptake by maize at 25 per cent RDF was 12.88 kg per ha which increased significantly to 20.49 kg per ha at 50 per cent RDF and to 23.93 kg per ha at 100 per cent RDF.

The interaction of manures x fertilizer levels on uptake of Mg by maize was significant. Combined application of organic manures and fertilizers

increased the Mg uptake significantly. The highest uptake of Mg was recorded with combined application of vermicompost @ 5.0 t per ha and 100 per cent RDF (28.43 kg ha<sup>-1</sup>) and it was significantly superior to all other treatment combinations.

#### 4.3.2.6 Sulphur

The uptake of S by maize in control was 7.91 kg per ha which increased significantly to 8.94 kg per ha due to addition to FYM. It increased significantly to 11.02 and 12.75 kg per ha due to application of vermicompost @ 2.5 and 5.0 t per ha, respectively and both were significantly superior to control and FYM treatment.

The uptake of S by maize at 25 per cent RDF was 6.58 kg per ha which increased significantly to 10.86 and to 13.01 kg per ha at 50 and 100 per cent RDF, respectively.

The interaction of manures x fertilizer levels on S uptake by maize was significant. Combined application of organic manures and fertilizers increased the S uptake significantly. Application of vermicompost @ 5.0 t per ha along with 100 per cent RDF recorded the highest uptake of S (15.76 kg ha<sup>-1</sup>) and it was significantly superior to all other treatment combinations except C<sub>4</sub>F<sub>2</sub> (14.51 kg ha<sup>-1</sup>).

#### 4.3.2.7 Zinc

The uptake of Zn by maize in control was 132 g per ha which increased significantly to 148 g per ha due to addition of FYM. Application of vermicompost @ 2.5 and 5.0 t per ha increased the Zn uptake significantly to 174 and 207 g per ha, respectively and both were significantly superior to control and FYM treatment.

The uptake of Zn at 25 per cent RDF was 113 g per ha which increased significantly to 174 g per ha at 50 per cent RDF and to 208 g per ha at 100 per cent RDF.

The interaction of manures x fertilizer levels on uptake of Zn by maize was significant. Combined application of organic manures and fertilizers increased the Zn uptake significantly. Application of vermicompost @ 5.0 t per ha in combination with fertilizers recorded significantly the highest Zn uptake at any given level of fertilizers. The uptake of Zn recorded due to combined application of vermicompost @ 2.5 t per ha alongwith 50 per cent RDF ( $182 \text{ g ha}^{-1}$ ) was equivalent to that recorded due to application of FYM alongwith 100 per cent RDF ( $186 \text{ g ha}^{-1}$ ).

#### 4.3.2.8 Manganese

The uptake of Mn by maize in control was 252 g per ha which increased significantly to 280 g per ha due to application of FYM. Application of vermicompost @ 2.5 and 5.0 t per ha significantly increased the uptake of Mn to 326 and 364 g per ha, respectively and both were significantly superior to control and FYM treatment.

The uptake of Mn at 25 per cent RDF was 219 g per ha which increased significantly to 320 and to 378 g per ha at 50 and 100 per cent RDF, respectively.

The interaction of manures x fertilizers levels on uptake of Mn by maize was significant. Combined application of organic manures and fertilizers

increased the Mn uptake significantly. The highest Mn uptake was recorded with the combined application of vermicompost @ 5.0 t per ha alongwith 100 per cent RDF (441 g ha<sup>-1</sup>) and it was significantly superior to all other treatment combinations except C<sub>3</sub>F<sub>3</sub> (415 g ha<sup>-1</sup>).

#### 4.3.2.9 Copper

The uptake of Cu by maize in control was 57 g per ha which increased significantly to 65 g per ha due to addition of FYM. Application of vermicompost @ 2.5 and 5.0 t per ha increased the Cu uptake significantly to 78 and 88 g per ha, respectively and both were significantly superior to control and FYM treatment.

The uptake of Cu by maize at 25 per cent RDF was 50 g per ha which increased significantly to 76 and to 91 g per ha at 50 and 100 per cent RDF, respectively.

The interaction of manures x fertilizer levels on uptake of Cu was significant. Combined application of organic manures and fertilizers increased the Cu uptake significantly. Application of vermicompost @ 5.0 t per ha alongwith 100 per cent RDF recorded highest uptake of Cu (108 g ha<sup>-1</sup>) and it was significantly superior to other treatment combinations except C<sub>3</sub>F<sub>3</sub> (101 g ha<sup>-1</sup>).

#### 4.3.2.10 Iron

The uptake of Fe by maize in control was 1193 g per ha which increased significantly to 1313 g per ha due to addition of FYM. Application of vermicompost @ 2.5 and 5.0 t per ha increased the Fe uptake significantly to 1556

and 1717 g per ha, respectively and both were significantly superior to control and FYM treatment.

The uptake of Fe by maize at 25 per cent RDF was 1055 g per ha which increased significantly to 1500 g per ha at 50 per cent RDF and to 1780 g per ha at 100 per cent RDF.

The interaction of manures x fertilizer levels on uptake of Fe by maize was significant. Combined application of FYM and fertilizers increased the Fe uptake significantly. Application of vermicompost @ 5.0 t per ha alongwith 100 per cent RDF recorded the highest uptake of Fe ( $2068 \text{ g ha}^{-1}$ ) and it was significantly superior to other treatment combination except  $\text{C}_3\text{F}_3$  ( $1959 \text{ g ha}^{-1}$ ).

#### **4.3.3 Effect of organic manures and fertilizer levels on soil properties after the harvest of maize crop**

The data on pH, electrical conductivity, organic carbon and available nutrient status of soil after the harvest of maize crop as influenced by the application of organic manures and fertilizer levels are presented in Table 17.

##### **4.3.3.1 Soil pH**

The pH of the soil in control was 8.33 which decreased significantly due to application of FYM (8.18), vermicompost @ 2.5 t per ha (7.99) and 5.0 t per ha (7.82).

The pH of the soil differed significantly due to fertilizer levels. The pH of the soil at 25 per cent RDF was 8.23 which reduced significantly to 8.07 at 50 per cent RDF and to 7.94 at 100 per cent RDF.

Table 17. Effect of organic manures and fertilizer levels on pH, E.C., organic carbon and available nutrient status of soil after the harvest of maize

Treatments	pH (1:2.5)	E.C (dSm <sup>-1</sup> )	Organic C (%)	Available nutrient (kg ha <sup>-1</sup> )				DTPA extractable micronutrient (mg kg <sup>-1</sup> )			
				N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	SO <sub>4</sub>	Zn	Mn	Cu	Fe
C <sub>1</sub> F <sub>1</sub>	8.57	0.18	0.55	209.79	25.18	423.67	14.30	0.94	13.17	0.30	8.62
C <sub>1</sub> F <sub>2</sub>	8.30	0.18	0.64	211.00	28.99	441.33	15.39	1.02	13.77	0.31	8.49
C <sub>1</sub> F <sub>3</sub>	8.13	0.20	0.65	214.83	35.11	473.00	17.10	1.10	13.48	0.27	8.15
C <sub>1</sub> mean	8.33	0.19	0.61	211.88	29.76	446.00	15.60	1.02	13.48	0.29	8.42
C <sub>2</sub> F <sub>1</sub>	8.30	0.18	0.60	214.12	31.30	434.00	15.03	1.06	15.35	0.25	8.72
C <sub>2</sub> F <sub>2</sub>	8.17	0.21	0.65	222.54	33.59	449.00	16.50	1.14	16.08	0.28	9.18
C <sub>2</sub> F <sub>3</sub>	8.07	0.19	0.68	224.91	36.64	459.67	18.58	1.24	16.63	0.33	9.68
C <sub>2</sub> mean	8.18	0.19	0.64	220.52	33.84	447.56	16.70	1.15	16.02	0.29	9.19
C <sub>3</sub> F <sub>1</sub>	8.13	0.22	0.64	229.66	34.35	418.33	14.80	1.25	17.82	0.28	9.75
C <sub>3</sub> F <sub>2</sub>	7.97	0.21	0.72	239.25	39.69	441.67	16.84	1.46	17.90	0.28	9.55
C <sub>3</sub> F <sub>3</sub>	7.87	0.21	0.79	248.33	41.21	458.33	19.26	1.60	18.17	0.29	9.92
C <sub>3</sub> mean	7.99	0.21	0.72	239.08	38.42	439.44	16.99	1.44	17.97	0.28	9.74
C <sub>4</sub> F <sub>1</sub>	7.93	0.18	0.73	240.17	36.64	448.33	15.72	1.48	18.47	0.31	11.21
C <sub>4</sub> F <sub>2</sub>	7.83	0.18	0.80	247.63	42.75	456.67	17.58	1.66	18.39	0.28	10.67
C <sub>4</sub> F <sub>3</sub>	7.70	0.18	0.84	261.96	45.04	475.67	19.53	1.75	19.26	0.28	10.84
C <sub>4</sub> mean	7.82	0.18	0.79	249.92	41.47	460.22	17.61	1.63	18.70	0.29	10.91
F mean											
F <sub>1</sub>	8.23	0.19	0.63	223.44	31.87	431.08	14.98	1.19	16.20	0.28	9.58
F <sub>2</sub>	8.07	0.20	0.70	230.11	36.26	447.17	16.58	1.32	16.53	0.29	9.47
F <sub>3</sub>	7.94	0.19	0.74	237.51	39.50	466.67	18.62	1.42	16.89	0.29	9.65
CD at 5%											
C	0.15	NS	0.061	6.49	4.33	12.21	0.49	0.109	1.02	NS	0.41
F	0.10	NS	0.051	5.74	2.34	8.58	0.76	0.110	NS	NS	NS
F x C	NS	NS	NS	11.47	NS	NS	NS	NS	NS	NS	NS
C x F	NS	NS	NS	10.67	NS	NS	NS	NS	NS	NS	NS

C<sub>1</sub> = Control, C<sub>2</sub> = FYM @ 20 t ha<sup>-1</sup>, C<sub>3</sub> = Vermicompost @ 2.5 t ha<sup>-1</sup> and

C<sub>4</sub> = Vermicompost @ 5.0 t ha<sup>-1</sup>

F<sub>1</sub> = 25 per cent RDF, F<sub>2</sub> = 50 per cent RDF and F<sub>3</sub> = 100 per cent RDF

The interaction effect of organic manures and fertilizer levels on soil pH after the harvest of maize crop was not significant.

#### **4.3.3.2 Electrical conductivity**

The electrical conductivity of soil after the harvest of maize crop ranged from 0.18 to 0.22 dSm<sup>-1</sup> and it was not affected significantly due to application of organic manures and fertilizer levels either individually or in combination.

#### **4.3.3.3 Organic carbon**

The organic carbon content of soil in control was 0.61 per cent which increased to 0.64 per cent due to application of FYM but the difference was not significant. Application of vermicompost @ 2.5 and 5.0 t per ha increased the organic carbon content of soil to 0.72 and 0.79 per cent, respectively and both were significantly superior to control and FYM treatment.

The organic carbon content of soil differed significantly due to fertilizer levels. It was 0.63 per cent at 25 per cent RDF which increased significantly to 0.70 per cent at 50 per cent RDF and to 0.74 per cent at 100 per cent RDF but the differences between 50 and 100 per cent RDF were not significant.

The interaction effect of manures x fertilizer levels on organic carbon content of soil was not significant.

#### **4.3.3.4 Available nitrogen**

The available nitrogen content of soil in control was 211.88 kg per ha which increased significantly to 220.52, 239.08 and 249.92 kg per ha due to

application of FYM, vermicompost @ 2.5 and 5.0 t per ha, respectively and they were significantly different from each other.

The available nitrogen content of soil differed significantly due to fertilizer levels. It was 223.44 kg per ha at 25 per cent RDF which increased significantly to 230.11 kg per ha at 50 per cent RDF and to 237.51 kg per ha at 100 per cent RDF.

The interaction effect of manures x fertilizer levels on the available N content of soil was significant. The combined application of vermicompost either @ 2.5 t per ha or 5.0 t per ha and fertilizers has significantly increased the available N content of soil at any given level of fertilizer. The highest available N content of soil ( $261.96 \text{ kg ha}^{-1}$ ) was recorded due to combined application of vermicompost @ 5.0 t per ha and 100 per cent RDF and it was significantly superior to all other treatment combinations.

#### **4.3.3.5 Available phosphorus**

The available  $\text{P}_2\text{O}_5$  content of soil in control was 29.76 kg per ha which increased significantly to 33.84 kg per ha due to application of FYM. Similarly, application of vermicompost @ 2.5 and 5.0 t per ha increased the available  $\text{P}_2\text{O}_5$  content of soil to 38.42 and 41.47 kg per ha, respectively and both were significantly superior to control and FYM treatment.

The available  $\text{P}_2\text{O}_5$  content of soil at 25 per cent RDF was 31.87 kg per ha which increased significantly to 36.26 and 39.50 kg per ha at 50 and 100 per cent RDF, respectively.

The interaction effect of manures x fertilizer levels on the available  $P_2O_5$  content of soil was not significant.

#### 4.3.3.6 Available potassium

The available  $K_2O$  content of soil in control was 446.00 kg per ha. Application of either FYM or vermicompost @ 2.5 t per ha did not affect the  $K_2O$  content of soil significantly but application of vermicompost @ 5.0 t per ha has significantly increased the available  $K_2O$  content of soil ( $460.22 \text{ kg ha}^{-1}$ ) over other treatments.

The available  $K_2O$  content of soil at 25 per cent RDF was 431.08 kg per ha which increased significantly to 447.17 kg per ha at 50 per cent RDF and to 466.67 kg per ha at 100 per cent RDF.

The interaction effect of manures x fertilizer levels on available  $K_2O$  content of soil was not significant.

#### 4.3.3.7 Available sulphur

The available sulphur content of soil in control was 15.60 kg per ha which increased significantly due to application of FYM ( $16.70 \text{ kg ha}^{-1}$ ) and vermicompost @ 2.5 t per ha ( $16.99 \text{ kg ha}^{-1}$ ). Application of vermicompost @ 5.0 t per ha has recorded significantly the highest content of available sulphur in soil ( $17.61 \text{ kg ha}^{-1}$ ).

The available sulphur content of soil increased significantly with increasing level of fertilizer application. Its content in soil at 25 per cent RDF was

14.98 kg per ha which increased significantly to 16.58 kg per ha at 50 per cent RDF and to 18.62 kg per ha at 100 per cent RDF.

The interaction effect of manures x fertilizer levels on available sulphur content of soil was not significant.

#### **4.3.3.8 DTPA extractable zinc**

The DTPA extractable Zn in control was 1.02 mg per kg which increased significantly to 1.15 mg per kg due to application of FYM. Similarly application of vermicompost @ 2.5 and 5.0 t per ha increased its content in soil to 1.44 and 1.63 mg per kg, respectively and both were significantly superior to control and FYM treatment.

The DTPA extractable Zn content of soil at 25 per cent RDF was 1.19 mg per kg which increased significantly to 1.32 and 1.42 mg per kg at 50 and 100 per cent RDF, respectively but the difference between 50 and 100 per cent RDF was not significant.

The interaction effect of manures x fertilizer levels on DTPA extractable Zn content of soil was not significant.

#### **4.3.3.9 DTPA extractable manganese**

The DTPA extractable Mn content of soil in control was 13.48 mg per kg which increased significantly to 16.02 mg per kg due to application of FYM. Application of vermicompost @ 2.5 and 5.0 t per ha has further increased its content in soil to 17.97 and 18.70 mg per kg, respectively and both were significantly superior to control and FYM treatment. Application of different levels of fertilizers did not influence the DTPA extractable Mn content of soil significantly.

Similarly, the interaction of manures and fertilizer levels on DTPA extractable Mn content of soil was not significant.

#### 4.3.3.10 DTPA extractable copper

The DTPA extractable Cu content of soil ranged from 0.25 to 0.33 mg per kg and it was not influenced significantly either by manures or fertilizer levels. Similarly, the interaction effect of manures x fertilizer levels was not significant.

#### 4.3.3.11 DTPA extractable iron

The DTPA extractable Fe content of soil in control was 8.42 mg per kg which increased significantly to 9.19 mg per kg due to application of FYM. Application of vermicompost @ 2.5 and 5.0 t per ha has further increased its content in soil to 9.74 and 10.91 mg per kg, respectively and both were significantly superior to control and FYM treatment.

The DTPA extractable Fe content of soil did not differ significantly due to fertilizer levels.

Similarly, the interaction effect of manures x fertilizer levels on DTPA extractable Fe content of soil was not significant.

### 4.4 Effect of *in situ* vermiculture and fertilizer levels on growth, yield and uptake of nutrients by maize and soil properties

#### 4.4.1 Growth and yield of maize

The data on growth and yield of maize as influenced by *in situ* vermiculture and fertilizer levels are presented in Table 18.

Table 18. Effect of *in situ* vermiculture and fertilizer levels on growth and yield of maize

Treatment	Plant height (cms)	1000 - grain wt. (g)	Grain wt. plant <sup>-1</sup> (g)	Grain yield (q ha <sup>-1</sup> )	Stover yield (q ha <sup>-1</sup> )
W <sub>1</sub> F <sub>1</sub>	167.7	205.5	61.0	34.90	45.67
W <sub>1</sub> F <sub>2</sub>	189.6	231.0	84.3	47.94	53.70
W <sub>1</sub> F <sub>3</sub>	205.0	247.3	92.7	53.04	66.25
W <sub>1</sub> mean	187.4	228.0	79.3	45.29	55.21
W <sub>2</sub> F <sub>1</sub>	177.3	209.2	76.7	37.43	47.27
W <sub>2</sub> F <sub>2</sub>	197.1	232.2	93.0	50.89	60.12
W <sub>2</sub> F <sub>3</sub>	216.1	250.9	103.3	56.11	73.18
W <sub>2</sub> mean	196.8	230.7	91.0	48.15	60.19
W <sub>3</sub> F <sub>1</sub>	194.5	218.2	81.0	46.40	52.98
W <sub>3</sub> F <sub>2</sub>	219.0	238.9	96.7	53.18	67.05
W <sub>3</sub> F <sub>3</sub>	229.9	261.6	105.3	57.85	78.17
W <sub>3</sub> mean	214.5	239.6	94.3	52.47	66.07
W <sub>4</sub> F <sub>1</sub>	211.3	235.1	91.7	52.39	66.62
W <sub>4</sub> F <sub>2</sub>	230.3	266.7	107.7	74.03	91.33
W <sub>4</sub> F <sub>3</sub>	236.7	269.2	110.7	74.78	94.32
W <sub>4</sub> mean	226.1	257.0	103.3	67.07	84.10
F mean					
F <sub>1</sub>	187.7	217.0	77.6	42.78	53.14
F <sub>2</sub>	207.0	242.2	95.4	56.51	68.05
F <sub>3</sub>	221.9	257.3	103.0	60.44	77.98
CD at 5%					
W	8.3	5.1	5.8	2.20	1.71
F	6.8	8.6	3.0	2.21	3.94
F x W	NS	NS	6.0	4.41	NS
W x F	NS	NS	7.0	4.07	NS

W<sub>1</sub> = No mulch no worms, W<sub>2</sub> = Mulch without worms,  
W<sub>3</sub> = Worms without mulch and W<sub>4</sub> = Worms with mulch  
F<sub>1</sub> = 25 per cent RDF, F<sub>2</sub> = 50 per cent RDF and  
F<sub>3</sub> = 100 per cent RDF

#### 4.4.1.1 Plant height

The plant height of maize in control was 187.4 cm, which increased significantly to 196.8 cm due to mulching. Further, it increased significantly to 214.5 and 226.1 cm due to *in situ* vermiculture and *in situ* vermiculture with mulching, respectively and both were significantly superior to control and mulching treatments.

The plant height at 25 per cent RDF was 187.7 cm which increased significantly to 209.0 cm at 50 per cent RDF and 221.9 cm at 100 per cent RDF.

The interaction effect of main treatments x fertilizer levels on plant height was not significant.

#### 4.4.1.2 Thousand grains weight

The weight of thousand grains in control was 228.0 g which increased to 230.7 g due to mulching but the difference was not significant. *In situ* vermiculture and *in situ* vermiculture with mulching increased the weight of thousand grains to 239.6 and 257.0 g, respectively and both were significantly superior to control and mulching treatment.

The thousand grain weight increased significantly with the increase in fertilizer level. It was 217.0 g at 25 per cent RDF which increased significantly to 242.2 and 257.3 g at 50 and 100 per cent RDF, respectively.

The interaction effect of main treatments x fertilizer levels on thousand grains weight of maize was not significant.

#### 4.4.1.3 Grain weight per plant

The grain weight per plant in control was 79.3 g which increased significantly to 91.0 and 94.3 g due to mulching and *in situ* vermiculture, respectively. The maximum grain weight per plant (103.3 g) was recorded due to *in situ* vermiculture with mulching and it was significantly superior to other treatments.

The grain weight per plant differed significantly due to fertilizer levels. It was 77.6 g at 25 per cent RDF which increased significantly to 95.4 g at 50 per cent RDF and to 103.0 g at 100 per cent RDF.

The interaction effect of main treatments x fertilizer levels on grain weight per plant was significant. Combined application of either mulching or *in situ* vermiculture and fertilizers increased the grain weight per plant significantly at any given level of fertilizer. The highest grain weight per plant (110.7 g) was recorded due to *in situ* vermiculture with mulching and 100 per cent RDF and it was significantly superior to other treatment combinations except  $W_4F_2$  (107.7 g)  $W_3F_3$  (105.3 g) and  $W_2F_3$  (103.3 g) treatments.

#### 4.4.1.4 Grain yield

The grain yield of maize differed significantly due to *in situ* vermiculture and mulching. The grain yield in control was 45.29 q per ha which increased significantly to 48.15 and 52.47 q per ha due to mulching and *in situ* vermiculture, respectively. The highest grain yield of 67.07 q per ha was recorded due to *in situ* vermiculture with mulching and was significantly superior to other treatments. It has accounted for 48.09, 39.29 and 27.82 per cent increase in yield over control, mulching and *in situ* vermiculture, respectively.

The grain yield of maize differed significantly due to fertilizer levels. The grain yield at 25 per cent RDF was 42.78 q per ha which increased significantly to 56.51 q per ha at 50 per cent RDF and 60.44 q per ha at 100 per cent RDF.

The interaction effect of main treatments x fertilizer levels on grain yield of maize was significant. Application of different levels of fertilizer alone has significantly increased the grain yield of maize over each level. The combination of fertilizer with mulching did not increase the grain yield of maize significantly at any given level of fertilizer. Whereas the treatments having combination of fertilizer and *in situ* vermiculture produced significantly higher grain yield at any given level of fertilizer application. A combination of *in situ* vermiculture with mulching and fertilizer application was significantly superior to other treatment combinations. The highest grain yield of maize ( $74.78 \text{ q ha}^{-1}$ ) was recorded due to *in situ* vermiculture with mulching and 100 per cent RDF application and it was significantly superior to other treatments except  $W_4F_2$  ( $74.03 \text{ q ha}^{-1}$ ) treatment. The grain yield obtained due to *in situ* vermiculture with mulching and application of only 25 per cent RDF ( $52.39 \text{ q ha}^{-1}$ ) was at par with that obtained due to application of 100 per cent RDF alone ( $53.04 \text{ q ha}^{-1}$ ).

#### 4.4.1.5 Stover yield

The stover yield of maize in control was 55.21 q per ha which increased significantly to 60.19 q per ha due to mulching. Further, *in situ* vermiculture and *in situ* vermiculture with mulching increased it significantly to 66.07 and 84.10 q per ha, respectively and both were significantly superior to control and mulching treatment.

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The stover yield of maize increased significantly due to increase in fertilizer levels. The stover yield at 25 per cent RDF was 53.14 q per ha which increased significantly to 68.05 q per ha at 50 per cent RDF and further to 77.98 q per ha at 100 per cent RDF.

The interaction effect of main treatments x fertilizer levels on stover yield of maize was not significant.

#### 4.4.1.6 Economics

The data on total cost of cultivation and net returns of maize cultivation due to *in situ* vermiculture and fertilizer levels are presented in Table 19 and 20, respectively.

The total cost of cultivation of maize was Rs. 7.59 thousand per ha in control which increased to Rs. 12.59 thousand and Rs. 12.09 thousand per ha due to *in situ* vermiculture and *in situ* vermiculture with mulching, respectively but it decreased to Rs. 7.09 thousand per ha due to mulching. The total cost of cultivation at 25 per cent RDF was Rs. 8.94 thousand per ha which increased to Rs. 9.62 thousand and Rs. 10.97 thousand per ha at 50 and 100 per cent RDF, respectively.

The net returns obtained from maize in control was Rs. 9.91 thousand per ha which increased significantly to Rs. 11.53 thousand and Rs. 13.87 thousand per ha due to only mulching and *in situ* vermiculture with mulching, respectively. The net returns reduced significantly to Rs. 7.72 thousand per ha due to *in situ* vermiculture without mulching. The net returns increased by 16.35 and 39.96 per

Table 19. Total cost of cultivation ( $\text{'000' Rs ha}^{-1}$ ) of maize cultivation with *in situ* vermiculture and fertilizer levels.

Treatments	F <sub>1</sub>	F <sub>2</sub>	F <sub>3</sub>	W mean
W <sub>1</sub>	6.69	7.37	8.72	7.59
W <sub>2</sub>	6.19	6.87	8.22	7.09
W <sub>3</sub>	11.69	12.37	13.72	12.59
W <sub>4</sub>	11.19	11.87	13.22	12.09
F mean	8.94	9.62	10.97	-

Table 20. Net returns ( $\text{'000' Rs ha}^{-1}$ ) realised due to *in situ* vermiculture and fertilizer levels

Treatments	F <sub>1</sub>	F <sub>2</sub>	F <sub>3</sub>	F mean
W <sub>1</sub>	6.86	11.06	11.80	9.91
W <sub>2</sub>	8.28	12.74	13.56	11.53
W <sub>3</sub>	6.17	8.22	8.78	7.72
W <sub>4</sub>	9.11	16.75	15.74	13.87
W mean	7.60	12.19	12.47	-

	SEm $\pm$		CD at 5%
W -	0.23	-	0.81
F -	0.27	-	0.82
F x W -	0.54	-	1.63
W x F -	0.50	-	1.51

cent over control due to only mulching and *in situ* vermiculture with mulching, respectively. Whereas it reduced by 22.10 per cent due to *in situ* vermiculture over control.

The net returns from maize was Rs. 7.60 thousand per ha at 25 per cent RDF which increased significantly to Rs. 12.19 thousand and Rs. 12.47 thousand per ha at 50 and 100 per cent RDF, respectively, however there was no significant difference between 50 and 100 per cent RDF. The net returns increased by 60.40 and 64.08 per cent due to 50 and 100 per cent RDF, respectively over 25 per cent RDF.

The interaction effect of main treatments x fertilizer levels was significant. *In situ* vermiculture with mulching and 100 per cent RDF gave significantly the highest net returns (Rs. 16.75 thousand ha<sup>-1</sup>).

#### 4.4.2 Effect of *in situ* vermiculture and fertilizer levels on uptake of nutrients by maize

The data on uptake of nutrients by maize as influenced by *in situ* vermiculture and fertilizer levels are presented in Table 21.

##### 4.4.2.1 Nitrogen

The uptake of N in control was 97.34 kg per ha which increased significantly to 108.46 kg per ha due to mulching. Further, it increased significantly to 122.34 and 166.77 kg per ha due to only *in situ* vermiculture and *in situ* vermiculture with mulching, respectively.

Table 21. Effect of in situ vermiculture and fertilizer levels on uptake of nutrients by maize

Treatment	Kg ha <sup>-1</sup>						g ha <sup>-1</sup>			
	N	P	K	Ca	Mg	S	Zn	Mn	Cu	Fe
W <sub>1</sub> F <sub>1</sub>	70.06	14.58	62.88	9.92	13.02	6.14	103	215	45	1005
W <sub>1</sub> F <sub>2</sub>	100.40	21.36	78.39	13.66	17.51	8.93	144	268	64	1259
W <sub>1</sub> F <sub>3</sub>	121.57	26.66	98.53	17.27	21.04	11.02	181	293	84	1568
W <sub>1</sub> mean	97.34	20.80	79.94	13.62	17.19	8.70	142	259	64	1278
W <sub>2</sub> F <sub>1</sub>	78.42	17.01	66.65	10.85	14.00	6.87	113	227	53	1062
W <sub>2</sub> F <sub>2</sub>	113.62	24.54	88.58	15.34	19.53	10.42	164	299	74	1441
W <sub>2</sub> F <sub>3</sub>	133.34	29.57	108.90	19.02	23.01	12.84	204	375	97	1782
W <sub>2</sub> mean	108.46	23.70	88.05	15.07	18.85	10.04	160	300	75	1428
W <sub>3</sub> F <sub>1</sub>	99.01	20.50	77.16	12.85	16.66	8.08	153	260	64	1230
W <sub>3</sub> F <sub>2</sub>	125.16	27.40	101.01	17.14	21.79	11.37	196	343	86	1615
W <sub>3</sub> F <sub>3</sub>	142.83	33.44	119.88	20.39	26.24	13.77	233	413	104	1938
W <sub>3</sub> mean	122.34	27.11	99.35	16.80	21.56	11.07	194	339	85	1594
W <sub>4</sub> F <sub>1</sub>	119.90	25.87	96.86	16.44	21.44	11.03	192	327	80	1542
W <sub>4</sub> F <sub>2</sub>	188.33	42.19	142.72	26.69	32.81	17.33	284	496	123	2269
W <sub>4</sub> F <sub>3</sub>	192.08	44.76	148.63	27.82	34.44	18.52	294	518	128	2378
W <sub>4</sub> mean	166.77	37.61	129.40	23.65	29.57	15.63	256	447	110	2063
F mean										
F <sub>1</sub>	91.85	19.51	75.89	12.52	16.28	8.03	140	257	61	1210
F <sub>2</sub>	131.88	28.80	102.68	18.21	22.91	12.01	197	352	87	1646
F <sub>3</sub>	147.46	33.61	118.99	21.13	26.18	14.04	228	400	103	1916
CD at 5%										
W	2.39	1.17	2.98	1.02	1.23	0.94	5.8	28.2	1.6	41
F	4.88	1.09	5.16	1.21	1.01	0.54	7.7	28.1	4.1	86
F x W	9.76	2.17	10.32	2.42	2.01	1.07	15.4	NS	8.3	171
W x F	8.23	2.04	8.82	2.16	1.96	1.19	13.6	NS	6.9	144

W<sub>1</sub> = No mulch no worms, W<sub>2</sub> = Mulch without worms,  
W<sub>3</sub> = Worms without mulch and W<sub>4</sub> = Worms with mulch  
F<sub>1</sub> = 25 per cent RDF, F<sub>2</sub> = 50 per cent RDF and  
F<sub>3</sub> = 100 per cent RDF

The uptake of N by maize at 25 per cent RDF was 91.85 kg per ha which increased significantly to 131.88 kg per ha at 50 per cent RDF and to 147.46 kg per ha at 100 per cent RDF.

The interaction effect of main treatments x fertilizer levels on N uptake by maize was significant. Combined application of fertilizers either with mulching, *in situ* vermiculture or *in situ* vermiculture with mulching increased the N uptake significantly with increase in fertilizer level except between  $W_4F_2$  and  $W_4F_3$ . Combination of *in situ* vermiculture with mulching and fertilizers recorded significantly higher uptake of N at any given level of fertilizers. The combined application of *in situ* vermiculture with mulching and 100 per cent RDF recorded the highest uptake of N ( $192.08 \text{ kg ha}^{-1}$ ) and was significantly superior to all other treatment combinations except  $W_4F_2$  ( $188.33 \text{ kg ha}^{-1}$ ).

#### 4.4.2.2 Phosphorus

The uptake of P by maize in control was 20.80 kg per ha which increased significantly to 23.70 kg per ha due to mulching. Similarly, *in situ* vermiculture and *in situ* vermiculture with mulching increased P uptake to 27.11 and 37.61 kg per ha, respectively and both were significantly superior to control and mulching.

The P uptake by maize at 25 per cent RDF was 19.51 kg per ha which increased significantly to 28.80 kg per ha at 50 per cent RDF and 33.61 kg per ha at 100 per cent RDF.

The interaction effect of main treatments x fertilizer levels on P uptake was significant. The combination of fertilizers with either mulching, *in situ*

vermiculture or *in situ* vermiculture with mulching increased P uptake significantly with increase in fertilizer levels. A combination of *in situ* vermiculture, mulching and fertilizer application was significantly superior to other treatment combinations at any given level of fertilizers. The highest P uptake of maize ( $44.76 \text{ kg ha}^{-1}$ ) was recorded due to *in situ* vermiculture with mulching and 100 per cent RDF and it was significantly superior to all other treatment combinations.

#### 4.4.2.3 Potassium

The K uptake by maize in control was 79.94 kg per ha which increased significantly to 88.05 kg per ha due to mulching. Similarly, *in situ* vermiculture increased it significantly to 99.35 kg per ha. Significantly the highest K uptake ( $129.40 \text{ kg ha}^{-1}$ ) was recorded due to *in situ* vermiculture with mulching.

The K uptake by maize at 25 per cent RDF was 75.89 kg per ha which increased significantly to 102.68 kg per ha at 50 per cent RDF and to 118.99 kg per ha at 100 per cent RDF.

The interaction effect of main treatments x fertilizer levels on K uptake by maize was significant. The combination of fertilizers with either mulching, *in situ* vermiculture or *in situ* vermiculture with mulching increased K uptake significantly with increase in fertilizers level except between  $W_4F_2$  and  $W_4F_3$ . A combination of *in situ* vermiculture, mulching and fertilizer application recorded significantly highest uptake of K at any given level of fertilizers. The highest K uptake by maize ( $148.63 \text{ kg ha}^{-1}$ ) was recorded due to *in situ* vermiculture with mulching and 100 per cent RDF and it was significantly superior to all other treatment combinations except  $W_4F_2$  ( $142.72 \text{ kg ha}^{-1}$ ).

#### 4.4.2.4 Calcium

The Ca uptake by maize in control was 13.62 kg per ha which increased significantly to 15.07 kg per ha due to mulching. Similarly, *in situ* vermiculture and *in situ* vermiculture with mulching increased it to 16.80 and 23.65 kg per ha, respectively and both were significantly superior to control and mulching.

The Ca uptake of maize at 25 per cent RDF was 12.52 kg per ha which increased significantly to 18.21 kg per ha at 50 per cent RDF and to 21.13 kg per ha at 100 per cent RDF.

The interaction effect of main treatments x fertilizer levels on Ca uptake by maize was significant. A combination of fertilizers with either mulching, *in situ* vermiculture or *in situ* vermiculture with mulching increased Ca uptake significantly with increase in fertilizer level except between  $W_4F_2$  and  $W_4F_3$ . A combination of *in situ* vermiculture with mulching and fertilizers recorded significantly highest uptake of Ca at any given level of fertilizers. The highest uptake of Ca ( $27.82 \text{ kg ha}^{-1}$ ) was recorded due to *in situ* vermiculture with mulching and 100 per cent RDF and it was significantly superior to other treatments except  $W_4F_2$  ( $26.69 \text{ kg ha}^{-1}$ ).

#### 4.4.2.5 Magnesium

The Mg uptake by maize in control was 17.19 kg per ha which increased significantly to 18.85 kg per ha due to mulching. Further, it increased to 21.56 and 29.57 kg per ha due to *in situ* vermiculture and *in situ* vermiculture with mulching, respectively and both were significantly superior to control and mulching treatment.

The Mg uptake by maize at 25 per cent RDF was 16.28 kg per ha which increased significantly to 22.91 kg per ha at 50 per cent RDF and to 26.18 kg per ha at 100 per cent RDF.

The interaction effect of main treatments x fertilizer levels on Mg uptake of maize was significant. The combinations of fertilizers with either mulching, *in situ* vermiculture or *in situ* vermiculture with mulching increased Mg uptake significantly with increase in fertilizers level except between  $W_4F_2$  and  $W_4F_3$ . A combination of *in situ* vermiculture with mulching and fertilizers recorded significantly highest uptake of Mg at any given level of fertilizers. The highest uptake of Mg ( $34.44 \text{ kg ha}^{-1}$ ) was recorded due to *in situ* vermiculture with mulching and 100 per cent RDF and it was significantly superior to other treatments except  $W_4F_2$  ( $32.81 \text{ kg ha}^{-1}$ ) treatment.

#### 4.4.2.6 Sulphur

The S uptake by maize in control was 8.70 kg per ha which increased significantly to 10.04 kg per ha due to mulching. Further, it increased to 11.07 and 15.63 kg per ha due to *in situ* vermiculture and *in situ* vermiculture with mulching, respectively and both were significantly superior to control and mulching treatments.

The S uptake by maize at 25 per cent RDF was 8.03 kg per ha which increased significantly to 12.01 kg per ha at 50 per cent RDF and to 14.04 kg per ha at 100 per cent RDF.

The interaction effect of main treatments x fertilizer levels on S uptake by maize was significant. A combination of fertilizers with either mulching,

*in situ* vermiculture or *in situ* vermiculture with mulching increased S uptake significantly with increase in fertilizer levels. The highest uptake of S was recorded due to *in situ* vermiculture with mulching at any given level of fertilizers and it was significantly superior to other treatments. A combination of *in situ* vermiculture with mulching and 100 per cent RDF recorded the highest uptake of S (18.52 kg ha<sup>-1</sup>) and it was significantly superior to any other treatment combinations except W<sub>4</sub>F<sub>2</sub> (17.33 kg ha<sup>-1</sup>).

#### 4.4.2.7 Zinc

The uptake of Zn by maize in control was 142 g per ha which increased significantly to 160 and 194 g per ha due to mulching and *in situ* vermiculture, respectively. The highest uptake of Zn (256 g ha<sup>-1</sup>) was recorded due to *in situ* vermiculture with mulching and it was significantly superior to other treatments.

The uptake of Zn by maize at 25 per cent RDF was 140 g per ha which increased significantly to 197 g per ha at 50 per cent RDF and to 228 g per ha at 100 per cent RDF.

The interaction effect of main treatments x fertilizer levels on uptake of Zn by maize was significant. The combination of fertilizers with either mulching, *in situ* vermiculture or *in situ* vermiculture with mulching increased the uptake of Zn significantly with increase in fertilizer level except between W<sub>4</sub>F<sub>2</sub> and W<sub>4</sub>F<sub>3</sub> treatments.

A combination of *in situ* vermiculture with mulching and fertilizers recorded significantly highest uptake of Zn at any given level of fertilizer. The

combined application of *in situ* vermiculture with mulching and 100 per cent RDF recorded the highest Zn uptake ( $294 \text{ g ha}^{-1}$ ) and it was significantly superior to any other treatment combinations except  $W_4F_2$  ( $284 \text{ g ha}^{-1}$ ) treatment.

#### 4.4.2.8 Manganese

The uptake of Mn by maize in control was 259 g per ha which increased significantly to 300 and 339 g per ha due to mulching and *in situ* vermiculture, respectively. The highest uptake of Mn ( $447 \text{ g ha}^{-1}$ ) was recorded due to *in situ* vermiculture with mulching and it was significantly superior to other treatments.

The uptake of Mn by maize at 25 per cent RDF was 257 g per ha which increased significantly to 352 g per ha at 50 per cent RDF and to 400 g per ha at 100 per cent RDF.

The interaction effect of main treatments x fertilizer levels on uptake of Mn by maize was not significant.

#### 4.4.2.9 Copper

The uptake of Cu by maize in control was 64 g per ha which increased significantly to 75 and 85 g per ha due to mulching and *in situ* vermiculture, respectively. The highest Cu uptake ( $110 \text{ g ha}^{-1}$ ) was recorded due to *in situ* vermiculture with mulching and it was significantly superior to other treatments.

The uptake of Cu by maize at 25 per cent RDF was 61 g per ha which increased significantly to 87 g per ha at 50 per cent and to 103 g per ha at 100 per cent RDF.

The interaction effect of main treatments x fertilizer levels on uptake of Cu by maize was significant. The combination of fertilizers with either mulching, *in situ* vermiculture or *in situ* vermiculture with mulching increased the uptake of Cu significantly with increase in fertilizers level except between W<sub>4</sub>F<sub>2</sub> and W<sub>4</sub>F<sub>3</sub> treatments. A combination of *in situ* vermiculture with mulching and fertilizers recorded significantly highest uptake of Cu at any given level of fertilizers. A treatment combination of *in situ* vermiculture with mulching and 100 per cent RDF recorded highest uptake of Cu (128 g ha<sup>-1</sup>) and it was significantly superior to other treatment combinations except W<sub>4</sub>F<sub>2</sub> (123 g ha<sup>-1</sup>) treatments.

#### 4.4.2.10 Iron

The uptake of Fe by maize in control was 1278 g per ha which increased significantly to 1428 and 1594 g per ha due to mulching and *in situ* vermiculture, respectively. The highest uptake of Fe (2063 g ha<sup>-1</sup>) was recorded due to *in situ* vermiculture with mulching treatment and it was significantly superior to other treatments.

The uptake of Fe by maize at 25 per cent RDF was 1210 g per ha which increased significantly to 1646 g per ha at 50 per cent RDF and to 1916 g per ha at 100 per cent RDF.

The interaction effect of main treatments x fertilizer levels on uptake of Fe by maize was significant. A combination of fertilizers with either mulching, *in situ* vermiculture or *in situ* vermiculture with mulching increased the uptake of Fe, significantly with increase in fertilizer levels except between W<sub>4</sub>F<sub>2</sub> and W<sub>4</sub>F<sub>3</sub>

treatments. Combined application of *in situ* vermiculture with mulching and fertilizers recorded significantly the highest uptake of Fe at any given level of fertilizers. A treatment combination of *in situ* vermiculture with mulching and 100 per cent RDF recorded highest uptake of Fe ( $2378 \text{ g ha}^{-1}$ ) and it was significantly superior to any other treatment combinations except  $W_4F_2$  ( $2269 \text{ g ha}^{-1}$ ) treatment.

#### 4.4.3 Effect of *in situ* vermiculture and fertilizer levels on soil properties after the harvest of maize crop

The data on pH, electrical conductivity, organic carbon and available nutrient status of soil after the harvest of maize crop as influenced by *in situ* vermiculture and fertilizer levels are presented in Table 22.

##### 4.4.3.1 Soil pH

The pH of the soil in control was 8.20 which decreased significantly to 7.87 due to mulching and to 7.78 due to *in situ* vermiculture. The lowest soil pH (7.41) was recorded due to *in situ* vermiculture and mulching treatment and it was significantly different from other treatments.

The soil pH differed significantly due to fertilizer levels. The soil pH at 25 per cent RDF was 7.91 which reduced significantly to 7.79 at 50 per cent RDF and 7.74 at 100 per cent RDF but the differences between 50 and 100 per cent RDF levels were not significant.

The interaction effect of main treatments x fertilizer levels on soil pH after the harvest of maize crop was not significant.

Table 22. Effect of *in situ* vermiculture and fertilizer levels on pH, E.C., organic carbon and available nutrient status of soil after the harvest of maize

Treatments	pH (1:2.5)	E.C (dSm <sup>-1</sup> )	Organic C (%)	Available nutrient (kg ha <sup>-1</sup> )				DTPA extractable micronutrient (mg kg <sup>-1</sup> )			
				N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	SO <sub>4</sub>	Zn	Mn	Cu	Fe
W <sub>1</sub> F <sub>1</sub>	8.33	0.20	0.60	217.87	29.77	427.33	14.88	1.12	16.99	0.29	10.81
W <sub>1</sub> F <sub>2</sub>	8.18	0.23	0.72	223.13	30.25	450.67	16.64	1.16	17.17	0.28	11.48
W <sub>1</sub> F <sub>3</sub>	8.08	0.20	0.75	236.25	36.64	469.33	18.30	1.17	17.03	0.27	10.87
W <sub>1</sub> mean	8.20	0.21	0.69	225.75	32.22	449.11	16.61	1.15	17.06	0.28	11.05
W <sub>2</sub> F <sub>1</sub>	8.02	0.21	0.76	223.12	31.30	450.00	15.40	1.17	17.05	0.29	11.09
W <sub>2</sub> F <sub>2</sub>	7.82	0.16	0.81	246.75	35.88	472.00	17.34	1.21	16.93	0.31	12.68
W <sub>2</sub> F <sub>3</sub>	7.77	0.18	0.84	249.38	41.98	482.33	19.74	1.15	17.27	0.25	13.11
W <sub>2</sub> mean	7.87	0.18	0.80	239.75	36.39	468.11	17.49	1.18	17.08	0.29	12.29
W <sub>3</sub> F <sub>1</sub>	7.83	0.18	0.76	257.25	33.59	470.33	16.04	1.19	18.72	0.27	11.72
W <sub>3</sub> F <sub>2</sub>	7.78	0.19	0.81	275.62	38.93	489.00	17.74	1.22	18.92	0.29	11.78
W <sub>3</sub> F <sub>3</sub>	7.73	0.17	0.88	299.25	42.75	506.00	20.74	1.22	19.09	0.29	12.30
W <sub>3</sub> mean	7.78	0.18	0.82	277.37	38.42	488.44	18.17	1.21	18.91	0.28	11.93
W <sub>4</sub> F <sub>1</sub>	7.47	0.19	1.04	320.25	54.20	522.67	20.68	1.55	21.63	0.31	15.45
W <sub>4</sub> F <sub>2</sub>	7.40	0.18	1.13	338.62	64.88	551.67	23.44	1.73	24.33	0.36	17.79
W <sub>4</sub> F <sub>3</sub>	7.37	0.17	1.17	351.75	66.41	570.67	25.92	1.86	26.57	0.41	18.23
W <sub>4</sub> mean	7.41	0.18	1.12	336.88	61.83	548.33	23.35	1.71	24.18	0.36	17.16
F mean											
F <sub>1</sub>	7.91	0.19	0.79	254.62	37.21	467.58	16.75	1.26	18.60	0.29	12.27
F <sub>2</sub>	7.79	0.19	0.87	271.03	42.49	490.83	18.79	1.33	19.34	0.31	13.43
F <sub>3</sub>	7.74	0.18	0.91	284.16	46.95	507.08	21.18	1.35	19.99	0.31	13.63
CD at 5%											
W	0.10	NS	0.05	7.67	4.96	15.41	0.83	0.11	0.27	0.04	1.29
F	0.08	NS	0.04	7.23	2.45	8.64	0.62	0.07	0.64	NS	0.56
F x W	NS	NS	NS	NS	NS	NS	NS	NS	1.28	NS	1.12
W x F	NS	NS	NS	NS	NS	NS	NS	NS	1.07	NS	1.44

W<sub>1</sub> = No mulch no worms, W<sub>2</sub> = Mulch without worms,  
W<sub>3</sub> = Worms without mulch and W<sub>4</sub> = Worms with mulch  
F<sub>1</sub> = 25 per cent RDF, F<sub>2</sub> = 50 per cent RDF and  
F<sub>3</sub> = 100 per cent RDF

#### 4.4.3.2 Electrical conductivity

The electrical conductivity of soil after the harvest of maize crop ranged from 0.16 to 0.23 dSm<sup>-1</sup> and it was not affected significantly due to either *in situ* vermiculture or fertilizer levels. Similarly the interaction effect of main treatments and fertilizer levels on electrical conductivity of soil after the harvest of maize crop was not significant.

#### 4.4.3.3 Organic carbon

The organic carbon content of soil in control was 0.69 per cent which increased significantly to 0.80 and 0.82 per cent due to mulching and *in situ* vermiculture, respectively but the differences between them were not significant. The highest organic carbon content of soil (1.12%) was recorded due to combined application of mulching and *in situ* vermiculture and it was significantly superior to other treatments.

The organic carbon content of soil at 25 per cent RDF was 0.79 per cent which increased significantly to 0.87 per cent at 50 per cent RDF and further to 0.91 per cent at 100 per cent RDF but the differences between 50 to 100 per cent RDF level were not significant.

The interaction effect of main treatments x fertilizer levels on organic carbon content of soil after the harvest of maize crop was not significant.

#### 4.4.3.4 Available nitrogen

The available nitrogen content of soil in control was 225.75 kg per ha which increased significantly to 239.75, 277.37 and 336.88 kg per ha due to

mulching, *in situ* vermiculture and mulching with *in situ* vermiculture, respectively and they differed significantly with each other.

The available nitrogen content of soil at 25 per cent RDF was 254.62 kg per ha which increased significantly to 271.03 kg per ha at 50 per cent RDF and to 284.16 kg per ha at 100 per cent RDF.

The interaction effect of main treatments x fertilizer levels on available N content of soil was not significant.

#### **4.4.3.5 Available phosphorus**

The available  $P_2O_5$  content of soil in control was 32.22 kg per ha which increased to 36.39 kg per ha due to mulching but the differences were not significant. However, it increased significantly to 38.42 kg per ha due to *in situ* vermiculture. Combined application of mulching with *in situ* vermiculture recorded significantly the highest amount of available  $P_2O_5$  ( $61.83 \text{ kg ha}^{-1}$ ) and it was significantly superior to all other treatments.

The available  $P_2O_5$  content of soil at 25 per cent RDF was 37.21 kg per ha which increased significantly to 42.49 kg per ha at 50 per cent RDF and to 46.95 kg per ha at 100 per cent RDF.

The interaction effect of main treatments x fertilizer levels on available  $P_2O_5$  content of soil was not significant.

#### **4.4.3.6 Available potassium**

The available  $K_2O$  content of soil in control was 449.11 kg per ha which increased significantly to 468.11 kg per ha due to mulching. Further, it

increased significantly to 448.44 and 548.33 kg per ha due to *in situ* vermiculture and *in situ* vermiculture with mulching, respectively and both were significantly superior to control and mulching treatment.

The available  $K_2O$  content of soil at 25 per cent RDF was 467.58 kg per ha which increased significantly to 490.83 at 50 per cent RDF and to 507.08 kg per ha at 100 per cent RDF.

The interaction effect of main treatments x fertilizer levels on available  $K_2O$  content of soil was not significant.

#### 4.4.3.7 Available sulphur

The available sulphur content of soil in control was 16.61 kg per ha which increased significantly to 17.49 and 18.17 kg per ha due to mulching and *in situ* vermiculture, however the differences between them were not significant. The highest amount of available sulphur in soil ( $23.35 \text{ kg ha}^{-1}$ ) was recorded due to combination of mulching and *in situ* vermiculture treatment and it was significantly superior to all other treatment combinations.

The available sulphur content of soil at 25 per cent RDF was 16.75 kg per ha which increased significantly to 18.79 kg per ha at 50 per cent RDF and 21.18 kg per ha at 100 per cent RDF.

The interaction effect of main treatments x fertilizer levels on available sulphur content of soil was not significant.

#### 4.4.3.8 DTPA extractable zinc

The DTPA extractable Zn content of soil in control was 1.15 mg per kg which increased to 1.18 and 1.21 mg per kg due to mulching and *in situ*

vermiculture, respectively but the differences were not significant. The highest DTPA extractable Zn content of soil ( $1.71 \text{ mg kg}^{-1}$ ) was recorded due to mulching with *in situ* vermiculture treatment and it was significantly superior to other treatments.

The DTPA extractable Zn content of soil at 25 per cent RDF was  $1.26 \text{ mg per kg}$  which increased to  $1.33 \text{ mg per kg}$  at 50 per cent RDF but the differences were not significant. Further it increased significantly to  $1.35 \text{ mg per kg}$  at 100 per cent RDF and which was significantly superior to 25 per cent RDF only.

The interaction effect of main treatments x fertilizer levels on DTPA extractable Zn content of soil was not significant.

#### 4.4.3.9 DTPA extractable manganese

The DTPA extractable Mn content of soil in control was  $17.06 \text{ mg per kg}$  which increased to  $17.08$  due to mulching, but the differences were not significant. However, its content in soil increased significantly to  $18.91$  and  $24.18 \text{ mg per kg}$  due to *in situ* vermiculture and *in situ* vermiculture with mulching, respectively and both were significantly superior to control and mulching treatment.

The DTPA extractable Mn content of soil at 25 per cent RDF was  $18.60 \text{ mg per kg}$  which increased significantly to  $19.34 \text{ mg per kg}$  at 50 per cent RDF and to  $19.99 \text{ mg per kg}$  at 100 per cent RDF but the differences between 50 and 100 per cent RDF were not significant.

The interaction effect of main treatments x fertilizer levels on DTPA extractable Mn content of soil was significant. Combined application of mulching

and fertilizers did not increase the DTPA extractable Mn content of soil at any given level of fertilizers. On the other hand, the combination of either *in situ* vermiculture or mulching with *in situ* vermiculture and fertilizers significantly increased the DTPA extractable Mn content of soil at any given level of fertilizer. The highest amount DTPA extractable Mn in soil was recorded ( $26.57 \text{ mg kg}^{-1}$ ) due to combined application of *in situ* vermiculture with mulching and 100 per cent RDF and it was significantly superior to all other treatment combinations.

#### 4.4.3.10 DTPA extractable copper

The DTPA extractable Cu content of soil in control was 0.28 mg per kg which increased to 0.29 mg per kg due to mulching but the differences were not significant. Similarly, its content in soil did not change significantly due to *in situ* vermiculture ( $0.28 \text{ mg kg}^{-1}$ ). On the contrary, *in situ* vermiculture with mulching recorded significantly the highest amount of DTPA extractable Cu in soil ( $0.36 \text{ mg kg}^{-1}$ ).

The DTPA extractable Cu content of soil at 25 per cent RDF was 0.29 mg per kg and its content did not change significantly due to increasing fertilizer levels.

Similarly, the interaction effect of main treatments x fertilizer levels on DTPA extractable Cu content of soil was not significant.

#### 4.4.3.11 DTPA extractable iron

The DTPA extractable Fe content of soil in control was 11.05 mg per kg which increased to 12.29 and 11.93 mg per kg due to mulching and *in situ*

vermiculture, respectively but the differences were not significant. On the contrary, *in situ* vermiculture with mulching increased the DTPA extractable Fe content of soil to 17.16 mg per kg and it was significantly superior to all other treatments.

The DTPA extractable Fe content of soil at 25 per cent RDF was 12.27 mg per kg which increased significantly to 13.43 mg per kg at 50 per cent RDF and to 13.63 mg per kg at 100 per cent RDF but there was no significant difference between 50 and 100 per cent RDF level.

The interaction effect of main treatments x fertilizer levels on DTPA extractable Fe content of soil was significant. Combination of *in situ* vermiculture with mulching and fertilizers recorded significantly higher values of DTPA extractable Fe in soil at any given level of fertilizers. The combined application of *in situ* vermiculture with mulching and 100 per cent RDF recorded the highest value of DTPA extractable Fe (18.23 mg kg<sup>-1</sup>) and it was significantly superior to all other treatment combinations except W<sub>4</sub>F<sub>2</sub> (17.79 mg kg<sup>-1</sup>) treatment.

#### 4.4.3.12 Infiltration rate

The data on infiltration rate of soil as affected by *in situ* vermiculture and fertilizer levels are presented in Table 23.

The infiltration rate of soil in control was 1.33 cm per hr which increased to 1.51 and 2.73 cm per hr due to mulching and only *in situ* vermiculture, respectively. The highest infiltration rate (3.47 cm hr<sup>-1</sup>) was recorded due to *in situ* vermiculture with mulching.

Table 23. Infiltration rate ( $\text{cm hr}^{-1}$ ) of soil as affected by *in situ* vermiculture and fertilizer levels

Treatments	F <sub>1</sub>	F <sub>2</sub>	F <sub>3</sub>	Mean
W <sub>1</sub>	1.20	1.30	1.50	1.33
W <sub>2</sub>	1.46	1.42	1.66	1.51
W <sub>3</sub>	2.46	2.68	3.06	2.73
W <sub>4</sub>	3.26	3.42	3.74	3.47
Mean	2.10	2.21	2.49	-

Table 24. Population and biomass of introduced and native worms as affected by mulch and fertilizer levels

Treatments	Introduced worms				Native worms				Total worms	
	Adults		Subadults		Adults		Subadults		Popul- ation ( $\text{m}^{-2}$ )	Biomass ( $\text{g m}^{-2}$ )
	Popul- ation ( $\text{m}^{-2}$ )	Biomass ( $\text{g m}^{-2}$ )	Popul- ation ( $\text{m}^{-2}$ )	Biomass ( $\text{g m}^{-2}$ )	Popul- ation ( $\text{m}^{-2}$ )	Biomass ( $\text{g m}^{-2}$ )	Popul- ation ( $\text{m}^{-2}$ )	Biomass ( $\text{g m}^{-2}$ )		
W <sub>1</sub> F <sub>1</sub>	-	-	-	-	11.00	14.20	8.00	1.86	19.00	16.06
W <sub>1</sub> F <sub>2</sub>	-	-	-	-	7.00	10.18	7.00	3.58	14.00	13.76
W <sub>1</sub> F <sub>3</sub>	-	-	-	-	11.00	13.01	7.00	3.68	18.00	16.69
W <sub>1</sub> mean	-	-	-	-	9.67	12.46	7.33	3.04	17.00	15.50
W <sub>2</sub> F <sub>1</sub>	-	-	-	-	14.00	21.84	11.00	6.44	25.00	28.28
W <sub>2</sub> F <sub>2</sub>	-	-	-	-	21.00	17.39	8.00	4.15	29.00	21.54
W <sub>2</sub> F <sub>3</sub>	-	-	-	-	17.00	21.68	7.00	4.08	24.00	25.75
W <sub>2</sub> mean	-	-	-	-	17.33	20.30	8.67	4.89	26.00	25.19
W <sub>3</sub> F <sub>1</sub>	14.00	9.11	-	-	11.00	14.32	7.00	2.69	32.00	26.12
W <sub>3</sub> F <sub>2</sub>	14.00	11.45	-	-	7.00	13.18	7.00	3.78	28.00	28.41
W <sub>3</sub> F <sub>3</sub>	10.00	10.59	-	-	10.00	14.65	6.00	3.40	26.00	28.64
W <sub>3</sub> mean	12.67	10.38	-	-	9.33	14.05	6.67	3.29	28.67	27.72
W <sub>4</sub> F <sub>1</sub>	25.00	40.24	13.00	5.54	18.00	25.84	7.00	4.95	63.00	76.57
W <sub>4</sub> F <sub>2</sub>	28.00	46.53	14.00	5.87	18.00	26.40	8.00	4.62	68.00	83.42
W <sub>4</sub> F <sub>3</sub>	26.00	52.37	13.00	6.82	17.00	24.45	7.00	5.20	63.00	88.84
W <sub>4</sub> mean	26.33	46.38	13.33	6.08	17.67	25.56	7.33	4.92	64.67	82.94
F <sub>1</sub> mean	19.50	24.68	-	-	13.50	19.05	8.25	3.98	34.75	36.76
F <sub>2</sub>	21.00	28.99	-	-	17.67	16.79	7.50	4.03	34.75	36.78
F <sub>3</sub>	18.00	31.48	-	-	13.75	18.45	6.75	4.09	32.75	39.98

W<sub>1</sub> = No mulch no worms, W<sub>2</sub> = Mulch without worms,  
W<sub>3</sub> = Worms without mulch and W<sub>4</sub> = Worms with mulch  
F<sub>1</sub> = 25 per cent RDF, F<sub>2</sub> = 50 per cent RDF and  
F<sub>3</sub> = 100 per cent RDF

The infiltration rate of soil at 25 per cent RDF was 2.10 cm per hr which increased to 2.21 cm per hr at 50 per cent RDF and to 2.49 cm per hr at 100 per cent RDF.

#### **4.4.3.13 Population and biomass of earthworms**

The data on population and biomass of introduced and native worms after the harvest of maize as affected by mulch and fertilizer levels are presented in Table 24.

The population of introduced adult worms in no mulch control was 12.67 per sq.m. which increased to 26.33 per sq.m. due to mulching. Similarly, the biomass of adult worms in no mulch control was 10.38 g per sq.m. which increased to 46.38 g per sq.m. due to mulching.

The population of introduced adult worms at 25 per cent RDF was 19.50 per sq.m. which increased to 21.00 per sq.m. at 50 per cent RDF but decreased to 18.00 per sq. m. at 100 per cent RDF. The biomass of adult worms at 25 per cent RDF was 24.68 g per sq.m. which increased to 28.99 and 31.48 g per sq.m. at 50 and 100 per cent RDF, respectively.

Introduced species of sub-adult worms were not observed in no mulch treatment but mulching recorded 13.33 sub-adults per sq.m with a biomass of 6.08 per sq.m. There was no adverse effect of fertilizers on sub-adults population but the biomass increased from 5.54 g per sq.m. at 25 per cent RDF to 5.87 and 6.82 g per sq.m. at 50 and 100 per cent RDF, respectively.

The population of native adult worms in no worms no mulch control was 9.67 per sq.m. which increased to 17.33 per sq.m. due to mulching. Similarly, the population of native adult worms in *in situ* vermiculture was 9.33 per sq.m. which increased to 17.67 per sq.m. due to *in situ* vermiculture with mulching. The biomass of adult worms in no worm no mulch control was 12.46 g per sq.m. which increased to 20.30, 14.05 and 25.56 g per sq.m. due to mulching, *in situ* vermiculture and *in situ* vermiculture with mulching, respectively.

The population of native adult worms at 25 per cent RDF was 13.50 per sq.m. which increased to 17.67 and 13.75 per sq.m. at 50 and 100 per cent RDF, respectively. But in contrast, the biomass of native adult worms at 25 per cent RDF was 19.05 g per sq.m. which decreased to 16.79 and 18.45 g per sq.m. at 50 and 100 per cent RDF, respectively.

The population and biomass of sub-adults of native worms increased slightly due to mulching but it was not affected due to fertilizer application.

The total population of earthworm in no worms no mulch control was 17 per sq.m. which increased to 26.00, 28.67 and 64.67 per sq.m. due to mulching, *in situ* vermiculture and *in situ* vermiculture with mulching, respectively. Similarly, the biomass of total worms in no worms no mulch control was 15.50 g per sq.m. which increased to 25.19, 27.72 and 82.94 g per sq.m. due to mulching, *in situ* vermiculture and *in situ* vermiculture with mulching, respectively.

There was no adverse effect of fertilizers on total population and biomass of worms.

# Discussion

## V. DISCUSSION

The organic farming largely excludes the use of synthetic fertilizers, pesticides, growth regulator etc. and relies upon efficient recycling of crop residues and manures, minimum mechanical cultivation, increase in the pest resistance through balanced nutrition of plants, biological pest control and efficient crop rotation to sustain soil productivity. In view of increasing awareness about sustainable agricultural system world-wide, many scientists are concentrating their research in understanding the relationship between earthworms, pedogenesis, sustainable soil fertility, crop yield and protection of the environment (Lee, 1992). Keeping this in view, laboratory studies were carried out to find out the optimum environmental conditions for the growth of earthworms (*Eudrilus eugeniae*) and their role in soil biotechnology. Similarly, field experiments were carried out to study the effect of vermicompost and *in situ* vermiculture in combination with different levels of inorganic fertilizers on the growth and yield of maize and soil properties.

The results obtained in the above investigations are discussed in this chapter under the following headings.

1. Effect of different physico-chemical conditions in the soil environment on the survival and growth of earthworm.
2. Role of earthworm in soil biotechnology.
3. Effect of application of organic manures and fertilizer levels on the growth, yield, uptake of nutrients by maize and soil properties.

4. Effect of *in situ* vermiculture in combination with different levels of fertilizers on growth, yield, uptake of nutrients by maize and soil properties.

## 5.1 Effect of different physico-chemical conditions in soil environment on the survival and growth of earthworm

### 5.1.1 Moisture

The biomass and growth rate of earthworm differed significantly due to moisture levels in soil (Fig. 3). The maximum biomass of 881 mg per worm was recorded at zero soil water potential (79.59% moisture). Significant reduction in biomass with increase in soil water potential was observed. The biomass of earthworms at 33 kPa (39.48% moisture) was 217 mg per worm which reduced by 123.47 and 197.7 per cent at 500 and 1000 kPa soil water potential, respectively. At 1500 kPa soil water potential (18.67% moisture), the earthworms did not survive. Similar trend was observed in the growth rate of earthworm. The above results indicated that the survival, biomass and growth rate of *Eudrilus eugeniae* species of earthworm was better at high soil moisture level (79.59%) exceeding field capacity, but decreased significantly with increase in soil water potential. This might be attributed to higher metabolic and burrowing activity of earthworm at high soil moisture level. These results are akin to those reported by Viljoen and Reinecke (1990) who observed that juveniles of *Eudrilus eugeniae* preferred moisture range between 77.5 to 79.0 per cent. Several workers have observed better growth and activity of different species of earthworm at relatively high soil moisture level (Scheu, 1987b; Kretschmar and Bruchou, 1991; Daniel, 1991; Gestel *et al.*, 1992; Hallatt *et al.*, 1992; Baker, *et al.*, 1993a; Muyima, *et al.*, 1994). This they attributed to increased metabolic activity, respiration and burrowing activity of

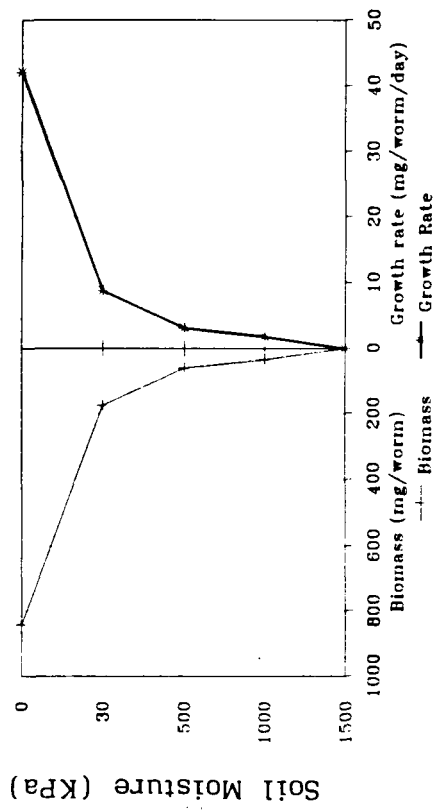


Fig 3. Moisture

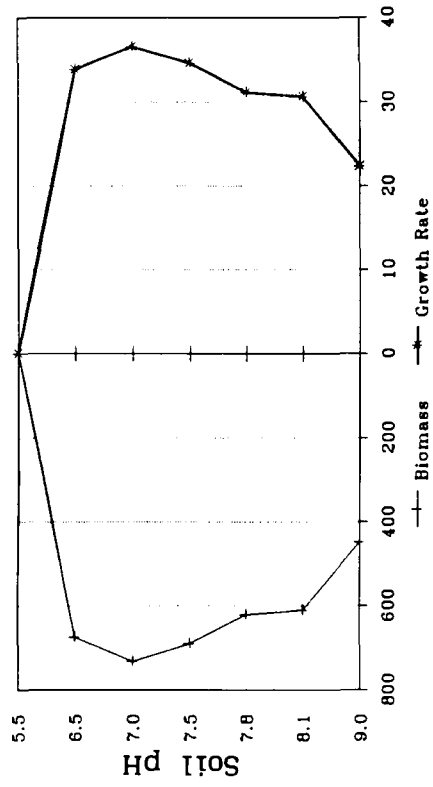


Fig 4. pH

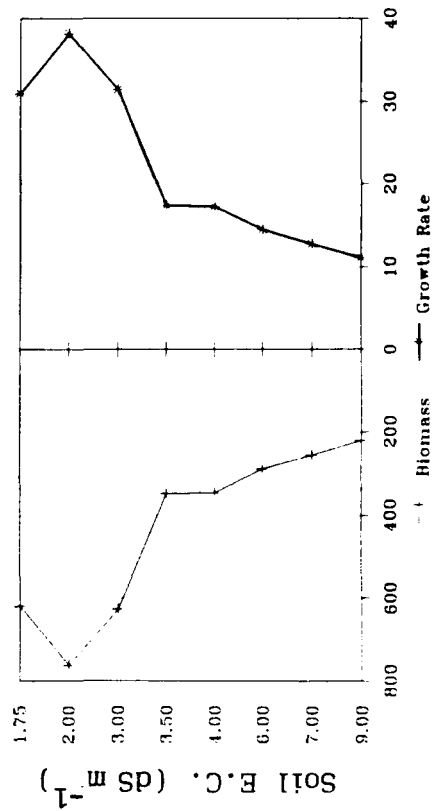


Fig 5. Salinity

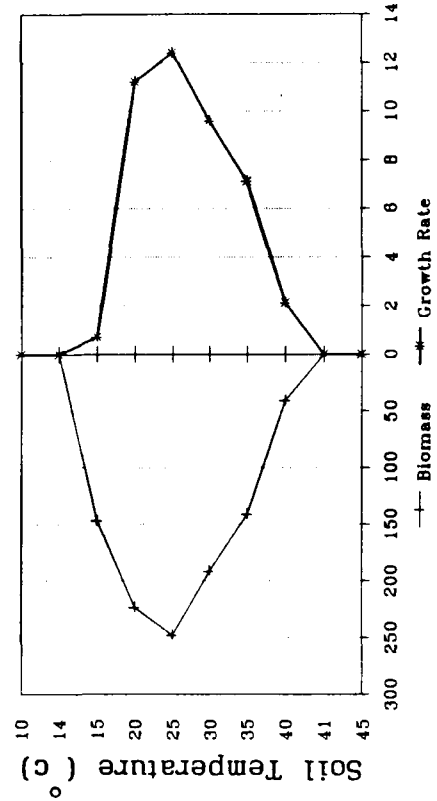


Fig 6. Temperature

Fig. Effect of different physico-chemical conditions in soil environment on biomass and growth rate of earthworm.

earthworm at high moisture level. Low soil moisture might have caused a general reduction in aerobic metabolism and growth, possibly due to lower oxygen diffusion across dry cuticle as earthworms had no physiological mechanism to cope with variations in soil water (Makulec, 1991; Kretzschmar and Bruchou, 1991; Daniel, 1991; Diehl and Williams, 1992; Baker *et al.*, 1993b).

#### 5.1.2 Soil reaction :

The biomass and growth rate of earthworm differed significantly due to soil pH (Fig. 4). Significantly the highest biomass of 768 mg per worm was recorded at soil pH 7.0 followed by 728 and 710 mg per worm at soil pH 7.5 and 6.5, respectively. Reducing the soil pH to 5.5, mortality of all earthworms was observed suggesting their sensory response to soil acidity. Similar adverse effect of soil acidity on growth and survival of earthworm was reported by Laverac (1961), Reddy and Alfred (1978), Robinson, *et al* (1991) and Ammer and Makeschin (1994). They attributed this to sensory response of earthworm to soil acidity. Increasing soil pH above 7.5 reduced the biomass significantly and it was lowest (486 mg worm<sup>-1</sup>) at soil pH 9.0. These findings are in confirmity with those reported by Sosa (1992) and Gestel *et al.* (1992) who observed poor growth and activity of earthworms at alkaline soil reaction. They attributed this due to sensory response of earthworm to soil alkalinity and poor physical condition of alkaline soil.

The results of the present study suggested that maximum biomass and growth rate of *Eudrilus eugeniae* species of earthworm was possible between soil pH 6.5 and 7.5. These results confirm the earlier findings of Staff (1987) and Reddy and Pasha (1993).

### 5.1.3 Salinity :

Soil salinity levels had significant influence on the biomass and growth rate of earthworm (Fig. 5). The highest biomass of earthworm (795 mg worm<sup>-1</sup>) was observed at EC 2.00 dSm<sup>-1</sup> followed by 658 and 653 mg per worm. at EC 3.00 dSm<sup>-1</sup> and EC 1.75 dSm<sup>-1</sup>, respectively. Increasing the level of soil salinity above 3.00 dSm<sup>-1</sup>, reduced the biomass of earthworm significantly. The results indicated that the electrical conductivity of soil between 1.75 and 3.00 dSm<sup>-1</sup> is optimum for higher growth and biomass production of earthworm whereas higher EC level had adverse effect possibly due to higher salt content and the resultant osmotic potential. These results are in accordance with those reported by Kale and Krishnamoorthy (1978); Reddy and Pasha (1993); Townsend and Hodgson (1973). They observed poor abundance and activity of earthworms at higher soil salinity levels.

### 5.1.4 Temperature :

The variation in soil temperature had significant effect on the survival, biomass and growth rate of *Eudrilus eugeniae* species of earthworm (Fig. 6). Soil temperature ranging from 20°C to 35°C recorded 100 percent survival. The highest biomass of earthworm (247 mg worm<sup>-1</sup>) was recorded at 25°C and it decreased significantly either by increasing or decreasing the soil temperature from 25°C. The survival of earthworm at 15°C and 40°C soil temperature was 30 and 45 per cent and the biomass of earthworm recorded at corresponding soil temperature was 43 and 69 mg per worm. Earthworms did not survive at soil temperature either below 15°C or above 40°C suggesting their sensory response to both low and high soil temperatures. Similar trend was observed in growth rate of earthworms. The

results indicated that the soil temperature ranging from 20° to 25°C was optimum for maximum growth and biomass production of *Eudrilus eugeniae* species of earthworm. Similar results were reported by Viljoen and Reinecke (1992). They observed that the highest mean biomass per worm was at 29°C temperature and the highest maturation rate was between 22 and 25°C temperature for the same species. The temperature tolerance range of *Eudrilus eugeniae* as observed by Viljoen and Reincke (1992) ranged from 12 to 30°C, whereas Kale and Bano (1992) reported that the temperature tolerance of same species ranged from 18 to 35°C. Similar discrepancies in temperature tolerance of *Perionyx excavatus* was reported by Nagabhushanam and Hanumante (1978). They found higher temperature tolerance (16.3-39.5°C) of *Perionyx excavatus* collected from Nagpur than those collected from Bangalore (8.0-30.0°C) by Kale and Rao (1973). They accounted this discrepancy due to ecological variation of the two population of same species of earthworm.

The above results indicated that the optimum soil condition for maximum survival, growth rate and biomass of earthworm (*Eudrilus eugeniae*) in the semi arid tropical conditions at Raichur are ; soil moisture content of 79.59 per cent, soil pH of 6.5 to 7.5, soil salinity of 1.75 to 3.00 dSm<sup>-1</sup> and soil temperature of 20 to 25°C.

## 5.2 Role of earthworm in soil biotechnology

### 5.2.1 Decomposition of crop residues

The decomposition of different crop residues added to soil was in the order of sunnhemp stalks (39.1%) > paddy straw (38.1%) > maize stover

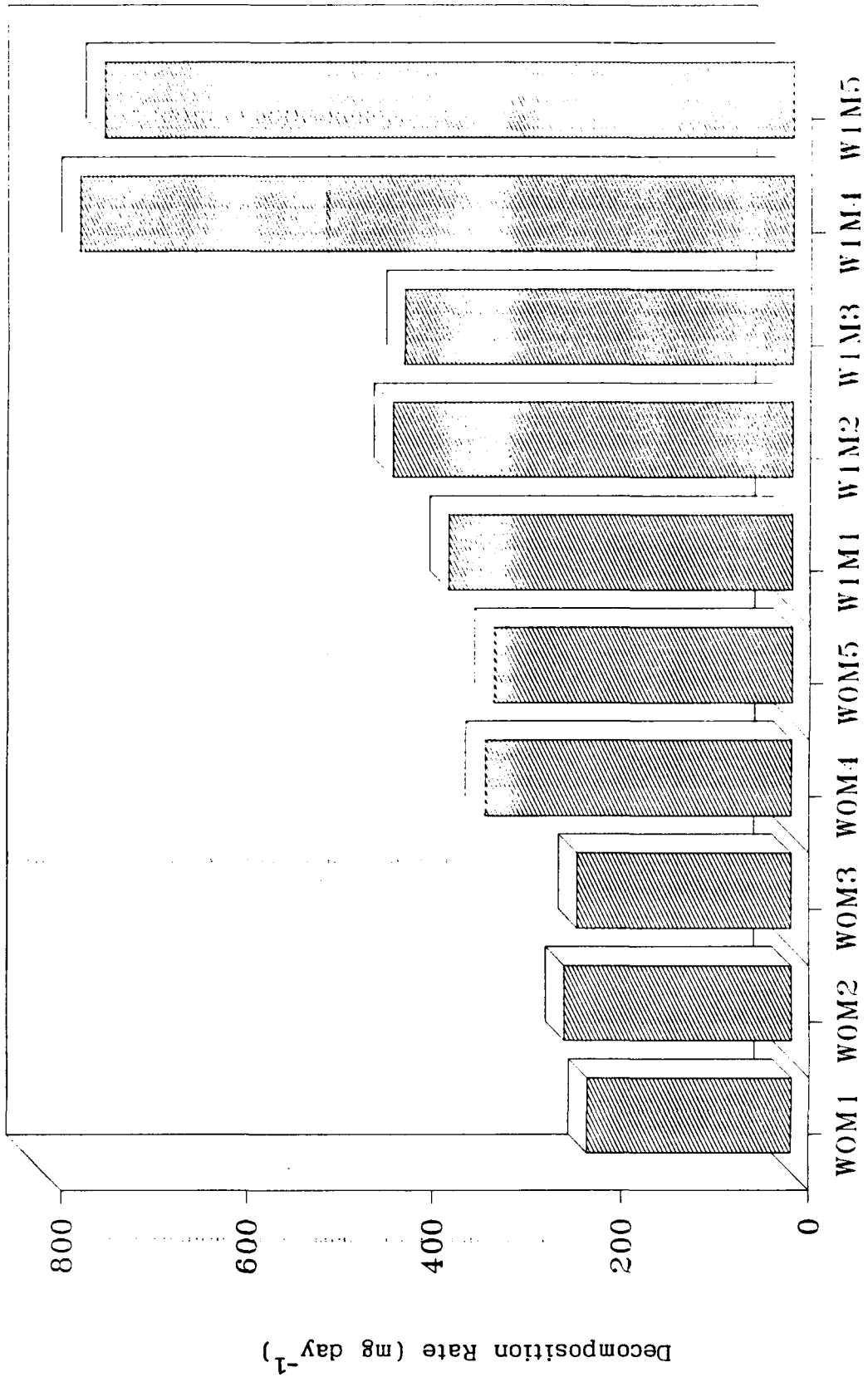


Fig 7. Decomposition of different crop residues by earthworm

(29.1%) > cotton stalks (27.4%) > sunflower stalks (26.1%). The decomposition of these crop residues was further enhanced significantly due to introduction of earthworms to soil (Fig. 7). Again the highest decomposition was recorded with sunnhemp stalks (91.5%) followed by paddy straw (88.4%) and both were significantly superior to sunflower stalks (44.1%), cotton stalks (49.3%) and maize stover (50.8%). The rate of decomposition of different crop residues followed the same trend. It was the highest with sunnhemp stalks with worms ( $762.96 \text{ mg day}^{-1}$ ) followed by paddy straw ( $736.66 \text{ mg day}^{-1}$ ) and both were significantly superior to other crop residues. The differences in the amount and rate of decomposition of different crop residues might be attributed to the variations in chemical composition (C:N ratio, lignin, tannin and other metabolite content etc.) and physical nature (bulkyness, woodyness and moisture absorbing capacity etc.) of crop residues. The sunnhemp stalks owing to its lower C:N ratio and higher moisture absorbing capacity might have enhanced the microbial and earthworm activity, thus resulting in higher rate of decomposition. In case of paddy straw, despite its higher C:N ratio, the higher rate of decomposition might be attributed to its higher moisture content and bulky nature which might have provided more surface area for microbial attack and earthworm activity.

The role of earthworms in enhancing the decomposition of surface applied crop residues have been reported by several workers (Zachmann and Linden, 1989; Curry and Byrne, 1992; Spain and Hodgen, 1994). They attributed this due to burrowing and casting activity of earthworms. The residue quality in terms of its carbon, nitrogen, lignin, tannin and polyphenol content was more important in deciding the earthworm induced decomposition of crop residues (Hendriksen, 1990;

Slapokas and Granhall, 1991; Martin and Lavelle, 1992; Zou, 1993; Tian *et al.*, 1993). They attributed this due to selective feeding habit of earthworms on nitrogen rich organic matter avoiding waxy and resinous plant residues containing higher amounts of less degradable and aromatic organic compounds.

### 5.2.2 Population and biomass of earthworms

Both the population and biomass of earthworms in soil increased significantly due to addition of different crop residues as mulch. In no residue control the juvenile population was nil but it increased due to addition of different crop residues. Juvenile population of earthworm was significantly the highest with sunnhemp stalks (67.3) followed by paddy straw (40.3). Similarly the population of sub-adult and adult earthworms increased significantly with different crop residues and was higher with sunnhemp stalks and paddy straw compared to other crop residues. The biomass of juvenile, sub-adult and adult earthworms followed the same trend as that of population. The decrease in population and biomass of earthworms in no residue control was attributed to the mortality of some worms in the absence of feed material and also possibly due to lack of favourable soil environment which might have hampered the growth and reproduction of earthworms. Whereas, the addition of crop residues especially the sunnhemp stalks and paddy straw as surface mulch has increased the population and biomass of earthworms, probably due to increased availability of food through the decomposition of crop residues and the favourable microclimatic effect of surface mulch. The beneficial effect of mulching with crop residues in increasing the population and biomass of earthworms were reported by many workers. Nuutinen (1992) observed increased population of epigeic earthworm (*Dendrobaeana rubidus*)

when chopped straw residue was applied on the soil surface. Tian *et al.* (1993) also reported that the mean population of earthworms was greater under any type of plant residues applied as mulch by 41 per cent compared to control. Further, they found that leucaena prunings supported the highest earthworm population due to higher N and lower lignin content of it. The results indicated favourable effect of mulching with crop residues on population and biomass of earthworms through their palatability and decomposibility and indirect effect on soil microclimate.

### 5.2.3 Enzyme activity

The activity of different enzymes in soil increased significantly due to addition of different crop residues and it was further enhanced due to earthworm activity. The dehydrogenase enzyme activity in absolute control was  $3.17 \mu\text{g TPF per g soil per 24 hr.}$ , which increased significantly due to addition of different crop residues and it was the highest with sunnhemp stalks ( $5.29 \mu\text{g TPF g}^{-1} \text{ soil } 24 \text{ hr}^{-1}$ ). This might be attributed to increased microbial activity due to addition of crop residues especially the sunnhemp stalks having lower C:N ratio. Introduction of earthworms significantly increased the dehydrogenase activity in all the treatments. However, it was more pronounced in treatments receiving sunnhemp stalks and paddy straw. This might be attributed to the favourable effect of earthworms in increasing the population and activity of soil microorganisms in the presence of crop residues. These results are in accordance with those reported by Weiss and Tresendorfer (1993) who observed increased dehydrogenase activity of soil due to earthworm activity.

The urease enzyme activity in soil followed the same trend as that of dehydrogenase enzyme activity. The urease activity in absolute control was 15.51

mg  $\text{NH}_4\text{-N}$  per 100 g soil per hr which increased significantly due to addition of different crop residues and was the highest with sunnhemp stalks (22.0 mg  $\text{NH}_4\text{-N}$  100  $\text{g}^{-1}$  soil  $\text{hr}^{-1}$ ) followed by paddy straw (19.83 mg  $\text{NH}_4\text{-N}$  100  $\text{g}^{-1}$  soil  $\text{hr}^{-1}$ ). The earthworm activity has further increased urease activity significantly but the trend remained unaltered. The increase in urease activity might be due to increase in the rate of decomposition of added crop residues by microbial activity which was favoured through earthworm activity. Tiunov (1993) reported that the urease activity in earthworm caprolites and on the surface of living galleries were several times higher than the surrounding soil. He attributed this due to general increase in microbial activity and the subsequent increase in rate of organic matter mineralization. Similar increase in urease activity of soil due to earthworm activity was reported by Chmielewski and Makulec (1993).

The catalase activity in soil increased slightly due to addition of different crop residues but introduction of earthworms increased it significantly in all the treatments. The highest catalase activity was observed with sunnhemp stalks followed by paddy straw. These differences might be due to variation in nutrient level of added organic residues which are essential for catalase activity. These results are similar to those reported by Singram and Kamalkumari (1995). They found higher catalase activity in soil with the addition of FYM than control. They attributed this due to release of nutrients through the decomposition of organic matter which were essential for catalase activity.

#### **5.2.4 Effect of earthworm activity on soil properties**

Addition of different crop residues to soil caused significant reduction in soil pH except the sunflower stalks. Introduction of earthworms caused further

reduction in soil pH, although a slight increase in soil pH was noticed in no residue control. The maximum reduction in soil pH was recorded with sunnhemp stalks (7.44) followed by paddy straw (7.57), maize stover (7.72) and cotton stalks (7.81). The reduction in soil pH was directly related to the rate of decomposition of different crop residues by microbial and earthworm activity and the associated release of organic acids during the decomposition of crop residues. The slight increase in soil pH in no residue with worm control might be attributed to the accumulation of  $\text{NH}_4\text{-N}$  by earthworm activity.

These results are in accordance with those reported by Bhawalkar and Bhawalkar (1992) and Venkatesh (1995). They observed reduction in soil pH from alkaline to near neutral reaction with *in situ* vermiculture and mulching treatments. They attributed this to increased decomposition of applied crop residues by earthworm activity.

Addition of different crop residues increased the organic carbon content of soil significantly. Introduction of earthworms to soil has further increased its content significantly except in sunflower stalks treatment (1.36%). The organic carbon content of soil has increased from 1.48 to 2.10 per cent with sunnhemp stalks; from 1.45 to 1.86 per cent with paddy straw; from 1.42 to 1.57 per cent with maize stover and from 1.36 to 1.49 per cent with cotton stalks. It is obvious that recycling of applied crop residues by burrowing and casting activity of earthworms and simultaneous mixing it with soil would enrich the organic matter content of soil. These results are similar to those reported by Makulec (1993) and Parkin and Berry (1994). They observed significant increase in organic carbon

content of soil due to earthworm activity involving cycling of organic matter from crop residues applied as mulch.

The available  $K_2O$  content of soil in no worm and no residue control was 370.98 mg per kg. Its content in soil increased significantly due to addition of different crop residues and introduction of earthworms into soil. It was in the order of : sunnhemp stalks (624.42 mg  $kg^{-1}$ ) > paddy straw (593.59 mg  $kg^{-1}$ ) > maize stover (543.96 mg  $kg^{-1}$ ) > sunflower stalks (528.14 mg  $kg^{-1}$ ) > cotton stalks (526.53 mg  $kg^{-1}$ ). The significant increase in the available  $K_2O$  content of soil due to earthworm activity might be attributed to increased mineralization of added crop residues and native organic matter by earthworms and also a shift in the equilibrium of soil K from relatively unavailable forms to available forms. Similar results were reported by Vimmerstedt (1969). He observed that the available potassium content of soil increased by 19 per cent due to earthworm activity. Similarly, Vimmerstedt and Finney (1973); Basker *et al.* (1992) and Makulec (1993) observed an increase in available potassium content of soil due to earthworm activity. It was attributed to the role of earthworms in shifting the equilibrium of K among relatively unavailable forms to available forms. Bhawalkar and Bhawalkar (1992) reported that the available potassium content of soil increased from 62.5 to 800 kg per ha due to *in situ* vermiculture with mulching. Similar results were reported by Gunjal and Nikam (1992), Balaji (1994) and Venkatesh (1995). They attributed this due to decomposition and mineralization of applied crop residues by earthworm activity.

Addition of different crop residues and introduction of earthworms into soil significantly increased the content of DTPA extractable micronutrients,

namely, zinc, manganese, copper and iron in soil. The availability of these microelements in soil was maximum with sunnhemp stalks (2.72 mg of Zn, 27.33 mg of Mn, 1.93 mg of Cu and 48.61 mg of Fe kg<sup>-1</sup>) followed by paddy straw (2.43 mg of Zn, 25.49 mg of Mn, 1.35 mg of Cu and 42.10 mg of Fe kg<sup>-1</sup>) and both were significantly superior to other treatments. This might be due to decomposition and mineralization of crop residues and native organic matter by earthworms and release of organic acids, resulting in reduction of soil pH and possibly due to chelation of micronutrients by organic acids. These results are akin to those reported by Yousuf and Shoreit (1992) who observed increased availability of microelements in soil due to introduction of earthworms. Similarly, Venkatesh (1995) reported that *in situ* vermiculture with mulching increased the availability of DTPA extractable Zn, Mn, Cu and Fe in soil. It was attributed to the decomposition of surface applied mulch by earthworms and release of microelements to soil. In addition reduction in soil pH from alkaline to near neutral reaction might have favoured the availability of these micronutrients in soil.

The available N, P<sub>2</sub>O<sub>5</sub> and SO<sub>4</sub> content of soil in no worm and no mulch control increased progressively with time and attained maximum values at 90th day of incubation. The content of available N in soil increased from 112.25 to 160.73 mg kg<sup>-1</sup>, that of available P<sub>2</sub>O<sub>5</sub> from 16.48 to 29.17 mg kg<sup>-1</sup> and available SO<sub>4</sub> from 9.41 to 14.72 mg kg<sup>-1</sup>. The increase in the available nutrients status of soil might be attributed to decomposition of added FYM and release of nutrients by soil microorganisms during incubation. Introduction of earthworms to soil has further intensified the mineralization of FYM and release of nutrients to soil.

Addition of different crop residues to soil, decreased the available N content of soil at 30th day of incubation and it was more pronounced with sunflower stalks followed by cotton stalks, maize stover and paddy straw. This might be due to higher C:N ratio of these crop residues and immobilization of native nitrogen in soil. However, with the advance in incubation time, the available N,  $P_2O_5$  and  $SO_4$  content of soil increased progressively in all the treatments and attained maximum values at 90th day of incubation.

The content of available N,  $P_2O_5$  and  $SO_4$  in soil at different stages of incubation was significantly higher with sunnhemp stalks followed by paddy straw compared to other crop residues. These differences might be attributed to the differences in chemical composition and preferential decomposibility of added crop residues by soil microorganisms.

Introduction of earthworms to soil with different crop residues has further increased the level of available N,  $P_2O_5$  and  $SO_4$  content in soil significantly at all the stages of incubation and attained maximum values at 90th day of incubation. In general, the availability of these nutrients in soil was significantly higher with sunnhemp stalks followed by paddy straw compared to other crop residues at all the stages of incubation. However, the availability of these nutrients in soil increased progressively with the advance in incubation time. The increased availability of these nutrients in soil is mainly due to the beneficial role of earthworm activity in cycling of nutrients through enhanced decomposition of FYM and crop residues applied as mulch, their interaction with beneficial soil microorganisms like N-fixers, P-solubilizers, etc. (Bano *et al.*, 1987; Kale *et al.*,

1992) and increased activity of enzymes like nitrogenase, phosphates, urease etc. in soil (Smic and Pizl, 1989; Weiss and Tresendorfer, 1993).

The initial N:P:S ratio of soil ranged from 35.5:2.2:1 to 37.6:2.6:1. At the 30th day of incubation, the N:P:S ratio of soil, in general, decreased in all the treatments and ranged from 19.2:2.0:1 to 32:2:1. This is mainly due to immobilization of native nitrogen by added crop residues. However, the values of N:P:S ratio were higher in all the treatments due to introduction of earthworms to soil. It is possible due to increased decomposition of added crop residues by earthworm activity and release of nitrogen and phosphorus to soil. At 60th day of incubation, the N:P:S ratio in soil increased in all the treatments ranging from 25.2:2.2:1 to 38.7:20:1. This could be attributed to higher rate of mineralization of native N and P and recycling of nutrients with progressive increase in the decomposition of added crop residues. The values of N:P:S ratio in soil decreased in all the treatments due to introduction of earthworms. This is possibly due to higher mineralization of organic S by burrowing and casting activity of earthworms. At 90th day of incubation, the N:P:S ratio of soil ranged from 24.1:2.3:1 to 33.1:2.6:1. These values in soil, in general, showed decreasing trend in all the treatments except in sunnhemp stalk treatment. The lower values of N:P:S ratio in soil suggested that the rate of mineralization of N and P was relatively lower than that of sulphur. On the contrary, the higher values of N:P:S ratio in soil in sunnhemp and paddy straw treatments might be attributed to the favourable chemical composition and physical nature of these crop residues in increasing the population and activity of earthworms thus resulting in higher cycling of N and P to soil.

Role of earthworms in nutrient cycling have been reported by many workers (Vimmerstedt, 1969; Vimmerstedt and Finney, 1973; Basak *et al.*, 1990; Gunjal and Nikam, 1992). Earthworm contribute to N mineralization directly through consumption of organic matter, digestion and excretion and indirectly by influencing the population and dynamics of other soil biota through predation or through affecting their environmental conditions favourably (Marinissen and Ruiters, 1993). Parkin and Berry (1994) also reported that N accumulation in wormcast was a reflection of N content of the crop residues used as a food source by the earthworms. Curry and Byrne (1992) also observed higher mineralization of nitrogen through excretion and tissue turnover due to earthworm activity. Lee (1992) through his classical work has established that the phosphorus bound in organic matter is transformed to available form when it passes through the gut of earthworm. Similar results of P mineralization through earthworm activity were reported by James (1991) and Hauser (1993). Venkatesh (1995) observed increased availability of  $\text{SO}_4$  in soil due to earthworm activity. This might be due to release of organic bound-s through enhanced decomposition of crop residues by earthworms.

The result of the present study indicated that sunnhemp stalks and paddy straw served as better sources of energy for the growth and reproduction of *Eudrilus eugeniae* species of earthworm in soil. Introduction of earthworms into soil enhanced the decomposition of different crop residues applied as mulch and increased the enzyme activity (dehydrogenase, urease and catalase). Further the burrowing and casting activity of earthworm significantly reduced the soil pH to near neutral reaction and increased the organic carbon content of soil. The above

factors might have been responsible for increasing the availability of N, P<sub>2</sub>O<sub>5</sub>, SO<sub>4</sub> and DTPA extractable micronutrients (Zn, Mn, Cu and Fe) in soil.

### **5.3 Effect of organic manures and fertilizer levels on growth, yield and uptake of nutrients by maize and soil properties**

#### **5.3.1 Growth and yield of maize**

The grain yield of maize in control was 42.07 q per ha which increased to 44.94 q per ha due to application of FYM @ 20 t per ha (Fig. 8). Application of FYM to soil might have increased the availability of nutrients in soil and their uptake by crop thus resulting in higher growth, yield attributes and grain yield of maize. Application of vermicompost to soil either at 2.5 or at 5.0 t per ha significantly increased the grain yield of maize to 52.38 and 61.53 q per ha, respectively. This has accounted for 24.51 and 46.26 per cent increase in yield over control and 16.56 and 36.92 per cent over FYM treatment, respectively. The significant increase in yield due to application of vermicompost might be attributed mainly to higher content of available nutrients in vermicompost, presence of beneficial microflora such as nitrogen fixers (Bano *et al.*, 1987; Kale *et al.*, 1992), phosphate solubilizers, VAM fungi etc. (Harinikumar *et al.*, 1991) and higher enzyme activity (nitrogenase, phosphatase, urease, dehydrogenase, catalase, etc.) (Tiwari *et al.*, 1989; Weiss and Tresendorfer, 1993) and biologically active metabolites (gibberellins, cytokinins, auxins and group B vitamins, etc.) (Gavrilov, 1962; Tomati *et al.*, 1983) which might have increased the availability of both the native and applied nutrients in soil and their uptake by plant because of improved root system. Scanning of data on growth and yield attributes of maize such as plant height, grain weight per plant, thousand grains weight etc. revealed that they were

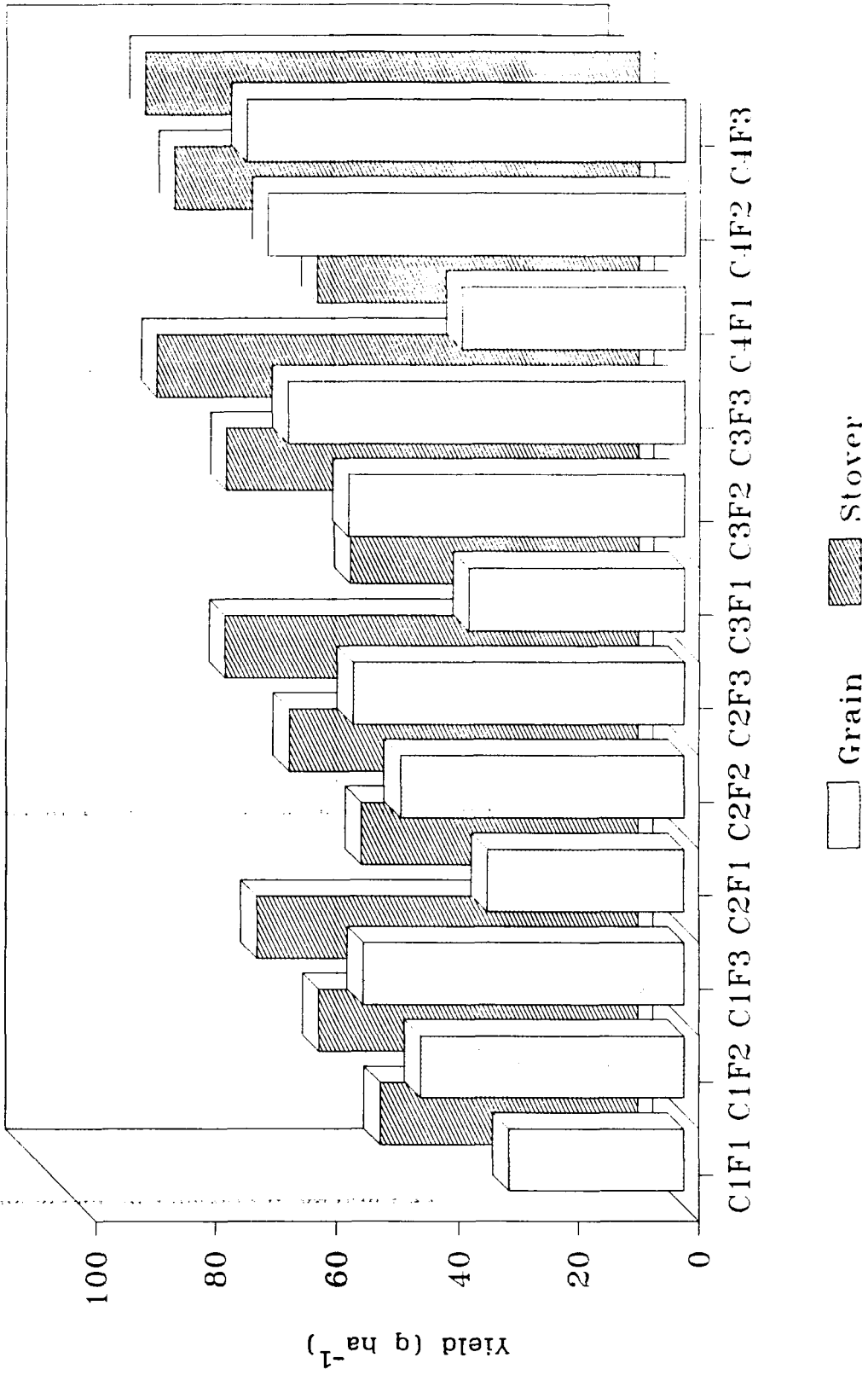


Fig 8. Effect of organic manures and fertilizer levels on yield of maize

significantly higher in vermicompost treatments compared to FYM and control treatments. These factors might have contributed for higher grain yield of maize in vermicompost treatment. It is now well established that vermicompost contains significant quantities of available nutrients, a large beneficial microbial population, biologically active metabolites, vitamins and several enzymes, which can be applied alone or in combination with organic or inorganic fertilizers so as to get better yield and quality of diverse crops (Gavrilov, 1962; Tomati *et al.*, 1983; Bano *et al.*, 1987). The results obtained in the present investigation are in accordance with those reported by Khan (1966). He observed that wormcast was superior to FYM in increasing the growth of maize. Stolyarenko *et al.* (1992) also reported that application of vermicompost stimulated the root and shoot growth of maize. Further, they observed that application of vermiculture products increased the productivity of maize (Stolyarenko *et al.*, 1994). Kale and Bano (1986) recorded better growth and yield of paddy due to application of vermicompost. They attributed this due to higher number of N-fixers in vermicompost treatment. Similar results were reported by several other workers (Dacayo, 1985; Evangelista, 1986; Rivera, 1986; Huang and Zhao, 1991; Kale *et al.*, 1987; Lui Shuxin *et al.*, 1991; Puranik, 1992; Vadiraj *et al.*, 1992).

Combined addition of different levels of chemical fertilizers with organic manures, namely, FYM and vermicompost increased the growth and yield of maize significantly. The highest grain yield of maize (72.50 q ha<sup>-1</sup>) was recorded due to combined application of vermicompost @ 5.0 t per ha and 100 per cent recommended dose of NPK fertilizers and it was significantly superior to other treatment combinations except C<sub>4</sub>F<sub>2</sub> treatment. The increase in yield due to above

treatment over 100 per cent RDF alone accounted for 36.41 per cent. Further, the grain yield obtained due to combined application of vermicompost @ 2.5 t per ha with only 50 per cent RDF ( $56.65 \text{ q ha}^{-1}$ ) was superior to that obtained with 100 per cent RDF treatment ( $53.15 \text{ q ha}^{-1}$ ). Suggesting that the quantity of chemical fertilizers for maize crop could be reduced by 50 per cent when applied with vermicompost. The above results also suggested that addition of some amount of chemical fertilizers alongwith organic manures is desirable so as to supplement the nutrient demand of crop in the initial stage of growth. However, in the latter stages of growth, the release of nutrients through decomposition and mineralization of vermicompost by soil microorganisms would help to sustain the nutritional requirement of the crop. Further, several enzymes and hormones present in vermicompost might have had direct stimulating effect on the root and shoot growth of maize and indirect effect in increasing the availability of both the native and applied nutrients in soil and their uptake by plant.

These results confirm the earlier findings of Zhao and Huang (1991). He observed that application of wormcast with  $^{15}\text{N}$  labelled chemical fertilizer increased the growth and yield of wheat which was attributed to the beneficial effect of microorganisms like N-fixers and nutrient content of wormcast. Kale *et al.* (1991) suggested that the quantity of chemical fertilizers for vegetable crops like raddish, tomato, carrot and brinjal could be reduced by 25 to 50 per cent when applied with vermicompost. Similar results were reported by Balaji (1994) in China aster and Venkatesh (1995) in vineyard of Thompson seedless grapes.

### 5.3.2 Economics

The net returns realized from maize was Rs. 11.69 thousand per ha in control which decreased significantly to Rs. 9.82 thousand per ha due to application of FYM @ 20 t per ha (Fig. 9). Relatively higher cost of cultivation with marginal increase in grain yield of maize in FYM treatment resulted in lesser net returns than control. Application of vermicompost either @ 2.5 t per ha or @ 5.0 t per ha has significantly increased the net returns to Rs. 14.17 thousand and Rs. 15.38 thousand per ha, respectively. It was mainly due to higher grain and stover yields of maize recorded in these treatments. The net returns realized due to above treatments were 21.22 and 31.56 per cent higher than control.

The combined application of vermicompost and fertilizers significantly increased the net returns. The net returns obtained due to combined application of vermicompost @ 2.5 t per ha and 50 per cent RDF (Rs. 15.64 thousand ha<sup>-1</sup>) was higher than that obtained with 100 per cent RDF alone (Rs. 14.78 thousand ha<sup>-1</sup>). Further, application of vermicompost @ 5.0 t per ha with 50 per cent RDF gave significantly the highest net returns (Rs. 19.56 thousand ha<sup>-1</sup>) but it was at par with those from C<sub>4</sub>F<sub>3</sub> and C<sub>3</sub>F<sub>3</sub> treatments. The results suggested that maximum net returns from maize cultivation could be achieved through combined application of vermicompost @ 5.0 t per ha and addition of only 50 per cent recommended dose of NPK fertilizers. By adopting this technology, it is not only possible to achieve higher yield of maize and net returns but also help to save 50 per cent cost on chemical fertilizers thus the foreign exchange.

These results are in confirmity with those reported by Barve (1992). He opined that the input cost in grape cultivation could be reduced from Rs. one



Fig 9. Net returns realized due to application of organic manures and fertilizer levels

lakh to Rs. 0.4 lakh per ha by application of vermicompost @ 5 t per ha without reduction in yield level. Desai (1992) also reported that application of vermicompost at the rate of one tonne per ha to *capsicum* resulted in little less yield compared to chemical plot but the net profit was more due to less total input cost. Balaji (1994) found that application of vermicompost @ 5.0 t per ha could reduce 50 per cent RDF in China aster cultivation. Similar results were reported by Venkatesh (1995) in Thompson seedless grapes.

### **5.3.3 Uptake of plant nutrients by maize**

#### **5.3.3.1 Nitrogen, phosphorus and potassium**

The uptake of N, P and K nutrients by maize in control was 85.01, 17.93 and 65.35 kg per ha which increased significantly to 98.11, 20.68 and 71.77 kg per ha, respectively due to application of FYM. This has been attributed to increased availability of these nutrients through mineralization of FYM by native soil microorganisms. Application of vermicompost either @ 2.5 tonne per ha or @ 5.0 t per ha has further increased the uptake of NPK nutrients by maize and was significantly higher (138.24 kg of N, 29.76 kg of P and 97.96 kg of K ha<sup>-1</sup>) at 5.0 t per ha level, which might be attributed to higher content of available NPK nutrients in vermicompost, presence of beneficial microflora such as N-fixers, P-solublizers, VAM fungi, etc. and several enzymes like nitrogenase, phosphates, etc. in the vermicompost. This might have increased the availability of NPK nutrients in soil and their uptake by maize. Stolyarenko, *et al.* (1992) reported that application of vermicompost stimulated the root growth of maize which might have efficiently extracted nutrients from soil. Lui Shuxin *et al.* (1991) reported that application of wormcast increased the N uptake of soyabean plants by 30 to 50 per cent. They also

observed that P and K contents in plants were twice than control. Significant increase in N and P content in lettuce leaves due to application of vermicompost was reported by Evangelista (1986). Similarly, Tomati *et al.* (1990) found increased protein synthesis in lettuce and raddish with the incorporation of vermicompost. Recently, Venkatesh (1995) also reported that application of vermicompost @ 5.0 t per ha increased the NPK content in petioles of Thompson seedless grapes. He attributed this to increased availability of these nutrients through beneficial microorganisms like N-fixers, P-solubilizers present in vermicompost.

The combined application of inorganic NPK fertilizers with organic manures increased the uptake of NPK nutrients by maize significantly over control. The maximum uptake of these nutrients by maize (169.41 kg of N, 37.87 kg of P and 121.31 kg of k ha<sup>-1</sup>) was recorded due to combined application of vermicompost @ 5.0 t per ha and 100 per cent RDF. The results suggested that addition of inorganic NPK fertilizers not only increased the availability of these nutrients in soil but also favoured the release of nutrients from organic sources through mineralization by microorganisms, hence their uptake by maize.

These results are in accordance with those reported by Huang and Zhao (1991). He observed that mixing of wormcast with chemical fertilizer increased the N content of stalk and seed and total N uptake by wheat. Similarly, Kale *et al.* (1992) reported that application of vermicompost in combination with inorganic fertilizers increased the N and P uptake by paddy. Venkatesh (1995) also reported that application of vermicompost @ 5.0 t per ha in combination with different levels of inorganic fertilizers increased NPK content in petioles of Thompson seedless grapes.

### 5.3.3.2 Calcium, magnesium and sulphur

The uptake of Ca, Mg and S nutrients by maize in control was 12.13, 15.45 and 7.91 kg per ha which increased significantly to 13.70, 17.54 and 8.94 kg per ha, respectively due to application of FYM. This might be attributed to increased availability of nutrients due to mineralization of FYM by soil microorganisms. Application of vermicompost either at 2.5 or at 5.0 t per ha significantly increased the uptake of these nutrients by maize and it was maximum at 5 t per ha level (18.03 kg of Ca, 23.09 kg of Mg and 12.72 kg of S ha<sup>-1</sup>), which might be attributed to higher content of available Ca, Mg and S nutrient elements in vermicompost. In addition, higher microbial and enzymatic activity in vermicompost might have favoured the availability of these nutrients in soil and their uptake by maize.

These results are in conformity with those reported by Evangelista (1986). He found that application of wormcast significantly increased the Ca and Mg content of lettuce leaves. Venkatesh (1995) also reported that application of vermicompost @ 5.0 t per ha increased the Ca and Mg content in petioles of Thompson seedless grapes which was attributed to increased availability of these nutrients in soil.

The combined application of inorganic fertilizers and organic manures has significantly increased the uptake of Ca, Mg and S by maize and maximum uptake of these nutrients (22.28 kg of Ca, 28.43 kg of Mg and 15.76 kg of S ha<sup>-1</sup>) was recorded due to combined application of vermicompost @ 5.0 t per ha and 100 per cent RDF. It was significantly superior to all other treatment combinations.

This might be attributed partly to direct addition of these nutrients to soil through single super phosphate and vermicompost and partly due to increased availability of native nutrients by microbial and enzymatic activity. These results are in confirmity with the findings of Venkatesh (1995) who reported that combined application of vermicompost and inorganic fertilizers increased the Ca, Mg and S content in petiole of Thompson seedless grapes.

#### **5.3.3.3 Zinc, manganese, copper and iron**

The uptake of Zn, Mn, Cu and Fe by maize in control was 132, 252, 57 and 1193 g per ha, respectively, which increased significantly to 148, 280, 65 and 1313 g per ha due to application of FYM. Microbial decomposition of FYM with simultaneous release of organic acids might have favoured the availability of micronutrients in soil and their uptake by maize. Application of vermicompost either at 2.5 or at 5.0 t per ha has further increased the uptake of micronutrients significantly and was maximum at 5.0 t per ha (207 g of Zn, 364 g of Mn, 88 g of Cu and 1717 g of Fe ha<sup>-1</sup>). As stated above, addition of organic manures to soil were found to increase the availability of micronutrients in soil and their uptake by maize. In addition, presence of higher microbial and enzymatic activity in vermicompost might have stimulated the root growth of maize and thus resulted in higher uptake of micronutrients by maize. These results are in accordance with those reported by Venkatesh (1995) who observed higher concentration of Zn, Mn, Cu and Fe in petioles of Thompson seedless grapes with the application of vermicompost.

The combined application of organic manures and fertilizers significantly increased the uptake of micronutrients by maize. The highest uptake of

micronutrients (253 g of Zn, 441 g of Mn, 108 g of Cu and 2068 g of Fe ha<sup>-1</sup>) by maize was recorded due to combined application of vermicompost @ 5.0 t per ha and 100 per cent RDF followed by C<sub>3</sub>F<sub>3</sub> and C<sub>4</sub>F<sub>2</sub> treatments and were significantly superior to other treatments. This might be attributed to increased availability of micronutrients in soil through higher microbial and enzymatic activity in vermicompost. Similar results were reported by Stolyarenko *et al.* (1992) and Venkatesh (1995).

#### **5.3.4 Soil properties**

##### **5.3.4.1 Soil pH**

The pH of the soil after the harvest of maize in control treatment was 8.33 which decreased significantly to 8.18, 7.99 and 7.88 due to application of FYM, vermicompost @ 2.5 t per ha and 5.0 t per ha<sup>-1</sup>, respectively. The reduction in soil pH might be attributed to the release of organic acids during the decomposition of added organic manures and increased microbial and enzymatic activity in soil. Similar results were reported by Venkatesh (1995) who found significant reduction in soil pH due to application of vermicompost @ 5.0 t per ha. The soil pH decreased significantly with increasing level of fertilizer application alongwith organic manures. It is an established fact that addition of acid forming inorganic nitrogenous fertilizers decrease the soil pH. This coupled with the release of organic acids might have further reduced the soil pH. These results are in confirmity with those reported by Venkatesh (1995).

##### **5.3.4.2 Organic carbon**

The organic carbon content of soil in control was 0.61 per cent which increased significantly to 0.72 and 0.79 per cent due to application of vermicompost

@ 2.5 and 5.0 t per ha, respectively. This is possible due to the direct addition of organic matter through vermicompost and the favourable effect of vermicompost application in increasing the root biomass of plant. Stolyarenko *et al.* (1992) observed higher growth of maize roots due to application of vermicompost. Similar results in different crops were reported by Evangelista (1986) and Vadiraj <sup>*et al.*</sup> (1992). Lui Shuxin *et al.* (1991) observed higher content of organic matter in soil after the harvest of soyabean crop due to application of wormcast and it was attributed mainly to increase in biomass of roots in vermicompost treatment.

#### 5.3.4.3 Nutrient availability in soil

The amount of available N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O and SO<sub>4</sub> in soil after the harvest of maize crop in control treatment was 211.8, 29.76, 446.00 and 15.60 kg per ha, respectively which increased significantly to 249.42, 41.47, 460.22 and 17.61 kg per ha, respectively due to application of vermicompost @ 5.0 t per ha. The increased availability of nutrients in soil is mainly due to direct addition of these nutrients to soil through vermicompost and due to mineralization of nutrients from organic matter through increased activity of soil microorganisms. In addition, presence of higher population of beneficial microorganisms like N-fixers, P-solubilizers and VAM fungi and increased enzymatic activity in vermicompost treatment might have favoured the availability of these nutrients in soil. The results of the present investigation were supported by the findings of Bano *et al.* (1987) and Kale *et al.* (1992) who reported that vermicompost harboured higher population of N-fixers and they were responsible for increasing the availability of N in soil. Similarly, Smick and Pizl (1989) observed higher nitrogenase activity, Harinikumar *et al.* (1991) noticed higher growth of VAM fungi and Tiwari *et al.* (1989) and

Weiss and Tresendorfer (1993) observed higher activity of phosphatase and several other enzymes in vermicompost treatment. Lui Shuxin *et al.* (1991) reported increase in total NPK and available P and K content of soil after the harvest of soyabean due to application of wormcast. Balaji (1994) and Venkatesh (1995) also reported increased availability of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O in soil due to vermicompost treatment.

Application of vermicompost either at 2.5 t per ha or at 5.0 t per ha in combination with NPK fertilizers recorded significantly higher available N content in soil. It was significantly the highest (261.96 kg ha<sup>-1</sup>) in the treatment receiving vermicompost @ 5.0 t per ha and 100 per cent RDF. This might be attributed to increased population of beneficial microorganisms like N-fixers, P-solubilizers and higher nitrogenase and urease enzyme activity in soil. These results are in accordance with those reported by Kale *et al.* (1992). They observed higher level of total N in paddy plots treated with vermicompost and relatively less quantity of N-fertilizers. Balaji (1994) and Venkatesh (1995) also reported increase in available N content of soil due to combined application of vermicompost and inorganic fertilizers.

The content of DTPA extractable Zn, Mn, Cu and Fe in soil after the harvest of maize crop was 1.02, 13.48, 0.29 and 8.42 mg per kg, respectively. Their content in soil increased significantly due to addition of FYM. This might be attributed to the release of organic acids through decomposition of organic matter which might have enhanced the availability of micronutrients in soil because of chelation and complexation reaction. The DTPA extractable Zn, Mn, and Fe content of soil has further increased due to application of vermicompost and it was

maximum at 5 t per ha level (1.63 mg of Zn, 18.7 mg of Mn, 0.29 mg of Cu and 10.91 mg of Fe kg<sup>-1</sup>). The effect of vermicompost in increasing the availability of micronutrients was similar to that of FYM. However, the presence of higher microbial and enzymatic activity in vermicompost treatment might have enhanced the availability of micronutrients in soil to a greater extent. These results are in accordance with the findings of Venkatesh (1995) who observed higher levels of DTPA extractable Zn, Mn, Cu and Fe in soil due to vermicompost treatment.

#### **5.4 Effect of *in situ* vermiculture and fertilizer levels on growth, yield and uptake of nutrients by maize and soil properties**

##### **5.4.1 Growth and yield of maize**

The grain yield of maize in control was 45.29 q per ha which increased significantly to 48.15 q per ha due to mulching (Fig. 10). It has accounted for 6.32 per cent increase in grain yield over control. This increase in yield might be attributed to the favourable microclimatic effect, particularly the soil moisture regime, on the release of plant nutrients from partially decomposing residues through increased population and activity of native microorganisms and earthworms which might have resulted in higher uptake of nutrients by plant. It was evident from the data on growth and yield attributes of maize such as plant height, grain weight per plant, thousand grains weight and stover yield which were significantly higher in mulch treatment than control. These attributes directly contributed for increased grain yield of maize. Favourable effects of mulching with crop residues in increasing the population and activity of earthworms have been reported by Tian *et al.* (1993). They attributed this due to nutritional and microclimatic effect of mulching. Similarly, Radford *et al* (1995) reported that

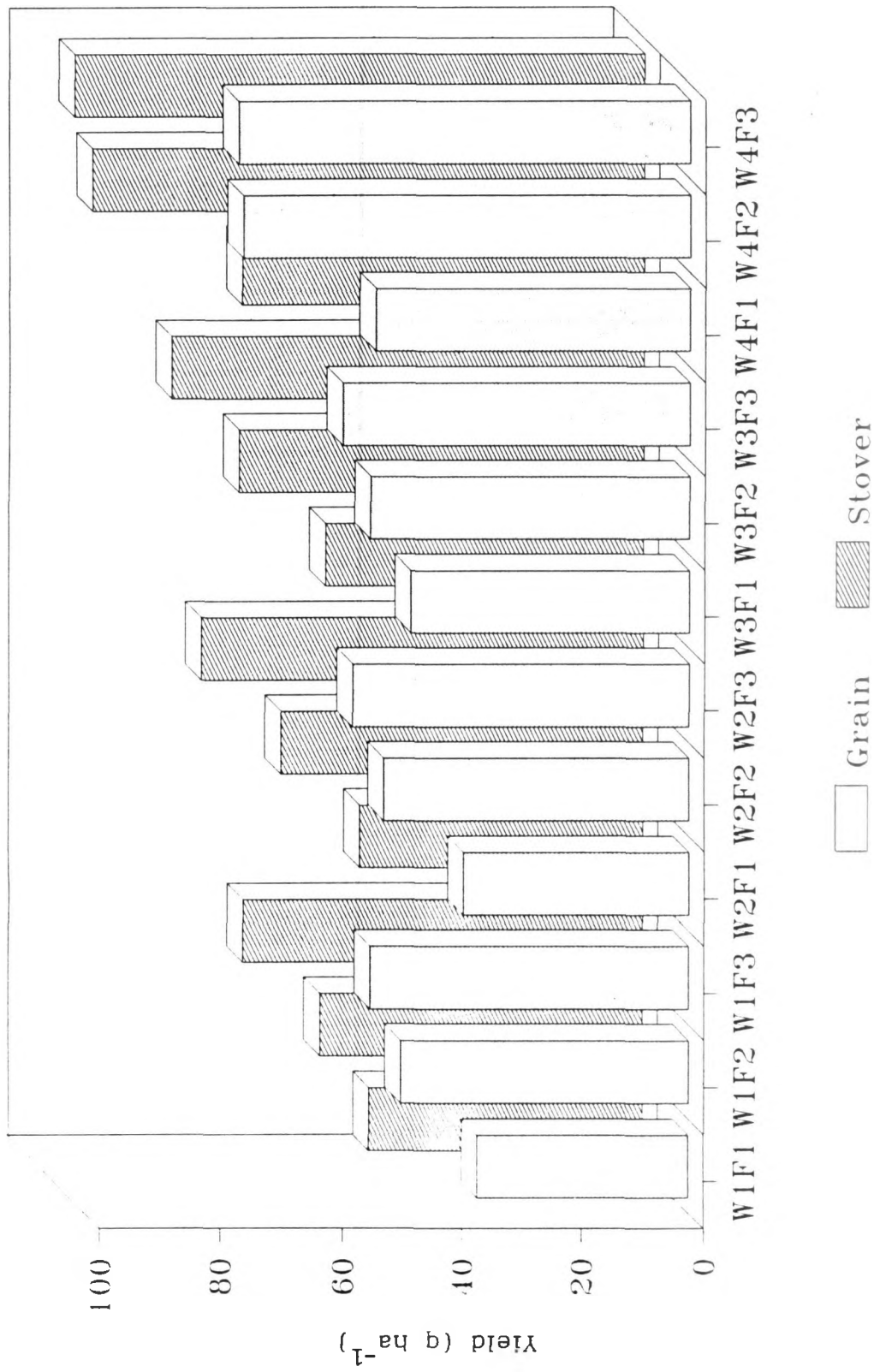


Fig 10. Effect of in situ vermiculture and fertilizer levels on the yield of maize

stubble mulching increased the worm population and grain yield of sorghum and wheat crops mainly because of increased storage of soil water and water use efficiency of crops.

The grain yield of maize increased significantly ( $52.47 \text{ q ha}^{-1}$ ) due to *in situ* vermiculture. The highest grain yield of 67.07 q per ha was recorded due to *in situ* vermiculture with mulching treatment. This has accounted for 48.09, 32.29 and 27.82 per cent increase in grain yield over control, mulching and *in situ* vermiculture treatments, respectively. The increase in yield due to *in situ* vermiculture might be attributed to increased availability of nutrients by earthworm activity. With the passage of time, some of the introduced worms might have died due to lack of food and unfavourable microclimatic conditions in the soil thus recycling of nutrients to soil, as worms are rich in nutrients, especially nitrogen. The burrowing and casting activity of earthworms improved the physical condition of soil and favoured the availability of nutrients manifold. As a result, the growth and yield attributes of maize and also the grain yield of maize might have increased significantly. The role of earthworms in nutrient cycling through their interaction with microorganisms is well established. In addition, the wormcast contained biologically active metabolites, particularly gibberellins, cytokinins, auxins and group B vitamins (Gavrilov, 1962; Tomati *et al.*, 1983) which were responsible for higher growth and yield of maize. The results of the present investigation support the findings of Sharma (1994) who observed significant increase in the growth and yield of maize due to introduction of earthworms in combination with organic wastes. Similarly, Spain *et al.* (1992) observed increased growth of maize and guinea grass in an infertile granite-derived soil with the introduction of earthworms. Several

other workers also reported significant increase in the growth and yield of different field crops due to *in situ* vermiculture and it has been attributed mainly to increased availability of nutrients through earthworm activity or mineralization of worm tissue after their death (Driedax, 1931; Hopp and Slater, 1949; Uhlen, 1953; Altanvinyte *et al.*, 1968; Edward and Lofty, 1978; Altanvinyte and Zim-Kuviene, 1985; Lui *et al.*, 1991). Similarly, the beneficial effect of earthworm activity in increasing the growth and biomass of pastures/grasses besides improving the soil physical properties and increasing the availability of nutrients to plants was reported by several workers (Nielson, 1965; Ross and Cairns, 1982; Springet and Syers, 1979; James, 1991; Lavelle *et al.*, 1991).

The highest growth and yield of maize recorded due to *in situ* vermiculture with mulching might be attributed to the favourable effect of mulching in increasing the population and activity of both introduced and native worms in soil and the beneficial effect of these earthworms in improving the physical conditions of soil and increasing the availability of nutrients to plant. The beneficial effects of *in situ* vermiculture with mulching in increasing the growth and yield of various crops have been reported by several workers (Raw, 1962; Huhta *et al.*, 1991; Huang and Zhao, 1991; Jari *et al.*, 1992; Robinson *et al.*, 1992; Edwards and Bater, 1992; Barve, 1992; Gunjal and Nikam, 1992; Bhawalkar and Bhawalkar, 1992; Balaji, 1994; Radford *et al.*, 1995; Venkatesh, 1995).

Addition of different levels of fertilizers to different treatments resulted in higher growth and yield of maize. Significantly the highest grain yield of maize (74.78 q ha<sup>-1</sup>) was recorded due to *in situ* vermiculture with mulching and

application of 100 per cent RDF. However, this treatment was at par with the corresponding treatment but receiving only 50 per cent RDF. Further, the grain yield obtained due to *in situ* vermiculture with mulching and only 25 per cent RDF was equivalent to that of 100 per cent RDF alone. These results suggested that addition of small amount of chemical fertilizers alongwith *in situ* vermiculture is required to supplement the demand of the crop for nutrients in the initial stage of crop growth. However, at the latter stages of crop growth, the nutrients recycled through earthworm activity might supplement the nutrient requirement of the crop. Moreover, when small quantity of chemical fertilizers are used in combination with *in situ* vermiculture, they did not have any adverse effect on earthworm activity. These results are in confirmity with those reported by Tiwari (1993).

#### 5.4.2 Economics

The net returns realized from maize was Rs. 9.91 thousand per ha in control which increased significantly to Rs. 11.53 thousand per ha due to mulching (Fig. 11). The increase in net returns is partly due to higher yields obtained with mulching and partly due to low cost of cultivation, particularly the saving on weeding expenditure. In spite of getting higher yield of maize in *in situ* vermiculture treatment the net returns decreased significantly because of more expenditure on worms, thus resulting in higher cost of cultivation and lesser net returns. The net returns obtained due to *in situ* vermiculture with mulching was significantly the highest (Rs. 13.87 thousand ha<sup>-1</sup>). It was mainly due to higher grain and straw yields of maize. The net returns realized in this treatment was 39.96 and 20.29 per cent higher than control and mulching treatments, respectively.

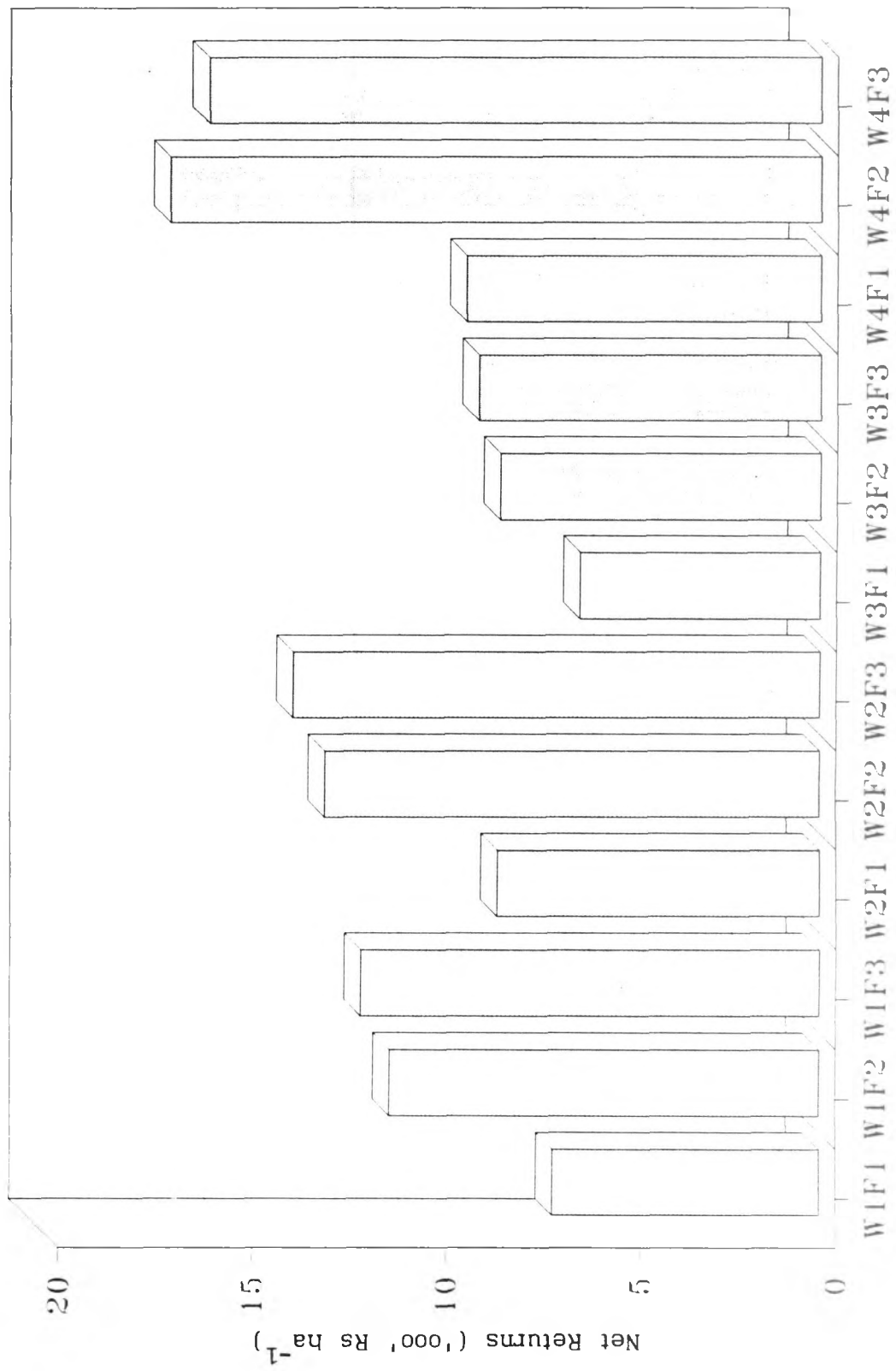


Fig 11. Net returns realized due to in situ vermiculture and fertilizer levels

The combined effect of *in situ* vermiculture with mulching and application of 50 per cent RDF recorded the highest net returns (Rs. 16.75 thousand ha<sup>-1</sup>) and it was significantly superior to all other treatment combinations except W<sub>4</sub>F<sub>3</sub> treatment. These results suggested that maximum net returns from maize cultivation could be achieved through *in situ* vermiculture with mulching and addition of only 50 per cent recommended dose of NPK fertilizers. By adopting this technology it is not only possible to achieve higher yields of maize and net returns but also help to save 50 per cent cost on chemical fertilizers thus save the foreign exchange.

These results are in accordance with those reported by Bhawalkar and Bhawalkar (1992). They realized a net profit of Rs. 1,23,500 per ha from *in situ* vermiculture with mulching compared to Rs. 45,000 per ha from chemical plot (FYM + fertilizers) from sugarcane grown on saline soil. This was attributed to improvement in physical and chemical properties of soil by earthworm activity and complete reduction in the cost of chemical fertilizers. The profitability of *in situ* vermiculture was demonstrated by several workers in various crops (Barve, 1992; Gunjal and Nikam, 1992). This was possible mainly due to complete reduction in the cost of chemical fertilizers and higher market price because of better quality of produce obtained in vermiculture treatment.

#### **5.4.3 Uptake of nutrients by maize**

##### **5.4.3.1 Nitrogen, phosphorus and potassium**

The uptake of N, P and K nutrients by maize in control treatment was 97.34, 20.80 and 79.94 kg per ha which increased significantly to 108.46, 23.70

and 88.05 kg per ha, respectively due to mulching. The uptake of these nutrients by maize has further increased significantly to 122.34, 27.11 and 99.35 kg per ha, respectively due to *in situ* vermiculture and it was significantly the highest due to *in situ* vermiculture with mulching treatment (166.77 kg of N, 37.61 kg of P and 129.40 kg of K ha<sup>-1</sup>). The significant positive effect of earthworm and mulching treatments on nutrient uptake by maize might be attributed to the favourable effect of mulching on microclimate particularly the soil moisture regime and the release of plant nutrients from partially decomposing residues through increased population and activity of native microorganisms and earthworms which might have resulted in higher uptake of nutrients by maize crop. The increased activity of earthworms besides improving soil physical conditions might have favoured mineralization of N and P nutrients through decomposition of added crop residues as well as native nutrients from minerals and organic matter of soil. As a result of increased availability of nutrients in soil, the growth of crop particularly the root development was better and thereby increased the uptake of nutrients by plant.

Similar beneficial effects of earthworm activity on nutrient uptake by crops was reported by James (1991). He observed that mineral N processed by earthworms was 10-12 per cent of annual plant N uptake while the P processed was equivalent to 50 per cent of annual uptake in prairie grass. Lavelle *et al.* (1991) also reported increased N and P contents in *Panicum maximum* due to earthworm activity. Similarly, Sharma (1994) noticed increased uptake of nutrients by maize and wheat crops due to earthworm activity. They opined that earthworms enhanced the recycling of nutrients from organic residues and thereby increased their uptake by plant. Jari *et al.* (1992) and Huhta *et al.* (1991) also observed increased N

content of birch seedling due to increased mineralization of surface litter through earthworm activity. Similarly, *in situ* vermiculture with mulching increased the concentration of NPK nutrients in petiole of Thompson seedless grapes due to increased availability of nutrients in soil (Bhawalkar and Bhawalkar, 1992; Venkatesh, 1995).

Combined application of NPK fertilizers either with mulching or *in situ* vermiculture significantly increased the uptake of nutrients by maize. The maximum uptake of NPK by maize was recorded due to *in situ* vermiculture with mulching and application of 100 per cent RDF which was significantly superior to all other treatment combinations except  $W_4F_2$ . These results suggested that addition of small dose of chemical fertilizers alongwith *in situ* vermiculture was essential to boost the crop growth in the early stage. However, at the latter stages of crop growth, the increased availability of nutrients through earthworm activity might supplement the nutrient requirement of crop. Several workers have reported increased activity of earthworm due to combined application of inorganic and organic fertilizers (Tiwari, 1993; Simpson *et al.*, 1993).

#### 5.4.3.2 Calcium, magnesium and sulphur

The uptake of Ca, Mg and S nutrients by maize in control was 13.62, 17.19 and 8.70 kg per ha, respectively which increased significantly to 15.07, 18.85 and 10.04 kg per ha, respectively due to mulching. As stated earlier, mulching might have provided favourable microclimatic conditions, particularly soil moisture regime for the activity of microorganisms and native earthworms which might have increased the availability of these nutrients in soil and their uptake by maize. Similar results were reported by Nuutinen (1992) and Tian *et al.* (1993).

The uptake of Ca, Mg and S nutrients by maize has further increased to 16.80, 21.56 and 11.07 kg per ha, respectively due to *in situ* vermiculture and their uptake was significantly the highest in *in situ* vermiculture and mulching treatment (23.65 kg of Ca, 29.57 kg of Mg and 15.63 kg of S ha<sup>-1</sup>). This might be due to the favourable effect of mulching and the beneficial role of earthworm activity in increasing the availability of Ca, Mg and S nutrients in soil and their uptake by maize. Kale and Krishnamoorthy (1980) stated that *Pontoscolex corethrurus* species of earthworm concentrated calcium in the calciferous glands and excreted it through their cast which contained 11.8 times higher calcium than the surrounding soil. Similar results were reported by Lee (1985). The beneficial effect of earthworms on litter burial and increasing the availability of Ca and Mg was reported by Vimmerstedt *et al.* (1973). Similarly, Hauser (1993) observed increased availability of Ca and Mg due to cycling of nutrients through earthworm activity in alley cropping. Bhawalkar and Bhawalkar (1992) and Venkatesh (1995) reported higher concentration of Ca, Mg and S in the petiole of grapevine due to *in situ* vermiculture with mulching.

A combination of fertilizers either with mulching or *in situ* vermiculture or *in situ* vermiculture with mulching increased the uptake of Ca, Mg and S by maize, significantly. The highest uptake of these nutrients was recorded due to *in situ* vermiculture with mulching and 100 per cent RDF application (27.82 kg of Ca, 34.44 kg of Mg and 18.52 kg of S ha<sup>-1</sup>) and it was significantly superior to all other treatment combinations except W<sub>4</sub>F<sub>2</sub>. This is because of the fact that addition of SSP might have increased the availability of Ca and S nutrients in soil.

In addition, mineralization of organic matter and decomposition of crop residues by microorganisms and earthworms in soil might have increased the availability of Ca, Mg and S in soil, thus resulting in higher uptake of these nutrients by maize. These results are in accordance with those reported by Tiwari (1993) and Simpson *et al.* (1993).

#### 5.4.3.3 Zinc, manganese, copper and iron

The uptake of Zn, Mn, Cu and Fe by maize in control was 142, 259, 64 and 1278 g per ha, respectively which increased significantly to 160, 300, 75 and 1428 g per ha due to mulching. The uptake of these nutrients by maize was higher due to *in situ* vermiculture and it was significantly the highest due to *in situ* vermiculture with mulching treatment (256 g of Zn, 447 g of Mn, 110 g of Cu, and 2063 g of Fe ha<sup>-1</sup>). The beneficial role of earthworm activity in increasing the availability of nutrients in soil has been discussed earlier in this chapter. The increased availability of micronutrients in soil due to *in situ* vermiculture and the favourable effect of mulching on soil moisture regime together might have enhanced the uptake of these micronutrients by maize.

Significant increase in the concentration of Zn, Mn, Cu and Fe nutrients in the petiole of Thompson seedless grapes due to *in situ* vermiculture with mulching was reported by Venktaesh (1995). He has attributed this due to increased availability of micronutrients in soil because of reduction in soil pH and chelation with organic acids. Similar results were reported by Bhawalkar and Bhawalkar (1992).

A combination of *in situ* vermiculture with mulching and application of 100 per cent recommended dose of NPK fertilizers recorded the highest uptake of Zn, Mn, Cu and Fe by maize and it was significantly superior to other treatment combinations except W<sub>4</sub>F<sub>2</sub>. It is because of the fact that the availability of these micronutrients in soil improved considerably due to the combined effect of inorganic NPK fertilizers and earthworm activity thus resulting in higher uptake of Zn, Cu and Fe by maize crop. Similar findings were reported by Tiwari (1993) and Simpson *et al.* (1993).

#### 5.4.4 Soil properties

##### 5.4.4.1 Soil pH

The pH of the soil in control was 8.20 which decreased significantly to 7.87 due to mulching. The soil pH has further decreased due to *in situ* vermiculture (7.78) and was significantly the lowest (7.41) in *in situ* vermiculture with mulching treatment. The reduction in soil pH might be attributed to the release of organic acids by the decomposing soil organic matter and crop residues applied as mulch by the activity of both microorganism and earthworms.

These results confirmed the earlier findings of several workers that the earthworm activity in soil altered the soil reaction towards near neutrality. Bhawalkar and Bhawalkar (1992) observed decrease in soil pH from 8.3 to 6.9 due to *in situ* vermiculture with mulching. They attributed this to the release of organic acids during decomposition of crop residues by microbial and earthworm activity. Similar results were reported by Venkatesh (1995).

The pH of the soil decreased significantly due to application of different levels of NPK fertilizers. It was significantly the lowest (7.74) at 100 per cent RDF level. It is an established fact that the acid forming nature of applied nitrogenous fertilizers and release of organic acids during the decomposition of added organics cause significant reduction in soil pH. These results are in accordance with those reported by Das, *et al.* (1966). He observed that application of NPK fertilizers decreased soil pH.

#### 5.4.4.2 Organic carbon

The organic carbon content of soil in control was 0.69 per cent which increased significantly to 0.80 and 0.82 per cent due to mulching and *in situ* vermiculture treatments, respectively. Significantly the highest content of organic carbon in soil (1.12%) was recorded due to *in situ* vermiculture with mulching treatment. This is because of the fact that recycling of applied crop residues and FYM by burrowing and casting activity of earthworm increased the total carbon content of soil. Darwin in 1881 through his classical work, established that earthworms were intimately involved in cycling of carbon in soil from surface applied organic residues due to their burrowing and casting activity. Several others have reported higher organic matter content in earthworm worked soil (Vimmerstedt, *et al.*, 1973; Basak, *et al.*, 1990; James, 1991). Recently, Makulec (1993) and Parkin and Berry (1994) also reported increase in total carbon content of soil due to earthworm activity. This was attributed to selective feeding habit of worms on decomposing particulate matter and subsequent mixing it into the soil by their burrowing and casting activity.

#### 5.4.4.3 Nutrient availability in soil

The content of available N,  $P_2O_5$ ,  $K_2O$  and  $SO_4$  in soil after the harvest of maize in control was 225.7, 32.22, 449.11 and 16.61 kg per ha, respectively which increased significantly to 239.75, 36.39, 468.11 and 17.49 kg per ha, respectively due to mulching. The availability of these nutrients in soil increased significantly due to *in situ* vermiculture and was significantly the highest due to *in situ* vermiculture with mulching treatment (336.88 kg of N, 61.83 kg of  $P_2O_5$ , 548.33 kg of  $K_2O$  and 23.35 kg of  $SO_4$   $ha^{-1}$ ). The increased availability of these nutrients in soil is mainly due to the beneficial role of earthworm activity in cycling of nutrients from organic matter, their interaction with soil microorganisms, particularly N-fixers and increased enzymatic activity in soil. Bano *et al.* (1987), Smick and Pizl (1989) and Kale *et al.* (1992) observed significant increase in available N content of soil due to earthworm activity and it was attributed to the beneficial effect of earthworms in increasing the population of N-fixers and increase in nitrogenase enzyme activity in soil. Similarly, the increase in available  $P_2O_5$  content of soil was found to be due to increased phosphatase enzyme activity associated with earthworm activity (Weiss and Tresendorfer, 1993). So also, the beneficial role of earthworm activity in shifting the equilibrium of soil K from relatively unavailable forms to available forms was demonstrated by Basker *et al.* (1992).

Similar results were reported by Vimmerstedt (1969). He reported 165 per cent increase in available phosphorus and 19 per cent increase in available potassium due to earthworm activity in infertile mine spoil bank. Several other workers also reported increased availability of N,  $P_2O_5$  and  $K_2O$  in soil due to earthworm activity (Basak *et al.*, 1990; Basker *et al.*,

1992; Makulec, 1993). Venkatesh (1995) reported that *in situ* vermiculture with mulching increased the availability of N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O and SO<sub>4</sub> in soil. He attributed this partly to increased mineralization of native nutrients and partly to cycling of nutrients through decomposition of crop residues by earthworm activity. Similar results were reported by many others (Gunjal and Nikam, 1992; Bhawalkar and Bhawalkar, 1992; Balaji, 1994).

The DTPA extractable zinc, manganese, copper and iron content of soil in control after the harvest of maize crop were 1.15, 17.06, 0.28 and 11.05 mg per kg, respectively. Their content in soil increased significantly due to *in situ* vermiculture. The treatment with *in situ* vermiculture and mulching recorded the maximum availability of all these micronutrients in soil. This was attributed to increased mineralization of native soil organic matter and enhanced decomposition of added crop residues by soil microorganisms associated with earthworm activity. All these factors together caused significant reduction in soil pH which had direct effect on the availability of micronutrients in soil. Indirectly, the organic acids released during the decomposition process might have increased the availability of these micronutrients through chelation and complexation reaction.

These results are in accordance with those reported by Yousuf and Shoreit (1992). They observed increased availability of micronutrients in soil due to introduction of earthworms. Venkatesh (1995) reported that *in situ* vermiculture with mulching in grape cultivation increased the levels of DTPA extractable Zn, Mn, Cu and Fe in soil. It was attributed to the release of organic acids through decomposition of applied crop residues by earthworms which altered the soil pH

from alkaline to near neutral reaction and thus favoured the availability of micronutrient in soil.

The available N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O content of soil after the harvest of maize crop increased significantly due to addition of different levels of NPK fertilizers and they were maximum at 100 per cent RDF level. It is an established fact that application of chemical fertilizers invariably resulted in increased availability of nutrients in soil because of residual effect of applied fertilizers. Shukla (1972) reported that application of N to corn resulted in increased N content of soil. Similarly, the residual effect of P and K fertilizers on the availability of these nutrients in soil were reported by several workers (Indira *et al.*, 1964; Kanwar and Grewal, 1966; Anderson, 1970; Shukla, 1972).

#### 5.4.4.4 Infiltration rate

The final infiltration rate of soil in control was 1.33 cm per hr which increased to 1.51 cm per hr due to mulching. It was further increased to 2.73 and 3.47 cm per hr due to *in situ* vermiculture and *in situ* vermiculture with mulching treatments, respectively. This might be attributed to the favourable effect of mulching in increasing the population and activity of both the native and released earthworms in soil which might have improved the structural aggregates of soil due to burrowing and casting activity of earthworm. These results are akin to those reported by Logsdon and Linden (1992) who observed that earthworm burrows can increase infiltration and reduce runoff. Several workers have shown that earthworm burrows and improved structural aggregates of soil due to earthworm activity promoted infiltration rate of soil and thus reduced surface runoff (Ehlers, 1975;

Kaldivko *et al.*, 1986; Zachmann and Linden, 1989; Edwards *et al.*, 1990; Hulugalle and Ezumah, 1991; Addan *et al.*, 1991; Hardin and Comis, 1991; Clements *et al.*, 1991; Springett *et al.*, 1992). The infiltration rate of soil at 25 per cent RDF level was 2.10 cm per hr which improved slightly at 50 and 100 per cent RDF level. This might be mainly due to increase in biomass of plant roots at higher levels of fertilizer application.

#### 5.4.4.5 Population and biomass of earthworms

The population of native earthworms in control was 17 per sq. meter which increased to 26 per sq. meter due to mulching. It is mainly due to the favourable nutritional and microclimatic effect of mulching on the growth and reproduction of native earthworms. The population of introduced worms in *in situ* vermiculture treatment decreased considerably, because of the competition for food and lack of favourable soil conditions for the growth and reproduction of epigeic, *Eudrilus eugeniae* species of earthworm. But the population and biomass of native species of earthworm remained unaltered as they can thrive well under harsh field conditions. Introduction of worms and mulching with crop residue increased the population of introduced worms by 58.64 per cent. The results suggested that mulching with crop residue is the critical input for increasing the growth and activity of introduced earthworm in soil, besides increasing the population of native worms. Since the two species of earthworm namely, epigeic (introduced) and endogeic (native) have differential feeding habit and vertical distribution in soil, there was no competition for food, hence both the species of earthworm survived well in this treatment. Similar trend was observed in the biomass of both native and introduced earthworms. These results are in accordance with those reported by Nuutinen

(1992) and Tian *et al.* (1993) who observed increased growth and activities of earthworms due to application of crop residues as mulch.

The population of earthworm was not affected by the application of different levels of fertilizers but their biomass increased slightly due to increase in fertilizer level. These results are in conformity with those reported by Tiwari (1993) and Simpson *et al.* (1993) who observed no adverse effect of fertilizers on earthworm activity.

## 5.5 PRACTICAL UTILITY OF RESULTS

Based on the results of laboratory incubation studies and field experiments, the following conclusions have emerged :

1. The optimum soil conditions for maximum survival, growth rate and biomass production of *Eudrilus eugeniae* species of earthworm in semi arid tropical conditions at Raichur are soil moisture content of 79.59 per cent, soil pH of 6.5 to 7.5, soil salinity of 1.75 to 3.00 dSm<sup>-1</sup> and soil temperature of 20 to 25°C.
2. Mulching of crop residues like sunnhemp stalks/paddy straw served as better sources of energy for the growth, reproduction and activity of earthworms (*Eudrilus eugeniae*) and improved the availability of nutrients in soil.
3. Application of organic manures in combination with inorganic NPK fertilizers increased the productivity of maize, besides sustaining soil fertility status. The maximum productivity of maize could be achieved with the application of vermicompost @ 5.0 t per ha alongwith 100 per cent recommended dose of chemical fertilizers. However maximum net returns

from maize are realized with the application of vermicompost @ 5.0 t per ha alongwith only 50 per cent RDF. Further, application of vermicompost @ 2.5 t per ha alongwith 50 per cent recommended dose of chemical fertilizers gave an yield equivalent to that obtained with 100 per cent RDF alone. By adopting this technology, it is not only possible to achieve higher yields of maize and net returns from maize cultivation but also help to save 50 per cent cost on chemical fertilizers, thus the foreign exchange.

4. Introduction of earthworms (*Eudrilus eugeniae*) into soil increased the productivity of maize crop, besides improving soil physical conditions, nutrient availability and biological activity in soil. The maximum yields of maize could be achieved by practicing *in situ* vermiculture with mulching and addition of 100 per cent recommended dose of chemical fertilizers. However, the maximum net returns from maize are realized due to *in situ* vermiculture with mulching treatment but receiving only 50 per cent RDF of chemical fertilizers. Further, *in situ* vermiculture with mulching and application of only 25 per cent RDF produced grain yield of maize equivalent to that obtained with 100 per cent RDF alone. Thus by adopting this technology, it is possible to reduce 50 to 75 per cent cost on chemical fertilizers and thus save valuable foreign exchange to be incurred on import of phosphatic and potassic fertilizers.

#### 5.6 FUTURE LINE OF RESEARCH WORK

1. To study the optimum physico-chemical and environmental conditions of soil for maximum growth and activity of different promising species of earthworm under semiarid tropical conditions of Raichur.

2. Long-term experiments need to be conducted on diverse crops and different soil types so as to ascertain the benefits of vermiculture biotechnology in improving yield and quality of crops and physical, chemical and biological properties of soil.
3. To study the fertilizer quality of vermicomposts obtained from different crop residues or their combinations with different epigeic species of earthworms.
4. To study the impact of cultivation/management practices on population and activity of different species of earthworm in soil.
5. To study the role of vermiculture biotechnology in reclamation of saline/sodic soils and management of wastelands by employing suitable species of earthworm.

# Summary

## VI. SUMMARY

The present investigation on the "Dynamics of earthworm (*Eudrilus eugeniae*), soil-plant relationship in semiarid tropics", was carried out at the College of Agriculture, Raichur. Series of laboratory incubation studies were conducted to evaluate the effect of various physico-chemical conditions in the soil environment, namely, moisture, pH, EC and temperature on the survival and growth of earthworm. In another laboratory incubation study, the role of earthworm in soil biotechnology was assessed. Two separate field experiments were conducted on Alfisol representing Rampur Series (Typic Haplustalf) at Agricultural College Farm, Raichur during *rabi* 1994-95. The first experiment was aimed to assess the fertilizer quality of vermicompost and its effect on maize yield and soil properties. The experiment consisted of four main plot treatments, namely, control, FYM @ 20 t ha<sup>-1</sup>, vermicompost @ 2.5 and 5.0 t ha<sup>-1</sup> and three sub plot treatments consisting of fertilizer levels (25, 50 and 100% RDF). The second experiment was aimed to suggest the management strategies that will enable to promote earthworm activity and maize productivity and to evaluate the beneficial effect of earthworm activity on soil properties. The second experiment consisted of four main plot treatments, namely, no mulch no worm control, mulch without worms, worms @ 2.5 lakh ha<sup>-1</sup> without mulch, worms @ 2.5 lakh ha<sup>-1</sup> with mulch and three sub plot treatments consisting of fertilizer levels (25, 50 and 100% RDF). Both the experiments were laid out in split-plot design with three replications. Hybrid maize (Cv. Deccan-103) was grown as a test crop by adopting recommended package of practices for the region. The growth and yield attributes of maize were recorded at harvest. Soil and plant samples collected after the harvest of crop were analyzed for relevant

properties. In the second field experiment, population and biomass of earthworms and infiltration rate of soil were recorded after the harvest of crop. The results of these experiments are presented and discussed in previous chapters. The highlights of the results are summarized below:

1. The maximum survival, growth rate and biomass of *Eudrilus eugeniae* species of earthworm could be achieved by maintaining soil moisture level at 79.59 per cent, soil pH between 6.5-7.5 and electrical conductivity ranging from 1.75 to 3.0 dSm<sup>-1</sup> and soil temperature from 20° to 25°C.
2. Surface mulching with chopped sunnhemp stalks or paddy straw served as a better source of energy for increasing the population and biomass of earthworm as compared to sunflower, cotton and maize crop residues.

Decomposition of different crop residues by earthworm significantly reduced soil pH and increased in organic carbon, available N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O and SO<sub>4</sub>-S content, DTPA extractable micronutrients content (Zn, Mn, Cu and Fe) and enzyme activity (dehydrogenase, urease and catalase) in soil.

3. The combined application of vermicompost and fertilizers increased the growth and yield of maize significantly. The maximum grain yield of maize was obtained due to combined application of vermicompost @ 5.0 t ha<sup>-1</sup> and 100 per cent RDF followed by 50 per cent RDF and both were significantly superior to all other treatment combinations. The increase in grain yield due to above treatments over 100 per cent RDF alone was 36.41 per cent and 29.90 per cent, respectively. Further, the grain yield obtained due to

application of vermicompost @  $2.5 \text{ t ha}^{-1}$  alongwith 50 per cent RDF was equivalent to that obtained with 100 per cent RDF alone. The net returns realized due to this treatment was higher than that from other treatments.

4. The uptake of both macro and micro nutrients by maize increased significantly due to combined application of vermicompost and fertilizers. The combined application of vermicompost @  $5.0 \text{ t ha}^{-1}$  and 100 per cent RDF recorded maximum uptake of NPK by maize. Similar trend was observed in the uptake of Ca, Mg, S, Zn, Mn, Cu and Fe by maize.
5. Application of vermicompost in combination with fertilizers caused significant reduction in soil pH and increase in organic carbon and available N,  $\text{P}_2\text{O}_5$ ,  $\text{K}_2\text{O}$  and  $\text{SO}_4\text{-S}$  and DTPA extractable Zn, Mn and Fe content of soil.
6. The growth and yield of maize differed significantly due to *in situ* vermiculture and fertilizer levels. Significantly the highest grain yield of maize was obtained due to combination of *in situ* vermiculture with mulching and 100 per cent RDF application but it was on par with *in situ* vermiculture with mulching and 50 per cent RDF application. The grain yield obtained due to *in situ* vermiculture with mulching and 25 per cent RDF was equivalent to that obtained due to 100 per cent RDF alone. The net returns realised from this treatment were significantly higher than that from other treatment combinations.
7. The uptake of both macro and micro nutrients by maize increased significantly due to *in situ* vermiculture with mulching and fertilizer

- application. The combination of *in situ* vermiculture with mulching and 100 per cent RDF application recorded the maximum uptake of both macro and micro nutrients by maize and it was significantly superior to all other treatment combinations.
8. The combination of *in situ* vermiculture with mulching and fertilizer application caused significant reduction in soil pH and improved the organic carbon and available N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O and SO<sub>4</sub>-S content and DTPA extractable micronutrients status of soil.
  9. Infiltration rate of soil increased slightly due to mulching and was almost doubled due to *in situ* vermiculture and tripled due to *in situ* vermiculture with mulching. It improved marginally due to fertilizer levels.
  10. The population and biomass of both the native and introduced worms increased due to mulching. Application of different levels of fertilizers did not have any adverse effect on population and biomass of earthworms.

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\* Original not seen.

# Appendices

Appendix 1. Chemical composition of crop residues

Crop residues	Elemental composition (%)							Carbon : Nutrient ratio				Micronutrients content (mg kg <sup>-1</sup> )			
	C	N	P	K	S	C/N	C/P	C/S	Zn	Mn	Cu	Fe			
Sunflower stalks	40.11	0.48	0.06	0.70	0.14	83.56	668.50	286.50	14.22	50.22	12.25	225			
Maize stover	42.20	0.45	0.17	1.26	0.11	93.78	248.24	383.64	15.47	41.37	9.53	214			
Cotton stalks	41.70	0.42	0.07	0.72	0.06	99.29	595.71	695.00	12.32	35.52	9.39	205			
Sunn hemp stalks	42.50	1.52	0.21	1.85	0.22	27.96	202.38	193.18	35.80	60.75	15.35	348			
Paddy straw	36.60	0.56	0.14	1.29	0.12	65.36	215.29	305.00	16.20	40.20	11.25	230			

Appendix 2. Quantity and cost of different inputs used for maize cultivation for one hectare.

Items	Quantity	Rate	Total Amount (Rs ha <sup>-1</sup> )
Seeds	15 kg	Rs. 11.00 kg <sup>-1</sup>	165
F.Y.M	20 t	Rs.150.00 t <sup>-1</sup>	3000
Vermicompost			
a) 2.5 t	2.5 t	Rs.600.00 t <sup>-1</sup>	1500
b) 5.0 t	5.0 t	---"---	3000
Earthworms	2,50,000	Rs.20.00 thousand worms <sup>-1</sup>	5000
Crop residue	5.0 t	Rs.100.00 t <sup>-1</sup>	500
Chemical fertilizers			
a) 100% RDF (150 kg N + 75 kg P <sub>2</sub> O <sub>5</sub> + 40 kg K <sub>2</sub> O)			
i) Urea	326 kg	Rs.3.40 kg <sup>-1</sup>	1108
ii) S.S.P	468 kg	Rs.2.79 kg <sup>-1</sup>	1307
iii) Muriate of Potash	67 kg	Rs.4.35 kg <sup>-1</sup>	291
			2706
b) 50 % RDF	-	-	1353
c) 25 % RDF	-	-	676
Preparatory tillage	-	-	500
Sowing and ferertilzer application	-	-	200
Weeding	-	-	1000
Irrigation	6 times	Rs.75.00 irrigation <sup>-1</sup>	450
Harvesting/threshing	-	-	500
Land rent and marketing charges	-	-	200

Appendix 3. Gross returns ('000' Rs ha<sup>-1</sup>) of maize as realized due to application of organic manures and fertilizer levels.

Treatments	F <sub>1</sub>	F <sub>2</sub>	F <sub>3</sub>	C mean
C <sub>1</sub>	11.45	16.91	20.50	16.29
C <sub>2</sub>	12.80	18.23	21.23	17.42
C <sub>3</sub>	13.96	21.51	25.34	20.27
C <sub>4</sub>	14.52	26.53	27.88	22.98
<b>F mean</b>	<b>13.18</b>	<b>20.79</b>	<b>23.74</b>	-

	SEm ±	CD at 5%
C -	0.52	1.81
F -	0.30	0.90
F x C -	0.60	1.79
C x F -	0.72	2.15

Appendix 4. Gross returns ('000' Rs ha<sup>-1</sup>) as realized due to *in situ* vermiculture and fertilizer levels.

Treatments	F <sub>1</sub>	F <sub>2</sub>	F <sub>3</sub>	F mean
W <sub>1</sub>	13.55	18.43	20.52	17.50
W <sub>2</sub>	14.47	19.61	21.78	18.62
W <sub>3</sub>	17.86	20.59	22.50	20.32
W <sub>4</sub>	20.30	28.62	28.96	25.96
<b>W mean</b>	<b>16.54</b>	<b>21.81</b>	<b>23.44</b>	-

	SEm±	CD at 5%
C -	0.23	0.81
F -	0.27	0.82
F x C -	0.54	1.63
C x F -	0.50	1.51

Note - Modal price of maize grain Koppal market during 1994-95 Rs.362 per quintal and market price of maize stover Rs.200 per ton.

Appendix 5. Effect of organic manures and fertilizer levels on nutrients content of maize grain

Treatment	Concentration (%)						Concentration (mg kg <sup>-1</sup> )			
	N	P	K	Ca	Mg	S	Zn	Mn	Cu	Fe
C <sub>1</sub> F <sub>1</sub>	1.54	0.223	0.330	0.067	0.137	0.057	11.97	8.80	2.10	20.00
C <sub>1</sub> F <sub>2</sub>	1.63	0.240	0.330	0.077	0.147	0.062	12.60	9.67	2.53	22.67
C <sub>1</sub> F <sub>3</sub>	1.71	0.267	0.343	0.077	0.153	0.063	13.13	10.13	2.87	24.67
C <sub>1</sub> mean	1.63	0.243	0.334	0.073	0.146	0.061	12.57	9.53	2.50	22.44
C <sub>2</sub> F <sub>1</sub>	1.57	0.237	0.330	0.067	0.143	0.060	12.53	9.13	2.33	21.67
C <sub>2</sub> F <sub>2</sub>	1.65	0.253	0.347	0.083	0.157	0.063	13.17	10.10	2.77	23.67
C <sub>2</sub> F <sub>3</sub>	1.73	0.277	0.350	0.083	0.163	0.067	14.03	10.60	3.03	25.33
C <sub>2</sub> mean	1.65	0.256	0.342	0.078	0.154	0.063	13.24	9.94	2.71	23.56
C <sub>3</sub> F <sub>1</sub>	1.67	0.247	0.340	0.073	0.143	0.062	12.53	9.30	2.67	27.33
C <sub>3</sub> F <sub>2</sub>	1.73	0.267	0.347	0.087	0.163	0.075	13.77	10.27	3.07	29.33
C <sub>3</sub> F <sub>3</sub>	1.80	0.283	0.360	0.087	0.167	0.077	14.70	10.70	3.40	31.67
C <sub>3</sub> mean	1.73	0.266	0.349	0.082	0.158	0.071	13.67	10.09	3.04	29.44
C <sub>4</sub> F <sub>1</sub>	1.73	0.253	0.343	0.083	0.147	0.065	13.80	9.77	2.83	26.33
C <sub>4</sub> F <sub>2</sub>	1.82	0.290	0.360	0.097	0.163	0.077	14.40	11.13	3.17	30.00
C <sub>4</sub> F <sub>3</sub>	1.83	0.300	0.363	0.097	0.173	0.080	14.83	11.27	3.37	31.67
C <sub>4</sub> mean	1.79	0.281	0.356	0.092	0.161	0.074	14.34	10.72	3.12	29.33
F mean										
F <sub>1</sub>	1.63	0.240	0.336	0.073	0.142	0.061	12.71	9.25	2.48	23.83
F <sub>2</sub>	1.71	0.263	0.346	0.086	0.158	0.069	13.48	10.29	2.88	26.42
F <sub>3</sub>	1.77	0.282	0.354	0.086	0.164	0.072	14.18	10.68	3.17	28.33
CD at 5%										
C	0.025	0.013	NS	0.014	0.012	0.009	0.76	0.40	0.29	2.57
F	0.033	0.010	0.008	0.006	0.006	0.005	0.26	0.30	0.18	0.97
F x C	NS	NS	NS	NS	NS	NS	0.52	NS	NS	NS
C x F	NS	NS	NS	NS	NS	NS	0.74	NS	NS	NS

C<sub>1</sub> = Control, C<sub>2</sub> = FYM @ 20 t ha<sup>-1</sup>, C<sub>3</sub> = Vermicompost @ 2.5 t ha<sup>-1</sup> and C<sub>4</sub> = Vermicompost @ 5.0 t ha<sup>-1</sup>

F<sub>1</sub> = 25 per cent RDF, F<sub>2</sub> = 50 per cent RDF and F<sub>3</sub> = 100 per cent RDF

Appendix 6. Effect of organic manures and fertilizer levels on nutrients content of maize stover

Treatment	Concentration (%)						Concentration (mg kg <sup>-1</sup> )			
	N	P	K	Ca	Mg	S	Zn	Mn	Cu	Fe
C <sub>1</sub> F <sub>1</sub>	0.323	0.110	1.17	0.157	0.160	0.087	13.93	38.47	8.33	200
C <sub>1</sub> F <sub>2</sub>	0.353	0.143	1.19	0.173	0.177	0.100	14.60	40.30	8.73	205
C <sub>1</sub> F <sub>3</sub>	0.400	0.163	1.26	0.177	0.183	0.112	15.57	41.20	9.13	213
C <sub>1</sub> mean	0.359	0.139	1.21	0.169	0.173	0.099	14.70	39.99	8.73	206
C <sub>2</sub> F <sub>1</sub>	0.367	0.123	1.21	0.163	0.173	0.090	14.30	39.37	9.03	205
C <sub>2</sub> F <sub>2</sub>	0.407	0.153	1.25	0.180	0.187	0.105	15.20	40.67	9.13	209
C <sub>2</sub> F <sub>3</sub>	0.440	0.183	1.28	0.183	0.187	0.117	15.93	42.23	9.43	215
C <sub>2</sub> mean	0.404	0.153	1.25	0.176	0.182	0.104	15.14	40.76	9.20	210
C <sub>3</sub> F <sub>1</sub>	0.393	0.147	1.22	0.163	0.170	0.098	14.40	40.00	8.87	207
C <sub>3</sub> F <sub>2</sub>	0.433	0.173	1.26	0.177	0.187	0.113	15.47	41.37	9.53	214
C <sub>3</sub> F <sub>3</sub>	0.473	0.193	1.30	0.180	0.187	0.115	16.40	43.10	9.87	219
C <sub>3</sub> mean	0.433	0.171	1.26	0.173	0.181	0.109	15.42	41.49	9.42	213
C <sub>4</sub> F <sub>1</sub>	0.400	0.157	1.23	0.170	0.173	0.103	16.23	39.90	9.23	209
C <sub>4</sub> F <sub>2</sub>	0.443	0.177	1.29	0.183	0.193	0.120	17.10	42.20	9.83	217
C <sub>4</sub> F <sub>3</sub>	0.453	0.197	1.31	0.187	0.193	0.122	17.73	43.83	10.20	220
C <sub>4</sub> mean	0.432	0.177	1.28	0.180	0.187	0.115	17.02	41.98	9.76	215
F mean										
F <sub>1</sub>	0.371	0.134	1.21	0.163	0.169	0.095	14.72	39.43	8.87	205
F <sub>2</sub>	0.409	0.162	1.25	0.178	0.186	0.110	15.59	41.13	9.31	211
F <sub>3</sub>	0.442	0.184	1.29	0.182	0.188	0.116	16.41	42.59	9.66	217
CD at 5%										
C	0.037	0.010	0.023	0.010	0.009	0.007	0.52	1.12	0.40	4.16
F	0.015	0.010	0.019	0.009	0.008	0.007	0.36	1.46	0.25	2.46
F x C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C x F	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

C<sub>1</sub> = Control, C<sub>2</sub> = FYM @ 20 t ha<sup>-1</sup>, C<sub>3</sub> = Vermicompost @ 2.5 t ha<sup>-1</sup> and  
 C<sub>4</sub> = Vermicompost @ 5.0 t ha<sup>-1</sup>  
 F<sub>1</sub> = 25 per cent RDF, F<sub>2</sub> = 50 per cent RDF and F<sub>3</sub> = 100 per cent RDF

Appendix 7. Effect of Organic manures and fertilizer levels on the uptake of N, P and K ( $\text{kg ha}^{-1}$ ) by maize

Treatments	N			P			K		
	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total
$C_1F_1$	44.96	13.82	58.79	6.53	4.69	11.23	9.70	34.18	43.88
$C_1F_2$	71.23	18.71	89.94	10.51	7.57	18.08	14.80	52.12	66.92
$C_1F_3$	91.08	25.21	106.29	14.17	10.32	24.50	18.26	66.98	85.25
$C_1$ mean	69.09	19.25	85.01	10.40	7.53	17.93	14.25	51.07	65.35
$C_2F_1$	51.49	16.84	68.33	7.76	5.69	13.45	10.83	39.77	50.61
$C_2F_2$	77.58	23.53	101.11	11.97	8.86	20.83	16.33	58.92	75.24
$C_2F_3$	94.72	30.16	124.88	15.18	12.57	27.76	19.23	70.22	89.45
$C_2$ mean	74.60	23.51	98.11	11.64	9.04	20.68	15.46	56.30	71.77
$C_3F_1$	59.99	18.80	78.79	8.85	7.00	15.85	12.20	43.66	55.86
$C_3F_2$	96.32	29.55	125.87	14.86	11.83	26.69	19.26	69.96	89.24
$C_3F_3$	118.36	37.79	156.03	18.59	15.44	34.03	23.60	85.27	108.87
$C_3$ mean	91.56	28.71	120.23	14.10	11.42	25.52	18.35	66.30	84.66
$C_4F_1$	64.22	21.30	85.51	9.42	8.33	17.76	12.74	45.75	58.49
$C_4F_2$	125.67	34.11	159.78	20.04	13.61	33.65	24.84	89.24	114.08
$C_4F_3$	132.30	37.11	169.41	21.76	16.11	37.87	26.37	94.93	121.31
$C_4$ mean	107.40	30.84	138.24	17.08	12.68	29.76	21.32	76.64	97.96
<b>F mean</b>									
$F_1$	55.17	17.69	72.86	8.14	6.43	14.57	11.37	40.84	52.21
$F_2$	92.70	26.48	119.18	14.34	10.47	24.81	18.81	67.56	86.37
$F_3$	109.12	32.57	139.15	17.43	13.61	31.04	21.86	79.35	101.22
<b>CD at 5%</b>									
C	8.26	1.92	8.96	1.74	0.67	2.01	2.01	6.59	8.51
F	4.01	1.76	5.80	0.77	0.84	1.12	0.95	2.94	3.80
F x C	8.02	3.51	11.60	1.54	NS	2.25	1.89	5.89	7.60
C x F	9.70	3.31	12.24	1.96	NS	2.53	2.33	7.46	9.64

$C_1$  = Control,  $C_2$  = FYM @ 20  $\text{t ha}^{-1}$ ,  $C_3$  = Vermicompost @ 2.5  $\text{t ha}^{-1}$  and

$C_4$  = Vermicompost @ 5.0  $\text{t ha}^{-1}$

$F_1$  = 25 per cent RDP,  $F_2$  = 50 per cent RDP and  $F_3$  = 100 per cent RDP

Appendix 8. Effect of organic manures and fertilizer levels on uptake of Ca, Mg and S ( $\text{kg ha}^{-1}$ ) by maize.

Treatments	Ca			Mg			S		
	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total
$C_1F_1$	1.97	6.71	8.67	4.02	6.86	10.87	1.67	3.71	5.38
$C_1F_2$	3.36	9.14	12.50	6.43	9.35	15.78	2.70	5.27	7.96
$C_1F_3$	4.07	11.13	15.20	8.15	11.55	19.70	3.37	7.03	10.40
$C_1$ mean	3.13	8.99	12.13	6.20	9.25	15.45	2.58	5.34	7.91
$C_2F_1$	2.19	7.49	9.68	4.71	7.97	12.68	1.97	4.12	6.09
$C_2F_2$	3.93	10.37	14.31	7.40	10.80	18.20	2.98	6.07	9.05
$C_2F_3$	4.56	12.54	17.10	8.96	12.79	21.75	3.66	8.02	11.67
$C_2$ mean	3.56	10.13	13.70	7.02	10.52	17.54	2.87	6.07	8.94
$C_3F_1$	2.63	7.80	10.43	5.15	8.11	13.26	2.22	4.71	6.93
$C_3F_2$	4.82	12.06	16.87	9.10	12.74	21.84	4.18	7.74	11.92
$C_3F_3$	5.68	14.38	20.06	10.93	14.92	25.85	5.04	9.17	14.21
$C_3$ mean	4.38	11.41	15.79	8.39	11.93	20.32	3.82	7.20	11.02
$C_4F_1$	3.11	9.08	12.18	5.46	9.25	14.71	2.43	5.47	7.90
$C_4F_2$	6.72	14.11	20.83	11.26	14.88	26.14	5.29	9.22	14.51
$C_4F_3$	6.99	15.29	22.28	12.59	15.84	28.43	5.79	9.98	15.76
$C_4$ mean	5.60	12.83	18.43	9.77	13.32	23.09	4.50	8.22	12.72
$F$ mean									
$F_1$	2.47	7.77	10.24	4.84	8.05	12.88	2.07	4.50	6.58
$F_2$	4.71	11.42	16.13	8.55	11.94	20.49	3.79	7.07	10.86
$F_3$	5.33	13.34	18.66	10.16	13.78	23.93	4.46	8.55	13.01
CD at 5%									
C	0.70	0.68	1.00	1.02	0.78	1.21	0.55	0.59	0.96
F	0.28	0.77	0.84	0.47	0.90	1.02	0.26	0.56	0.67
F x C	0.55	NS	1.68	0.94	NS	2.05	0.51	NS	1.35
C x F	0.75	NS	1.62	1.16	NS	1.97	0.63	NS	1.38

$C_1$  = Control,  $C_2$  = FYM @ 20 t  $\text{ha}^{-1}$ ,  $C_3$  = Vermicompost @ 2.5 t  $\text{ha}^{-1}$  and  $C_4$  = Vermicompost @ 5.0 t  $\text{ha}^{-1}$   
 $F_1$  = 25 per cent RDF,  $F_2$  = 50 per cent RDF and  $F_3$  = 100 per cent RDF

Appendix 9. Effect of organic manures and fertilizer levels on uptake of micronutrients ( $\text{g ha}^{-1}$ ) by maize

Treatments	Zn			Mn			Cu			Fe		
	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total
$C_1F_1$	35	60	94	26	165	190	6.2	36	42	59	855	914
$C_1F_2$	55	77	132	42	213	255	11.1	46	57	99	1085	1184
$C_1F_3$	70	98	168	51	260	311	15.2	58	73	131	1341	1482
$C_1$ mean	53	78	132	40	213	252	10.8	46	57	96	1094	1193
$C_2F_1$	41	66	107	30	181	211	7.7	40	48	71	940	1012
$C_2F_2$	62	88	150	48	235	282	13.1	53	66	112	1207	1318
$C_2F_3$	77	109	186	58	289	347	16.6	65	81	139	1471	1610
$C_2$ mean	60	88	148	45	235	280	12.5	52	65	107	1206	1313
$C_3F_1$	45	69	114	33	191	224	9.6	42	52	98	989	1086
$C_3F_2$	77	106	182	57	282	340	17.1	65	82	163	1458	1621
$C_3F_3$	96	131	227	70	344	415	22.3	79	101	208	1752	1959
$C_3$ mean	73	102	174	54	273	326	16.4	62	78	156	1400	1556
$C_4F_1$	51	86	138	36	213	249	10.5	49	60	98	1112	1210
$C_4F_2$	100	132	231	77	325	402	21.8	76	98	207	1667	1875
$C_4F_3$	108	145	253	82	359	441	24.4	84	108	230	1804	2068
$C_4$ mean	86	121	207	65	299	364	18.9	70	88	178	1528	1717
F mean												
$F_1$	43	70	113	31	187	219	8.5	42	50	81	974	1055
$F_2$	73	101	174	56	264	320	15.8	60	76	145	1354	1500
$F_3$	88	121	208	65	313	378	19.6	71	91	177	1592	1780
CD at 5%												
C	7.0	5.5	8.4	5.1	16.8	17.2	1.8	3.2	4.2	21.1	82	84
F	3.6	5.6	6.8	2.9	15.8	16.0	1.1	3.7	4.0	7.9	80	86
F x C	7.1	11.1	13.6	5.8	31.7	32.1	2.2	7.4	8.0	15.9	160	172
C x F	8.4	10.3	13.3	6.5	29.7	30.1	2.3	6.7	7.5	22.4	148	158

$C_1$  = Control,  $C_2$  = FYM @  $20 \text{ t ha}^{-1}$ ,  $C_3$  = Vermicompost @  $2.5 \text{ t ha}^{-1}$  and

$C_4$  = Vermicompost @  $5.0 \text{ t ha}^{-1}$

$F_1$  = 25 per cent RDF,  $F_2$  = 50 per cent RDF and  $F_3$  = 100 per cent RDF

Appendix 10. Effect of in situ vermiculture and fertilizer levels on nutrients content of maize grain.

Treatment	Concentration (%)						Concentration (mg kg <sup>-1</sup> )			
	N	P	K	Ca	Mg	S	Zn	Mn	Cu	Fe
W <sub>1</sub> F <sub>1</sub>	1.55	0.233	0.227	0.070	0.147	0.058	12.17	9.53	2.30	20.67
W <sub>1</sub> F <sub>2</sub>	1.67	0.253	0.247	0.083	0.157	0.067	12.97	10.27	2.80	23.67
W <sub>1</sub> F <sub>3</sub>	1.76	0.273	0.263	0.097	0.163	0.068	14.13	10.67	3.00	27.00
W <sub>1</sub> mean	1.66	0.253	0.246	0.083	0.156	0.064	13.09	10.16	2.70	23.78
W <sub>2</sub> F <sub>1</sub>	1.62	0.257	0.237	0.083	0.150	0.062	12.57	9.73	2.60	24.33
W <sub>2</sub> F <sub>2</sub>	1.74	0.273	0.257	0.093	0.163	0.075	14.07	10.17	2.93	28.00
W <sub>2</sub> F <sub>3</sub>	1.80	0.283	0.267	0.100	0.167	0.077	14.93	10.77	3.30	30.33
W <sub>2</sub> mean	1.72	0.271	0.253	0.092	0.160	0.071	13.86	10.22	2.94	27.56
W <sub>3</sub> F <sub>1</sub>	1.70	0.263	0.250	0.083	0.153	0.062	13.03	10.23	2.87	26.67
W <sub>3</sub> F <sub>2</sub>	1.83	0.283	0.277	0.087	0.170	0.075	14.27	11.57	3.30	30.33
W <sub>3</sub> F <sub>3</sub>	1.87	0.303	0.293	0.100	0.173	0.078	15.37	12.07	3.77	34.00
W <sub>3</sub> mean	1.80	0.283	0.273	0.090	0.166	0.072	14.22	11.29	3.31	30.33
W <sub>4</sub> F <sub>1</sub>	1.77	0.273	0.263	0.093	0.163	0.068	13.87	10.47	3.20	27.67
W <sub>4</sub> F <sub>2</sub>	1.96	0.307	0.287	0.113	0.180	0.080	15.43	12.17	3.67	33.00
W <sub>4</sub> F <sub>3</sub>	1.96	0.317	0.293	0.117	0.183	0.082	15.40	12.60	3.83	33.33
W <sub>4</sub> mean	1.90	0.299	0.281	0.108	0.176	0.077	14.90	11.74	3.57	31.33
F mean										
F <sub>1</sub>	1.66	0.257	0.244	0.083	0.153	0.063	12.91	9.99	2.74	24.83
F <sub>2</sub>	1.80	0.279	0.267	0.094	0.168	0.074	14.18	11.04	3.18	28.75
F <sub>3</sub>	1.85	0.294	0.279	0.103	0.172	0.076	14.96	11.52	3.48	31.17
CD at 5%										
W	0.05	0.011	0.007	0.011	0.012	0.008	0.50	0.32	0.20	1.61
F	0.03	0.007	0.008	0.008	0.008	0.005	0.28	0.25	0.21	2.18
F x W	NS	NS	NS	NS	NS	NS	0.56	0.49	NS	NS
W x F	NS	NS	NS	NS	NS	NS	0.60	0.48	NS	NS

W<sub>1</sub> = No mulch no worms, W<sub>2</sub> = Mulch without worms,  
W<sub>3</sub> = Worms without mulch and W<sub>4</sub> = Worms with mulch  
F<sub>1</sub> = 25 per cent RDF, F<sub>2</sub> = 50 per cent RDF and  
F<sub>3</sub> = 100 per cent RDF

Appendix 11. Effect of in situ vermiculture and fertilizer levels on nutrients content of maize stover

Treatment	Concentration (%)						Concentration (mg kg <sup>-1</sup> )			
	N	P	K	Ca	Mg	S	Zn	Mn	Cu	Fe
W <sub>1</sub> F <sub>1</sub>	0.350	0.143	1.20	0.163	0.173	0.090	13.17	39.83	8.10	204
W <sub>1</sub> F <sub>2</sub>	0.380	0.163	1.24	0.180	0.187	0.107	15.23	40.80	9.40	210
W <sub>1</sub> F <sub>3</sub>	0.423	0.183	1.28	0.183	0.187	0.112	16.00	42.10	10.27	215
W <sub>1</sub> mean	0.384	0.163	1.24	0.175	0.182	0.103	14.80	40.91	9.26	210
W <sub>2</sub> F <sub>1</sub>	0.380	0.157	1.22	0.163	0.177	0.097	13.93	40.23	9.23	205
W <sub>2</sub> F <sub>2</sub>	0.420	0.177	1.26	0.177	0.187	0.110	15.43	41.20	9.90	216
W <sub>2</sub> F <sub>3</sub>	0.440	0.187	1.28	0.183	0.187	0.117	16.40	43.00	10.73	220
W <sub>2</sub> mean	0.413	0.173	1.25	0.174	0.183	0.108	15.26	41.48	9.96	214
W <sub>3</sub> F <sub>1</sub>	0.380	0.157	1.24	0.170	0.180	0.098	17.37	40.13	9.40	209
W <sub>3</sub> F <sub>2</sub>	0.417	0.183	1.29	0.187	0.190	0.110	17.90	41.93	10.27	217
W <sub>3</sub> F <sub>3</sub>	0.450	0.203	1.32	0.187	0.203	0.118	18.40	43.97	10.57	223
W <sub>3</sub> mean	0.416	0.181	1.28	0.181	0.191	0.109	17.89	42.01	10.08	216
W <sub>4</sub> F <sub>1</sub>	0.410	0.173	1.25	0.173	0.193	0.112	17.80	40.80	9.50	210
W <sub>4</sub> F <sub>2</sub>	0.470	0.213	1.33	0.200	0.213	0.125	18.63	44.40	10.53	222
W <sub>4</sub> F <sub>3</sub>	0.480	0.223	1.34	0.207	0.220	0.132	18.93	44.93	10.53	226
W <sub>4</sub> mean	0.453	0.203	1.31	0.193	0.209	0.123	18.46	43.38	10.18	219
F mean										
F <sub>1</sub>	0.380	0.158	1.23	0.168	0.181	0.099	15.60	40.25	9.06	207
F <sub>2</sub>	0.422	0.184	1.28	0.186	0.194	0.113	16.80	42.08	10.02	216
F <sub>3</sub>	0.448	0.199	1.31	0.190	0.199	0.120	17.40	43.50	10.52	221
CD AT 5%										
W	0.026	0.011	0.026	0.013	0.014	0.011	1.38	1.10	0.53	3.62
F	0.017	0.007	0.015	0.010	0.009	0.006	0.73	0.63	0.40	2.65
F x W	NS	0.014	0.029	NS	NS	NS	NS	1.26	NS	NS
W x F	NS	0.015	0.031	NS	NS	NS	NS	1.35	NS	NS

W<sub>1</sub> = No mulch no worms, W<sub>2</sub> = Mulch without worms,  
W<sub>3</sub> = Worms without mulch and W<sub>4</sub> = Worms with mulch  
F<sub>1</sub> = 25 per cent RDF, F<sub>2</sub> = 50 per cent RDF and  
F<sub>3</sub> = 100 per cent RDF

Appendix 12. Effect of in situ vermiculture and fertilizer levels on uptake of N,P and K (kg ha<sup>-1</sup>) by maize.

Treatments	N			P			K		
	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total
W <sub>1</sub> F <sub>1</sub>	54.07	16.00	70.06	8.13	6.88	14.68	7.90	54.38	62.88
W <sub>1</sub> F <sub>2</sub>	80.01	20.39	100.40	12.30	8.76	21.06	11.82	66.58	78.39
W <sub>1</sub> F <sub>3</sub>	93.54	28.03	121.57	14.50	12.16	26.66	13.96	84.57	98.53
W <sub>1</sub> mean	75.87	21.47	97.34	11.64	9.27	20.80	11.23	68.71	79.94
W <sub>2</sub> F <sub>1</sub>	60.48	17.94	78.42	9.60	7.40	17.01	8.87	57.78	66.65
W <sub>2</sub> F <sub>2</sub>	88.40	25.23	113.62	13.91	10.63	24.54	13.05	75.53	88.58
W <sub>2</sub> F <sub>3</sub>	101.18	32.16	133.34	15.90	13.67	29.57	14.97	93.94	108.90
W <sub>2</sub> mean	83.35	25.11	108.46	13.14	10.57	23.70	12.30	75.75	88.05
W <sub>3</sub> F <sub>1</sub>	78.89	20.12	99.01	12.21	8.30	20.50	11.62	65.54	77.16
W <sub>3</sub> F <sub>2</sub>	97.22	27.95	125.16	15.09	12.31	27.40	14.73	86.28	101.01
W <sub>3</sub> F <sub>3</sub>	107.63	35.20	142.83	17.54	15.89	33.44	16.97	102.91	119.88
W <sub>3</sub> mean	94.58	27.76	122.34	14.95	12.17	27.11	14.44	84.91	99.35
W <sub>4</sub> F <sub>1</sub>	92.56	27.34	119.90	14.32	11.55	25.87	13.80	83.06	96.86
W <sub>4</sub> F <sub>2</sub>	145.36	42.98	188.33	22.71	19.48	42.19	21.21	121.51	142.72
W <sub>4</sub> F <sub>3</sub>	146.80	45.29	192.08	23.69	21.07	44.76	21.93	126.70	148.63
W <sub>4</sub> mean	128.24	38.53	166.77	20.24	17.37	37.61	18.98	110.42	129.40
F mean									
F <sub>1</sub>	71.50	20.35	91.85	11.07	8.53	19.51	10.55	65.34	75.89
F <sub>2</sub>	102.74	29.14	131.88	16.00	12.80	28.80	15.20	87.47	102.68
F <sub>3</sub>	112.29	35.17	147.46	17.91	15.70	33.61	16.96	102.03	118.99
CD at 5% )									
W	2.76	0.79	2.39	0.79	0.53	1.17	0.61	2.78	2.98
F	3.88	2.02	4.88	0.66	0.84	1.09	0.62	4.96	5.16
F x W	7.76	4.04	9.76	1.33	NS	2.17	1.24	9.92	10.32
W x F	6.77	3.37	8.23	1.28	NS	2.04	1.14	8.45	8.82

W<sub>1</sub> = No mulch no worms, W<sub>2</sub> = Mulch without worms,  
W<sub>3</sub> = Worms without mulch and W<sub>4</sub> = Worms with mulch  
F<sub>1</sub> = 25 per cent RDF, F<sub>2</sub> = 50 per cent RDF and  
F<sub>3</sub> = 100 per cent RDF

Appendix 13. Effect of in situ vermiculture and fertilizer levels on uptake Ca, Mg and S (kg ha<sup>-1</sup>) by maize

Treatments	Ca			Mg			S		
	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total
W <sub>1</sub> F <sub>1</sub>	2.46	7.46	9.92	5.12	7.90	13.02	2.04	4.10	6.14
W <sub>1</sub> F <sub>2</sub>	3.98	9.68	13.66	7.50	10.01	17.51	3.20	5.73	8.93
W <sub>1</sub> F <sub>3</sub>	5.13	12.14	17.27	8.66	12.38	21.04	3.63	7.40	11.02
W <sub>1</sub> mean	3.86	9.76	13.62	7.09	10.10	17.19	2.96	5.74	8.70
W <sub>2</sub> F <sub>1</sub>	3.13	7.28	10.85	5.63	8.37	14.00	2.30	4.55	6.87
W <sub>2</sub> F <sub>2</sub>	4.73	10.64	15.34	8.30	11.23	19.53	3.82	6.60	10.42
W <sub>2</sub> F <sub>3</sub>	5.62	13.41	19.02	9.35	13.67	23.01	4.30	8.55	12.84
W <sub>2</sub> mean	4.49	10.59	15.07	7.76	11.09	18.85	3.47	6.56	10.04
W <sub>3</sub> F <sub>1</sub>	3.85	9.00	12.85	7.13	9.54	16.66	2.87	5.21	8.08
W <sub>3</sub> F <sub>2</sub>	4.62	12.52	17.14	9.06	12.73	21.79	4.00	7.37	11.37
W <sub>3</sub> F <sub>3</sub>	5.79	14.60	20.39	10.02	15.88	26.24	4.53	9.24	13.77
W <sub>3</sub> mean	4.76	12.04	16.80	8.74	12.72	21.56	3.80	7.28	11.07
W <sub>4</sub> F <sub>1</sub>	4.90	11.54	16.44	8.57	12.88	21.44	3.58	7.45	11.03
W <sub>4</sub> F <sub>2</sub>	8.40	18.29	26.69	13.31	19.50	32.81	5.93	11.41	17.33
W <sub>4</sub> F <sub>3</sub>	8.73	19.09	27.82	13.71	20.73	34.44	6.11	12.41	18.52
W <sub>4</sub> mean	6.32	16.31	23.65	11.86	17.70	29.57	5.21	10.42	15.63
F mean									
F <sub>1</sub>	3.58	8.93	12.52	6.61	9.67	16.28	2.70	5.33	8.03
F <sub>2</sub>	5.43	12.78	18.21	7.54	13.37	22.91	4.24	7.78	12.01
F <sub>3</sub>	6.32	14.81	21.13	10.43	15.66	26.18	4.64	9.40	14.04
CD at 5%									
W	0.47	0.64	1.02	0.50	0.89	1.23	0.37	0.70	0.94
F	0.41	0.99	1.21	0.49	0.84	1.01	0.27	0.44	0.54
F x W	0.82	NS	2.42	0.97	1.69	2.01	0.53	0.87	1.07
W x F	0.79	NS	2.16	0.91	1.58	1.96	0.54	0.93	1.19

W<sub>1</sub> = No mulch no worms, W<sub>2</sub> = Mulch without worms,  
W<sub>3</sub> = Worms without mulch and W<sub>4</sub> = Worms with mulch  
F<sub>1</sub> = 25 per cent RDF, F<sub>2</sub> = 50 per cent RDF and  
F<sub>3</sub> = 100 per cent RDF

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Appendix 14. Effect of in situ vermiculture on uptake of micronutrients by maize ( $\text{g ha}^{-1}$ )

Treatments	Zn			Mn			Cu			Fe		
	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total
W <sub>1</sub> F <sub>1</sub>	42	60	103	33	182	215	8.0	37	45	72	933	1005
W <sub>1</sub> F <sub>2</sub>	62	82	144	49	219	268	13.4	50	64	113	1129	1259
W <sub>1</sub> F <sub>3</sub>	75	106	181	57	236	293	15.9	68	84	143	1425	1568
W <sub>1</sub> mean	60	83	142	46	212	259	12.5	52	64	110	1162	1278
W <sub>2</sub> F <sub>1</sub>	47	66	113	36	190	227	9.7	44	53	91	971	1062
W <sub>2</sub> F <sub>2</sub>	72	93	164	52	248	299	14.9	60	74	142	1299	1441
W <sub>2</sub> F <sub>3</sub>	84	120	204	60	315	375	18.5	79	97	170	1612	1782
W <sub>2</sub> mean	68	93	160	50	251	300	14.4	61	75	134	1294	1428
W <sub>3</sub> F <sub>1</sub>	61	92	153	48	213	260	14.3	50	64	124	1106	1230
W <sub>3</sub> F <sub>2</sub>	76	120	196	62	281	343	17.6	69	86	162	1453	1615
W <sub>3</sub> F <sub>3</sub>	89	144	233	70	344	413	21.8	83	104	197	1741	1938
W <sub>3</sub> mean	75	119	194	60	279	339	17.9	67	85	161	1433	1594
W <sub>4</sub> F <sub>1</sub>	73	119	192	55	272	327	16.8	63	80	145	1397	1542
W <sub>4</sub> F <sub>2</sub>	114	170	284	90	405	496	27.2	96	123	244	2024	2269
W <sub>4</sub> F <sub>3</sub>	115	179	294	94	424	518	28.7	99	128	249	2128	2378
W <sub>4</sub> mean	101	156	256	80	367	447	24.2	86	110	213	1850	2063
F mean												
F <sub>1</sub>	56	84	140	43	214	257	12.2	48	61	108	1102	1210
F <sub>2</sub>	81	116	197	63	288	352	18.3	69	87	165	1476	1646
F <sub>3</sub>	91	137	228	70	330	400	21.2	82	103	190	1727	1916
CD at 5%												
W	3.7	6.5	5.8	3.3	26.5	28.2	1.4	1.9	1.6	7.5	38	41
F	3.4	6.1	7.7	2.4	27.5	28.1	1.5	3.6	4.1	12.4	86	86
F x W	6.7	12.1	15.4	4.9	NS	NS	NS	7.2	8.3	24.8	NS	171
W x F	6.4	11.4	13.6	4.9	NS	NS	NS	4.9	6.9	21.3	NS	144

W<sub>1</sub> = No mulch no worms, W<sub>2</sub> = Mulch without worms,  
W<sub>3</sub> = Worms without mulch and W<sub>4</sub> = Worms with mulch  
F<sub>1</sub> = 25 per cent RDF, F<sub>2</sub> = 50 per cent RDF and  
F<sub>3</sub> = 100 per cent RDF