EFFECTS OF SOIL MANAGEMENT ON ECOSYSTEM-STRUCTURE OF EARTHWORM AND SOIL ARTHROPOD POPULATIONS IN SEMI-ARID TROPICAL ALFISOL AGROECOSYSTEM

V. RAVINDER REDDY M.Sc.

Under the Guidance of
Dr. M. VIKRAM REDDY
Reader in Zoology
(Environmental Biology)

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WARANGAL-506 009, ANDHRA PRADESH, INDIA

May, 1994

DEDICATED TO MY

BELOVED PARENTS

Page No.

DECLARATION

I hereby declare that the research work of this thesis entitled "EFFECTS OF SOIL MANAGEMENT ON ECOSYSTEM-STRUCTURE OF EARTHWORM AND SOIL ARTHROPOD POPULATIONS IN SEMI-ARID TROPICAL ALFISOL AGROECOSYSTEM" has been originally carried out by me in the Department of Zoology, Kakatiya University, Warangal and at ICRISAT Center, Patancheru 502 324, (Andhra Pradesh, India), and it has not been submitted either in full or in part for the award of any degree or diploma to any other Institution/University.

Ravinder Reddy

V. RAVINDER REDDY
CSIR Sr. Research Fellow

Environmental Biology Unit
Department of Zoology
Kakatiya University
Warangal-506 009 (A.P.)

Dr. M. Vikram Reddy
Reader in Zoology (Environmental Biology), &
Visiting Scientist at ICRISAT
(under the Rockefeller Foundation Environmental Research Fellowship in International Agriculture)

Environmental Biology Unit
Department of Zoology
Kakatiya University
Vidyaranya Puri
WARANGAL-506 009
A.P., India

CERTIFICATE

I certify that the thesis entitled "EFFECTS OF SOIL MANAGEMENT ON ECOSYSTEM-STRUCTURE OF EARTHWORM AND SOIL ARTHROPOD POPULATIONS IN SEMI-ARID TROPICAL ALFISOL AGROECOSYSTEM" submitted by Mr. V. Ravinder Reddy in fulfilment of the requirements for the degree of Doctor of Philosophy incorporates the results of original investigation carried out by him under my supervision in Department of Zoology, Kakatiya University, Warangal and at ICRISAT Center, Patancheru 502 324, (Andhra Pradesh, India). I, further, certify that he has not submitted this research work either in full or in part for the award of any degree or diploma to any other Institute/University prior, to this.

Date : 16th May, 1994
Place : Warangal

M. VIKRAM REDDY
Research Supervisor

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V. Ravinder Reddy

LIST OF PLATES

LIST OF FIGURES

S.No.	Description	Page No.

LIST OF TABLES

GENERAL INTRODUCTION

Agriculture is one of the major components of any country's economy and, at the cost of the environment, it produces food and fiber needed for the society altering the natural ecological balance. At present, agriculture is considered as the largest a real contributor to nonpoint source water pollution in United States (National Research Council, 1989). Besides, the increased use of modern technology in agriculture is having far reaching consequences in the biosphere increasing threat and damage to the environment. Modern technological revolutions have affected the sustainability in Agriculture. Therefore, efforts have been made in long-term ensuring large and good-quality yield while avoiding harm to the environment. Considerable progress has been made on agricultural mechanisation but the eco-friendly solutions have been very expensive so far, and most of the developing countries can hardly afford them (Krause, 1993) Thus, higher degree of mechanisation can be integrated into agriculture provided special care is taken for the protection of the environment and the mother "earth". Since the mother earth is used for intensive agriculture for more than thousand of years both in east and west, the management of mother earth is at a critical stage for maintaining sustainable production.

Intensive farming including extensive cereal production is often associated with a serious degree of land degradation, usually in the form of wind and water erosion of soil. The soil physical properties and climatic factors combine together to make the soils vulnerable to erosion which causes the major debilitating effects dislocating agriculture and threatening to its sustainability by reducing soil fertility. It is the knowledge of causes, and effects of soil erosion which forms the basis for soil management. With the proper soil management practices, the soil erosion can be controlled. Soil management such as no-tillage reduced water erosion by 95% (Dickey et al, 1984) causing the improved storage of water which increased the crop production and more crop-residue cover in turn, improved erosion control. Thus, soil degradation could be arrested by proper soil management. Scattered data even indicated that it is possible to reverse the soil degradation process (Unger et al, 1991) and by proper soil management the soils can recover some of the productivity potential which was lost during last 5 to 6 decades of mechanical agriculture (Peterson et al, 1992).

The soil environment represent an intricate relationship between the biotic and abiotic components and is affected by various anthropogenic activities including modern agricultural practices (Fig. 1). Soil is a complex system full of life teeming with activity. To improve the soil quality, we have to understand the structure and function of its biotic component in relation to external disturbances. Soil environment is affected by various agricultural management practices such as tillage, organic amendments and crop-covers directly or indirectly. These soil management practices also interact with each other, for example, tillage influence the placement and incorporation of organic residues of both plant and animal origin and in turn control the accessibility of these substrates to soil organisms (Doran and Linn, 1993). The residue placement influences the soil physical factors such as moisture, and temperature, and in turn, the relative activity of certain soil

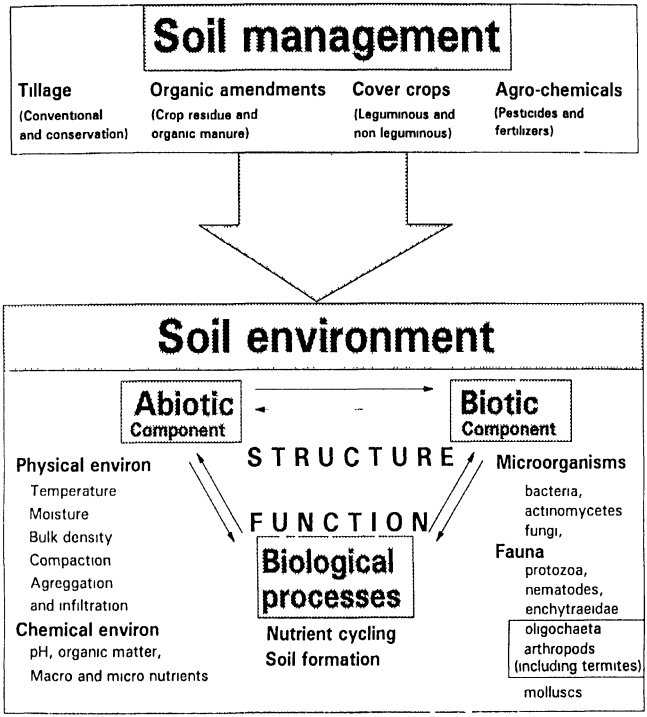

Figure 1 Soil management and soil environment

organisms. The soil abiotic environment which in turn is influenced by climate and vegetation, affect structure and function of the soil biota and the soil biota particularly the invertebrates is responsible for all the ecosystem processes. Partly because of their sheer numbers, they are the biological foundations of every ecosystem. It has been stated that the global ecosystem would collapse if all the invertebrates are removed and the humans and other vertebrates would probably last only a few months.

These invertebrates which occupy the microhabitats of the soil are influenced by the degree of soil disturbance associated with soil management. Conservation tillage is an effective management tool. Its major environmental benefits include reduced soil erosion, more available water particularly surface water under drought conditions, enhanced soil quality, conservation of energy, reduced fossil fuel, machinery investment and labour requirements (Phillips and Phillips, 1984). Soil tillage affects a multitude of properties of the soil environment. It affects directly the soil porosity and its associated microbial and faunal activities. In the 1980s, "no-tillage" was considered ideal for small-scale farming in tropical Africa, where mechanical tillage has caused considerable damage to fragile and shallow soils. But the system was a flop in Africa (Madeley, 1993), because of economic and cultural problems. Moreover, it was a high input system which required a large amount of chemical herbicides to control weeds. Small farmers could hardly afford such huge quantities of herbicides, with the cash squeeze that crunched Africa in recent years. Zero-tillage was something outside the tradition and experiences of small-scale farmers. It can make some sense on large farms. An agroeconomist (Dunstand Spencer) directing IITA's Resource and Crop Management Programme has said that "the institute has admitted defeat".

Plant residues are localized on and near the soil surface in minimum tillage systems, which promotes fungal growth and immobilization of nutrients. This leads to soil biota dominated by fungi, with an abundance of mycophagous nematodes and soil arthropods (Hendrix et al, 1986), and earthworms (Lee, 1985). Zero-tillage increases earthworm activity which turns over soil without causing the kind of erosion that is common with conventional tillage. With conventional tillage, most plant residues are incorporated into the plough layer where they are immediately available for colonization and decomposition by soil organisms. Because of the soil disturbance, soil biotic communities tend to be dominated by aerobic microorganisms (typically bacteria) with high metabolic rates (Doran and Linn, 1993). This results in increasing abundance of bacterivorous fauna (protozoa, nematodes and enchytraeids) in cultivated soils (Hendrix et al, 1986), with rapid decomposition of plant residues and nutrient mineralization. Other soil management practices such as the crop residue mulching has multiple uses (Lal, 1989), and the surface mulching as said earlier, is used as an important tool to conserve soil and water, and improve the soil physical, chemical and biological properties leading to soil productivity. The use of crop residue is the best means of controlling soil erosion. According to Lucas Brader, the IITA director, "maintaining a cover of organic matter on top soil is the essential principal for preventing soil degradation". The cover-crops which may be leguminous and non-leguminous, are important because they not only serve both as persistent live mulch, but act as a protective layer of vegetation that controls weeds, reduces evaporation, prevents erosion, lowers day time soil temperature and, especially if it is leguminous, can enrich the soil with nitrogen and organic matter, Brader said (Madeley, 1993). Cover-crops represent a time honored agricultural practice, and also protects the beneficial soil biota. These soil management practices through the chain of events, protect our most important resources like soil and water and regulate the soil environmental quality and productivity.

Although studies on the effects of modern agricultural management practices such as spraying of pesticides on beneficial soil invertebrate fauna are in replete, unfortunately, few studies have been conducted to evaluate the impact of different soil management practices on their population structure. Investigations on the soil improving management practices for sustainable farming has been undertaken on a piecemeal basis. Extension of the research results to the higher level of complexity, including climate, soil biological gradients and yields has not been accomplished. Many other questions pertaining soil environmental quality have been posed that are unanswerable without proper data sets. For example, what are the effects of intensified cropping and the associated soil management on beneficial soil biota and soil organic matter (SOM). If we are to achieve the goal of improving the soil sustainability, we need to understand its biotic component and its relation to soil quality. Moreover, an understanding of the ecosystem processes associated with soil management practices and their effect on beneficial soil biota is essential for successful maintenance of soil productivity. Therefore, the present investigation was undertaken as a part of the ICRISAT-QDPI research project at ICRISAT Center to evaluate the effects of different soil management practices on the population structure of the beneficial non-target soil macroinvertebrates such as earthworms and arthropods including termites (although termites are pests, they are beneficial in improving the soil structure). The results are presented in the form of a thesis comprising of four chapters. Beginning, with a brief description of the study site and its environmental conditions, the I-Chapter of the thesis deals with the effects of the soil management practices on the population structure of earthworms; II-Chapter describes the effects of such soil management practices on the population structure of soil surface inhabiting arthropods; the III-Chapter deals with the effects of such practices on the population structure of soil inhabiting microarthropods and the IV-Chapter depicts the effects of these practices on the population structure of termites.

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STUDY SITE AND ITS ENVIRONMENTAL CONDITIONS

The present experiment was established in July 1989, and carried out in the field designated RM 19B on the research farm at the ICRISAT Center (Long: 78^0 17′0′E, Lat. 17^0 28′58′N", altitude Ca 547 m.s.l.), at Patancheru, 26 km northwest of Hyderabad, in Medak district of Andhra Pradesh, India (Fig. 2). The slope on the land surface is in the range of 1.5-2.0%.

Soil type: The soil of the study area belonged to the Patancheru series which is a member of the clayey-skeletal, mixed, isohyperthermic family of Udic Rhodustalfs (Murthy et al., 1982). Analytical data of this soil type are given in El-Swaify et al (1987). The soil is locally regarded as a crusting, and profile-hardening soil. The textural profile consisted of a sandy loam merging to sandy clay loam or light clay at 10-15 cm and then to gravelly sandy loam overlying murrum (parent material) rich in quartz gravel at depths ranging from 30 to 70 cm. It was formed on weathered granite-gneiss.

Geomorphology and drainage: Geomorphic study revealed that the area forms part of a peneplained surface of the ancient and stable Deccan Peninsula which had undergone several cycles of erosion, deposition and uplift. Sporadic monolithic domes and tors are also present. The general elevation ranges from 500 to 620 m above mean sea level (m.s.l.). In the basaltic terrain in the south-west of the area, the highest point is 620 m and the lowest is 580 m above m.s.l. and in the granite-gneiss terrain, the highest point is 610 m and the lowest is 500 m above m.s.l. Slope breaks in the basaltic terrain occur at 10 to 15 m intervals.

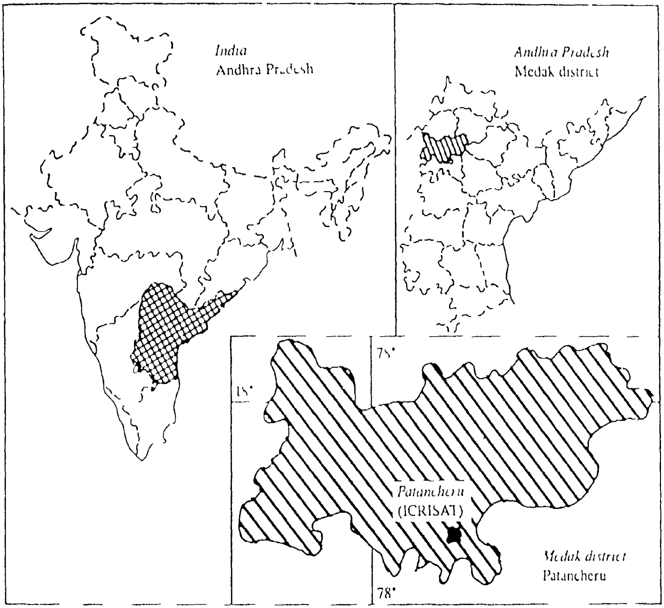


Figure 2 Map showing location of ICRISAT (Patancheru) in Medak district, Andhra Pradesh, India

The type area is characterised by dendritic and parallel to sub-parallel drainage systems of different densities. The streams are mostly seasonal and active during the rainy season. The northwestern part is drained by the Manjira river and the south-western part by the Musi river. The major portion drains into the Manjira river and its tributaries the Nakkavagu and the Palmavagu streams. The drainage system is most intricate in the east of the Type area where there are several small, seasonal tanks. The drainage pattern is similar in the north-west and tanks are fewer but larger.

Geology: The geological formations of the area comprise the oldest rock formations of the earth's crust overlaid by stratified deposits including Quaternary alluvium. The rocks belong to the precambrian and Upper Cretaceous to Lower Miocene periods. The rocks of the Precambrian period are generally coarse-grained granite, granite-gneiss and diorite with scattered dolerite dykes. These rocks are grouped under Unclassified Crystallines. Quartz veins and amethyst crystals are commonly found in these rocks. Coarse-grained granite, one of the major rock formations, is characterised by large blems of fieldspars and quartz grains of uniform size with flakes of biotite and muscovite micas. At places, the rocks are traversed by granitised basic materials which on weathering have given rise to calcareous veins and concretionary carbonate materials. The alteration of fieldspars to pockets of Kaolin is a common feature. The complex gneissic formations consist of gray granite, pink granite and granite-gneiss of the texture. The mineralogical composition of these rocks consists of quartz, fieldspars, biotite and muscovite. Gneissic formations are not so well marked in the area as in the coarse-grained granite.

Dolerite dykes (fine to medium grained) occur at places, and consist mainly of plagioclase fieldspars and augite. The rocks occur as exposed boulders of varying size oriented along strike lines. In the south-west of the area, there is a thin capping of basalt. Isolated mounds of Laterite occur in this basaltic region. Recent and older alluvium are confined to flood plains and filled valleys. The basalts occur as tongues confined mainly to the south-western portion of the area and are extensions of the vast Deccan Trap to the north and the west. The maximum thickness of the basaltic flow is about 30 m at the highest point near Shankarpalli. It thins out gradually towards the granitic area. Near Indrakaran and Jolki, it is barely 1 m thick and the superimposition of basalt over granite was observed. At places between the trap rocks some fluviatile or lacustrine deposits were seen. They were called Intertrappean beds.

Climate: The climate of the area is semi-arid, characterised by mild to hot summers and mild winter. The semi-arid tropics (SAT) is the region within the tropics where mean monthly rainfall exceeds mean potential evapotranspiration (PET) during February to July months of the year (Troll's 1965). Two sub-zones are recognized in the SAT such as the dry SAT and wet-dry SAT. The dry SAT is characterized by thorny savannah vegetation with rainfall exceeding PET during February to middle of April months of the year while the wet-dry SAT is characterized by dry savannah vegetation with rainfall exceeding PET during middle of April to July months. The type area around Patancheru, including the ICRISAT Farm, lies within the wet-dry SAT.

The weather of the present study area is generally dry except during the south-west monsoon season extending from June to October. May, usually is the hottest pre-monsoon month with air temperatures of 42^0 to 43^0C. December is the coldest month with mean temperature around 20^0C. The mean annual air temperature is 25.9^0C. May is followed by stormy pre-monsoon cloud bursts in the early part of June. The regular monsoon rain occurs from the second half of June to the first week of October. The mean annual rainfall is 764.4 mm of which nearly 80% falls during four months extending from June to September. Intermittent dry spells occur occasionally during the rainy season. The pattern of rainfall is bimodal with two peaks, one in July and another in September, although there is considerable variation in rainfall from year to year.

Natural vegetation: The vegetation is tropical dry deciduous type. The common trees are *Acacia sundra, Soymida bebrifuga, Boswellia serrata* and *Terminalia arjuna.* Some dry evergreen species like *Ixora, Memecylon edule* and *Mimusops hexandra* also occur intermixed with the dry deciduous species. The common shrubs are Cassia species, *Gymnosporia montana, Helicteres isora, Holarrhena antidysenterica, Grewia* spp., *Woodfordia floribunda,* and *Nyctanthes arobortristis.* The common grasses are *Sehima hervosum* (Canary grass), *Dochanthium annulatum* and

Chrysopogon montans.

Soils of ICRISAT Center Farm:

The ICRISAT Farm covers an area of 1394 ha (Fig. 3) and includes six soil series, such as Icri Series, Kasireddipalli series, Lingampalli series, Manmool series, Patancheru series. The present investigation was carried out on the **Patancheru series.** Patancheru series soils are 1.0 m or more deep. They have fine-loamy surface horizons 18 to 20 cm thick with 14 to 28% clay and 67 yo 79% sand which change abruptly to dense, clayey argillic Horizons with 20% or more clay than in the surface horizons. Such strongly contrasting textures within the solum may seriously affect the movement and retention of water in the soil. These soils occur on nearly level to very gently sloping (1-3%) and gently sloping (3-5%) lands. Gravels and rock fragments increase in amounts from 36 to 65% with depth. Patancheru soils cover an area of 247.7 ha or 17.77% of the farm area.

Abiotic environmental conditions:

Abiotic environmental factors recorded during the present investigation are rainfall, temperature and relative humidity. *Rainfall rate was measured at the study site, RM 19B at one month interval with a tipping bucket pluviograph monitor sensors calibrated at 0.2 mm per tip connected to a Campbell scientific CR 10 data logger. Temperature and relative humidity recorded automatically at the Agroclimatology data recording station in the ICRISAT Farm.*

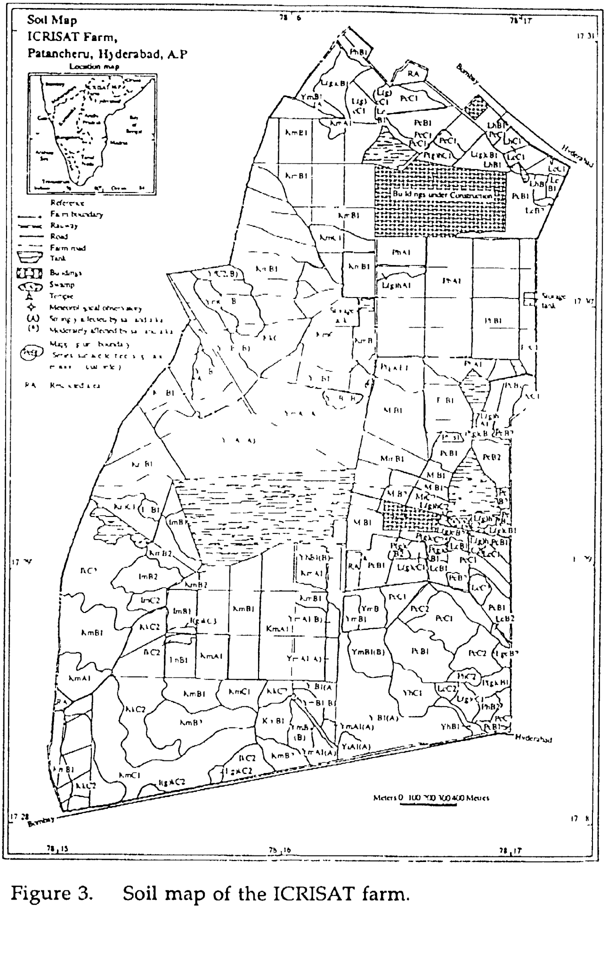


Figure 3. Soil map of the ICRISAT farm.

Seasonal variation in physical factors:

Rainfall: The seasonal variation in total monthly rainfall (mm) during study period at the study site in ICRISAT farm presented in Fig. 4a showed that it ranged between 0 to 430.5 mm, the latter being recorded during July 1989. Rainfall was minimum (5.2 mm) during November 1990 and there was no rainfall during January and February, April, November and December, 1989 and January to April, and December, 1990. The rainfall was 65.6 mm in March 1989 and was 47 mm during May and further increased to 113.4 mm during June. It increased to 430.5 mm in July followed by a decrease to 95.7 mm in August. It again increased to 241.7 mm in September and decreased to 26.8 mm in October. It was 146.2 mm in May 1990 which decreased to 104 mm in June and further decreased to 75.7 mm in July. It increased to 242.7 mm in August followed by a decrease to 107.3 mm in September and slight increase (127.2 mm) in October and decreased to 5.2 mm in November.

Relative humidity: The variation in the monthly average of relative humidity (%) during the study period at the study site presented in Fig. 4b showed that during 1989 in the morning (0700 hrs.) it ranged between 53.8 and 94.2%, the former being recorded during May 1989, and the latter during September 1989, and in the afternoon (1400 hrs.), it ranged from 18.4 to 68.8% the former being recorded during February 1989, and the latter during September 1989. During 1990, in the morning (0700 hrs.), it ranged from 56 to 93.8% the former being recorded during April 1990, and the latter during October 1990, and in the afternoon (1400 hrs.),

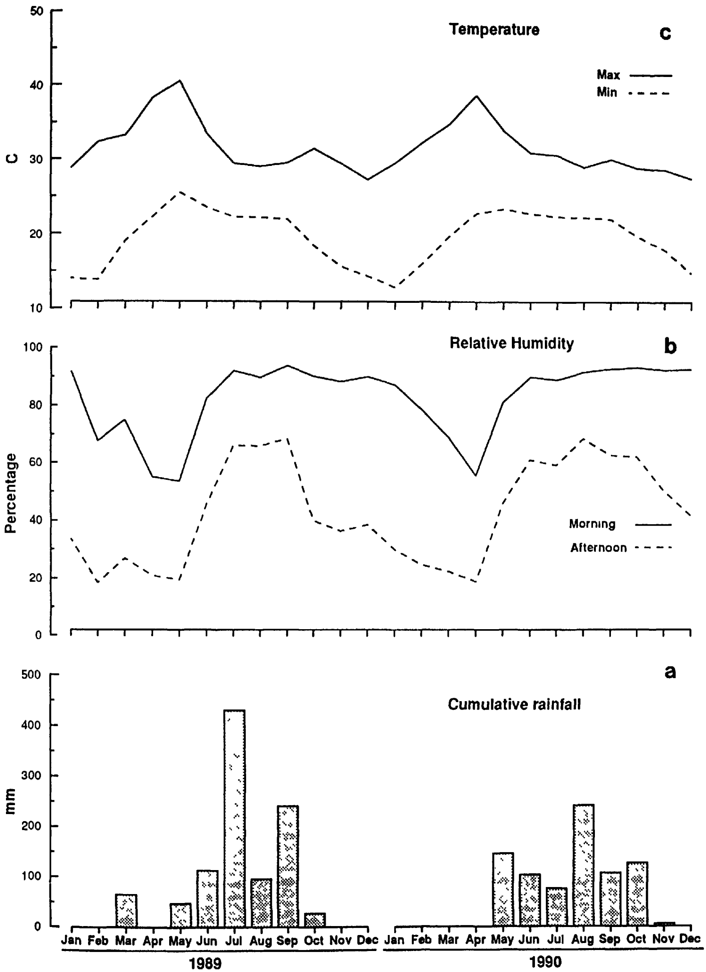


Figure 4. Seasonal variation, rainfall, relative humidity and temperature during 1989-1990 at the experimental site.

it ranged from 19 to 68.9% the former being recorded during April 1990, and the latter during August 1990. It fluctuated irregularly during the study period. However, it did not show much fluctuations during June 1989 to January 1990 and May 1990 to December 1990.

Temperature: The seasonal variation in the monthly average maximum and minimum temperature (^{0}C) at study site during the study period presented in Fig. 4c showed that the maximum temperature during 1989 ranged between 27.2 and 40.3^{0}C, the former being recorded during December 1989 and the latter during May 1989. It was 28.7^{0}C during January 1989 and gradually increased reaching the peak in May (40.3^{0}C) followed by a gradual decrease during June to December 1989 with a slight increase during September and October 1989. The maximum temperature during 1990, ranged between 27.4 and 38.5^{0}C, the former being recorded during December 1990 and the latter during April 1990. It was 29.4^{0}C during January 1990 which gradually increased reaching the peak in April (38.5^{0}C) with a gradual decrease during June to December 1990 with a slight increase during September 1990.

The monthly average minimum temperature during 1989, ranged between 13.8 and 25.4^{0}C, the former being recorded during February and the latter during May. It was 14^{0}C during January and gradually increased reaching the peak in May (25.4^{0}C), followed by gradual decrease during June to December 1989. The minimum temperature during 1990, ranged between 12.8 and 23.3^{0}C, the former being recorded during January and the latter during May. It was 12.8^{0}C during January which gradually increased reaching the peak in May 23.3^{0}C, with a gradual decrease during June to December 1990.

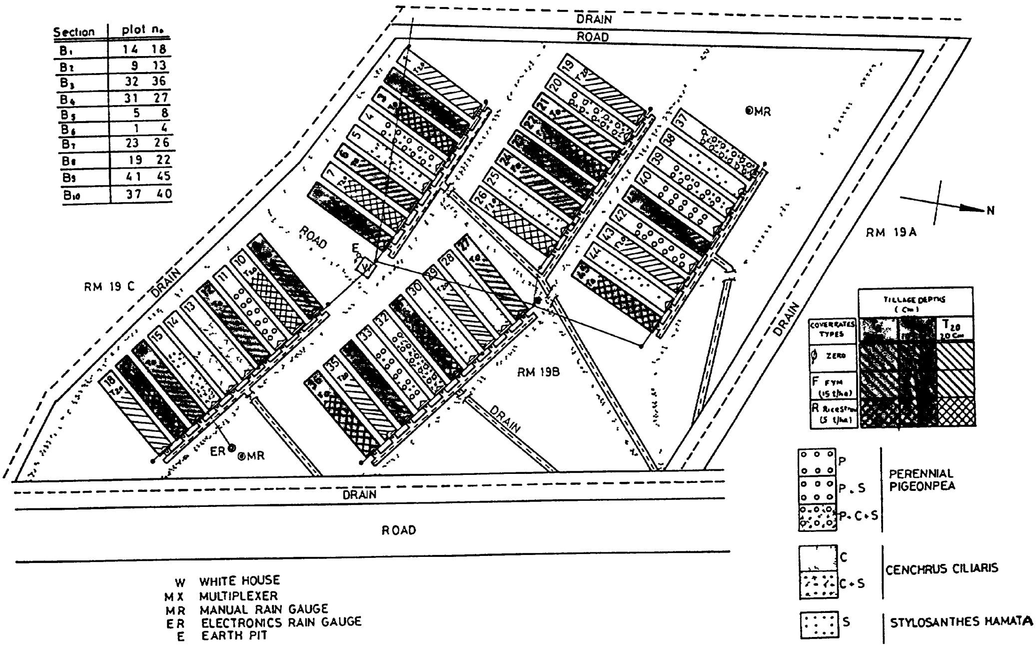
The experimental design:

The experimental design was an incomplete randomised block design with an embedded factorial (Murari Singh, Personal Communication, 1987). There were three tillage treatments and three organic amendment treatments (cropped annually) in the factorial plus an additional six perennial species treatments (with no annual tillage or mulching) (Table 1). There were three replicates of each of the 15 treatments. The layout of the 15 treatments is shown in Fig. 5. Analysis of variance was carried out within the factorial to show the effects of tillage depth and mulch or within the randomised block to compare all treatments. Plots were 5 m wide by 28.5 m long and 1.5 m apart. They were enclosed by a sheet metal strip embedded 10 cm into, and projecting 10 cm above the soil to define the catchment area.

Table 1. Treatments of soil management on an Alfisol at the study site.

Treatments			Plate No.
Annual	Tillage	Organic amendments	
	Zero (T_0)	Bare)	I
		FYM[1])	
		Rice-straw[2]	II
	10 cm depth (T_{10})	Bare)	III
		FYM[1])	
		Rice-straw[2])	IV
	20 cm depth (T_{20})	Bare)	
		FYM[1])	V
		Rice-straw[2])	
Perennial	Ley crop combination		
	Perennial pigeonpea (PP))		VI
	PP + Verano stylo (S))		
	PP+S+buffel grass (C))		VII
	C)		
	C+S)		VIII
	S)		

[1] FYM = farmyard manure, 15 t ha^{-1} (air dry)
[2] Straw = rice-straw, 5 t ha^{-1} (air dry)



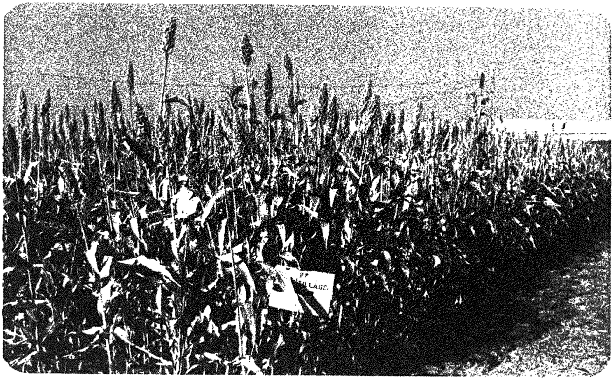
Section	plot no.	
B1	14	18
B2	9	13
B3	32	36
B4	31	27
B5	5	8
B6	1	4
B7	23	26
B8	19	22
B9	41	45
B10	37	40

Fig. 5. The layout of Soil Management Practices in Alfisol, ICRISAT farm.

PLATE-I

Zero tillage with Sorghum crop: (a) bare treatment, and (b) farmyard manure treatment

PLATE - I



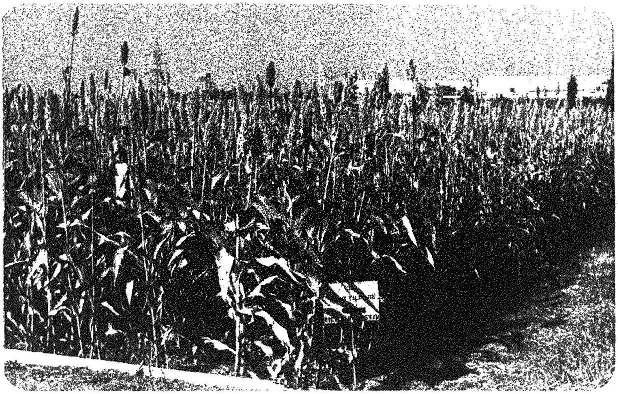
a

b

PLATE-II

Zero tillage with Sorghum crop: (a) prior to harvesting, and (b) after harvesting the crop under Rice-straw treatment

PLATE - II



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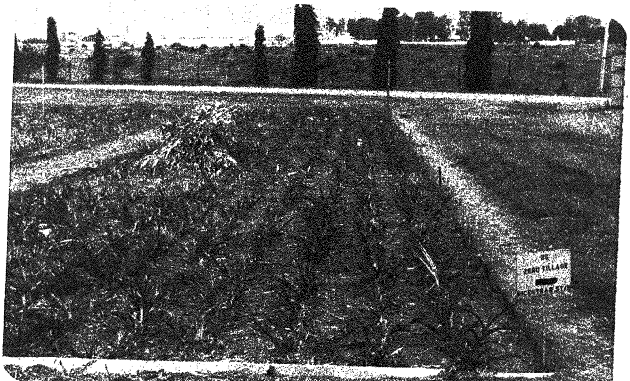


b

PLATE-III

Shallow tillage with Sorghum crop: (a) bare treatment, and (b) farmyard manure treatment

PLATE - III

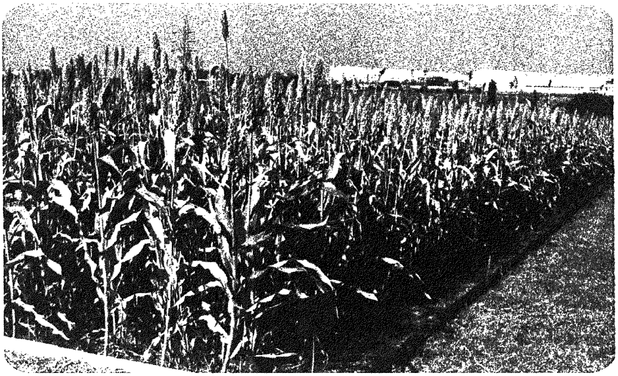
a

b

PLATE-IV

(a) Shallow tillage with Sorghum crop: Rice-straw treatment, and (b) Deep tillage with Sorghum crop: bare treatment

PLATE - IV



a

b

PLATE-V

Deep tillage with Sorghum crop: (a) farmyard manure treatment, and (b) rice-straw treatment

PLATE-V

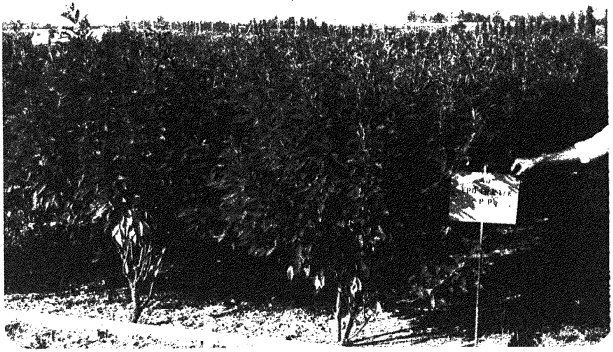
a

b

PLATE-VI

Zero tillage with perennial ley crop treatments: (a) Pigeonpea treatment, and (b) Pigeonpea plus *Stylosanthes hamata* treatment

PLATE - VI



a

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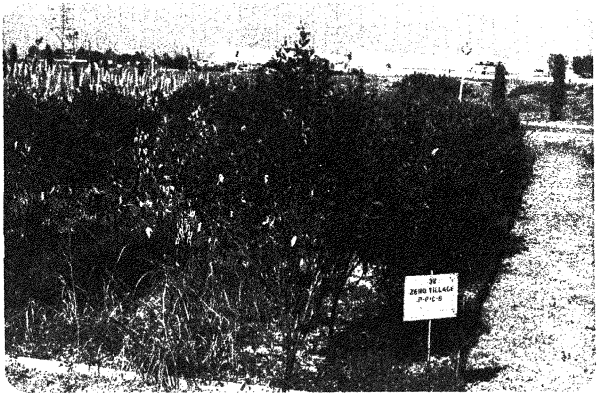
PLATE-VII

Zero tillage with perennial ley crop treatments: (a) Pigeonpea plus *S. hamata* plus *Cenchrus ciliaris* and (b) Sole *C. ciliaris*

PLATE - VII



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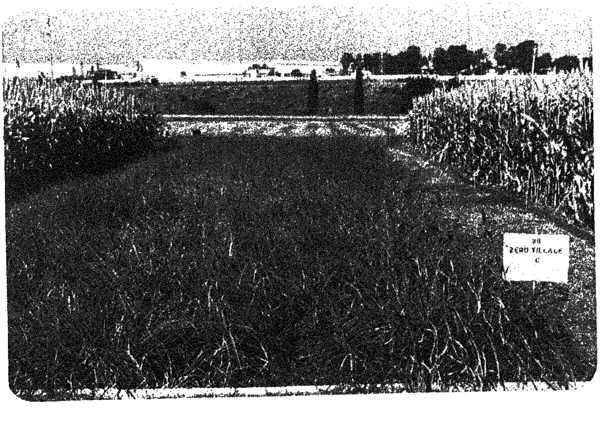

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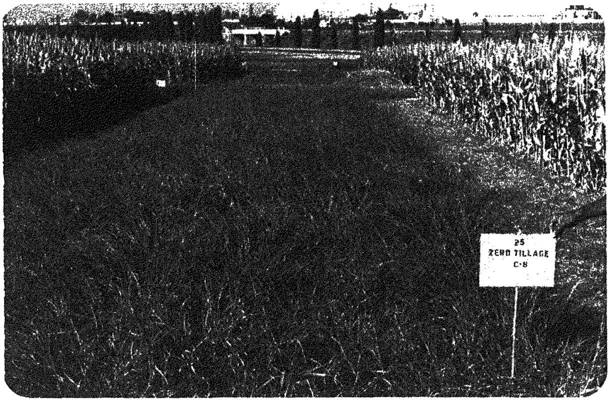
PLATE-VIII

Zero tillage with perennial ley crop treatments: (a) *C. ciliaris* plus *S. hamata,* and (b) Sole *S. hamata*

PLATE-



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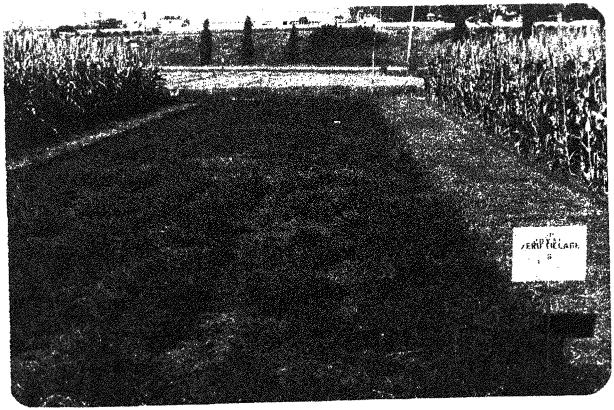

b

Treatments:

Tillage: Tillage depths were 0, 10, and 20 cm (referred to as T_0, T_{10}, and T_{20}, respectively) (Table 1). The tillage was imposed after initial rains in early June. Tilled plots initially received a shallow tine with duck foot tillage (0.05-0.07 m depth) to break the surface crust and to control weeds. After further rains, typically 10 to 14 days, a second tillage was imposed using narrow tines and 50 cm spacing to the treatment depth. Tines were chosen for tillage because they caused soil disturbance similar to that of the wooden country plough used by Indian farmers. Tines were mounted on a tractor-drawn tool bar and T_{10} and T_{20} plots were subjected to one pass with the depth set at 10 cm. Chisel tines, 4 cm wide and spaced 60 cm apart, were passed once through T_{20} plots after the shallow tillage operation. These chisel tines had been used earlier at ICRISAT in tillage studies with bullock-drawn equipment. Hence, although a tractor was used, the soil disturbance during deep tillage was consisted with that resulting from using animal traction power (Smith et al, 1992).

Organic amendments: The mulch treatments were applied [(15 t ha^{-1} farmyard manure (FYM), 5 t ha^{-1} rice-straw *Oryza sativa* L.)] in three equal increments after each of these cultural operations (Table 1) (Smith et al, 1992). Rice-straw was removed to facilitate tillage and than replaced. It was cut at ground level and carried from a nearby field was used because it provides a high surface area per unit weight and, compared to sorghum straw, it was not as much in demand for other uses. Moreover rice-straw increased soil fauna activities in an Alfisol in

Nigeria when applied as a mulch at 6 and 10 t ha^{-1} (Lal et al. 1980). Farmyard manure (FYM) was applied at the rate of relatively high rate of 15 t ha^{-1} because 5 t ha^{-1} applied over 8 years had no visible effect on soil structure on a similar soil (K.L. Sahrawat, Personal Communication, 1987). No mulch materials were applied to the perennial ley treatments. The mulch treatments were applied within 10 days after sowing as surface cover between the rows of emerging seedlings in the tillage treatments. The materials were not mechanically incorporated into the soil. This was to ensure that the soil surface was protected from temperature extremes, from raindrop impact and to provide a suitable habitat for soil fauna.

Cover crops (perennials): Perennial species selected in the present experiment alone and in combinations (Table 1). These were perennial pigeonpea (*Cajanus cajan* (L.) Millsp.), verano stylo (*Stylosanthes hamata* (L.) TAUBERT) and buffel grass (*Cenchrus ciliaris* (L.)) (Smith et al, 1992). Perennial pigeonpea was selected because of the beneficial effect of pigeonpea on the subsequent crop (Kumar Rao et al., 1983). Buffel grass and verano stylo were selected on the basis of their earlier good performance in observation trials at ICRISAT (M.M. Sharma, Personal Communication, 1987) and on Alfisols in India (R.P. Singh, and Y.P. Singh, Personal Communication, 1987). The effects of these species on soil structure were not known, but it was considered preferable to use the species that might be acceptable to farmers on the basis of productivity of high-quality fodder rather than those known for their effects on soil structure. Verano stylo fixes appreciable amounts of nitrogen and was the basis of ley pasture systems used in Alfisols in northern Australia (Cogle et al, 1991). Verano stylo and buffel grass have also some potential to improve soil structure in Alfisols in northern Australia (Bridge et al, 1983). Apart from the formation of sowing furrows soil in these treatments was not tilled.

Sowing: Sorghum (CSH 9) was sown in mid-July after imposing the treatments in late June-early July, during 1989 and 1990 in the tillage depth x mulch type factorial. On 19th July 1989 seeds were sown by hand in rows 60 cm apart. Small sowing furrows were formed by drawing the chisel tines at a depth of 5 cm in all tillage treatments. In deep tillage plots, the sorghum rows were located over the path of the deep tillage tines. Buffel grass and verano stylo were sown in alternate rows 38 cm apart in mixed swards. Perennial pigeonpea (cultivar 'ICPL 88040') was sown in rows 1 m apart, with plants within rows being 1.2 m apart. The seeds were covered with soil by hand-raking. In July 1989, carbofuran insecticide granules (40 kg ha^{-1}) were applied to the soil in the planting rows to control shoot fly (*Atherigona soccata* Rond.). Again in July and August 1990, carbofuran granules (5 kg ha^{-1}) were applied to the whorls of the sorghum seedlings for shoot fly control. Fertilizer applied was 100 kg ha^{-1} Diammonium phosphate at planting and 200 kg ha^{-1} urea by side dressing. Paraquat (1 kg a.i.ha^{-1}) was applied to all plots on June 29th and July 20th, 1989 and to no till mulch on July 5, 1990. The annual sorghum crop was harvested in November in 1989 and 1990. The *S. hamata* and *C. ciliaris* plots were harvested twice per year and the cut material were removed. The perennial pigeonpea was pruned in 1989 to control growth. In 1990, the perennial pigeonpea were replanted because wilt (*Fusarium udum*), termites (*Odontotermes obesus* (Rambur) and *Microtermes obesi* Holmgren) attack and drought (Reddy et al., 1992). Considerable leaf fall occurred from perennial pigeonpea, much of which was retained in the PP+S and PP+S+C plots but it was blown away from PP plots which consequently have generally bare soil throughout the year. The *S. hamata* produced a thick cover up to 0.3 cm high during the rainy season while *C. ciliaris* plots had complete projected foliage cover but grass tufts were separated by bare soil areas. *C. ciliaris* and *S. hamata* plants were trimmed early in the growing season and were then allowed to go to seed to thicken the stand. Pigeonpea yield was measured by picking pods and trimming plants 80 cm above the ground.

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CHAPTER-I

EARTHWORM POPULATION STRUCTURE

INTRODUCTION

"The plough is one of the most ancient and most valuable of man's inventions; but long before he existed, the land was in fact regularly ploughed and still continued to be thus ploughed by earthworms"

Charles Darwin, 1881

Earthworms are known for their beneficial role in the soil system since the time of Charles Darwin (1881). They are beneficial to soil due to their influence on soil physico-chemical and biological properties such as porosity, aeration, and nutrient status and microbial biomass. Many authors have investigated the relationships between earthworms and soil fertility (Guild, 1948; Evans and Guild, 1948; Satchell, 1958, 1960, Edwards and Lofty, 1972, Lee, 1985, and Marinissen and Deruiter, 1993), and there is good evidence of earthworms improving soil aeration and water infiltration (Russell, 1973; Edwards and Lofty, 1977; Ehlers, 1975; Baeumer and Bakermans, 1973; Barnes and Ellis, 1979). The macropores and tunnels are created by them by exerting pressure to push soil aside or by ingesting the soil and hence making tunnels (Dexter, 1991). These burrows and macropores, in the soil profile influence the aeration, infiltration and ease root penetration while the medium pores created by their casting influence the water-holding capacity of the soil (Guild, 1955; Syers and Springett, 1984; Lee, 1985). These tunnels provide pathways of low mechanical resistance for root penetration, and extensive rooting in the tunnels is often observed (Wilkinson, 1975; Edwards, 1975; Edwards and Lofty, 1976, 1978, 1980; Ehlers et al. 1983; Wang et al. 1986). It has been calculated that earthworm burrows increase the soil-air volume from 8% to 30% of the total soil volume, but this was in rather culture (unnatural) conditions (Wollny, 1890). Stockli (1928) estimated that in a garden soil with 2.4 million earthworms per ha, their burrows occupied 9-67% of the total soil-air space, which can be compared with 38 and 66% for a ley and a pasture respectively (Evans, 1948). Probably, a more realistic estimate is that earthworm burrows constitute only 5% of the total soil volume (Stockli, 1949). Teotia et al. (1950) claimed that earthworm activity increased the porosity of two soils from 27.5 to 31.6% and 58.8 to 61.8%, respectively. Clearly, earthworms greatly increase the aeration and structure of soils. These effects are usually beneficial in the sense of making the soil more suitable for agricultural use (Dexter, 1991).

Soils with earthworms drain from four to ten times faster than soils without earthworms (Guild, 1952; Teotia et al. 1950; Hopp and Slater, 1949). Their activity increased cumulative rainfall intake (Peterson and Dixon 1971, Cogle and Reddy 1994 unpublished data). They have increased the field capacity of some New Zealand soils, compared with soils without their activity by as much as 17% (Stockdill and Cossens, 1966). Similar results have been obtained in savannah in Nigeria, where cropping was shown to influence earthworm populations which in turn affected infiltration rates (Wilkinson, 1975). Clearly, earthworms influence the drainage of water from soil and the moisture-holding capacity of soil, both of which are important factors for growing crops.

They also play a significant role in amelioration of soil fertility by depositing a thick layer of surface casts particularly during the rainy season in tropics (Edwards and Lofty, 1977; Lee, 1985). It has been proved so conclusively that earthworms aid soil fertility, and there have been many attempts to add earthworms to poor soil or to encourage the build up of populations by addition of organic matter or fertilizers. The addition of earthworms to soil seems particularly promising in reclaiming flooded areas that are subsequently drained and put into cultivation, as in the Dutch polders (Van Rhee, 1969, 1971). Earthworms have been successfully introduced to newly-established areas of artesian irrigation in Uzbekistan, U.S.S.R., in order to improve soil formation (Ghilarov and Mamajev 1966). Adding earthworm casts to soil also improved greatly its structure and fertility (Reddy et al, 1994). Casts usually have a higher pH, and more total and nitrate nitrogen, organic matter, total and exchangeable magnesium, available phosphorus, base capacity, and moisture equivalent (Lunt and Jacobson, 1944; Graff, 1971; Powers and Bollen, 1935; Puh, 1941; Stockli, 1949; Ponomareva 1950; Finck, 1952; Nye, 1955; Czerwinski et al., 1974; Pasha, 1993).

They burry and incorporate plant residues from the litter layer into the soil (Lavelle, 1983). Because earthworms process the organic matter, their presence speeds the cycling of nutrients in the soil. They break up and mix organic matter mechanically and incorporate in the soil, and bring it in close contact with roots and mineral fractions (Syers and Springett, 1983). Earthworms can significantly affect the decomposition of organic matter in agroecosystems. They accelerate the decomposition of crop residue, indirectly by incorporating organic matter into soil and stimulating microbial activity in casts and around burrows (Hamilton and Dindal, 1983; Shaw and Pawluk, 1986). Soils with only few earthworms often have a well developed layer of undecomposed organic matter lying on the soil surface (Edwards and Lofty, 1980). Earthworms seem able to consume very large amounts of litter, and the amount of litter they turn-over, seems to be more dependent on the total amount of suitable organic matter available than on other factors. If physical soil conditions are suitable, the numbers of worms usually increase until food becomes a limiting factor.

Earthworms in particular the surface-feeding worms pass through their guts a mixture of organic and inorganic matter when feeding or burrowing. The smaller earthworms that feed on litter in woodlands produce casts that are almost entirely fragmented litter, whereas larger species consume a large proportion of soil, and there is relatively less amount of organic matter in their casts. The final process in organic matter decomposition is known as humification. Although much of the humification process is due to small soil organisms, such as micro-organisms, mites, spring tails and other arthropods, it is also accelerated by the passage through the guts of earthworms feeding on decomposed organic matter together with mineral soil. Probably some of the final stages of humification are due to the intestinal microflora in the earthworm's gut. Most of the evidence indicate that the chemical processes of humification are caused more by the microflora than by the fauna. The major contribution of earthworms seems to be in breaking up organic matter, combining it with soil particles and enhancing microbial activity when humification is well advanced.

The earthworms convert the nutrients such as nitrogen and phosphorus into more available forms needed for plant growth and metabolize the organic matter and release the metabolic products particularly nitrogen into the soil. This is important in improving soil fertility. They increase soil fertility, and at least part of this must be due to the increased amounts of mineralized nitrogen that they make available for plant growth. There have been reports of increased amounts of nitrogen in soils in which earthworms were reared (Russell, 1910; Blancke and Giesecke, 1924; Lindquist, 1941), but this could be from decay of the bodies of dead worms. Earthworms consume large amounts of plant organic matter that contains considerable quantities of nitrogen, and much of this is returned to the soil in their excretions. It has been estimated that of the total nitrogen excreted by worms, about half is secreted as mucoproteins by gland cells in the epidermis, and half in the form of ammonia, urea, and possibly uric acid and allantoin, in a fluid urine excreted from the nephridiopores. The exact proportions of these constituents and the total amount of nitrogen excreted depends upon the species of worm, and its feeding (Lee, 1985).

They influence the rate of nutrient cycling (Sharpley et al, 1979, Paoletti et al, 1993). Earthworm activity increases N,P,K levels in the soil and thus, crop productivity (Edwards and Lofty, 1982a). Anderson (1983) reported on nitrogen turnover by earthworms in arable land treated with farmyard manure and slurry. Christensen (1988) investigated on the direct effects of earthworm on nitrogen turnover in cultivated soils. Parmelee and Crossley (1988) worked on their role in the nitrogen cycle in a no-tillage agroecosystem on the Georgia piedmont.

Many researchers have investigated on the different aspects of ecology of earthworms in agricultural fields particularly on their population densities and role in the soil turnover in the form of casts and breakdown of organic matter and nutrient dynamics in different agricultural soils (Hopp, 1948; Barley, 1961; Van Rhee, 1963; Barley and Kleinig, 1964; Edwards, 1983; Anderson, 1987; Bostrom, 1988; Atlavinyte and Zimkuviene, 1985). However, their value in crop production is not clearly demonstrated due to the many-interacting factors. Mathur and Christensen (1988) investigated on the surface movements of earthworms in agricultural land, and Marinissen (1991) reported on colonization of arable fields by earthworms in a newly reclaimed polder and recently, Marinissen and Dereitur (1993) investigated their role in carbon and nitrogen cycling in the Netherlands. Curry and Byrne (1992) studied the contribution of earthworms to straw decomposition and nitrogen cycling in arable land in Ireland. Baker et al (1993) monitored monthly changes in the abundance of earthworms in three sites used for cereal and lucerne production in South Australia. Nevertheless, earthworms are desirable animals to have in cropping soils for several reasons. Firstly, they feed on decaying crop stubbles and speed up the crop-residue breakdown process returning nutrients to the soil for subsequent crops. Secondly, earthworms increase water retention of soils by creating tunnels and drain water into the deeper layers of soil rather than being lost as runoff. They also mix finely ground organic matter and soil during their feeding. They incorporate organic matter into the soil which increases its water-holding capacity without increasing water logging. Their activity in the soil increases the soil strength because of the binding properties of the organic matter thereby potentially reducing soil erosion. Thirdly, earthworms improve soil structure by their tunnelling which improve water infiltration, and reduce mechanical impedance to root growth. The roots are known to follow earthworm tunnels deep into the soil where moisture is available.

The **Review of literature** on the effects of various agricultural management practices on earthworm populations in different agroecosystems revealed the existence of a considerable amount of literature on the effects of various pesticides on earthworm populations (Lee, 1985; Kladivko and Timmenga, 1990; Edwards and Bohlen, 1992; Greig-Smith et al, 1992). However, very few studies dealt with the effects of soil management on soil fauna particularly the earthworms. Various types of agricultural practices such as mechanical tillage expose the beneficial soil fauna like earthworms by inverting the soil, and thus, they are attacked by various predators. Many of them die of body damage caused by mechanical tillage implements and drying and deccication. It takes a longer time to recover such losses of soil faunal wealth particularly the earthworm fauna (Evans, 1982). Hopp and Hopkins (1946) investigated on the effects of cropping systems on the winter population and influence of agricultural practices on earthworms. Some researchers have investigated on the effects of cultivation on earthworm production of different soil types (Edwards and Lofty, 1969; Ellis and Barnes, 1977; Christensen et al, 1987; Haukka, 1988). Edwards (1980) and Abbott and Parker (1981) investigated on the interaction between agricultural practice and earthworms and their soil environment. Gerard and Hay (1979) reported the long-term effects of four cultivation methods on earthworms in a continuous barley experiment and the relationship between number of earthworms and nitrogen fertilizer application. De st. Remy and Daynard (1982) showed the effects of tillage methods on earthworm populations in monoculture corn. House and Parmelee (1985) compared the effect of conventional tillage and continuous no-tillage on the densities of earthworms. Andersen (1987) gave a general impression of the influence of agricultural practices on earthworms. He reported the effects of direct drilling and ploughing on population structure of earthworms. Nuutinen (1992) showed the response of earthworm community to tillage and residue management on different soil types. Lofs-Holmin (1983) and Mackay and Kladivko (1985) conducted a survey to determine the numbers and biomass of earthworms in soils receiving different tillage and agricultural cropping treatments.

Barnes and Ellis (1979) investigated on the effects of different methods of cultivation and direct drilling and disposal of straw-residues, on populations of earthworms. The effects of conservation tillage practices on the populations of earthworms in different types of agricultural ecosystems have also been investigated (Edwards and Lofty 1982a; Rovira et al, 1987; Parmelee et al, 1990; Edwards et al, 1990; Buckerfield, 1992). The effects of different other soil management practices have also been reported. Teotia et al (1950) investigated on the effects stubble mulching on number and activity of earthworms.

In semi-arid tropical arable soils, structural degradation through repeated cultivation is a major problem and the activity of beneficial soil organisms like earthworms may decrease due to such disturbance (Rovira et al, 1987). However, very little information is available on the effects of such management practices on earthworm population densities in different tropical agroecosystems particularly in India. Reddy and Reddy (1990) reported on the response of population structure and biomass of earthworms to conventional tillage in a semi-arid tropical grassland. Yule et al (1991) presented a preliminary report on the effects of soil management on population abundance and biomass of earthworms in a semi-arid tropical Alfisol. Tiwari (1993) investigated on the effects of different fertilizers including FYM on earthworm population densities. Therefore, the present investigation was undertaken to assess the effects of various soil management practices (the details of which are presented under study area and environmental conditions of this thesis) on earthworm population structure both number and biomass (wet) across rainy and postrainy seasons under the sorghum crop.

MATERIALS AND METHODS

The earthworms were sampled by hand-sorting method in three randomly selected areas, each of size 25 x 25 cm and 25 cm depth in each plot (replicate) every month during two crop seasons (July to September, 1989 and June to October, 1990) each covering both rainy (June to September) and postrainy (October to January) seasons. Thus, their populations were sampled eight times in total during the period, 1989-1990. Each time, an iron grid of 25 cm^2 size was placed on the randomly selected area and cleared up the above ground vegetation inside the frame and dug up to the depth of 25 cm in the morning hours (0600 to 0800 hours). The earthworms were searched and collected from each such area, put in a polythene bag and brought to the laboratory. They were washed of the adhered soil particles, soaked with filter paper to remove the water attached to their outer body wall and their number was enumerated. They were weighed (with gut content) for biomass (wet), narcotised with absolute ethanol, and sorted into various age groups such as adults (with clitellum) and juveniles (without clitellum and small worms). They were processed through 4% formalin overnight, and preserved in 80% ethanol. The adults were identified approximately, sent for more precise (specific) identification to expert taxonomist at Zoological Survey of India.

Their population densities were converted m^{-2} across the 15 treatments. The data on the population densities of adult and juvenile earthworms and their biomass across the soil management treatments and seasons were analysed by ANOVA using GENSTAT.

RESULTS

Qualitative Composition:

The earthworms sampled across the 15 soil management treatments such as different tillage and organic amendments with annual crop and the perennial ley treatments belonged to two species *Octochaetona phillotti* (Michaelsen) (Octochaetidae) and *Lampito mauritti* Kinberg (Megascolecidae), the former being dominant. The mean percentage composition of the adults and juveniles of these two species of earthworms under the different soil management practices presented in Fig. 6 showed that the percentage composition of their adults ranged between <1 and 17.2% across the treatments. In zero, shallow and deep tillage treatments, their percentage composition was low in bare amendments ranging between <1 to 2.1% and were slightly high ranging between 2 to 3.1% in farmyard manure amendments, respectively. In perennial ley treatments their percentage composition ranged between 9.1% in pigeonpea treatment and 17.2% in *S. hamata* treatment.

The percentage composition of the juvenile earthworms ranged between 1.5 to 14.9% across the treatments. In zero tillage treatments their percentage composition ranged between 2.1% in rice-straw amendment and 4.9% in farmyard manure amendment. In shallow tillage treatments its percentage composition ranged from 1.5% in bare amendment to 2.3% in farmyard manure amendment. In deep tillage treatments its percentage composition ranged from 2% in rice-

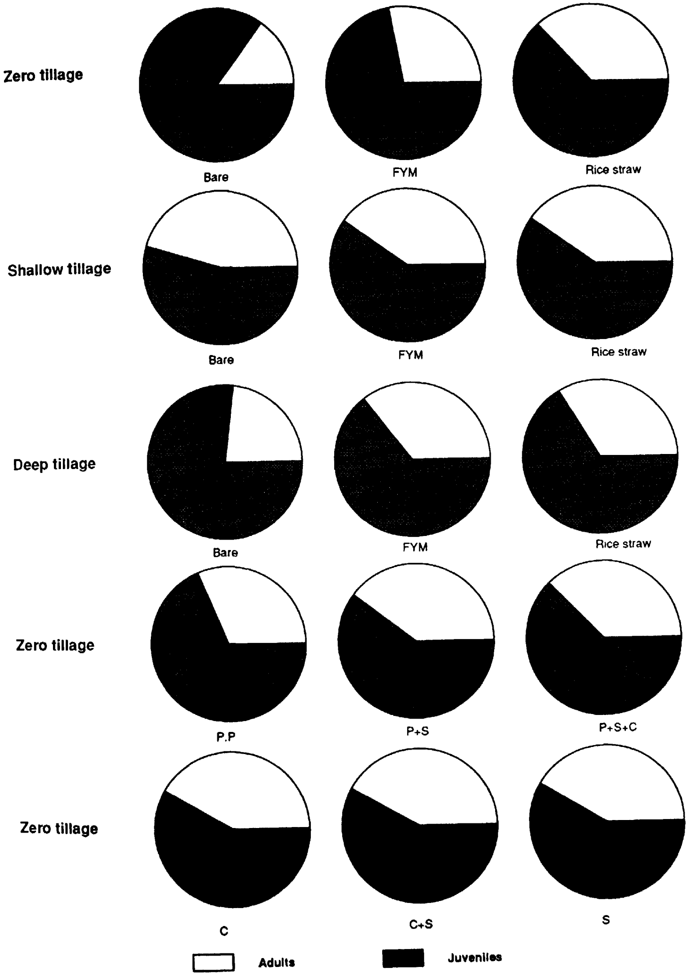

Figure 6. Percentage composition of different age-groups of earthworms (adults and juveniles) across the fifteen soil management treatments.

straw amendment to 2.5% in bare amendment. In perennial ley treatments their percentage composition ranged between 12.1% in pigeonpea treatment and 14.9% in *S. hamata* treatment, as seen in adults.

The percentage composition of earthworm biomass (wet) across the treatments ranged between <1 and 21.7%. In zero tillage treatments it ranged from <1 in bare amendment to 3.3% in farmyard manure amendment. In shallow tillage treatments it ranged between 1.5% in rice-straw amendment and 2.1% in bare amendment. In deep tillage treatments it ranged between 1.2% in rice-straw amendment and 1.5% in bare amendment. In perennial ley treatments it ranged from 9.5% in pigeonpea + *S. hamata* + *C. ciliaris* treatment to 21.7% in *S. hamata* treatment.

Temporal Variation:

Total earthworm: The seasonal fluctuation in the population densities of total earthworms across the 15 different soil management treatments presented in Figs. 7a and b revealed that the density was low (43 m^{-2}) in zero tillage bare and deep tillage rice-straw amendments and increased to nearly three folds high in shallow tillage farmyard manure amendment (117 m^{-2}), followed by that of zero tillage farmyard manure (112 m^{-2}) amendment 10 days after sowing during the beginning of the rainy season (July, 1989). However, the density varied and was low (27 m^{-2}) in deep tillage bare amendment and increased to more than five folds higher in pigeonpea treatment (144 m^{-2}) 30 days after sowing during the middle

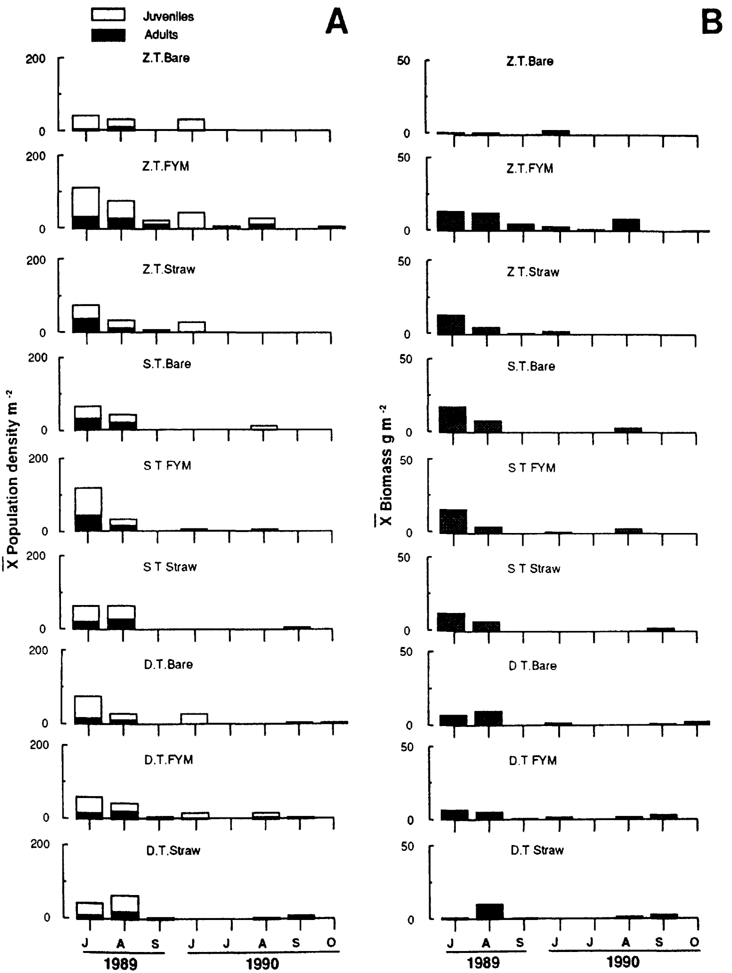

Figure 7a. Seasonal fluctuation in the population densities of adult and juvenile earthworms m^{-2} (A) and that of biomass of g m^{-2} (B) across different tillage and organic amendment treatments.

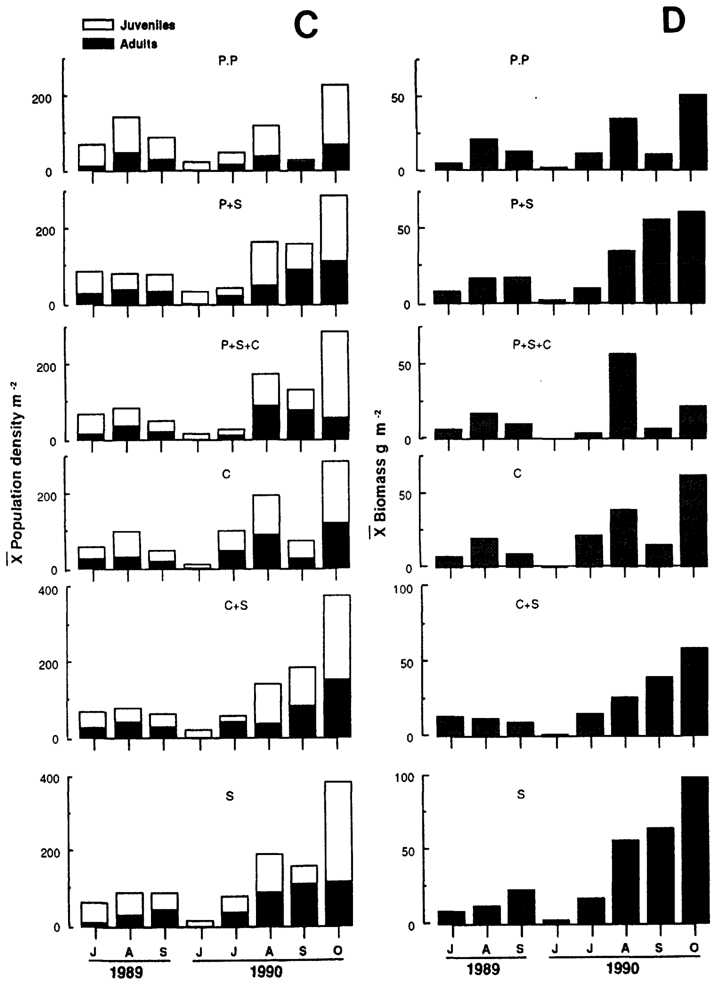

Figure 7b. Seasonal fluctuation in the population densities of adult and juvenile earthworms m^{-2} (C) and that of biomass of g m^{-2} (D) under perennial ley crop treatments.

of the rainy season (August, 1989). 60 days after sowing towards the end of the rainy season (September, 1989), it was low (3 m^{-2}) in zero tillage rice-straw amendment and increased to more than thirty folds high in *S. hamata* treatment (91 m^{-2}), followed by that of pigeonpea treatment (88 m^{-2}). During the following fallow period, its density reduced to 5 m^{-2} in shallow tillage farmyard manure amendment and increased to more than eight folds higher in zero tillage farmyard manure amendment (43 m^{-2}) 210 days after harvesting the crop when it was the beginning of the following rainy season (June, 1990). During the 2nd crop season, its density was low, 5 m^{-2} in zero tillage farmyard manure amendment and increased to more than twenty folds high in *C. ciliaris* treatment (102 m^{-2}) just a day after sowing during the beginning of the rainy season (July, 1990). It was low, 5 m^{-2} in shallow tillage farmyard manure and deep tillage rice-straw amendments and increased to nearly forty folds higher in *C. ciliaris* treatment (198 m^{-2}) followed by *S. hamata* treatment (193 m^{-2}) 50 days after sowing during the middle of the rainy season (August, 1990). It was low (5 m^{-2}) in shallow tillage rice-straw, deep tillage bare and farmyard manure amendments and increased to more than thirty seven folds high (188 m^{-2}) in *C. ciliaris* + *S. hamata* treatment 75 days after sowing (September, 1990). It was low (5 m^{-2}) in zero tillage farmyard manure and deep tillage bare amendments, which increased to more than seventy seven folds high (386 m^{-2}) in *S. hamata* treatment, followed by that of *C. ciliaris* + *S. hamata* (381 m^{-2}) treatment 90 days after sowing towards the end of the rainy season (October, 1990).

ANOVA revealed that the total earthworm population densities in tillage and organic amendment treatments were significantly different between rainy and postrainy seasons being more than five folds higher in densities during postrainy season compared to that of rainy season, the difference being statistically significant (Table 2). Besides, their population densities showed significant variation across perennial ley treatments among the seasons. They were more than three folds higher during the postrainy season than that of the rainy season, the difference being statistically significant (Table 2).

Adult earthworms: The seasonal fluctuation in population densities of adult earthworms across the 15 soil management treatments presented in Figs. 7a and b revealed that the density was low (5 m^{-2}) in zero tillage bare amendment and increased to more than eight folds high in shallow tillage farmyard manure amendment (43 m^{-2}), followed by that of zero tillage rice-straw (37 m^{-2}) amendment 10 days after sowing during the beginning of the rainy season (July, 1989). Its density was low (11 m^{-2}) in zero tillage bare, rice-straw, and deep tillage bare amendments and increased to more than four folds higher in pigeonpea treatment (48 m^{-2}), followed by that of *C. ciliaris* + *S. hamata* (43 m^{-2}) treatment 30 days after sowing during the middle of the rainy season (August, 1989). The density was low (3 m^{-2}) in zero tillage rice-straw and deep tillage farmyard manure amendments and increased to fifteen folds higher (45 m^{-2}) in *S. hamata* treatment 60 days after sowing during the end of the rainy season (September, 1989). During the following fallow period, i.e., 210 days after

Table 2. Response of total, adult, and juvenile earthworms (m^{-2}) and their biomass (gm^{-2}) to soil management treatments during 1989-1990.

	Tillage and organic amendment treatments			Perennial ley treatments		
Population density and biomass	Rainy	Postrainy	At 1% LSD	Rainy	Postrainy	At 1% LSD
Population density:						
Total earth-worms m^{-2}	42	236	38	136	472	83
Adult earth-worms m^{-2}	15	98	22	59	162	36
Juvenile earth-worms m^{-2}	26	138	24	77	309	57
Total Biomass ($g\ m^{-2}$)	10	36	7	24	68	10

harvesting the crop during the beginning of the following rainy season (June, 1990) the adults were not recorded in all the 15 treatments. During the 2nd crop season, the adult density was low (11 m^{-2}) in pigeonpea + *S. hamata* + *C. ciliaris* treatment and increased to more than four folds high in *C. ciliaris* treatment (48 m^{-2}), followed by that of *C. ciliaris* + *S. hamata* (43 m^{-2}) treatment just a day after sowing during the beginning of the rainy season (July, 1990). Its density was low (5 m^{-2}) in shallow tillage farmyard manure and deep tillage farmyard manure and rice-straw amendments and increased to more than eighteen folds high (91 m^{-2}) in pigeonpea + *S. hamata* + *C. ciliaris* and *C. ciliaris*, and *S. hamata* treatments 50 days after sowing during the middle of the rainy season (August, 1990). Its density was low (5 m^{-2}) in shallow tillage rice-straw and deep tillage farmyard manure and rice-straw amendments and increased to more than twenty two folds high (113 m^{-2}) in *S. hamata* treatment 75 days after sowing (September, 1990). Its density was low (5 m^{-2}) in deep tillage bare amendment and increased to more than thirty one folds high (156 m^{-2}) in *C. ciliaris* + *S. hamata* treatment 90 days after sowing towards the end of the rainy season (October, 1990).

ANOVA revealed that the adult earthworm population densities in tillage and organic amendment treatments were significantly different between the rainy and postrainy seasons being more than six folds higher in densities during postrainy season than that of rainy season (Table 2.). Besides, their population densities showed significant variation across perennial ley treatments among the seasons. They were more than two folds higher during the postrainy season than that of the rainy season, the difference being statistically significant (Table 2).

Juvenile earthworms: The seasonal fluctuation in population densities of juvenile earthworms across the 15 soil management treatments presented in Figs. 7a and b revealed that the density was low (32 m^{-2}) in shallow tillage bare, deep tillage rice-straw and *C. ciliaris* treatments and increased to more than two and half folds high (80 m^{2}) in zero tillage farmyard manure amendment, followed by that of shallow tillage farmyard manure (75 m^{-2}) amendment 10 days after sowing during the beginning of the rainy season (July, 1989). Its density was reduced to 16 m^{-2} in shallow tillage farmyard manure and deep tillage bare amendments and increased to six folds high (96 m^{-2}) in pigeonpea treatment 30 days after sowing during the middle of the rainy season (August, 1989). It was low (3 m^{-2}) in zero tillage rice-straw and deep tillage farmyard manure amendments and increased to nearly twenty folds high (59 m^{-2}) in pigeonpea treatment 60 days after sowing towards the end of the rainy season (September, 1989). During the following fallow period, the density was low (5 m^{-2}) in shallow tillage farmyard manure amendment and increased to more than eight folds high (43 m^{-2}) in zero tillage farmyard manure amendment 210 days after harvesting the crop during the beginning of the following rainy season (June, 1990). During the 2nd crop season the density was low (5 m^{-2}) in zero tillage farmyard manure amendment and increased to more than ten folds high in *C. ciliaris* treatment just a day after sowing during the beginning of the rainy season (July, 1990). It was low (11 m^{-2}) in shallow tillage bare and deep tillage farmyard manure amendments and increased to more than ten folds high (118 m^{-2}) in pigeonpea + *S. hamata* treatment 50 days after sowing during the middle of the rainy season (August, 1990). It was low (5 m^{-2}) in deep tillage bare and rice-straw amendments and increased to more than twenty folds high (102 m^{-2}) in *C. ciliaris* + *S. hamata* treatment 75 days after sowing (September, 1990). Its density was low (5 m^{-2}) in zero tillage farmyard manure amendment and increased to fifty four folds high (268 m^{-2}) in *S. hamata* treatment 90 days after sowing during the end of the rainy season (October, 1990).

ANOVA revealed that the juveniles population densities in tillage and organic amendment treatments were significantly different between the rainy and postrainy seasons being more than five folds higher in densities during postrainy season than that of the rainy season (Table 2). Besides, their population densities showed significant variation across perennial ley treatments among the seasons, they were four folds higher during the postrainy season than that of the rainy season, the difference being statistically significant (Table 2).

Total biomass: The seasonal variation in biomass (wet) of the earthworms across the 15 soil management treatments presented in Figs. 7a and b revealed that it was low (1 g m^{-2}) in zero tillage bare and deep tillage rice-straw amendments and increased to seventeen folds higher in shallow tillage bare amendment (17 g m^{-2}), followed by that of shallow tillage farmyard manure amendment (16 g m^{-2}) 10 days after sowing during the beginning of the rainy season (July, 1989). It was 4 g m^{-2} in shallow tillage farmyard manure amendment and increased to more than five folds higher in pigeonpea treatment (21 g m^{-2}), followed by that of *C. ciliaris* (20 g m^{-2}) treatment 30 days after sowing during the middle of the rainy season (August, 1989). It was decreased to 1 g m^{-2} in zero tillage rice-straw, deep tillage farmyard manure and rice-straw amendments and increased to twenty three folds higher (23 g m^{-2}) in *S. hamata* treatment 60 days after sowing towards the end of the rainy season (September, 1989). During the following fallow period, it was low (1 g m^{-2}) in deep tillage bare, *C. ciliaris* and *C. ciliaris* + *S. hamata* amendments and increased to three folds higher (3 g m^{-2}) in zero tillage farmyard manure amendment 210 days after harvesting the crop during the beginning of the rainy season (June, 1990). During the 2nd crop season it was low (1 g m^{-2}) in zero tillage farmyard manure amendment and increased to twenty two folds higher (22 g m^{-2}) in *C. ciliaris* treatment just a day after sowing during the beginning of the rainy season (July, 1990). It was 2 g m^{-2} in deep tillage farmyard manure and rice-straw amendments and increased to more than twenty eight folds higher (57 g m^{-2}) in pigeonpea + *S. hamata* + *C. ciliaris* treatment, followed by that of *S. hamata* (56 g m^{-2}) treatment 50 days after sowing during the middle of the rainy season (August, 1990). It was low (1 g m^{-2}) in shallow tillage rice-straw and deep tillage bare amendments and increased to sixty four folds higher (64 g m^{-2}) in *S. hamata* treatment 75 days after sowing (September, 1990). It was low (1 g m^{-2}) in zero tillage farmyard manure amendment and increased to ninety eight folds higher (98 g m^{-2}) in *S. hamata* treatment 90 days after sowing towards the end of the rainy season (October, 1990).

ANOVA revealed that the total earthworms biomass in tillage and organic amendment treatments were significantly different between the rainy and postrainy seasons being more than three folds higher during postrainy season than that of rainy season, the differences being statistically significant (Table 2). Besides, the biomass showed significant variation across perennial ley treatments among the seasons, they were more than two folds higher during the postrainy season than that of the rainy season, the differences being statistically significant (Table 2).

Treatment Effect:

Total earthworm: The population densities of total earthworms across the 15 soil management treatments presented in Fig. 8 revealed that the density was significantly low in the annual treatments (13 m^{-2}) compared to that of the perennial ley treatments (135 m^{-2}) ($P < 0.05$). Under annual crop, in zero tillage treatments the density was low in the bare amendment (13 m^{-2}) which increased to more than two folds higher in farmyard manure amendment (36 m^{-2}). In shallow tillage treatments, there was not much variation in between the organic amendments, as the densities ranged between 15 to 20 m^{-2}. In deep tillage treatments, the densities ranged between 16 to 18 m^{-2} across the organic amendments. In perennial ley treatments they were in low density in pigeonpea treatment (94 m^{-2}) which increased to 135 m^{-2} in *S. hamata* treatment.

The population densities of total earthworms significantly differed across

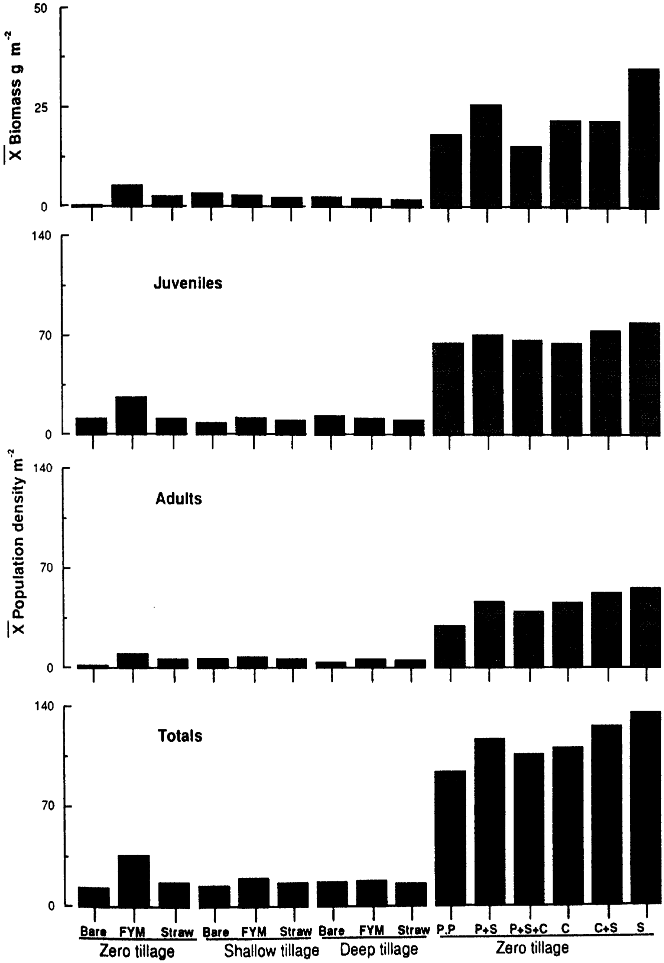

Figure 8. Population densities of adult, juvenile and total earthworms m^{-2} and their biomass of g m^{-2} across the fifteen soil management treatments.

the 15 treatments as revealed by the ANOVA, during rainy season (P <0.05) and postrainy season (P <0.01) (Table 3), the tillage and organic amendment treatments (Table 4) and perennial ley treatments (Table 5) between the seasons (P <0.01). ANOVA of the monthly data showed the population densities of total earthworms differed significantly across all the treatments during August 1989 (P <0.01), September 1989 (P <0.001), and July, August, and September 1990 (P <0.01) and October 1990 (P <0.05) (Table 6), across both the tillage and organic amendments during September 1989 (P <0.05), tillage during June 1990 (P <0.01), organic amendment during August, 1990 (P <0.05), and tillage and organic amendment interaction during August, 1990 (P <0.05) (Table 7). Their densities also differed significantly across the perennial treatments during September 1989 (P <0.05) (Table 8).

Adult earthworms: The population densities of adult earthworms across the 15 soil management treatments presented in Fig. 8 revealed that they were significantly low in number in the annual treatments (2 m^{-2}) compared to those of the perennial ley treatments (60 m^{-2}) (P <0.05). Under annual crop, in zero tillage treatments its density was low in bare amendment (2 m^{-2}) while it was higher in farmyard manure amendment (10 m^{-2}). In shallow tillage treatments they were lower in number in bare and rice-straw amendments (7 m^{-2}) and higher in farmyard manure amendment (8 m^{-2}). In deep tillage treatments their number was low in bare amendment (4 m^{-2}) and was high in farmyard manure amendment (6 m^{-2}). In perennial ley treatments they were low in number in

Table 3. Analysis of variance (mean squares) of the data on population densities of total, adult, and juvenile earthworms and their biomass across the 15 soil management treatments in two seasons.

Seasons	SOURCE OF VARIATION				Mean abundance
	Blocks (Ignoring treatments)	Entries (Eliminating blocks)	Within entries (Errors)	F (14, 21)	
Total:					
Rainy	2537	5521	2428	2.3*	80
Postrainy	9083	24158	3652	6.6**	330
Adults:					
Rainy	533	1774	162	10.9***	35
Postrainy	518	1570	137	11.4***	126
Juveniles:					
Rainy	2041	6449	525	12.3***	45
Postrainy	85	204	10	21.0***	205
Biomass:					
Rainy	19255	45814	8223	5.6**	17
Postrainy	377	932	219	4.3**	50

* Significant at $P < 0.05$; ** Significant at $P < 0.01$; *** Significant at $P < 0.001$.

Table 4. Analysis of variance (mean squares) of the data on population densities of total, adult, and juvenile earthworms and their biomass across the tillage and organic amendment treatments. (number in parentheses represent degrees of freedom).

	SOURCE OF VARIATION								
Population density & biomass	Seasons (S) (1)	Amend-ment (A) (2)	SxA (2)	Til-lage (T) (2)	SxT (4)	TxA (4)	SxTxA (4)	Error (28)	Mean abund-ance
Population density:									
Total earthworms	507698**	44	915	524	1224	3850	2586	2690	139
Adult earthworms	92587**	357**	73	119	369	1238	344	858	57
Juvenile earthworms	166889**	569	1452	249	277	848	2173	1051	82
Total Biomass	9335**	10	14	20	18	163	22	93	23

** Significant at $P < 0.01$.

Table 5. Analysis of variance (mean squares) of the data on population densities of total, adult, and juvenile earthworms and their biomass across the perennial ley crop treatments. (number in parentheses represent degrees of freedom).

	SOURCE OF VARIATION				
Population density & biomass	Seasons (1)	Treatment (5)	SxT (5)	Error (16)	Mean abundance
Population density:					
Total earthworms	1013713**	1220	760	8214	304
Adult earthworms	95481**	2080	1160	1506	115
Juvenile earthworms	485809**	1269	1874	3796	189
Total Biomass	17778**	242	71	128	49

* Significant at $P < 0.01$.

Table 6. Analysis of variance (mean squares) of the data on population densities of earthworms across the 15 soil management treatments during different months - 1989-1990.

Year & Month		SOURCE OF VARIATION				
		Blocks (Ignoring treatments)	Entries (Eliminating blocks)	Within entries (Errors)	F (14, 21)	Mean abundance
Total population densities:						
1989	August	1331	2463	704	3.5**	66.1
	September	2691	2354	117	20.2***	30.2
1990	July	1354	3079	630	4.9**	24.3
	August	6831	20598	5320	3.9**	71
	September	6174	13065	4108	3.2**	51.6
	October	31952	68335	22330	3.1*	125.2
Adult population densities:						
1989	September	362	492	49	9.9***	12.8
1990	July	352	778	96	8.1**	11.7
	August	1876	3127	446	7.1**	28.3
	September	2628	4000	1520	2.6*	29
	October	4527	8935	2190	4.1**	43
Juvenile population densities:						
1989	August	807	1088	358	3.1*	40
	September	1130	745	95	7.8**	17.6
1990	July	383	900	386	2.3*	12.5
	August	2671	8533	3540	2.4*	42.6
	September	1062	2899	854	3.4**	22.5
	October	14002	29511	11974	2.5*	82.3

contd...

Table 6. Continued

Year & Month		SOURCE OF VARIATION: Blocks (Ignoring treatments)	Entries (Eliminating blocks)	Within entries (Errors)	F (14, 21)	Mean abundance
Total Biomass:						
1989	July	32	87	37	2.4*	8.9
	August	31	103	23	4.5**	10.4
	September	125	95	5	17.7***	5.8
1990	June	2	3	1	2.5*	1.2
	July	40	156	17	9.4**	5.3
	August	849	886	212	4.2**	17.6
	September	360	1298	172	7.6**	13.3
	October	1404	2567	505	5.1**	23.7

* Significant at $P < 0.05$; ** Significant at $P < 0.01$; *** Significant at $P < 0.001$.

Table 8. Analysis of variance (mean squares) of the data on population densities of earthworms across perennial ley crop treatments during different months – 1989-1990. (number in parentheses represent degrees of freedom).

		SOURCE OF VARIATION		
Year & Month		Treatment (5)	Error (4)	Mean abundance
Total population densities:				
1989	September	984*	101	70
1990		(the mean squares of different months of 1990 were not significant)		
Adult population densities:				
1989		(the mean squares of different months of 1989 were not significant)		
1990		(the mean squares of different months of 1990 were not significant)		
Juvenile population densities:				
1989	July	1317*	220	49.8
	August	1394*	188	58.7
1990		(the mean squares of different months of 1990 were not significant)		
Total Biomass:				
1989	September	58**	4	13.5
1990	June	4**	1	1.4

* Significant at $P < 0.05$; ** Significant at $P < 0.01$.

pigeonpea treatment (29 m^{-2}) and were higher in *S. hamata* treatment (56 m^{-2}).

The adults population densities differed significantly across all the 15 treatments, as revealed by the ANOVA, during rainy and postrainy seasons ($P < 0.001$) (Table 3), and across the annual and perennial treatments between the seasons ($P < 0.01$) (Tables 4 and 5). ANOVA of the monthly data showed that the population densities differed significantly across all the treatments during September 1989 ($P < 0.001$), July and August 1990 ($P < 0.01$), September 1990 ($P < 0.05$), and October 1990 ($P < 0.01$) (Table 6). The densities also differed significantly across the tillage and amendment during September 1989 ($P < 0.01$) (Table 7). However, the densities did not differ significantly across the perennial ley treatments during any month of the study period (Table 8).

Juvenile earthworms: The population density of juveniles recorded across the 15 soil management treatments presented in Fig. 8 revealed that they were significantly low in number in the annual treatments (8 m^{-2}) compared to those of the perennial ley treatments (79 m^{-2}) ($P < 0.05$). Under annual crop, in zero tillage treatments its density was low in the rice-straw amendment (11 m^{-2}) while it was higher in farmyard manure amendment (26 m^{-2}). In shallow tillage treatments its number was low in bare amendment (8 m^{-2}) and was higher in farmyard manure amendment (12 m^{-2}). In deep tillage treatments their number was low in rice-straw amendment (11 m^{-2}) and was higher in bare amendment (13 m^{-2}). In perennial ley treatments their number was low in pigeonpea treatment

(65 m^{-2}) and was higher in *S. hamata* treatment (79 m^{-2}).

The juvenile population densities differed significantly across all the 15 treatments as revealed by the ANOVA during rainy and postrainy seasons ($P < 0.001$) (Table 3), the tillage and organic amendment treatments (Table 4) and perennial ley treatments (Table 5) between the seasons ($P < 0.01$). ANOVA of the monthly data showed that the population densities differed significantly across all the treatments during August 1989 ($P < 0.05$), September 1989 ($P < 0.01$), July and August 1990 ($P < 0.05$), September 1990 ($P < 0.01$), and October 1990 ($P < 0.05$) (Table 6), across the annual tillage treatments during June, 1990 ($P < 0.01$) (Table 7) and the perennial ley treatment during July and August 1989 ($P < 0.05$) (Table 8).

Biomass: The biomass (wet) of earthworms across the 15 soil management treatments presented in Fig. 8 revealed that it was significantly low in the annual treatments (0.4 g m^{-2}) compared to those of the perennial ley treatments (35 g m^{-2}) ($P < 0.05$). Under the annual crop, in zero tillage treatments it was low in bare amendment (0.4 g m^{-2}) and was higher in farmyard manure amendment (5.3 g m^{-2}). In shallow tillage treatments it was 2.4 g m^{-2} in rice-straw amendment and increased to 3.4 g m^{-2} in bare amendment. In deep tillage treatments the biomass was 2 g m^{-2} in rice-straw amendment and increased to 2.5 g m^{-2} in bare amendment. In perennial ley treatments it was 15.4 g m^{-2} in pigeonpea + *S. hamata* + *C. ciliaris* treatment which increased to 35 g m^{-2} in *S. hamata* treatment.

The earthworm biomass differed significantly across all the 15 treatments as revealed by the ANOVA, during rainy and postrainy seasons ($P < 0.01$) (Table 3), and the annual (Table 4) and perennial (Table 5) treatments between the seasons ($P < 0.01$). ANOVA of the monthly data showed that the biomass differed significantly across all the treatments during July 1989 ($P < 0.05$), August 1989 ($P < 0.01$), September 1989 ($P < 0.001$), and June 1990 ($P < 0.05$), July, August, September, and October, 1990 ($P < 0.01$) (Table 6), across the annual treatments during July 1989 ($P < 0.05$), and tillage and amendment interaction during August and September 1989 ($P < 0.05$) (Table 7). The biomass also differed significantly across the perennial ley treatments during September 1989 and June 1990 ($P < 0.01$) (Table 8).

DISCUSSION

The number of species present in a community is a simple measure of biodiversity and is related to niche partitioning and sharing of resources among the species (Lee, 1985). There is little information on the effects of different soil management practices on species composition of earthworms which may be because of lack of long-term ecological investigations on these aspects. The number of species did not vary between the soil management treatments during the present study as only two species i.e., *O. phillotti* and *L. mauritti* were found across the treatments. Using Sorenson's quotient of similarity and Cole's coefficient of similarity, Phillipson et al (1976) showed two species association to be particularly frequent and concluded that the differences in soil characteristics including quantity and quality of organic matter and moisture regimes have direct effects on earthworm species associations. Gerard and Hay (1979) reported eight species of Lumbricidae under ploughing, tined cultivation, and direct drilling of a continuous barley ecosystem. House and Parmelee (1985) found two species of lumbricidae under no-tillage and conventional tillage practices. Parmelee et al (1990) recorded two species of Lumbricidae, two species of Acanthodrilidae, one species of Ocnerodrilidae in conventional and no-tillage agroecosystems. Mackay and Kladivko (1985) identified five species of Lumbricidae in soils receiving different tillage and cropping treatments. Two species of Lumbricidae and two species of Megascolecidae were recorded under four contrasting soil management practices in an andosol cropped system (Nakamura, 1988). Buckerfield (1992) found two species of Acanthodrilidae and one species of Lumbricidae in dryland cropping soils under conservation-tillage in South Australia. Two species of Lumbricidae and two species of Acanthodrilidae were found in Cereal and lucerne production system (Baker, et al. 1993).

Seasonal abundance of earthworms and their biomass across the soil management treatments showed higher density (1878 m^{-2}) during postrainy season that of rainy season (712 m^{-2}) and low density was recorded during late rainy season. The maximum density being (386 m^{-2}) and they were not recorded during the dry winter and summer which may be because of dry soil conditions (Reddy and Pasha, 1993). The earthworms may be to escape from these unfavourable conditions, might have moved downwards to the deeper layers as dry conditions prevailed due to the approach of winter season and the upper soil layers became unsuitable for feeding. These findings are in consistence with those of Baker et al (1993) that higher densities of earthworms were recorded during rainy period, the maximum density being 303 m^{-2}. The population density recorded during the middle of the rainy season (July) of 1989 across the treatments were within the ranges reported by different investigators for arable soils (Edwards and Lofty, 1977; Robertson, 1989). The earthworm densities recorded in the annual treatments during rainy season of 1989 was different from that of 1990 rainy season, which may be due to the application of carbofuran insecticide to control sorghum shoot fly.

All the treatments i.e., tillage, organic amendments and perennial ley treatments significantly affected the total population densities and population of adults and juveniles, and biomass during different months of rainy and postrainy seasons (*P* <0.01) (Tables 2 to 8).

The zero tillage treatments under annual crop contained significantly higher population densities and biomass of earthworms compared to shallow and deep tillage treatments. This may be due to less soil disturbance and reduced damage. These findings are in support of several researchers who demonstrated that earthworm densities and biomass were greater under reduced or no-till systems compared to conventionally tilled systems (Teotia et al. 1950; McCalla, 1953; Lal, 1974; 1976; Ghilarov, 1975; Barnes and Ellis, 1979; Gerard and Hay 1979; Stinner and Crossley, 1980; Edwards and Lofty, 1982b; De St. Remy and Daynard, 1982; Edwards, 1983; House and Parmelee, 1985; Mackay and Kladivko, 1985; Lee, 1985; Anderson 1987; Haukka, 1988; Hendrix et al, 1992). Elimination of soil disturbance and stratification of organic matter contributed to the higher densities and biomass of earthworms under no-tillage. Moreover, no tillage provided a more favourable environment for soil and surface-residue dwelling organisms like earthworms by reducing moisture loss, regulating temperature extremes and fluctuations, and supplying relatively continuous substrate as food material (Crossley et al, 1984). Parmelee et al (1990) investigated that earthworm densities and biomass in the conventionally tilled soils were, on average, only 70% of the no-till values, and these results support the general conclusion that earthworm populations are greater in no-till than in conventional-till agroecosystems. Dotzler (1992) showed that up to 50% of an earthworm population can be damaged by cultivation. Nuutinen (1992) showed that the abundance of earthworms was low in ploughed soil than the spring stubble cultivated soil both in terms of numbers and dry weights. Edwards (1983) and Lee (1985) reviewed the possible adverse effects of cultivation on earthworm populations, and concluded that the most important factors may be the loss of surface litter mulch and the consequent decline in soil organic matter that led to reduction in food resources causing reduction in the population densities biomass of the earthworms.

Farmyard manure is animal dung often mixed with straw, and is the product of farm house sheltering the farm animals. The earthworm densities and biomass were higher in farmyard manure amendment across the tillage treatments compared to the bare and rice-straw amendments. This may be due to the fact that FYM is important source of organic nutrients and increased earthworm population. Moreover, the addition of FYM to the soil may have provided balanced nutrition to the earthworms as it contains all the three primary nutrients such as nitrogen, phosphorus, and potassium. The present investigation was supported by the findings of Satchell (1967) that fields which received higher amount of FYM and guano (35 t/ha of FYM and 0.75 t/ha of guano) every fourth year harbored a lumbricid earthworm population three times higher than that of an unmanured field and there is a linear correlation between the applied quantity of FYM and earthworm abundance (Edwards and Lofty, 1982a). Morris (1922 and

1927) reported that earthworm population densities increased from 2 to 2.5 times in FYM treated plots compared to that of control. Lee (1985) reported that organic fertilizers increased earthworm populations more than inorganic fertilizers in arable lands for equivalent increments of N, and this was attributed to the additional food (organic matter) provided by the FYM to earthworms. Standen (1984) and Mackay and Kladivko (1985) reported that organic matter additions in the form of manures or sewage sludges, greatly increased earthworms. Mackay and Kladivko (1985) reported that highest populations were found under a pasture receiving animal manure, intermediate populations were found under sod border strips, and the lowest populations were found under soybeans and maize. Anderson (1980 and 1983) reported that the deep burrowing species are favoured by FYM compared to slurry, and also Anderson (1987) reported that FYM is able to sustain a greater biomass than slurry, which in part may be due to a greater dry matter content. Tiwari (1993) found the increase in the earthworm population densities and biomass after treatment of FYM compared to that of control.

Earthworms were higher in number in initial months of 1989 under annual crop with tillage treatments and the density was low during remaining months of 1989 and 1990 in tillage treatments. The reduction of earthworm population densities and biomass under tillage plots during June to October 1990 may be due to the deleterious effects of ploughing as well as carbofuran insecticide that was applied for shoot fly control. Most of the earthworms might have died due to effect of carbofuran (Parmelee et al, 1990). The plots cropped to sorghum consistently showed decrease of earthworms. Negligible numbers of juveniles and adults were subsequently found indicating further toxic effects due to either residual carbofuran from 1989 or the small additional application of carbofuran again in July 1990. . Parmelee et al (1990) reported that in the winter fall, carbofuran reduced the large annelid biomass and organic matter breakdown was inhibited in the no-till system. Raw (1962), Mackay and Kladivko (1985), and Hendrix et al (1987) reported that in the summer-spring, the no -till annelid biomass was significantly reduced and greater standing stocks of organic matter occurred after carbofuran application. According to Edwards (1980) and Lee (1985) many insecticides and fungicides are toxic to earthworms, the placement of the insecticides may affect earthworm mortality by affecting the proportion of the population exposed to the chemical.

It has been found that earthworm density and biomass was higher in perennial ley treatments with *S. hamata*. These treatments had generally more earthworms than the treatments which had less vegetational cover (pigeonpea). The treatments with perennial species either maintained or increased population and biomass compared to the annual treatments. These results are in consistence with the findings of Evans and Guild (1948), Hopp and Hopkins (1946) and Barley (1959), who reported that the earthworm populations are higher under permanent pasture than under continuously cropped land, primarily because of the much greater supply of organic materials under pasture. Barley (1959) comparing earthworm populations in a two year pasture and permanent pasture, reported that the earthworm populations were higher in two years of pasture and in permanent pasture treatments than the tilled treatments. The marked difference in the numbers of earthworms was found under continuously cropped land compared to established pasture (Evans and Guild, 1948; Hopp and Hopkins, 1946; Barley, 1961). This is attributed primarily to the difference in the total amount of decomposed plant residue available to earthworms as food; litter in the pasture may provide some abundant food source for the earthworms. Besides, the perennial ley crop treatments provided continuous favourable microclimate and unperturbed environment for the earthworms compared to the annual crop treatments.

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CHAPTER-II

MACROARTHROPOD POPULATION STRUCTURE

INTRODUCTION

The soil surface covers one-third of our planet and shows a great variety of physico-chemical and biological characteristics, which influence each other. The abiotic characteristics particularly the climatic ones, change rapidly and induce changes in the biotic communities, thus, the individuals of the biotic communities react to the extremes of abiotic conditions either by falling into resting stages or by moving towards the places of favourable conditions.

Soil macrofauna constitute a major component of the biotic communities inhabiting the soil surface which includes both phytophagous and predatory species. The activities of soil macrofauna are important in maintaining soil structure and regulating the physico-chemical properties of the soil (Hole, 1980; Lal, 1988; Lee and Foster, 1991) which contribute to the stability of the soil resource. However, there have been few studies which have quantified the effects of soil macrofaunal activity in arable soils (Abbott et al, 1979; Abbott and Parker, 1980), particularly in tropical countries. They possibly influence the availability of nutrients for plants (Weidemann, 1978). Besides, they help in soil aeration, turnover, and infiltration (Hole, 1980). They contribute to the breakdown, decomposition and mineralization of organic matter in soil (Neumann, 1973; Springett, 1978; Coleman et al. 1984; Seastedt, 1984).

Many of the predators are very important in agriculture having a decisive influence on the structure and function of detritus food-web (Connell, 1970; Paine, 1974; and Reise, 1977). The predatory arthropods by feeding on the prey, prevent them from reaching a population size that exceeds the specific carrying capacity. Thus, together with other factors, they contribute to the attainment and maintenance of the ecosystem equilibrium (Odum and Reochholf, 1980). The ground beetles belonging to Carabidae and Staphylinidae are important as predators of the immature stages of the cabbage root fly especially of eggs (Wright, 1956; Wishart et al, 1956; Coaker and Williams, 1963). Scherney (1959) and Demster (1967) stated that the carabid beetles are known to be effective predators of many insect pests and especially cabbage root fly eggs (Hughes, 1959; El Titi, 1977; Rajumov and Bogdanov, 1980; Mowat and Martin, 1981). Thus, they have identified as important predator group in the soil litter system of different agroecosystems suppressing the pest population in the field (Ferguson and McPherson, 1985). Wright et al, (1960) stated that the predatory beetles could greatly reduce the root maggots and the crop damage. Besides, these beetles may serve as natural control agents of many other agricultural pests (Basedow, 1973; Edwards et al, 1979). Several species of Carabidae feed on the soil insects (Frank, 1971; Edwards et al, 1975; Best and Beagle, 1977), and others may aid in weed control through seed eating (Lund and Turpin, 1977).

Many investigators have explored on the possibility of soil surface arthropods as indicators of various factors (Franz, 1949; Murphy, 1953; Mahoney, 1976; Majer, 1977, 1978; Reddy and Venkataiah, 1986). They may possibly indicate vegetation and soil characteristics (Thiele, 1977; Reddy, 1989). Thus, it is now realised that a consideration of these invertebrates is of crucial importance in environmental decision making. Thiele (1977) reported that the carabid populations have enormous potential biological indicators through their response to environmental perturbations. Carabid populations are supposed to have indicational value for environmental changes owing to anthropogenous perturbations (Thiele and Weiss, 1976).

Different ecological aspects of the various species of the ground beetles have been studied in several agricultural fields, such as soybean (Rivard, 1966; Deitz et al, 1976; House and All, 1981; Price and Shepard, 1980; Ferguson and McPherson, 1985), Cotton (Bishop and Blood, 1980), wheat (Doane, 1981), Alfalfa (Los and Allen, 1982) and others. Lagerlof (1987) and Baker and Dunning (1975) reported on some effects of soil type and crop density on the activity and abundance of the epigeic fauna, particularly carabidae. Honek (1988) investigated on the effect of density of cereal stands on polyphagous predators of aphids, carabids, staphylinids and lycosids. Holopainen (1983) identified seasonal occurrence of various carabid species associated with cruciferous crops and compared the abundance and the density of carabid communities in organically and conventionally managed fields.

Soil management practices like tillage causes a number of changes in the properties of soils, including increased rates of plant residue decomposition. It alters the soil faunal communities (Andren and Lagerlof, 1983; Edwards, 1983; Hendrix et al, 1986; Ryszkowski, 1985). Periodic soil tillage, which tends to minimize water and nutrient competition between cultivated plants and weeds in orchards, is one of the most ancient soil management methods. When the plant cover is removed, the bare soil is subject the degradation of its soil structure leading to soil erosion, and reduction in soil biota (Seastedt, 1984; Dindal, 1990).

The **literature review** on the effects of soil management on soil surface arthropod populations indicated that most studies on insects in no-tillage systems have focused on their detrimental activities (Musick, 1970; Gregory, 1974; Harrison et al, 1980). Research on soil arthropods of no-tillage systems is relatively recent and sparse. Very little work on the insect related problems of no-tillage systems was attempted prior to 1970. Musick (1973) studied the control of army worm in no-till corn and Musick and Petty (1973) reported on insect control in conservation tillage systems. Raney (1974) investigated on insect problems associated with no-till soybeans. Gregory (1974) studied on no-tillage corn insect pests of Kentucky. Gregory and Musick (1976) investigated on the insect management in reduced tillage system. All and Gallaher (1976) reported on insect infestations in no-tillage corn cropping systems. All (1978) studied the insect relationships in no-tillage cropping. Shams et al (1981) investigated on the effects of no-till corn production methods on specific soil mesofaunal population. Grant et al (1982) reported on invertebrates associated with alfalfa seedling loss in complete tillage and no-tillage plantings. Funderburk et al (1983) investigated on seed corn maggot (Diptera: Anthomyiidae) emergence in conventional and reduced-tillage soybean systems. House and Stinner (1983) discussed current concepts relating to insects with no-tillage systems and he reported preliminary results comparing insect community composition, seasonal dynamics, and ecosystem interactions in conventional and no-tillage soybean agroecosystems. Blumberg and Crossley (1983) compared the habitat diversity of the soil surface arthropod populations in conventional, no-tillage and old field systems. Stinner et al (1988) reported on soil and foliage arthropod communities in conventional, reduced and no-tillage corn (maize, *Zea mays* L.) systems. House and Stinner (1983) reported on arthropods in no-tillage soybean agroecosystem. Gaylor et al (1984) and House and Stinner (1987) studied arthropods in conservation tillage system. Barney and Pass (1987) investigated the influence of no-tillage plowing on foliage inhabiting arthropods of alfalfa. Zehnder and Linduska (1987) compared and evaluated the influence of minimum tillage on Colarado potato beetle numbers in rotated and non-rotated tomato fields. Stinner and House (1990) studied on arthropods in conservation tillage system. Musick and Collins (1971) investigated the northern corn rootworm being affected by tillage. Abbott et al (1979) studied on changes in the abundance of large soil animals and physical properties of soils following cultivation. Sloderbeck and Edwards (1979) reported the effects of different tillage practices and row spacings on mexican bean beetle, and red legged grass hopper. McPherson et al (1982) reported the effects of different cropping systems on beneficial arthropod populations. Carter (1982) reported on the population of soil macroarthropods under different cropping systems. House and Stinner (1983) studied the effects of tillage systems on insect community composition, seasonal dynamics, and ecosystem interactions. Troxclair and Boethel (1984) investigated on the influence of tillage practices and row spacing on soybean insect populations. Carter et al (1985) compared the population numbers and biomass of macroarthropods under the annual and perennial crops. Curry (1986) studied on above-ground arthropod fauna of four Swedish cropping systems. Anderson (1988) investigated on the role of soil fauna in agricultural systems. Braman and Pendley (1993) investigated the seasonal dynamics of predators, parasitoids and decomposers and their response to management practices.

Carabid beetles together with staphylinid beetles and spiders are the predominant group of soil surface arthropod fauna in agroecosystems (Baker and Dunning, 1975; Finalyson and Campbell, 1976; Tischler, 1980). The impacts of intense agricultural techniques on these arthropods are far from being fully understood (Basedow et al, 1976). Although carabid beetle communities of agroecosystems are well researched in general (Thiele, 1977), very little is known about the effects of alternative agricultural techniques on them. Carabid beetles were studied in different agroecosystems under various soil management practices (House and All, 1981; Pietraszko and Chercq, 1981; Andren and Lagerlof, 1983; and Steen, 1983). Hokkanen and Holopainen (1986) studied on carabid species activity and densities in biologically and conventionally managed cabbage fields. Kromp (1989) investigated the differences in numbers of species and individuals owing to farming methods and features characterising carabid populations in biologically and conventionally farmed fields. Dritschilo and Wanner (1980, 1982) studied on ground beetle abundance in organically and conventionally managed corn fields. Purvis and Curry (1984) investigated on the influence of weeds and farmyard manure (FYM) on the activity of carabidae and other ground dwelling arthropods.

Musick and Suttle (1973) investigated the suppression of army worm damage due to no-tillage corn applied with granular carbofuran. All and Gallaher (1977) studied the detrimental impact of no-tillage corn cropping systems involving insecticides, hybrids and irrigation on lesser corn stalk borer infestation. Rivers et al (1977) investigated the influence of insecticide and corn tillage systems on larval control of *Phyllophaga auxia*. All et al (1979) investigated the influence of planting date, preplanting weed control, irrigation, conservation tillage practices and insecticide application on lesser corn stalk borer in corn field. Brust et al (1985) investigated tillage and soil insecticide effects on predator-black cutworm interactions in corn agroecosystems.

No-tillage retains existing soil spaces as living space for the dominant soil arthropods, like collembola. The living pore space in the deeper layers in the soil profile decreases and collembola populations also decline or shift toward smaller forms such as those of the genera, *Isotoma* and *Onychiurus* (Dhillon and Gibson, 1962). Loring et al (1981) reported the effect of three tillage practices on collembola and acarina populations. Moore et al (1984) investigated on the effects of different management systems on collembola and acarina in corn crop systems. Michalak (1984) compared the collembola associated with organic and conventional agroecosystems. Lagerlof and Andren (1988) studied on the abundance and activity of soil mites in four cropping systems. Perdue and Crossley (1989) examined the seasonal fluctuations of soil mite abundance in conventional and no-tillage experimental agroecosystems. Lagerlof and Andren (1990) studied abundance and activity of collembola under four arable crops. Unfortunately, in India, there have been few studies to quantify the effects of soil macrofauna activity in farmland, and on the effects of farm practices on the structure and function of soil arthropod populations (Reddy, 1984). Thus, the present investigation was undertaken and efforts were made to assess the response of soil surface arthropod population structure to 15 different soil management practices across rainy, postrainy and dry seasons in an Alfisol sorghum agroecosystem.

MATERIALS AND METHODS

The relative population density of soil-surface inhabiting arthropods were monitored using pitfall traps. Pitfall traps have been used often in studies examining the occurrence and activity of epigaeic invertebrates (Southwood, 1978). The details of the method are given in Southwood (1978) and Reddy and Venkataiah (1986). These arthropods were sampled in each plot every month during three seasons, i.e., rainy (June to September), postrainy (October to January) and summer seasons (February to May). Each pitfall trap consisted of glass jar (12 cm high with a diameter of 5 cm at the mouth), which were sunk in to the ground so that its upper rim (mouth of the bottle) was flushed with the soil surface. The jars were covered with plastic plate (9 x 9 cm) to hinder the rain and dust from getting into the traps. The space between the plate and soil surface was at least 3 cm. The jars contained about 100 ml ethylene glycol solution to kill and preserve the trapped arthropods. These traps were established by using a cylindrical soil core sampler. While installing the traps, care was taken not to disturb the immediate surrounding of the trap. One trap was placed in the middle of each plot. The total trapping period was 24 hours (one day), after which the traps were removed gently, tightly capped, labelled and brought to the laboratory. The contents of each jar was emptied in a petry dish and examined under a stereoscopic binocular microscope (Wild Heerbrug) and identified into different taxa of arthropods. Differences in relative population densities of the soil surface arthropods across the treatments were analysed by ANOVA by using GENSTAT.

RESULTS

Qualitative Composition:

The soil surface inhabiting arthropods sampled across the 15 soil management treatments such as different tillage and organic amendments with annual crop and perennial ley treatments, belonged to 25 different arthropod taxa such as Araneae, Pseudoscorpions and Acarina — Prostigmata, Cryptostigmata, Mesostigmata, and Astigmata; Diplopoda, Collembola — Entomobryidae, Isotomidae, Poduridae and Sminthuridae; Coleoptera — Carabidae, Staphylinidae, *Megalodicne*. sp. and Coleoptera larvae; Hymenoptera, Isoptera, Psocoptera, Dermaptera, Orthoptera, Thysanoptera, Hemiptera, Homoptera, Diptera and Lepidoptera larvae. The mean percentage composition of different arthropod taxa under various soil management practices presented in Figs. 9a and b. **Hymenoptera:** It was dominant, among all the taxa its percentage composition ranged between 27.3 and 63.9% across the 15 treatments. Under annual crop, in zero tillage treatments its percentage composition ranged from 27.3% in bare amendment to 47.7% in farmyard manure amendment. In shallow tillage treatments its percentage composition ranged between 34.2% in rice-straw amendment and 63.9% in bare amendment. In deep tillage treatments its percentage composition ranged from 34.1% in bare amendment to 42.9% in farmyard manure amendment. In perennial ley treatments its percentage composition ranged between 29.2% in C. *ciliaris* + S. *hamata* treatment and 44.5% in pigeonpea + S. *hamata* + C. *ciliaris* treatment.

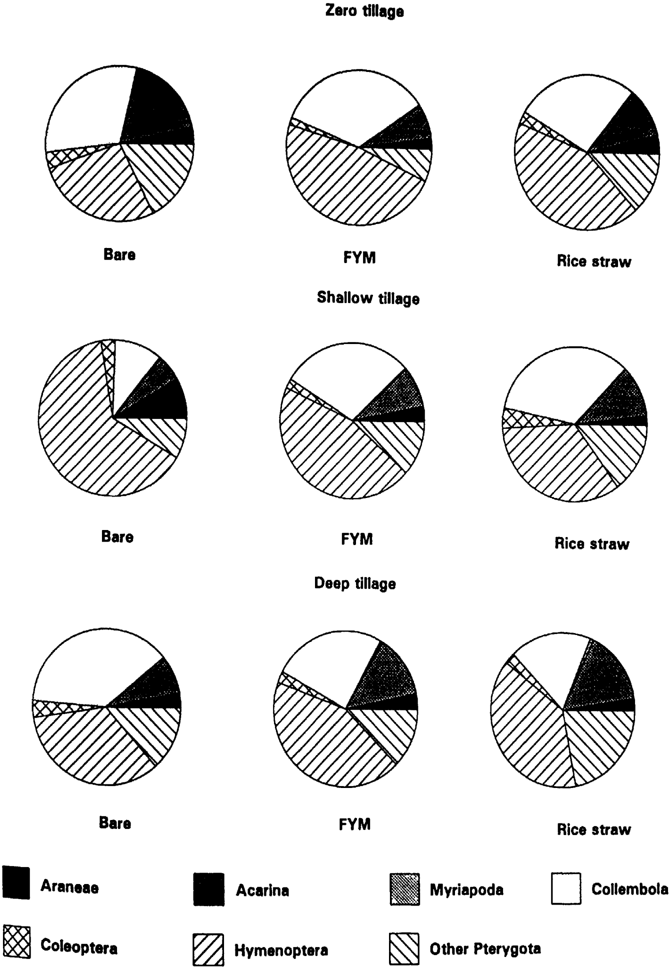

Figure 9a. Percentage composition of different soil surface arthropods caught in the pitfall traps across tillage and organic amendment treatments.

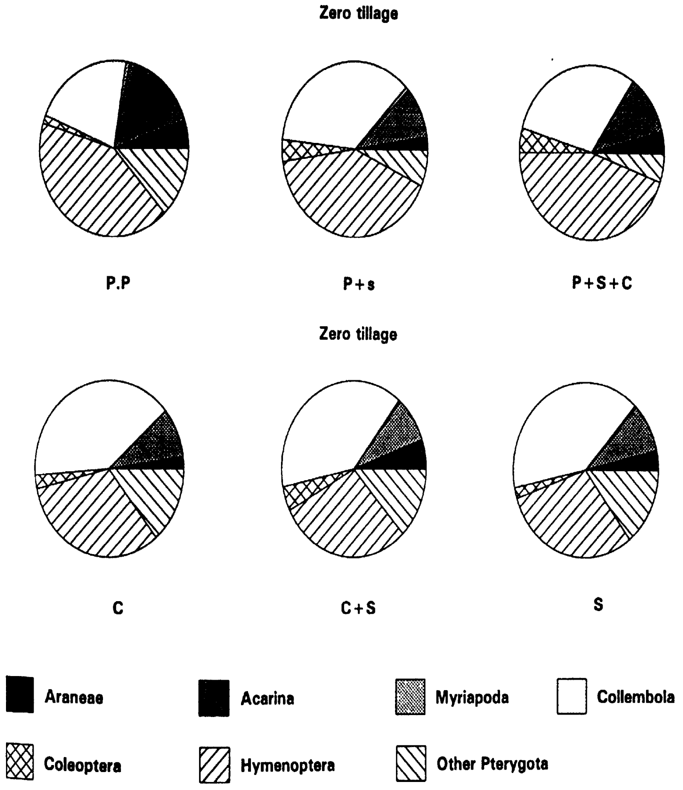

Figure 9b. Percentage composition of different soil surface arthropods caught in the pitfall traps under perennial ley crop treatments.

Collembola: It was the next dominant taxa. It composed of Poduridae, Entomobryidae, Isotomidae, and Sminthuridae. The percentage composition of Collembola ranged between 10.3 and 40.1%, the former being in shallow tillage bare amendment and latter in *S. hamata* treatment. Under annual crop, in zero tillage treatments their percentage composition ranged between 27.2% in rice-straw amendment and 34.4% in farmyard manure amendment. In shallow tillage treatments their percentage composition ranged from 10.3% in bare amendment to 34% in rice-straw amendment. In deep tillage treatments their percentage composition ranged from 18.4% in rice-straw amendment to 38% in bare amendment. In perennial ley treatments their percentage composition ranged between 21.2% in pigeonpea treatment and 40.1% in *S. hamata* treatment. Among the Collembola **Poduridae** being dominant taxa, its percentage composition ranged from 1.2 to 23.5%, the former being in deep tillage rice-straw amendment and later in pigeonpea + *S. hamata* treatment. Under annual crop, in zero tillage treatments its percentage composition ranged from 7% in rice-straw amendment to 17.2% in farmyard manure amendment. In shallow tillage treatments its percentage composition ranged between 2.9% in bare amendment and 14% in farmyard manure amendment. In deep tillage treatments its percentage composition ranged from 1.2% in rice-straw amendment to 20.8% in bare amendment. In perennial ley treatments its percentage composition ranged between 8.2% in pigeonpea treatment and 23.5% in pigeonpea + *S. hamata* treatment. The percentage composition of **Sminthuridae** ranged between 2 and 21.2%, the former being in deep tillage farmyard manure amendment and latter in shallow tillage rice-straw amendment. Under annual crop, in zero and shallow tillage treatments its percentage composition ranged from 7 and 2.8% in bare amendment to 9 and 21.2% in rice-straw amendment, respectively. In deep tillage treatments its percentage composition ranged between 2% in farmyard manure amendment and 8.7% in rice-straw amendment. In perennial ley treatments its percentage composition ranged from 4.4% in pigeonpea treatment to 13.9% in *S. hamata* treatment.

The percentage composition of **Isotomidae** ranged between 2.3 and 11.2%, the former being in shallow tillage rice-straw amendment and latter in deep tillage bare amendment. Under annual crop, in zero tillage treatments its percentage composition ranged between 6.2% in farmyard manure amendment and 8.9% in bare amendment. In shallow tillage treatments its percentage composition ranged from 2.3% in rice-straw amendment to 4.3% in farmyard manure amendment. In deep tillage treatments its percentage composition ranged between 5.3% in farmyard manure amendment and 11.2% in bare amendment. In perennial ley treatments its percentage composition ranged from 2.9% in pigeonpea + *S. hamata* treatment to 9% in *C. ciliaris* treatment. The percentage composition of **Entomobryidae** ranged between 1.3 and 7%, the former being in deep tillage rice-straw and *C. ciliaris* + *S. hamata* treatments and latter in zero tillage bare amendment. Under annual crop, in zero tillage treatments its percentage composition ranged between 2.8% in farmyard manure amendment and 7% in bare amendment. In shallow tillage treatments its percentage composition ranged from 1.4% in bare amendment to 3.2% in farmyard manure amendment. In deep tillage treatments its percentage composition ranged between 1.3% in rice-straw amendment and 3.6% in bare amendment. In perennial ley treatments its percentage composition ranged between 1.3% in *C. ciliaris* + *S. hamata* treatment and 3.9% in pigeonpea treatment.

Acarina: The percentage composition in Acarina which composed of Prostigmata, Mesostigmata, Cryptostigmata, and Astigmata, ranged between 4 and 16.1%, the former being in shallow tillage bare treatment and latter in pigeonpea treatment. Under annual crop, in zero tillage treatments their percentage composition ranged between 6.9% in farmyard manure amendment and 13.6% in bare amendment. In shallow and deep tillage treatments their percentage composition ranged from 4 and 7.1% in bare amendment to 10.1 and 13.6% in rice-straw amendment, respectively. In perennial ley treatments their percentage composition ranged between 8.4% in *C. ciliaris* + *S. hamata* treatment and 16.1% in pigeonpea treatment. The percentage composition of **Prostigmata** the dominant taxa, among the Acarina, ranged between 1.3 and 8.8%, the former being in shallow tillage bare amendment and latter in zero tillage bare amendment. Under annual crop, in zero tillage treatments its percentage composition ranged between 2.5% in farmyard manure amendment and 8.8% in bare amendment. In shallow and deep tillage treatments its percentage composition ranged from 1.3 and 2.2% in bare amendment to 3.8 and 6% in rice-straw amendment, respectively. In perennial ley treatments its percentage composition ranged between 1.9% in pigeonpea +

S. hamata treatment and 8.1% in pigeonpea treatment.

Mesostigmata: Its percentage composition ranged between 1.6 and 5.7%, the former being in shallow tillage bare treatment and latter in deep tillage rice-straw amendment. Under annual crop, in zero tillage treatments its percentage composition ranged between 2.2% in farmyard manure amendment and 4.1% in bare amendment. In shallow and deep tillage treatments its percentage composition ranged from 1.6% and 2.5% in bare amendment to 2.4% and 5.7% in rice-straw amendment, respectively. In perennial ley treatments its percentage composition ranged between 3.5% in *C. ciliaris* treatment and 5.5% in pigeonpea treatment. **Cryptostigmata:** Its percentage composition ranged between 0.3 and 3.6%, the former being in *S. hamata* treatment and latter in shallow tillage rice-straw amendment. In zero and shallow tillage treatments its percentage composition ranged from <1 and 1.1% in bare amendment to 2.3 and 3.6% in rice-straw amendment, respectively. In deep tillage treatments its percentage composition ranged between 1.6% in rice-straw amendment and 2.1% in farmyard manure amendment. In perennial ley treatments its percentage composition ranged between <1% in *S. hamata* treatment and 2.5% in pigeonpea treatment. The percentage composition of **Astigmata** was too low to show any distinct variation among the 15 soil management treatments.

Myriapoda: Among the Myriapoda only **Diplopoda** was recorded. Its percentage composition was <1% across the treatments.

Coleoptera: The percentage composition of Coleoptera which comprised of **Carabidae, *Megalodicne* Sp., Staphylinidae, and Coleoptera larvae,** ranged between 1.5 and 4.5%, the former being in zero tillage farmyard manure and pigeonpea treatments and latter in pigeonpea + *S. hamata* + *C. ciliaris* and *C. ciliaris* + *S. hamata* treatments. Under annual crop, in zero tillage treatments their percentage composition ranged between 1.5% in farmyard manure amendment and 3.4% in bare amendment. In shallow tillage treatments their percentage composition ranged between 2% in farmyard manure amendment and 4.2% in rice-straw amendment. In deep tillage treatments their percentage composition ranged between 2.3% in rice-straw amendment and 3.5% in bare amendment. In perennial ley treatments their percentage composition ranged between 1.5% in pigeonpea treatment and 4.5% in pigeonpea + *S. hamata* + *C. ciliaris* and *C. ciliaris* + *S. hamata* treatments. **Carabidae** was dominant taxa among the Coleoptera. Its percentage composition ranged between <1 and 2.7%, the former being recorded in zero tillage farmyard manure and pigeonpea treatments, and latter in pigeonpea + *S. hamata* + *C. ciliaris* treatment. Under annual crop, in zero tillage treatments its percentage composition ranged between <1% in farmyard manure amendment and 2% in bare amendment. In shallow tillage treatments its percentage composition ranged between <1% in bare amendment and 1.4% in rice-straw amendment. In deep tillage treatments its percentage composition showed very little variation, ranging between 0.8 to 1.1% across the amendments. In perennial ley treatments its percentage composition ranged between <1% in pigeonpea treatment and 2.7% in pigeonpea + *S. hamata* + *C. ciliaris* treatment.

***Megalodicne* Sp.,:** Its percentage composition ranged between 0.3 and 1.4%, the former being recorded in pigeonpea + *S. hamata* + *C. ciliaris* treatment and latter in shallow tillage rice-straw, deep tillage bare and *C. ciliaris* treatments. Under annual crop, in zero tillage treatments its percentage composition showed very little variation (0.7 to 1%) across the amendments. In shallow tillage treatments its percentage composition ranged between <1% in farmyard manure amendment and 1.4% in rice-straw amendment. In deep tillage treatments its percentage composition ranged between 1.2% in rice-straw amendment and 1.4% in bare amendment. In perennial ley treatments its percentage composition ranged between <1% in pigeonpea + *S. hamata* + *C. ciliaris* treatment and 1.4% in *C. ciliaris* treatment. **Staphylinidae:** Its percentage composition ranged between <1 and 2%, the former being in *C. ciliaris* treatment and latter in pigeonpea + *S. hamata* treatment. Under annual crop, in zero and shallow tillage treatments its percentage composition was <1% across the organic amendment treatments. In deep tillage treatments its percentage composition ranged between <1 (0.3%) in rice-straw amendment and 1% in farmyard manure amendment. In perennial ley treatments its percentage composition ranged between <1% in pigeonpea and *S. hamata* treatments and 2% in pigeonpea + *S. hamata* treatment.

Coleoptera larvae: The percentage composition of Coleoptera larvae ranged between 0.1 and 2.4%, the former being recorded in deep tillage bare and *C. ciliaris* treatments and latter in *C. ciliaris* + *S. hamata* treatment. Under annual crop, in zero and deep tillage treatments its percentage composition was <1%

across the amendments. In shallow tillage treatments its percentage composition showed very little variation ranging between 0.9 to 1% salcross the amendments. In perennial ley treatments its percentage composition ranged from <1% in *C. ciliaris* treatment to 2.4% in *C. ciliaris* + *S. hamata* treatment.

Other Pterygota: The percentage composition of other Pterygota which comprised of **Psocoptera, Dermaptera, Hemiptera, Orthoptera, Homoptera, Thysanoptera, Isoptera, Diptera,** and **Lepidoptera** larvae ranged between 5.4 and 22%, the former being in pigeonpea + *S. hamata* + *C. ciliaris* treatment and latter in deep tillage rice-straw amendment. In zero tillage treatments their percentage composition ranged between 6.9% in farmyard manure amendment and 17.5% in bare amendment. In shallow tillage treatments their percentage composition ranged between 8.4% in bare amendment and 14.8% in rice-straw amendment. In deep tillage treatments their percentage composition ranged between 12.5% in farmyard manure amendment and 22% in rice-straw amendment. In perennial ley treatments their percentage composition ranged between 5.4% in pigeonpea + *S. hamata* + *C. ciliaris* treatment and 14.4% in *S. hamata* treatment. **Psocoptera:** Among the other Pterygota, Psocoptera was dominant. Its percentage composition ranged between 1 and 10.4%, the former being recorded in pigeonpea + *S. hamata* + *C. ciliaris* treatment and latter in *C. ciliaris* treatment. Under annual crop, in zero tillage treatments its percentage composition ranged between 2.9% in farmyard manure and rice-straw amendments and 5.9% in bare amendment. In shallow and deep tillage treatments its percentage composition ranged from

4.4 and 4.6% in bare amendment to 6.8% and 8.6% in rice-straw amendment, respectively. In perennial ley treatments its percentage composition ranged between 1% in pigeonpea + *S. hamata* + *C. ciliaris* treatment and 10.4% in *C. ciliaris* treatment.

Dermaptera: Its percentage composition ranged between <1 and 5.4%, the former being recorded in pigeonpea + *S. hamata* treatment and latter in zero tillage rice-straw amendment. Under annual crop, in zero tillage treatments its percentage composition ranged between 1.7% in farmyard manure amendment and 5.4% in rice-straw amendment. In shallow tillage treatment its percentage composition ranged between 2.1% in bare amendment and 4.2% in rice-straw amendment. In deep tillage treatments its percentage composition ranged between 1.6% in farmyard manure amendment and 5% in rice-straw amendment. In perennial ley treatments its percentage composition ranged from <1% in pigeonpea + *S. hamata* treatment to 2.3% in *C. ciliaris* + *S. hamata* treatment. **Hemiptera:** Its percentage composition ranged between <1 and 7.3%, the former being in *S. hamata* treatment and latter in deep tillage rice-straw amendment. Under annual crop, in zero tillage treatments its percentage composition ranged between 1.4% in farmyard manure amendment and 2.6% in bare amendment. In shallow and deep tillage treatments its percentage composition ranged from 0.9 and 1.4% in bare amendment to 2.3 and 7.3% in rice-straw amendment, respectively. Its percentage composition was <1% across the perennial treatments.

Orthoptera: The percentage composition of Orthoptera ranged between 0.1 and 3.5%, the former being recorded in deep tillage farmyard manure amendment and latter in *S. hamata* treatment. In zero and shallow tillage treatments its percentage composition ranged from <1% in farmyard manure amendment to 1.7 and 1% in rice-straw amendment, respectively. In deep tillage treatments its percentage composition ranged between <1% in farmyard manure amendment and 1.7% in bare amendment. In perennial ley treatments its percentage composition ranged between <1% in pigeonpea treatment and 3.5% in *S. hamata* treatment. The percentage composition of **Homoptera** ranged between 0.2 and 1.5%, the former being in deep tillage farmyard manure and pigeonpea + *S. hamata* + *C. ciliaris* treatments and latter in zero tillage bare amendment. Under annual crop, in zero tillage treatments its percentage composition ranged between <1% in rice-straw amendment and 1.5% in bare amendment. In shallow and deep tillage treatments its percentage composition was <1% across the amendments. In perennial ley treatments its percentage composition ranged from <1% in pigeonpea + *S.hamata* + *C. ciliaris* and *C. ciliaris* treatments and 1.4% in pigeonpea + *S. hamata* treatment.

Thysanoptera: The percentage composition of Thysanoptera ranged between 0.1 and 1.5%, the former being in shallow tillage bare treatment and latter in zero tillage bare amendment. Under annual crop, in zero tillage treatments its percentage composition ranged between <1% in rice-straw amendment and 1.5% in bare amendment. In shallow tillage treatments its percentage composition was <1% across the amendments, while in deep tillage treatments its percentage composition ranged between <1% in farmyard manure amendment and 1.1% in bare amendment. In perennial ley treatments its percentage composition ranged from <1% in pigeonpea + *S. hamata* and *C. ciliaris* treatments to 1% in *C. ciliaris* + *S. hamata* treatment. The percentage composition of **Isoptera, Diptera,** and **Lepidoptera larvae** was too low to show any distinct variation across the 15 different soil management treatments.

Araneae: The percentage composition of Araneae which composed of *Thanatus* Sp., and Pseudoscorpions, ranged between 2 and 8.4%, the former being recorded in shallow tillage rice-straw amendment and latter in shallow tillage bare amendment. Under annual crop, in zero tillage treatments its percentage composition ranged between 2.2% in farmyard manure amendment and 3.9% in rice-straw amendment. In shallow tillage treatments its percentage composition ranged between 2% in rice-straw amendment and 8.4% in bare amendment. In deep tillage treatments its percentage composition ranged between 2.5% in rice-straw amendment and 3.2% in farmyard manure amendment. In perennial ley treatments its percentage composition ranged between 2.2% in *C. ciliaris* treatment and 5.5% in *C. ciliaris* + *S. hamata* treatment. ***Thanatus* Sp.:** Among the Araneae, *Thanatus* sp. was dominant. Its percentage composition ranged between 2 and 8%, the former being in shallow tillage rice-straw amendment and latter in shallow tillage bare treatment. Under annual crop, in zero tillage treatments its percentage composition ranged between 2.2% in farmyard manure amendment and 3.6% in bare and rice-straw amendments. In shallow tillage treatments its percentage composition ranged between 2% in rice-straw amendment and 8% in bare amendment. In deep tillage treatments its percentage composition ranged between 2.5% in farmyard manure and rice-straw amendments and 3% in bare amendment. In perennial ley treatments its percentage composition ranged between 2.1% in *C. ciliaris* amendment and 5.4% in *C. ciliaris* + *S. hamata* amendment. **Pseudoscorpions:** The percentage composition of Pseudoscorpions was also too low to show any distinct variation among the 15 different soil management treatments.

Temporal Variation:

Total macroarthropods: The seasonal fluctuation in their relative population densities across the 15 soil management treatments in Fig. 10 revealed that the mean densities was 3.7 in number in shallow and deep tillage bare amendments and increased to nearly three folds higher (11) in pigeonpea and pigeonpea + *S. hamata* treatments, followed by pigeonpea + *S. hamata* + *C. ciliaris* treatment (10) 10 days after sowing during the crop season (July, 1989). The mean density was <1 in zero tillage farmyard manure amendment and increased to ninety folds higher (27) in pigeonpea + *S. hamata* + *C. ciliaris* treatment, followed by *C. ciliaris* treatment (23) 30 days after sowing (August, 1989). It was 7.7 in shallow tillage bare amendment and increased to more than nine folds higher (72) in *S. hamata* treatment 60 days after sowing (September, 1989). It was 14 in *C. ciliaris* treatment and more than six folds higher (97.3) in zero tillage rice-straw amendment, followed by pigeonpea + *S. hamata* treatment (95) 90 days after

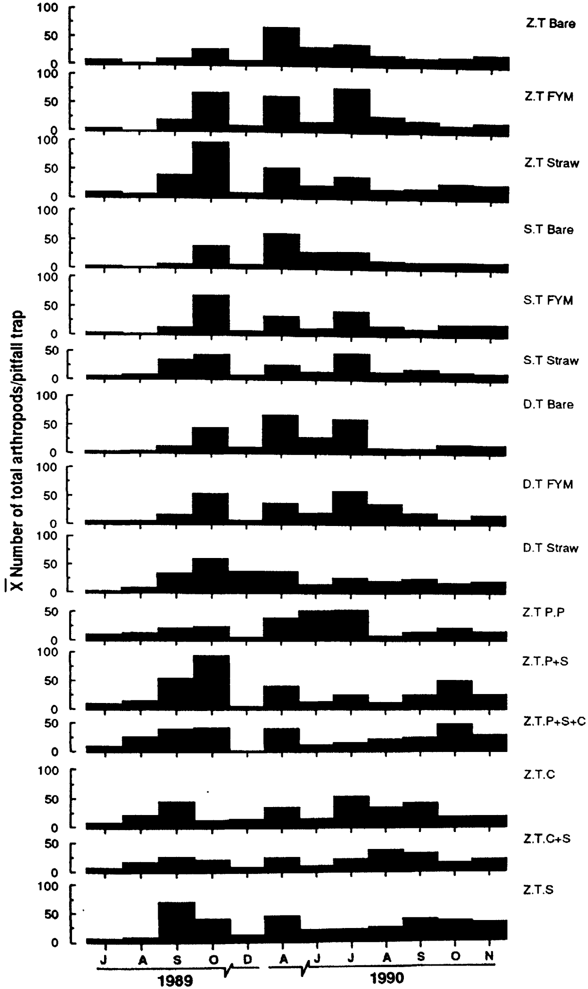

Figure 10. Seasonal fluctuation in the relative population densities of total soil surface arthropods caught in the pitfall traps across the fifteen soil management treatments.

sowing (October, 1989). During the following fallow period, the mean density was 2 in pigeonpea + *S. hamata* + *C. ciliaris* treatment and increased to nineteen folds higher (38) in deep tillage rice-straw amendment 60 days after harvesting the crop (December, 1989). It was low 25 in *C. ciliaris* + *S. hamata* treatment and increased more than two folds higher (67) in deep tillage bare treatment, followed by zero tillage farmyard manure amendment (62) 170 days after harvesting (April, 1990). It was 11 in *C. ciliaris* + *S. hamata* treatment and increased to more than four folds higher (52.3) in pigeonpea treatment 200 days after harvesting (June, 1990).

During the 2nd crop season, the density was 16 in pigeonpea + *S. hamata* + *C. ciliaris* treatment and increased to more than four folds higher (78) in zero tillage farmyard manure amendment 10 days after sowing during the crop (July, 1990). It was 9 in pigeonpea treatment and increased to more than four folds higher (38) in *C. ciliaris* + *S. hamata* treatment, followed by deep tillage farmyard manure amendment (37) 50 days after sowing (August, 1990). It was 9 in deep tillage bare treatment and increased to nearly five folds higher (43.3) in *C. ciliaris* treatment, followed by *S. hamata* treatment (41) 75 days after sowing (September, 1990). It was 10 in deep tillage farmyard manure amendment and increased to five folds higher (50) in pigeonpea + *S. hamata* treatment, followed by pigeonpea + *S. hamata* + *C. ciliaris* treatment (49) 90 days after sowing (October, 1990). During the following fallow period, it was 12 in shallow tillage rice-straw amendment and increased to nearly three folds higher (34) in *S. hamata* treatment, followed by pigeonpea + *S. hamata* + *C. ciliaris* treatment (30) 20 days after harvesting the crop (November, 1990).

Entomobryidae: The seasonal fluctuation in its relative population densities across the treatments presented in Fig. 11a revealed that the mean density was <1 in shallow tillage bare, pigeonpea, pigeonpea + *S. hamata* and *C. ciliaris* + *S. hamata* treatments and increased to nearly seven folds higher (2) in zero tillage bare amendment 10 days after sowing during the crop season (July, 1989). The mean density was <1 in deep tillage bare and *C. ciliaris* + *S. hamata* treatments which increased to more than seven folds higher (2.3) in *S. hamata* treatment 30 days after sowing (August, 1989). It was <1 in shallow tillage farmyard manure and *C. ciliaris* treatments and increased to more than four folds higher (3) in pigeonpea + *S. hamata* + *C. ciliaris* treatment, followed by *S. hamata* treatment (2.7) 60 days after sowing (September, 1989). It was <1 in shallow tillage bare, deep tillage farmyard manure, and pigeonpea + *S. hamata* + *C. ciliaris* treatments and increased to more than twelve folds higher (3.7) in zero tillage farmyard manure amendment 90 days after sowing (October, 1989). During the following fallow period, they were not recorded in any treatments 60 days after harvesting the crop (December, 1989). The mean density was <1 in deep tillage bare and pigeonpea + *S. hamata* + *C. ciliaris* treatments and increased to more than four folds higher (3) in zero tillage rice-straw amendment, followed by deep tillage farmyard manure amendment (2.7) 170 days after harvesting the crop (April, 1990). It was <1 in shallow tillage bare, farmyard manure and rice-straw, deep

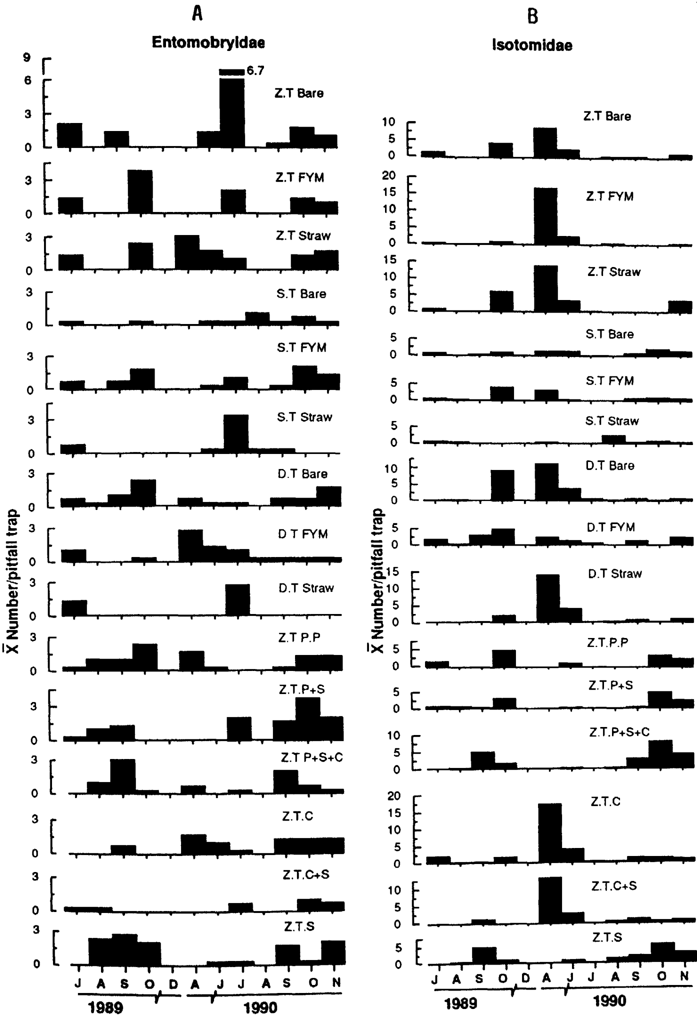

Figure 11. Seasonal fluctuation in the relative population density of Entomobryidae (A) and that of Isotomidâe (B) caught in the pitfall traps across the fifteen soil management treatments.

tillage bare, pigeonpea, and *S. hamata* treatments which increased to nearly six folds higher (1.7) in zero tillage rice-straw amendment, followed by zero tillage bare and deep tillage farmyard manure amendments (1.3) 200 days after harvesting (June, 1990).

During the 2nd crop season, the density was <1 in shallow and deep tillage bare, pigeonpea + *S. hamata* + *C. ciliaris*, *C. ciliaris* and *S. hamata* treatments which increased to more than twenty two folds higher (6.7) in zero tillage bare treatment 10 days after sowing during the crop (July, 1990). It was <1 in shallow tillage rice-straw and deep tillage farmyard manure amendments and increased to more than three folds higher (1) in shallow tillage bare treatment 50 days after sowing during the crop (August, 1990). It was <1 in zero tillage bare, shallow tillage bare, farmyard manure, rice-straw, deep tillage farmyard manure and pigeonpea treatments and increased to nearly seven folds higher (2) in pigeonpea + *S. hamata* + *C. ciliaris* treatment followed by pigeonpea + *S. hamata* and *S. hamata* treatments (1.7) 75 days after sowing (September, 1990). It was <1 in deep tillage farmyard manure and *S. hamata* treatments and increased to more than twelve folds higher (3.7) in pigeonpea + *S. hamata* treatment, followed by shallow tillage farmyard manure amendment (2) 90 days after sowing the crop (October, 1990). During the following fallow period, it was <1 in shallow tillage bare, deep tillage farmyard manure and pigeonpea + *S. hamata* + *C. ciliaris* treatments which increased to more than six folds higher (2) in pigeonpea + *S. hamata*, and *S. hamata* treatments, followed by zero tillage rice-straw and deep tillage bare amendments (1.7) 20 days after harvesting the crop (November, 1990).

Isotomidae: The seasonal fluctuation in its relative population densities across the treatments presented in Fig. 11b revealed that their mean densities were too few to show any distinct variation till 30 days after sowing (August, 1989). It was <1 in shallow tillage bare, pigeonpea + *S. hamata* and *C. ciliaris* treatments and increased to nearly seventeen folds higher (5) in pigeonpea + *S. hamata* + *C. ciliaris* treatment, followed by *S. hamata* treatment (4.7) 60 days after sowing (September, 1989). It was <1 in zero tillage farmyard manure amendment and increased to nearly thirteen folds higher (9) in deep tillage bare treatment, followed by zero tillage rice-straw amendment (6) 90 days after sowing (October, 1989). During the following fallow period, none of them were recorded across the treatments 60 days after harvesting the crop (December, 1989). The mean density was <1 in shallow tillage rice-straw amendment which increased to nearly fifty eight folds higher (17.3) in *C. ciliaris* treatment, followed by zero tillage farmyard manure amendment (17) 170 days after harvesting the crop (April, 1990). It was <1 in shallow tillage farmyard manure, pigeonpea + *S. hamata* and pigeonpea + *S. hamata* + *C. ciliaris* treatments and increased to more than thirteen folds higher (4) in deep tillage rice-straw and *C. ciliaris* treatment, followed by deep tillage bare treatment (3.7) 200 days after harvesting the crop (June, 1990).

During the 2nd crop season, the mean densities were very few in number and did not show any distinct temporal variation till 75 days after sowing the crop (September, 1990). It was <1 in deep tillage bare and *C. ciliaris* + *S. hamata* treatments and increased to nearly twenty seven folds higher (8) in pigeonpea + *S. hamata* + *C. ciliaris* treatment, followed by *S. hamata* treatment (5) 90 days after sowing the crop (October, 1990). During the following fallow period, it was <1 in zero tillage farmyard manure and shallow tillage rice-straw amendments and increased to more than fourteen folds higher (4.3) in pigeonpea + *S. hamata* + *C. ciliaris* treatment, followed by zero tillage rice-straw amendment (3.3) 20 days after harvesting the crop (November, 1990).

ANOVA revealed that the Isotomidae densities in tillage and organic amendment treatments during dry season were significantly different from that of the wet seasons being more than fifteen folds higher and more than five folds higher in abundance during dry season, than that of postrainy season, the differences being statistically significant (Table 9).

Poduridae: The seasonal fluctuation in its relative population densities across the treatments presented in Fig. 12a revealed that the mean density was <1 in zero tillage farmyard manure, deep tillage farmyard manure and rice-straw amendments and it increased to more than seven folds higher (5.3) in *C. ciliaris* treatment 10 days after sowing during the crop season (July, 1989). It was <1 in pigeonpea and *S. hamata* treatments and increased to more than thirty five folds higher (11) in *C. ciliaris* treatment, followed by pigeonpea + *S. hamata* + *C. ciliaris* treatment (8.3) 30 days after sowing (August, 1989). It was <1 in zero and deep

Table 9. Response of population densities of soil surface arthropods to soil management treatments during 1989-1990.

	Tillage and organic amendment treatments				Perennial ley treatments			
Arthropod taxa	Rainy	Post-rainy	Dry	At 1% LSD	Rainy	Post-rainy	Dry	At 1% LSD
Isotomidae	0.5	1.4	7.8	4.4	--	--	--	--
Poduridae	4.1	0.1	--	1.8	--	--	--	--
Sminthuridae	2.4	1.1	0.04	0.8	3.2	1.4	--	1.7
Prostigmata	0.8	0.2	4.3	2.1	1.3	0.1	2.1	0.9
Mesostigmata	1.07	0.4	--	0.5	1.7	0.7	--	0.5
Hymenoptera	5.0	14.5	27.9	17.1	6.3	10.1	33.6	20.6*
Psocoptera	1.3	0.8	2.59	1.14	--	--	--	--
Dermaptera	0.3	1.7	0.04	0.4	0.1	0.9	--	0.4
Orthoptera	0.1	0.4	--	0.2	--	--	--	--
Hemiptera	--	2.0	0.07	1.2	--	--	--	--
Araneae	0.4	1.0	2.4	1.53	0.6	1.0	3.1	1.1

* Significant at ($P < 0.05$).

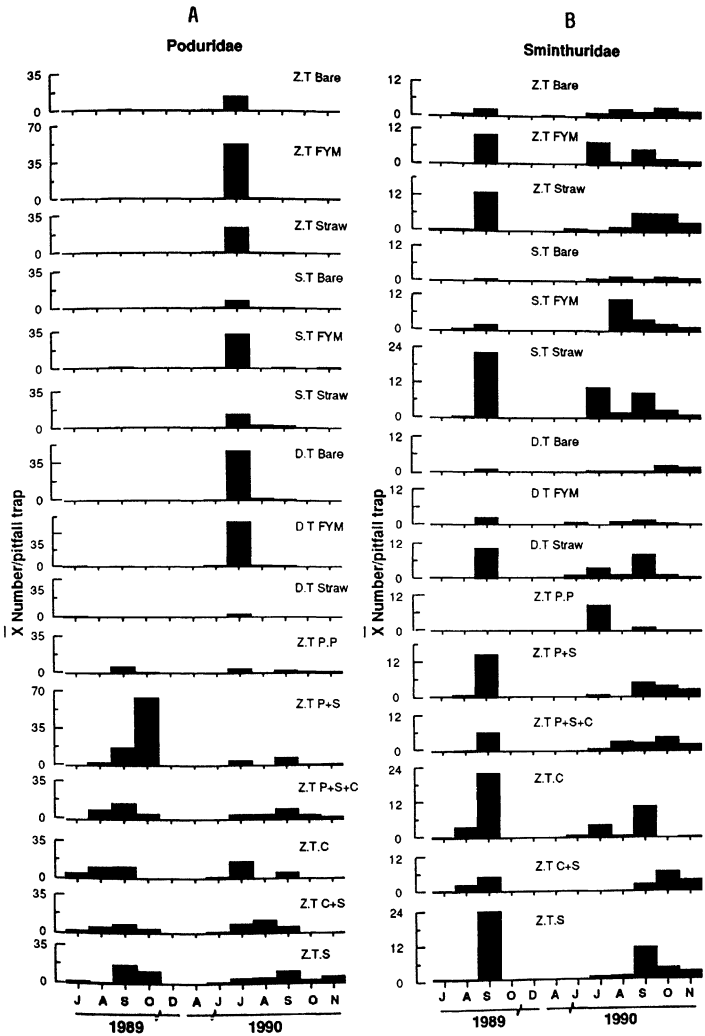

Figure 12. Seasonal fluctuation in the relative population density of Poduridae (A) and that of Sminthuridae (B) caught in the pitfall traps across the fifteen soil management treatments.

tillage farmyard manure amendments and increased to more than fifty seven folds higher (17.3) in *S. hamata* treatment, followed by pigeonpea + *S. hamata* treatment (17) 60 days after sowing (September, 1989). It was 1.3 in pigeonpea treatment and increased to more than forty nine folds higher (64.3) in pigeonpea + *S. hamata* treatment 90 days after sowing (October, 1989). During the following fallow period, Poduridae was not recorded across the treatments 60 and 170 days after harvesting the crop (December, 1989 and April, 1990, respectively). Its mean density was <1 in zero tillage rice-straw, shallow tillage bare, farmyard manure and rice-straw, deep tillage bare, pigeonpea and pigeonpea + *S. hamata* treatments and increased to more than five folds higher (1.7) in *C. ciliaris* treatment, followed by *C. ciliaris* + *S. hamata* and *S. hamata* treatments (1.3) 200 days after harvesting the crop (June, 1990).

During the 2nd crop season, its mean density was 2.7 in deep tillage rice-straw amendment and increased to more than nineteen folds higher (52) in zero tillage farmyard manure amendment, followed by deep tillage farmyard manure amendment (47.3) 10 days after sowing during the crop (July, 1990). It was <1 in zero tillage rice-straw and shallow tillage bare amendments and increased to forty folds higher (12) in *C. ciliaris* + *S. hamata* treatment 50 days after sowing during the crop (August, 1990). It was <1 in zero tillage bare and rice-straw, shallow tillage bare and deep tillage rice-straw amendments and increased to nearly thirty eight folds higher (11.3) in *S. hamata* treatment, followed by pigeonpea + *S. hamata* + *C. ciliaris* treatment (9.3) 75 days after sowing the crop

(September, 1990). It was <1 in zero tillage farmyard manure amendment and increased to more than five folds higher (3.7) in pigeonpea + *S. hamata* + *C. ciliaris* treatment, followed by *S. hamata* treatment (3) 90 days after sowing the crop (October, 1990). During the following fallow period, it was one in zero tillage farmyard manure amendment and increased to more than six folds higher (6.3) in *S. hamata* treatment 20 days after harvesting the crop (November, 1990).

ANOVA revealed that the Poduridae densities in tillage and organic amendment treatments during rainy season were significantly different from that of postrainy season being more than forty folds higher and absent during the dry season (Table 9).

Sminthuridae: The seasonal fluctuation in its relative population density across the treatments presented in Fig. 12b revealed that the mean densities were very few in number and distinct show any distinct temporal variation till 30 days after sowing (August, 1989). It was <1 in shallow and deep tillage bare treatments and increased to forty folds higher (28) in *S. hamata* treatment, followed by shallow tillage rice-straw and *C. ciliaris* treatments (22) 60 days after sowing (September, 1989). None of these collembolans were recorded across the treatments 90 days after sowing (October, 1989). During the following fallow period, these Collembolans were not recorded across the treatments 60 days after harvesting the crop (December, 1989). Its mean density was <1 in zero tillage bare treatment, and were not recorded in other treatments 170 days after harvesting the crop

(April, 1990). It was <1 in zero tillage rice-straw, deep tillage farmyard manure and *C. ciliaris* treatments and was one in deep tillage rice-straw amendment 200 days after harvesting the crop (June, 1990).

During the 2nd crop season, the mean density was <1 in zero tillage rice-straw and deep tillage bare amendments and increased to more than thirty four folds higher (10.3) in shallow tillage rice-straw amendment, followed by pigeonpea treatment (9) 10 days after sowing during the crop (July, 1990). It was <1 in deep tillage bare treatment and increased to more than thirty six folds higher (11) in shallow tillage farmyard manure amendment 50 days after sowing during the crop (August, 1990). It was <1 in deep tillage bare treatment and increased to nearly thirty seven folds higher (11) in *S. hamata* treatment, followed by *C. ciliaris* treatment (10.7) 75 days after sowing (September, 1990). It was <1 in pigeonpea treatment which increased to more than twenty two folds higher (6.7) in *C. ciliaris* + *S. hamata* treatment, followed by zero tillage rice-straw amendment (6.3) 90 days after sowing the crop (October, 1990). During the following fallow period, the mean densities were very few in number and did not show any distinct temporal variation till 20 days after harvesting the crop (November, 1990).

ANOVA revealed that the population densities of Sminthuridae in tillage and organic amendment treatments during rainy season differed significantly from that of the postrainy and dry seasons being sixty folds higher than that of dry season, and more than two folds higher in rainy season, than that of postrainy season (Table 9). Besides, its population density showed significant variations under perennial ley treatments among the seasons. The abundance was more than two folds higher during the rainy season than that of the postrainy season, the difference being statistically significant, whereas its abundance was absent during dry season (Table 9).

Prostigmata: The seasonal fluctuation in its relative population densities across the treatments presented in Fig. 13a revealed that the mean densities were very few and did not show any distinct temporal variation till 10 days after sowing during the crop season (July, 1989). It was <1 in shallow tillage farmyard manure and *C. ciliaris* + *S. hamata* treatments and increased to twenty nine folds higher (8.7) in pigeonpea treatment 30 days after sowing (August, 1989). It was <1 in zero tillage rice-straw, pigeonpea + *S. hamata* and *C. ciliaris* + *S. hamata* treatments and increased to eleven folds higher (3.3) in *S. hamata* treatment 60 days after sowing (September, 1989). It was <1 in zero tillage rice-straw, pigeonpea and *C. ciliaris* treatments and increased to more than four folds higher (1.3) in shallow tillage rice-straw amendment followed by pigeonpea + *S. hamata* + *C. ciliaris* treatment (1) 90 days after sowing (October, 1989). During the following fallow period, the mean densities were too few to show any distinct temporal variation 60 days after harvesting the crop (December, 1989). It was <1 in *S. hamata* treatment and increased to nearly twelve folds higher (8.3) in zero tillage bare treatment, followed by zero tillage rice-straw and deep tillage farmyard manure

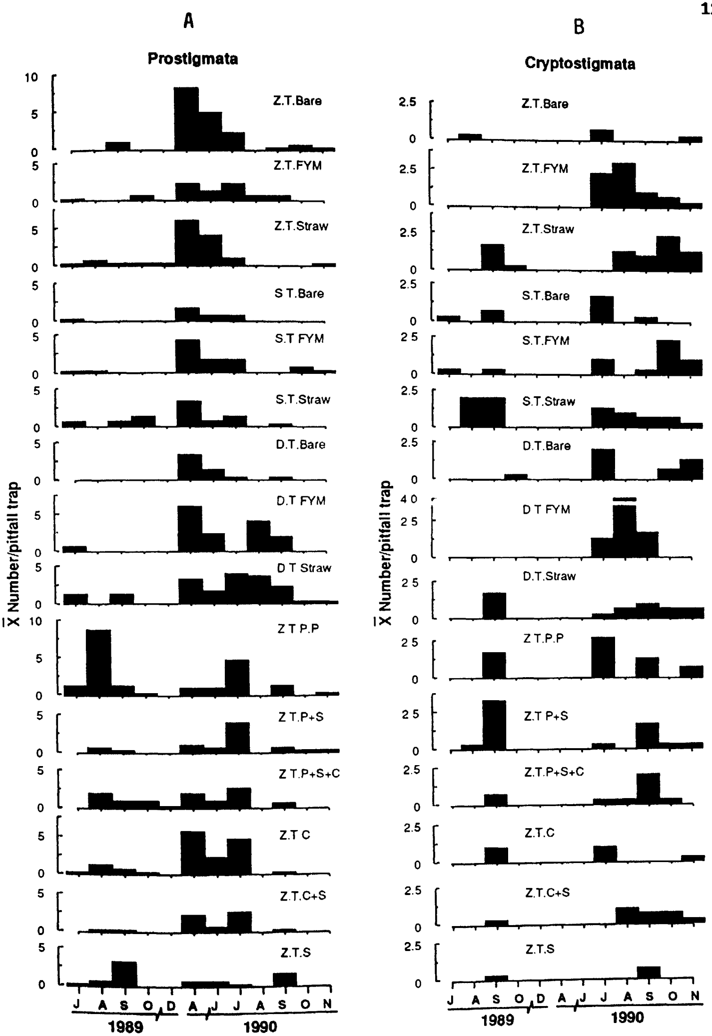

Figure 13. Seasonal fluctuation in the relative population density of Prostigmata (A) and that of Cryptostigmata (B) caught in the pitfall traps across the fifteen soil management treatments.

amendments (6) 170 days after harvesting the crop (April, 1990). It was <1 in shallow tillage bare and rice-straw, pigeonpea + *S. hamata, C. ciliaris* + *S. hamata* and *S. hamata* treatments and increased to more than seven folds higher (5) in zero tillage bare treatment, followed by zero tillage rice-straw amendment (4) 200 days after harvesting the crop (June, 1990).

During the 2nd crop season the mean density was <1 in deep tillage bare and *S. hamata* treatments and increased to nearly sixteen folds higher (4.7) in pigeonpea and *C. ciliaris* treatments, followed by deep tillage rice-straw and pigeonpea + *S.hamata* treatments (4) 10 days after sowing during the crop (July, 1990). It was <1 in zero tillage farmyard manure amendment and increased to nearly six folds higher (4) in deep tillage farmyard manure amendment, followed by deep tillage rice-straw amendment (3.7) and none of these collembola were recorded in other treatments 50 days after sowing during the crop (August, 1990). It was <1 in zero tillage bare, shallow tillage rice-straw, deep tillage bare, *C. ciliaris* + *S. hamata* treatments and increased to nearly eight folds higher (2.3) in deep tillage rice-straw amendment, followed by deep tillage farmyard manure amendment (2) 75 days after sowing (September, 1990). The mean densities were very few and did not show any distinct temporal variation till 90 days after sowing the crop (October, 1990), and during the following fallow period across the treatments 20 days after harvesting the crop (November, 1990).

ANOVA revealed that the population densities of Prostigmata in tillage and organic amendment treatments during dry season differed significantly from that of rainy and postrainy season being more than twenty one folds higher in abundance, than that of postrainy season and more than five folds higher in abundance during dry season, than that of rainy season (Table 9). Besides, its population abundance showed significant variation under perennial ley treatments among the seasons. The abundance during the dry season was twenty one folds higher, than that of postrainy season, and thirteen folds higher during the rainy season, than that of the postrainy season, the differences being statistically significant (Table 9).

Cryptostigmata: The seasonal fluctuation in its relative population densities across the treatments presented in Fig. 13b revealed that the mean densities were recorded in very few numbers ranging between <1 and 3.3 during the 1989 crop season and were not recorded during the following fallow period. During the 2nd crop season, the mean density was <1 in deep tillage rice-straw, pigeonpea + *S. hamata* and pigeonpea + *S. hamata* + *C. ciliaris* treatments and increased to nine folds higher (2.7) in pigeonpea treatment, followed by zero tillage farmyard manure amendment (2.3) 10 days after sowing during the crop (July, 1990). It was <1 in pigeonpea + *S. hamata* + *C. ciliaris* treatment and increased to more than thirteen folds higher (4) in deep tillage farmyard manure amendment, followed by zero tillage farmyard manure amendment (3) 50 days after sowing during the crop (August, 1990). They were too few in number to ranging between <1 to 2.3 till 90 days after sowing the crop (October, 1990), and during the following fallow period. The population densities of these mites did not show any significant differences among the seasons.

Mesostigmata: The seasonal fluctuation in its relative population densities across the treatments presented in Fig. 14a revealed that the mean densities were very few in number and did not show any significant variation till 30 days after sowing (August, 1989). It was <1 in zero tillage bare and pigeonpea + *S. hamata* + *C. ciliaris* treatments and increased to twenty one folds higher (6.3) in pigeonpea + *S. hamata* treatment, followed by deep tillage rice-straw amendment (5.3) 60 days after sowing (September, 1989). They were in very few numbers till 90 days after sowing of 1989 crop, and during the following fallow period, the mean densities were very few in number and did not show any distinct temporal variation till 200 days after harvesting the crop (June, 1990) and during the 2nd crop season, the mean density was <1 in zero tillage bare treatment and increased to nearly seven folds higher (2) in pigeonpea treatment 10 days after sowing during the crop (July, 1990). It was <1 in shallow tillage farmyard manure and rice-straw amendments and increased to more than twenty three folds higher (7) in pigeonpea + *S. hamata* + *C. ciliaris* treatment, followed by deep tillage farmyard manure amendment (4.7) 50 days after sowing during the crop (August, 1990). It was <1 in shallow tillage bare, farmyard manure and rice-straw amendments and increased to nearly sixteen folds higher (4.7) in pigeonpea + *S. hamata* treatments, followed by deep tillage rice-straw treatment (3.3) 75 days after sowing the crop (September, 1990). It was <1 in shallow tillage bare, deep tillage

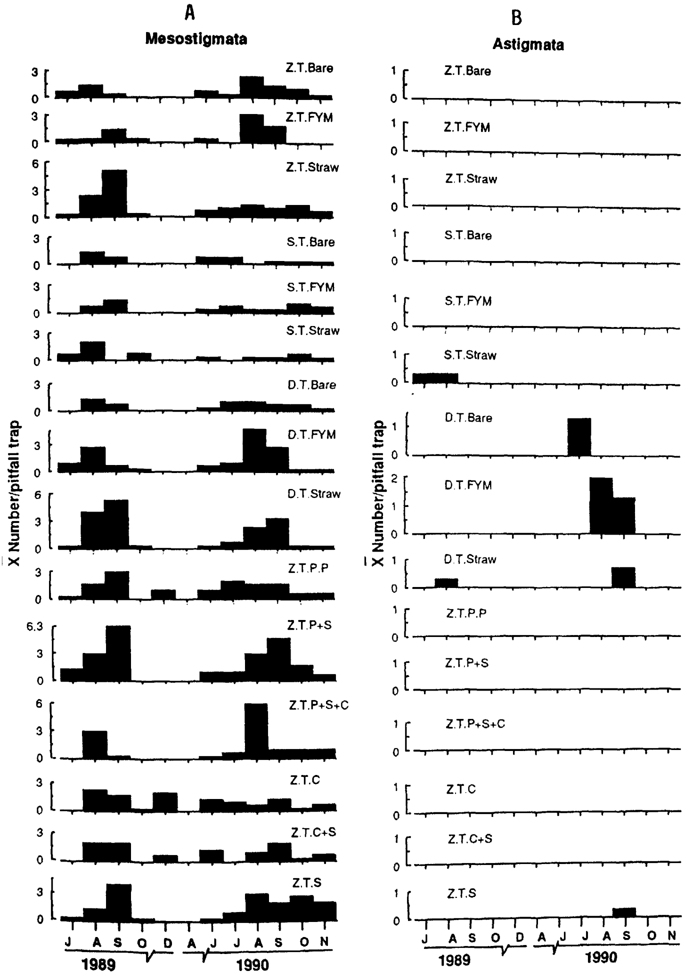

Figure 14. Seasonal fluctuation in the relative population density of Mesostigmata (A) and that of Astigmata (B) caught in the pitfall traps across the fifteen soil management treatments.

farmyard manure and rice-straw and *C. ciliaris* and *C. ciliaris* + *S. hamata* treatments which increased to nine folds higher (2.7) in *S. hamata* treatment, followed by pigeonpea + *S. hamata* treatment (1.7) 90 days after sowing the crop (October, 1990). During the following fallow period, it was <1 in zero tillage bare, shallow tillage bare, and rice-straw, deep tillage bare, farmyard manure, and rice-straw amendments and increased to nearly seven folds higher (2) in *S. hamata* treatment, followed by pigeonpea + *S. hamata* + *C. ciliaris* treatment (1) 20 days after harvesting the crop (November, 1990).

ANOVA revealed that the population densities of mesostigmata in tillage and organic amendment treatments during rainy season differed significantly from that of postrainy and dry season being more than two folds higher than that of postrainy season and they were not recorded during the dry season (Table 9). Besides, the population densities showed significant variation across perennial ley treatments among the seasons. The abundance was more than two folds higher during rainy season, than that of postrainy season, the difference being statistically significant, whereas they were not recorded during dry season (Table 9).

Astigmata: The seasonal fluctuation in its relative population densities across the treatments presented in Fig. 14b revealed that their mean densities were too few to show any significant seasonal differences.

Diploda: The seasonal fluctuation in its relative population densities across the treatments presented in Fig. 15 revealed that their mean densities were too few to show any significant seasonal differences.

Carabidae: The seasonal fluctuation in its relative population densities across the treatments presented in Fig. 16a revealed that the mean densities were recorded in very few numbers ranging between <1 and 7.3 during the 1989 crop season, during the following fallow period, and the 1990 crop season, their mean densities were very few in number and did not show any distinct temporal variation.

Staphylinidae: The seasonal fluctuation in its relative population densities across the treatments presented in Fig. 16b revealed that the mean density was <1 in shallow tillage rice-straw and *S. hamata* treatments and increased to more than twelve folds higher (3.7) in pigeonpea + *S. hamata* treatment 10 days after sowing during the crop season (July, 1989). They were not recorded across the treatments 30 days after sowing (August, 1989). The density was <1 in zero and deep tillage rice-straw, pigeonpea, pigeonpea + *S. hamata* + *C. ciliaris* and *S. hamata* treatments and increased to nine folds higher (2.7) in deep tillage farmyard manure amendment 60 days after sowing (September, 1989). They were not recorded across the treatments 90 days after sowing (October, 1989) and, during the following fallow period, 60, 170 and 200 days after harvesting the crop (December, 1989, April and June, 1990, respectively). During the 2nd crop season, their mean densities were too few to show any significant seasonal difference.

***Megalodicne* sp.:** The seasonal fluctuation in its relative population densities

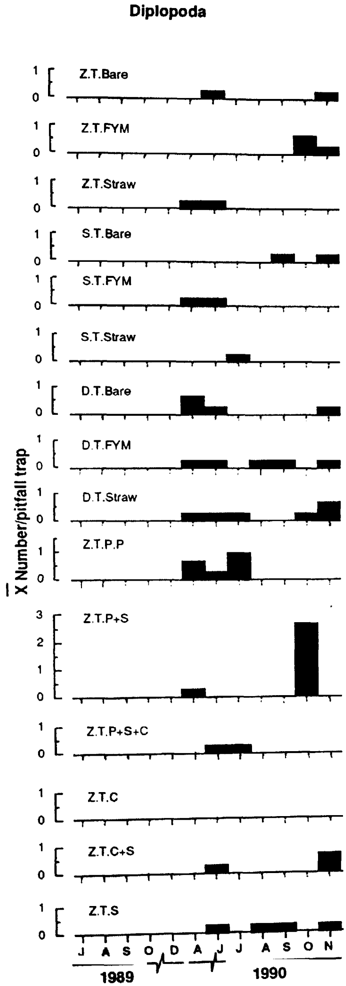

Figure 15. Seasonal fluctuation in the relative population density of Diplopoda caught in the pitfall traps across the fifteen soil management treatments.

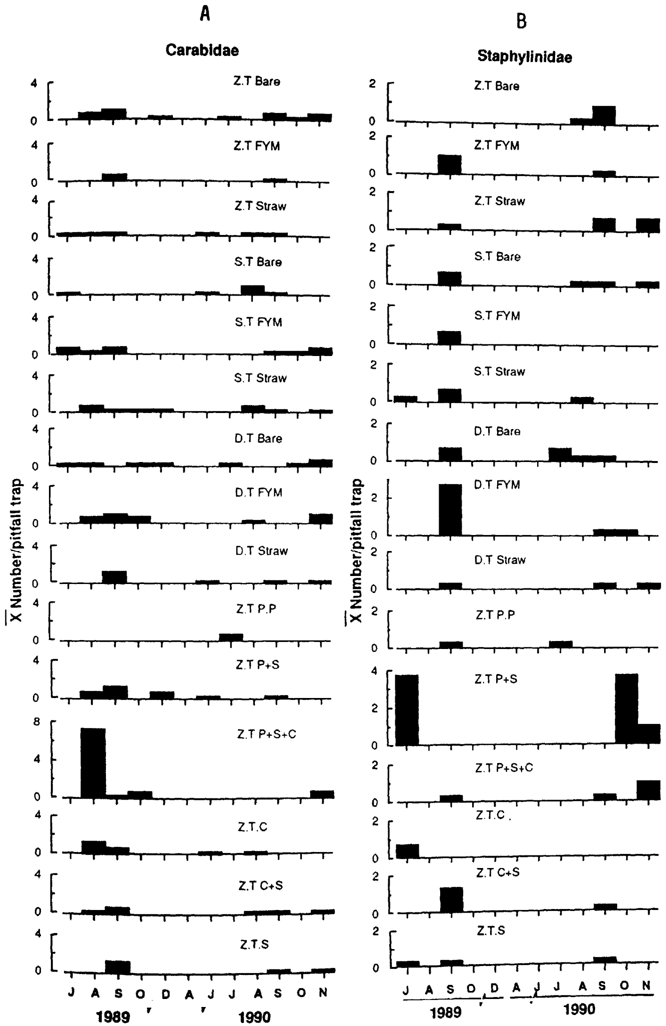

Figure 16. Seasonal fluctuation in the relative population density of Carabidae (A) and that of Staphylinidae (B) caught in the pitfall traps across the fifteen soil management treatments.

across the treatments presented in Fig. 17a and that of **Coleoptera larvae** (Fig. 17b) revealed that their densities were too few to show any significant seasonal differences.

Hymenoptera: The seasonal fluctuation in its relative population densities across the treatments presented in Fig. 18a revealed that their mean densities were <1 in shallow tillage rice-straw and deep tillage farmyard manure amendments and increased to more than ten folds higher (7.3) in *C. ciliaris* treatment, followed by pigeonpea + *S. hamata* treatment (6.3) 10 days after sowing during the crop season (July, 1989). It was <1 in zero tillage bare, shallow tillage bare and rice-straw and *C. ciliaris* treatments and increased to ten folds higher (3) in *S. hamata* treatment, followed by pigeonpea + *S. hamata* + *C. ciliaris* treatment (2.7) 30 days after sowing (August, 1989). It was <1 in zero tillage bare treatment and increased to more than twenty four folds higher (7.3) in deep tillage rice-straw amendment, followed by deep tillage farmyard manure amendment (6) 60 days after sowing (September, 1989). It was 7.3 in *C. ciliaris* treatment and increased to nearly eight folds higher (56.3) in shallow tillage farmyard manure amendment, followed by zero tillage farmyard manure amendment (56) 90 days after sowing (October, 1989). During the following fallow period, the mean density was 2.7 in zero tillage bare treatment and increased to more than ten folds higher (28) in deep tillage rice-straw amendment 60 days after harvesting the crop (December, 1989). It was 4 in *C. ciliaris* + *S. hamata* treatment and increased to more than twenty folds higher (82) in pigeonpea + *S. hamata* treatment, followed by shallow tillage

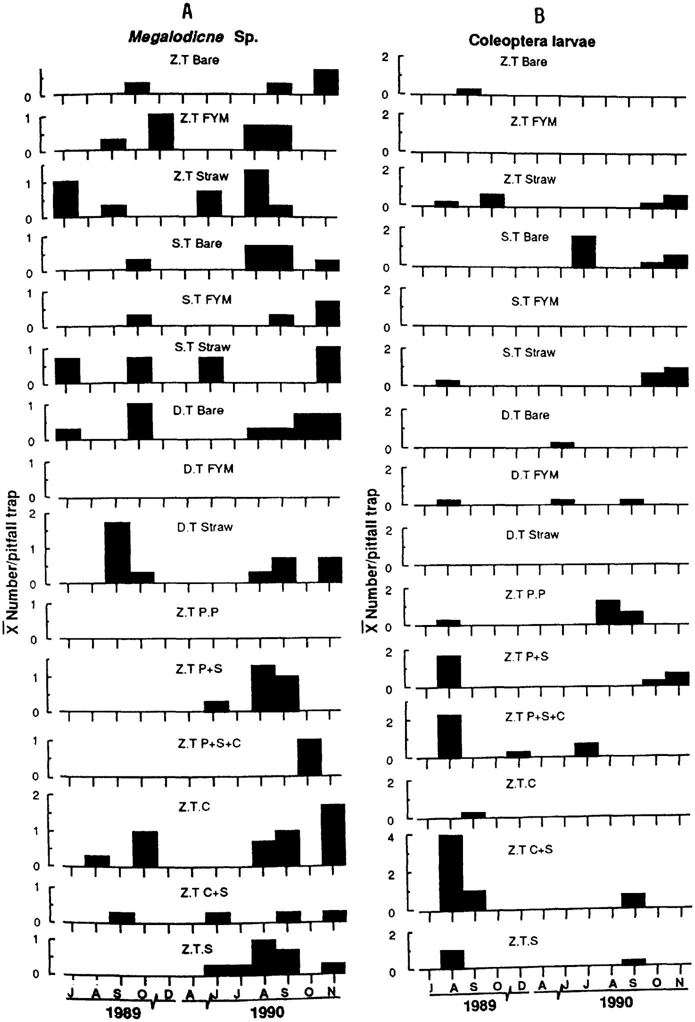

Figure 17. Seasonal fluctuation in the relative population density of *Megalodicne* Sp. (A) and that of Coleoptera larvae (B) caught in the pitfall traps across the fifteen soil management treatments.

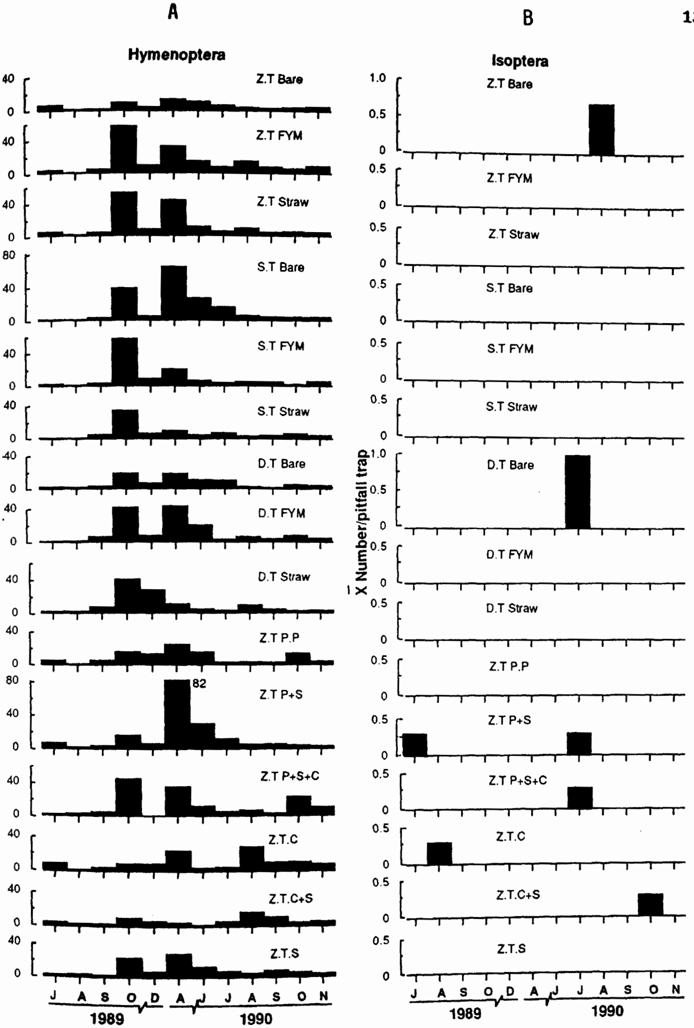

Figure 18. Seasonal fluctuation in the relative population density of Hymenoptera (A) and that of Isoptera (B) caught in the pitfall traps across the fifteen soil management treatments.

bare treatment (64) 170 days after harvesting the crop (April, 1990). It was 1.3 in *C. ciliaris* + *S. hamata* treatment and increased to more than twenty three folds higher (30) in pigeonpea + *S. hamata* treatment, followed by shallow tillage bare treatment (26) 200 days after harvesting the crop (June, 1990).

During the 2nd crop season, the mean density was 3 in pigeonpea treatment which increased to more than five folds higher (16) in shallow tillage bare treatment, followed by pigeonpea + *S. hamata* treatment (12) 10 days after sowing the crop (July, 1990). It was 2.3 in shallow tillage rice-straw amendment and increased to more than twelve folds higher (27.7) in *C. ciliaris* treatment 50 days after sowing during the crop (August, 1990). It was 2 in deep tillage bare treatment and increased to more than five folds higher (11) in *C. ciliaris* + *S. hamata* treatment, followed by *C. ciliaris* treatment (9) 75 days after sowing the crop (September, 1990). It was 1.3 in shallow tillage farmyard manure amendment and increased to more than seventeen folds higher (23) in pigeonpea + *S. hamata* + *C. ciliaris* treatment 90 days after sowing the crop (October, 1990). During the following fallow period, it was 2.7 in pigeonpea + *S. hamata* treatment and increased to nearly four folds higher (10.3) in pigeonpea + *S. hamata* + *C. ciliaris* treatment, followed by zero tillage farmyard manure amendment (9) 20 days after harvesting the crop (November, 1990).

ANOVA revealed that the population densities in tillage and organic amendment treatments during dry season differed significantly from that of rainy season being more than five folds higher (Table 9). Besides, its population abundance showed significant variation across perennial ley treatments among the seasons. The abundance was more than five folds higher during dry season, than that of rainy season, and was more than three folds higher than that of postrainy season, the differences being statistically significant (Table 9).

Isoptera: The seasonal fluctuation in its relative population densities across the treatments presented in Fig. 18b revealed that their mean densities were too few to depict any significant seasonal difference.

Psocoptera: The seasonal fluctuation in its relative population densities across the treatments presented in Fig. 19a revealed that their mean densities across the seasons and treatments were not in large number, and did not show any distinct variation till 60 days after sowing (September, 1989). It was <1 in shallow tillage farmyard manure and rice-straw, pigeonpea and *S. hamata* treatments and increased to more than thirteen folds higher (4) in zero tillage rice-straw amendment, followed by *C. ciliaris* treatment (3) 90 days after sowing (October, 1989). During the following fallow period, the mean densities were in negligible numbers across the treatment till 60 days after harvesting the crop (December, 1989). It was one in pigeonpea + *S. hamata* treatment and increased to five folds higher (5) in shallow tillage rice-straw amendment, followed by deep tillage bare treatment (4) 170 days after harvesting the crop (April, 1990). They were in very few numbers till 200 days after harvesting the crop (June, 1990).

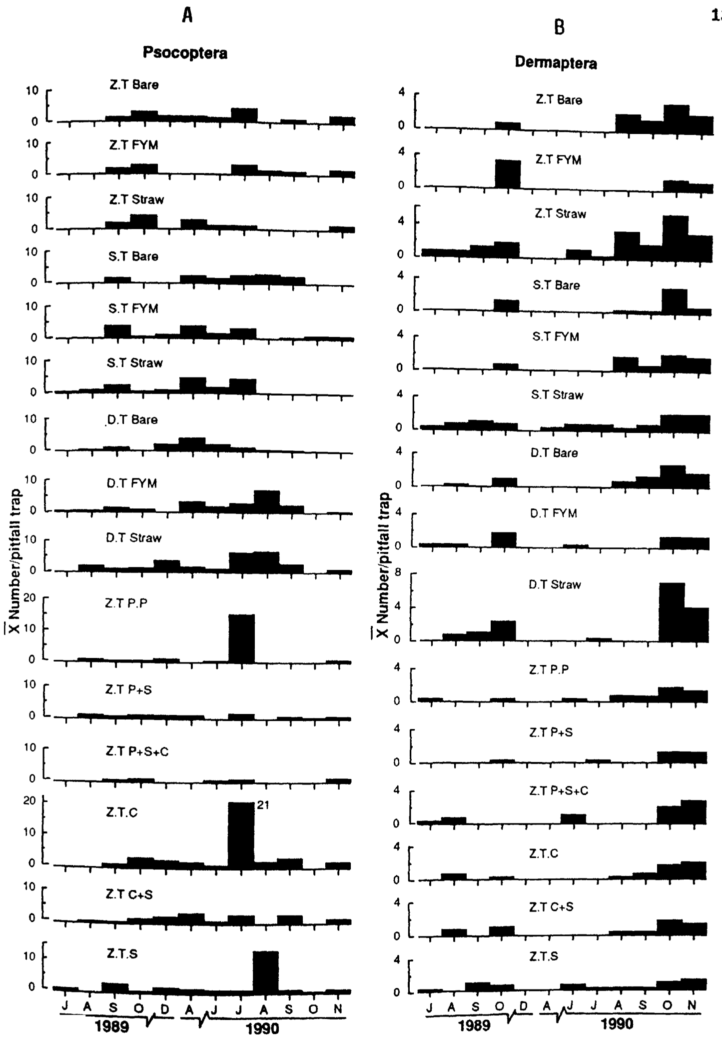

Figure 19. Seasonal fluctuation in the relative population density of Psocoptera (A) and that of Dermaptera (B) caught in the pitfall traps across the fifteen soil management treatments.

During the 2nd crop season, the density was one in zero tillage rice-straw, deep tillage bare, pigeonpea + *S. hamata* + *C. ciliaris* and *S. hamata* treatments and increased to twenty one folds higher (21) in *C. ciliaris* treatment 10 days after sowing during the crop (July, 1990). It was <1 in deep tillage bare treatment and increased to more than forty six folds higher (14) in *S. hamata* treatment 50 days after sowing during the crop (August, 1990). They were in negligible numbers and did not so much variation till 90 days after sowing the crop (October, 1990), and during the following fallow period.

ANOVA revealed that the population densities in tillage and organic amendment treatments during dry season differed significantly from that of postrainy season being more than three folds higher and more than one fold higher than that of rainy season, the differences being statistically significant (Table 9).

Dermaptera: The seasonal fluctuation in its relative population densities across the treatments presented in Fig. 19b revealed that their mean densities were too few to show any distinct variation till 60 days after sowing (September, 1989). It was <1 in pigeonpea, pigeonpea + *S. hamata* and *C. ciliaris* treatments and increased to eleven folds higher (3.3) in zero tillage farmyard manure amendment 90 days after sowing (October, 1989).

During the following fallow period and during the 2nd crop season, their mean densities were very few and did not show any distinct temporal variation till 10 days after sowing the crop (July, 1990). It was <1 in shallow tillage bare and rice-straw, *C. ciliaris* and *C. ciliaris* + *S. hamata* and *S. hamata* treatments and increased to eleven folds higher (3.3) in zero tillage rice-straw amendment 50 days after sowing during the crop (August, 1990). It was <1 in shallow tillage bare, *C. ciliaris* + *S. hamata*, and *S. hamata* treatments and increased to nearly six folds higher (1.7) in zero tillage rice-straw amendment, followed by zero and deep tillage bare treatments (1.3) 75 days after sowing the crop (September, 1990). It was one in *S. hamata* treatment and increased to seven folds higher (7) in deep tillage rice-straw amendment, followed by zero tillage rice-straw amendment (5.3) 90 days after sowing the crop (October, 1990). During the following fallow period, it was <1 in shallow tillage bare treatment and increased to more than five folds higher (4) in deep tillage rice-straw amendment, followed by zero tillage rice-straw amendment (3) 20 days after harvesting the crop (November, 1990).

ANOVA revealed that the population densities of Dermaptera in tillage and organic amendment treatments during postrainy season differed significantly from that of dry season being more than forty two folds higher in abundance and more than five folds higher than that of rainy season, the differences being statistically significant (Table 9). Besides, its population abundance showed significant variation across perennial ley treatments among the seasons. The mean density was nine folds higher during the postrainy season than that of the rainy season, the difference being statistically significant and they were not recorded during dry season (Table 9).

Orthoptera: The seasonal fluctuation in its relative population densities across the treatments presented in Fig. 20a revealed that their mean densities were too few to show any distinct variation till 30 days after sowing (August, 1989). It was <1 in shallow tillage farmyard manure and rice-straw, deep tillage rice-straw, and *C. ciliaris* treatments and increased to nearly eight folds higher (2.3) in *S. hamata* treatment, followed by zero tillage rice-straw, pigeonpea + *S. hamata* and *C. ciliaris* + *S. hamata* treatments (1.3) and were not recorded in other treatments 60 days after sowing (September, 1989). It was <1 in *C. ciliaris* + *S. hamata* treatment and were not recorded in other treatments 90 days after sowing (October, 1989). During the following fallow period, the mean densities were too few to show any distinct temporal variation till 200 days after harvesting the crop (June, 1990).

During the 2nd crop season, the density was <1 in deep tillage rice-straw and *C. ciliaris* + *S. hamata* treatments and increased to eleven folds higher (3.3) in *S. hamata* treatment 10 days after sowing the crop (July, 1990). They were in very few numbers till 75 days after sowing the crop (September, 1990). It was <1 in zero tillage farmyard manure, shallow tillage rice-straw and *C. ciliaris* treatments and increased to eleven folds higher (3.3) in *S. hamata* treatment, followed by zero tillage rice-straw and *C. ciliaris* + *S. hamata* treatments (2) 90 days after sowing the crop (October, 1990). It was <1 in zero tillage bare, shallow tillage farmyard manure and rice-straw amendments and increased to nearly seven folds higher

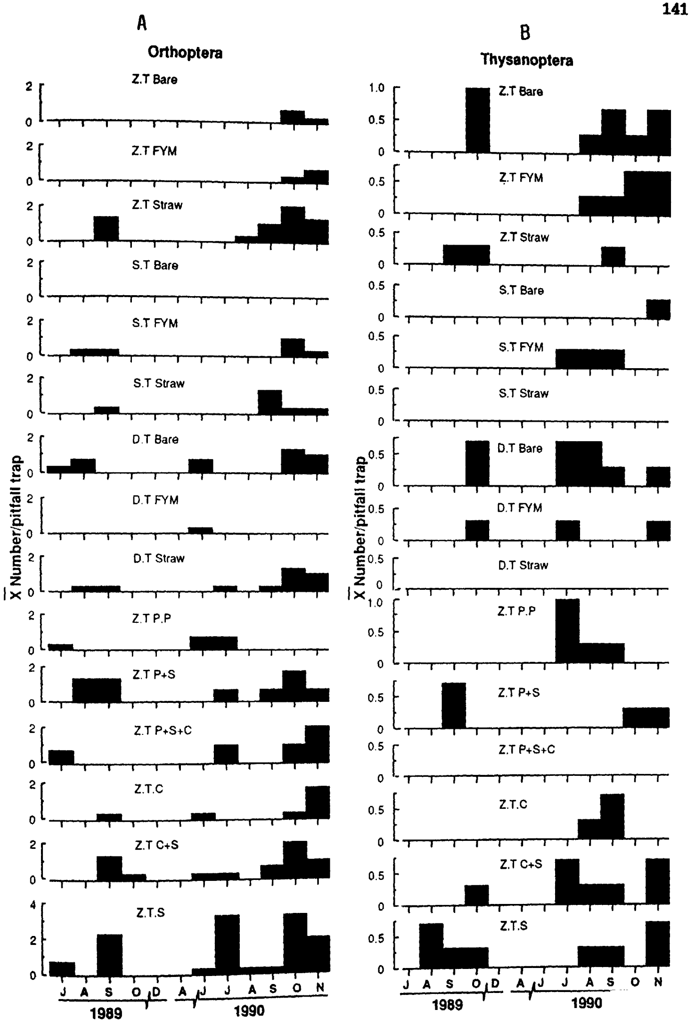

Figure 20. Seasonal fluctuation in the relative population density of Orthoptera (A) and that of Thysanoptera (B) caught in the pitfall traps across the fifteen soil management treatments.

(2) in pigeonpea + *S. hamata* + *C. ciliaris* and *S. hamata* treatments, followed by *C. ciliaris* treatment (1.7) 20 days after harvesting the crop (November, 1990).

ANOVA revealed that the population densities of Orthoptera in tillage and organic amendment treatments during postrainy season differed significantly from that of rainy season being four folds higher in abundance and they were not recorded during dry season (Table 9).

Thysanoptera: The seasonal fluctuation in its relative population densities across the treatments presented in Fig. 20b revealed that their densities were too few to show any significant seasonal differences.

Hemiptera: The seasonal fluctuation in its relative population densities across the treatments presented in Fig. 21a revealed that they were not recorded in all the treatments 10, 30 and 60 days after sowing during the crop season (July, August and September, 1989, respectively). It was one in pigeonpea and pigeonpea *S. hamata* + *C. ciliaris* treatments and increased to more than sixteen folds higher (16.3) in deep tillage rice-straw amendment 90 days after sowing (October, 1989). During the following fallow period and during the 2nd crop season, their mean densities were too few to show any significant variation till 75 and 90 days after sowing the crop (September and October, 1990, respectively). During the following fallow period, it was <1 in *S. hamata* treatment and increased to more than eight folds higher (5.7) in deep tillage farmyard manure amendment,

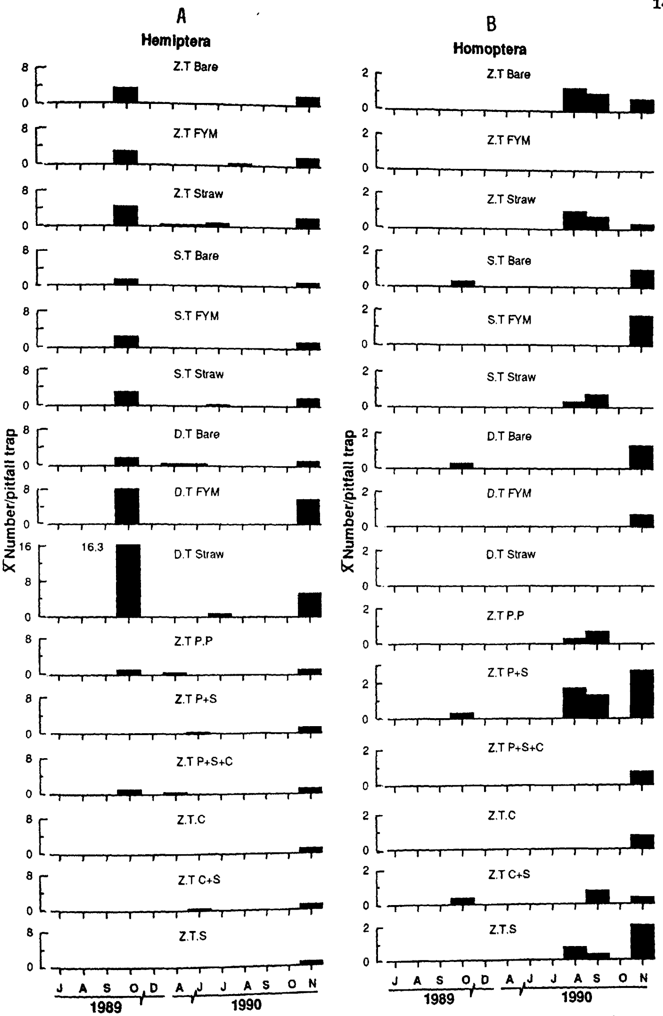

Figure 21. Seasonal fluctuation in the relative population density of Hemiptera (A) and that of Homoptera (B) caught in the pitfall traps across the fifteen soil management treatments.

followed by deep tillage rice-straw amendment (5.3) 20 days after harvesting the crop (November, 1990).

ANOVA revealed that the population densities of Hemiptera in tillage and organic amendment treatment during postrainy season differed significantly from that of dry season being more than twenty eight folds higher in abundance and they were not recorded during rainy season (Table 9).

Homoptera: The seasonal fluctuation in its relative population densities across the treatments (Fig. 21b), that of **Diptera** (Fig. 22a) and **Lepidoptera larvae** (Fig. 22b) showed that their densities were too few to show any significant seasonal difference.

Araneae: The seasonal fluctuation in its relative population densities across the treatments presented in Fig. 23a revealed that their mean densities were too few to show any distinct seasonal difference till 60 days after sowing (September, 1989). The mean density was <1 in pigeonpea and *S. hamata* treatments which increased to more than fifty folds higher (16) in shallow tillage bare treatment 90 days after sowing (October, 1989). During the following fallow period, the density was <1 in zero tillage farmyard manure treatment and increased to nearly six folds higher (1.7) in shallow tillage bare treatment, followed by zero tillage bare treatment (1.3) 60 days after harvesting the crop (December, 1989). It was <1 in zero tillage bare and shallow tillage rice-straw amendments and increased

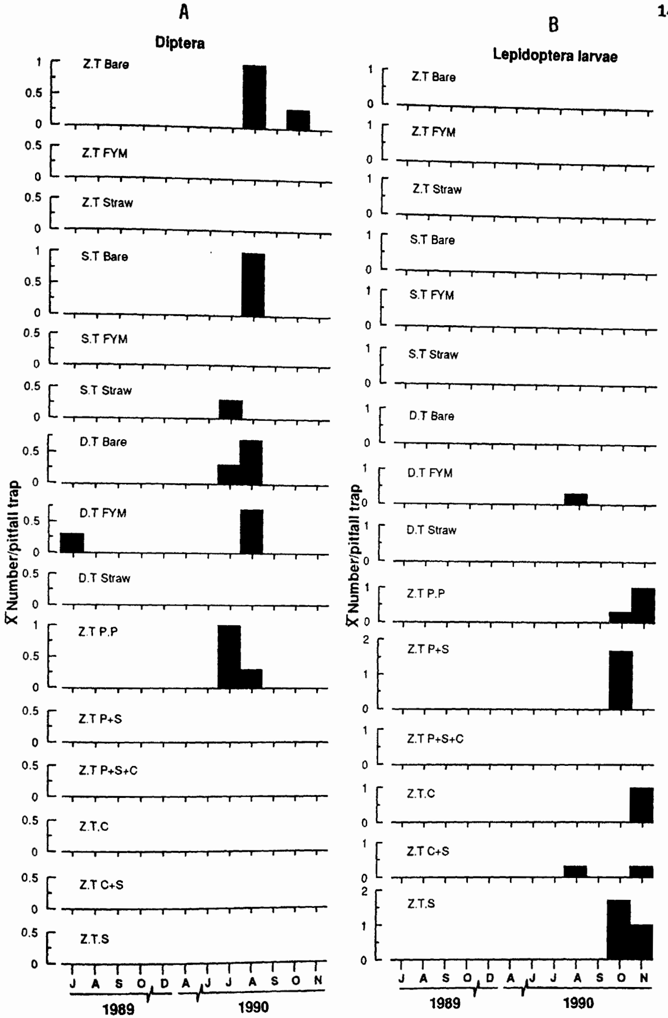

Figure 22. Seasonal fluctuation in the relative population density of Diptera (A) and that of Lepidoptera larvae (B) caught in the pitfall traps across the fifteen soil management treatments.

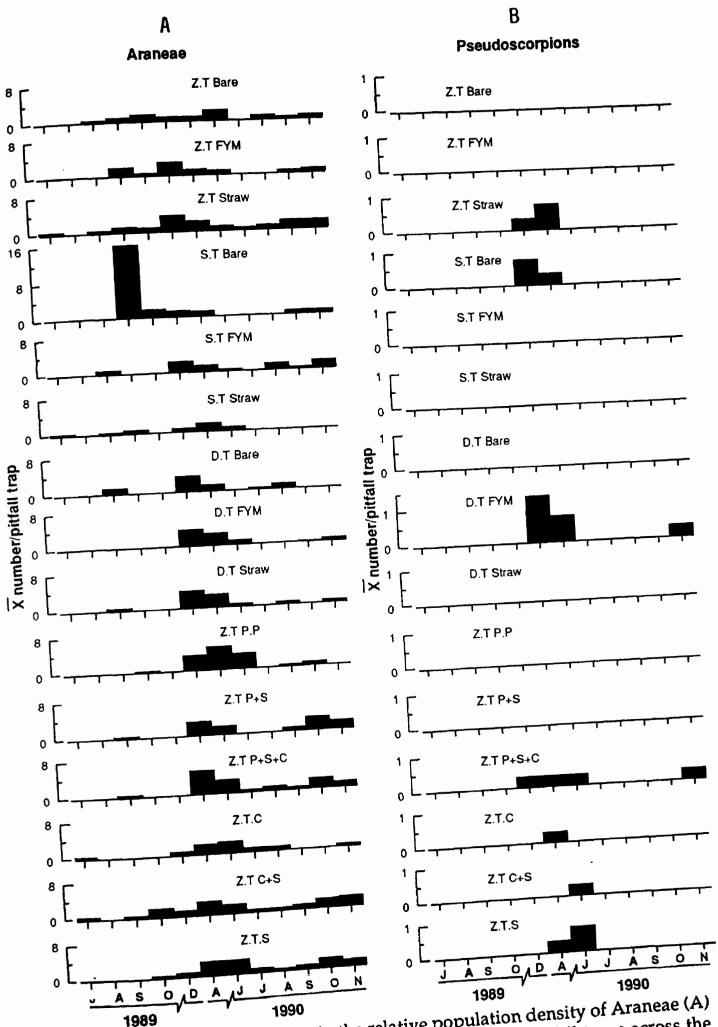

Figure 23. Seasonal fluctuation in the relative population density of Araneae (A) and that of Pseudoscorpions (B) caught in the pitfall traps across the fifteen soil management treatments.

to more than seven folds higher (5) in pigeonpea + *S. hamata* + *C. ciliaris* treatment, followed by deep tillage farmyard manure and rice-straw amendments (4) 170 days after harvesting the crop (April, 1990). It was <1 in zero tillage bare treatment and increased to more than seven folds higher (5) in pigeonpea treatment, followed by *S. hamata* treatment (3) 200 days after harvesting the crop (June, 1990).

During the 2nd crop season, their mean densities were too few to show any significant variation till 75 days after sowing the crop (September, 1990). It was <1 in zero tillage bare, farmyard manure, shallow and deep tillage farmyard manure amendments and increased to nine folds higher (2.7) in pigeonpea + *S. hamata* treatment, followed by pigeonpea + *S. hamata* + *C. ciliaris* and *S. hamata* treatments (2) 90 days after sowing the crop (October, 1990). During the following fallow period, it was <1 in deep tillage rice-straw and *C. ciliaris* treatments and increased to nearly seven folds higher (2) in *C. ciliaris* + *S. hamata* treatment, followed by zero tillage rice-straw, shallow tillage farmyard manure and pigeonpea + *S. hamata* treatment, followed by zero tillage rice-straw, shallow tillage farmyard manure and pigeonpea + *S. hamata* treatments (1.7) 20 days after harvesting the crop (November, 1990).

ANOVA revealed that the population densities of Araneae in tillage and organic amendment treatments during dry season differed significantly from that of rainy season being six folds higher in abundance (Table 9). Besides, its population abundance showed significant variation under perennial ley treatments among the seasons. The abundance was more than five folds higher during dry season than that of rainy season, and the abundance was more than three folds higher than that of postrainy season, the differences being statistically significant (Table 9).

Pseudoscorpions: The seasonal fluctuation in its relative population densities across the treatments presented in Fig. 23b revealed that their densities were very few in number and did not show any significant seasonal difference.

Treatment Effect:

Total soil surface arthropods: The response of the relative population densities of different groups of arthropods inhabiting the soil surface across the 15 different soil management treatments presented in Figs. 24a and b. The mean density of total arthropods were significantly low in annual treatments (16.5) compared to those of the perennial ley treatments (35) (Fig. 24a). Under annual crop, in zero tillage treatments, the density was low in bare amendment (16.5) while it was high in rice-straw amendment (29.4). In shallow tillage treatments it was lower in rice-straw amendment (18.4) and increased to 22 in bare amendment. In deep tillage treatments it was low in bare amendment (20) which increased to 28 in farmyard manure amendment. In perennial ley treatments the density was low in *C. ciliaris* + *S. hamata* treatment (19.7) which reached 35 in pigeonpea + *S. hamata* treatment.

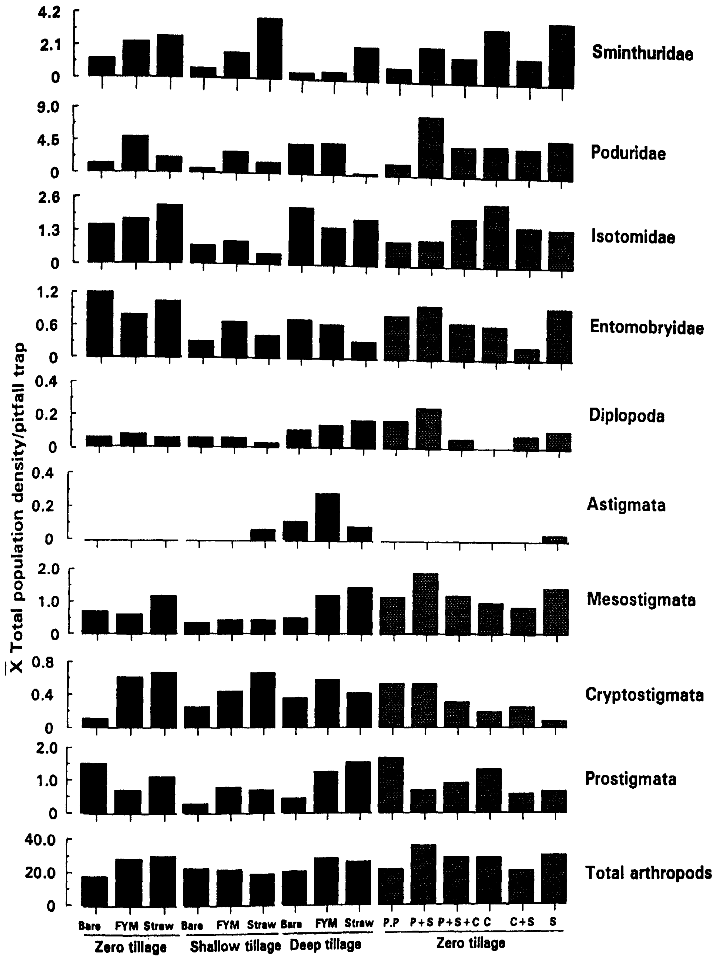

Figure 24a. Relative population densities of some of the soil surface arthropods across the fifteen soil management treatments.

Entomobryidae: Its relative population densities across the 15 soil management treatments presented in Fig. 24a revealed that the mean population density was significantly low in number (0.25) in perennial ley treatments compared to those of the annual treatments (1.2). It indicated that they were too few to show any discernible variation across the annual and perennial treatments. The Entomobryidae densities did not differ significantly across the tillage and organic amendment treatments (Table 10a) and perennial ley treatments (Table 10b) and across all the 15 treatments (Tables 11a, 11b) as revealed by the ANOVA. Besides, ANOVA of the monthly data also did not differ significantly across all the treatments (Table 12) and the tillage and organic amendment treatments (Table 13). However, ANOVA of the monthly data of perennial ley treatments showed that the densities differed significantly across the treatments during June 1990 ($P < 0.05$) (Table 14).

Isotomidae: Its relative population densities across the 15 soil management treatments, presented in Fig. 24a revealed that the population was low (0.4) in number in annual treatments compared to those of the perennial ley treatments (2.5). Under annual crop, in zero tillage treatments the density was low (1.5) in bare amendment while it was high (2.3) in rice-straw amendment. In shallow tillage treatments, its densities were <1. In deep tillage treatments the density was low in farmyard manure amendment (1.5) and increased to 2.25 in bare amendment. In perennial ley treatments its density was low (<1) in pigeonpea treatment, which increased to 2.5 in *C. ciliaris* treatment. ANOVA showed that

Table 10a. Analysis of variance (mean squares) of the data on mean population densities of soil arthropods across the tillage and organic amendment treatments (number in parentheses represent degrees of freedom).

Arthropod taxa	SOURCE OF VARIATION								Mean abundance
	Seasons (S) (2)	Amendment (A) (2)	SxA (4)	Tillage (T) (2)	SxT (4)	TxA (4)	SxTxA (8)	Error (46)	
Araneae	29.37**	0.11	4.20	0.34	8.20	3.03	2.82	4.36	1.3
Pseudo-scorpions	0.60*	0.09	0.09	0.09	0.09	0.25	0.34*	0.15	0.1
Prostigmata	130.81**	0.35	0.48	7.37	4.02	14.14	6.18	8.48	1.8
Crypto-stigmata	2.12**	0.38	0.16	0.01	0.01	0.14	0.72**	0.25	0.3
Mesostigmata	7.86**	0.94	0.38	0.90	1.51*	0.70	0.50	0.52	0.5
Diplopoda	0.34*	0.01	0.01	0.16	0.11	0.07	0.11	0.08	0.1
Isotomidae	434.31**	4.94	4.83	117.42*	94.58*	5.09	28.66	36.54	3.3
Poduridae	150.83**	18.23	14.46	3.60	3.83	14.53	5.18	6.14	1.4
Sminthuridae	39.37**	10.48**	10.57**	4.78*	1.93	0.86	1.93	1.16	1.2
Carabidae	0.48**	0.15	0.07	0.04	0.13	0.08	0.11	0.08	0.1
Megalodicne sp.	0.60**	0.05	0.05	0.01	0.12	0.06	0.07	0.13	0.1
Coleoptera larvae	0.16*	0.09	0.11	0.09	0.05	0.05	0.05	0.05	0.1
Hymenoptera	3558.93**	369.78	824.26	221.45	93.48	209.25	63.06	540.26	16
Psocoptera	21.09**	2.24	0.23	4.68	5.12	0.23	4.24	2.42	1.6
Dermaptera	22.75*	4.31**	0.96*	0.46	0.61	0.23	0.75	0.37	0.7
Orthoptera	0.97**	0.23	0.07	0.31*	0.14	0.03	0.11	0.11	0.2
Thysanoptera	0.26**	0.15	0.07	0.11	0.09	0.05	0.05	0.06	0.1
Hemiptera	34.72**	2.38	2.38	4.46	4.01	1.43	2.26	2.84	0.7
Homoptera	0.16*	0.05	0.12*	0.01	0.09	0.07	0.05	0.05	0.1

* Significant at $P < 0.05$; ** Significant at $P < 0.01$.

Table 10b. Analysis of variance (mean squares) of the data on mean population densities of soil surface arthropods across perennial ley crop treatments (number in parentheses represent degrees of freedom).

Arthropod taxa	SOURCE OF VARIATION Seasons (S) (2)	Treatment (T) (5)	SxT (10)	Error (28)	Mean abundance
Araneae	34.13**	1.03	1.26	1.32	1.6
Prostigmata	18.87**	3.62**	4.01**	0.96	1.2
Cryptostigmata	0.72**	0.13	0.19	0.10	0.2
Mesostigmata	14.39**	0.09	0.68	0.34	0.8
Poduridae	150.24*	70.65	44.15	45.30	3.3
Sminthuridae	48.57**	2.79	6.97*	3.29	1.6
Coleoptera larvae	0.39**	0.13	0.17**	0.06	0.1
Hymenoptera	3931.80*	781.01	1167.66	941.10	17
Dermaptera	4.79**	0.16	0.13	0.17	0.4
Orthoptera	2.35**	0.52	0.22	0.35	0.4
Hemiptera	0.7**	0.21	0.06	0.12	0.2
Homoptera	0.57**	0.34**	0.15	0.09	0.1
Lepidoptera larvae	0.65**	0.09	0.09	0.06	0.1

* Significant at P <0.05; ** Significant at P <0.01.

Table 11a. Analysis of variance (mean squares) of the data on mean population densities of Sminthuridae and Acarina across the 15 soil management treatments during different seasons.

Seasons	SOURCE OF VARIATION				Mean abundance
	Blocks (Ignoring treatments)	Entries (Eliminating blocks)	Within entries (Errors)	F (14, 21)	
COLLEMBOLA:					
Sminthuridae					
Rainy	10.65	9.77	4.08	2.39*	2.7
Postrainy	0.93	1.72	1.63	1.05	1.1
Dry	0.02	0.02	0.02	0.88	0.02
ACARINA:					
Prostigmata					
Rainy	0.19	1.25	0.14	8.86**	0.4
Postrainy	0.02	0.05	0.09	0.52	0.9
Dry	8.35	16.35	18.33	0.89	0.1
Cryptostigmata					
Rainy	0.20	0.32	0.14	2.36*	0.7
Postrainy	0.39	0.16	0.24	0.68	0.3
Dry	(The mean squares of dry season were not recorded)				
Astigmata					
Rainy	0.03	0.04	0.02	2.32*	1.7
Postrainy	(The mean squares of postrainy season were not recorded)				
Dry	(The mean squares of dry season were not recorded)				

* Significant at $P < 0.05$; ** Significant at $P < 0.01$;

Table 11b. Analysis of variance (mean squares) of the data on the mean population densities of Coleoptera larvae, Dermaptera, Homoptera and Araneae across the 15 soil management treatments during different seasons.

	SOURCE OF VARIATION				
Seasons	Blocks (Ignoring treatments)	Entries (Eliminating blocks)	Within entries (Errors)	F (14, 21)	Mean abundance
Coleoptera larvae					
Rainy	0.09	0.19	0.08	2.32*	0.13
Postrainy	0.08	0.12	0.10	1.26	0.11
Dry	(The mean squares of dry season were not recorded)				
Dermaptera					
Rainy	0.10	0.44	0.13	3.56**	0.2
Postrainy	1.29	1.71	0.64	2.69*	1.4
Dry	0.03	0.02	0.02	0.80	0.02
Homoptera					
Rainy	0.04	0.05	0.05	1.01	1.04
Postrainy	0.17	0.36	0.16	2.33*	0.2
Dry	(The mean squares of dry season were not recorded)				
Araneae					
Rainy	0.22	0.10	0.04	2.71*	0.5
Postrainy	3.07	4.74	3.36	1.41	0.9
Dry	5.05	4.67	4.21	1.11	2.7

* Significant at $P < 0.05$; ** Significant at $P < 0.01$.

Table 12. Analysis of variance (mean squares) of the data on the mean population densities of soil surface arthropods across the 15 soil management treatments during different months, 1989-1990.

Year & month		Arthropod taxa	SOURCE OF VARIATION				Mean abundance
			Blocks (Ignoring treatments)	Entries (Eliminating blocks)	Within entries (Errors)	F (14, 21)	
1990,	July	Araneae	2	2	1	2.8*	0.7
1989,	August	Prostigmata	4	12	1	13.0***	1
1990,	July	Prostigmata	5	10	3	3.4**	2.2
	August	"	3	5	1	4.9**	0.6
	September	"	0.4	2	0.5	3.5**	0.7
1989,	August	Cryptostigmata	0.4	0.6	0.1	4.2**	0.2
1990,	August	"	4	4	1	3.2**	0.8
1989,	December	Mesostigmata	0.4	1	0.4	2.5*	0.2
1990,	September	"	3	4	2	2.6*	1.6
1990,	August	Astigmata	0.6	0.7	0.2	2.9*	0.1
	September	"	0.2	0.4	0.1	5.8**	0.2
1990,	August	Poduridae	39	25	9	3.0*	3.4
	October	"	6	5	0.5	11.0***	0.9
1990,	July	Sminthuridae	8	21	9	2.4*	1.8
1990,	November	Carabidae	0.4	0.4	0.2	2.4*	0.3
1989,	December	*Megalodicne* Sp.	0.1	0.2	0.1	2.5*	0.1
1990,	September	"	1.1	0.5	0.2	2.5*	0.4
1989,	August	Coleoptera larvae	1.6	4	1.2	3.0*	0.7
1990,	August	"	0.2	0.3	0.1	3.1**	0.1
1989,	December	Hymenoptera	69	148	30	4.9**	8.3
1990,	September	"	18	24	8	3.0*	5.1
1990,	August	Psocoptera	21	43	15	2.9*	2.2
1990,	August	Dermaptera	3	2	1	2.3*	0.7
1990,	July	Orthoptera	3.4	1.2	0.2	6.7**	0.4
	September	"	0.2	0.5	0.2	2.6*	0.3
1990,	September	Homoptera	0.2	0.6	0.3	2.3*	0.4

* Significant at $P < 0.05$; ** Significant at $P < 0.01$; *** Significant at $P < 0.001$.

Table 13. Analysis of variance (mean squares) of the data on the mean population densities of soil surface arthropods across tillage and organic amendment treatments during different months, 1989-1990 (number in parentheses represent degrees of freedom).

			SOURCE OF VARIATION				
Year & month		Arthropod taxa	Amendment (A) (2)	Tillage (T) (2)	TxA (4)	Error (10)	Mean abundance
1990,	July	Araneae	0.04	1.6	2.0*	1	0.6
	September	"	0.1	--	1.2*	0.3	0.4
1989,	September	Prostigmata	1.4*	0.2	0.4	0.2	0.1
1990,	August	"	6.0*	18.0**	3	2	1
	September	"	1.0*	5.0**	1	0.3	0.7
1989,	August	Cryptostigmata	1.2*	1.2*	0.6	0.2	0.3
1990,	August	"	12.0*	4	5	2	1.1
1990,	August	Mesostigmata	6	15.0*	1	4	2
	September	"	2	8.0*	1	2	1.3
1990,	September	Astigmata	0.4*	1.3**	0.3	0.8	0.2
1990,	April	Isotomidae	14	305.0*	23	71	8
	June	"	4	16.0*	4	4	2
	October	"	1	4.0*	0.3	1	0.4
1990,	July	Poduridae	2245	576	2174.0*	656	26
	November	"	2.0*	0.5	0.4	0.4	0.4
1989,	August	Sminthuridae	0.04	0.3	0.4*	0.1	0.2
	September	"	479.0*	45	33	45	7
1990,	September	"	105.0*	3	7	17	4.1
1990,	November	Carabidae	0.3	0.5*	0.7**	0.1	0.4
1990,	June	*Megalodicne* Sp.	0.6*	0.2	0.1	0.1	0.1
1989,	December	Hymenoptera	285.0*	316.0**	113.0*	27	10
1990,	August	"	70.0*	57.0**	14.0*	4	6.3
	November	"	8	26.0*	8	5	4.6
1989,	December	Psocoptera	3	6.0*	3	1	1
1990,	August	"	7	48.0**	10	7	2
	September	"	0.3	4.0**	3.0**	0.6	1
	November	"	0.1	5.0**	0.4	0.8	0.8
1989,	August	Dermaptera	1.0*	0.2	0.3	0.2	0.3
	September	"	4.0*	0.04	0.1	0.6	0.4

Contd...

Table 13. Continued

Year & month		Arthropod taxa	SOURCE OF VARIATION				Mean abundance
			Amendment (A) (2)	Tillage (T) (2)	TxA (4)	Error (10)	
1990,	June	Dermaptera	0.8**	0.1	0.4	0.2	0.2
	July	"	0.6**	0.04	0.05	0.1	0.1
	August	"	1	6.0*	2.3	1.2	1
	October	"	23.0**	4	7	4	3.1
	November	"	8.0*	2	1.4	1.6	2
1990,	September	Orthoptera	2.4**	0.3	0.2	0.2	0.3
1990,	October	Thysanoptera	0.1	0.3*	0.1	0.1	0.1

* Significant at *P* <0.05; ** Significant at *P* <0.01.

Table 14. Analysis of variance (mean squares) of the data on the mean population densities of soil surface arthropods across perennial ley treatments during different months, 1989-1990 (number in parentheses represent degrees of freedom).

Year & month		Arthropod taxa	SOURCE OF VARIATION		Mean abundance
			Treatment (5)	Error (4)	
1989,	July	Prostigmata	0.5*	0.1	0.3
	August	"	27.0**	1.3	2.3
1990,	April	Prostigmata	8.0**	0.7	2.1
	June	"	1.3*	0.1	3.2
1990,	August	Cryptostigmata	0.5*	0.1	0.2
1989,	December	Mesostigmata	2.3*	0.4	0.6
1990,	October	"	2.3*	0.3	1.1
1990,	November	Diplopoda	0.6**	0.1	0.2
1990,	June	Entomobryidae	1.0*	0.2	0.3
1990,	June	Isotomidae	4.0**	0.2	1.4
1990,	November	Poduridae	10.0**	1	1.9
1989,	August	Sminthuridae	5.0**	0.1	1.2
1989,	October	*Megalodicne* Sp.	0.5*	0.1	0.2
1990,	September	"	1.0*	0.2	0.5
	November	"	0.5*	0.1	0.4
1990,	September	Hymenoptera	21.0*	2	6.6
1989,	August	Psocoptera	0.7*	0.1	0.3
1990,	July	"	255.0*	25	7.1
1990,	July	Orthoptera	3.0*	0.5	1
	September	"	0.4*	0.1	0.3
1990,	October	Lepidoptera larvae	1.5*	0.2	0.6

* Significant at $P < 0.05$; ** Significant at $P < 0.01$.

the densities of Isotomidae were significantly different in the tillage and organic amendment treatments across seasons (*P* <0.01), tillage (*P* <0.05), season and tillage interaction (*P* <0.05) (Table 10a). ANOVA of the monthly data showed that the densities were also different across the tillage during April, June, and October 1990 (*P* <0.05) (Table 13). Besides, the densities differed significantly across the perennial ley treatments during June 1990 (*P* <0.01) (Table 14).

Poduridae: Its relative population densities across the 15 soil management treatments presented in Fig. 24a revealed that the mean density was significantly low (<1) in number in annual treatments compared to those of the perennial ley treatments (8.3). Under annual crop, in zero and shallow tillage treatments the density was low in bare amendments (1.25) and (0.64) which increased to 4.8 and 2.9 in farmyard manure amendments, respectively. In deep tillage treatments its density was <1 in rice-straw amendment and increased to 4.4 in farmyard manure amendment. In perennial ley treatments its density was 1.7 in pigeonpea treatment which increased to 8.3 in pigeonpea + *S. hamata* treatment. ANOVA showed that the densities of Poduridae were significantly different in the tillage and organic amendment treatments (*P* <0.01) and perennial ley treatments (*P* <0.05) between seasons (Tables 10a and b). ANOVA of the monthly data showed the population densities of Poduridae were significantly different across all the treatments during August (*P* <0.05) and October 1990 (*P* <0.001) (Table 12). Besides, their densities were also significantly different across the tillage x amendment interaction during July and across organic amendment treatments (*P*

<0.05) during November 1990 (Table 13). The densities were also significantly different across the perennial ley treatments during November 1990 (P <0.01) (Table 14).

Sminthuridae: Its relative population densities across the 15 treatments presented in Fig. 24a revealed that the mean density was <1 in number in deep tillage bare treatment which increased to 3.9 in shallow tillage rice-straw amendment. Under annual crop, in zero, shallow and deep tillage treatments its densities were low (1.2, 0.6, and 0.5) in bare amendments and increased in rice-straw amendments (2.6, 3.9, and 2.2), respectively. In perennial ley treatments its density was 0.9 in pigeonpea treatment and increased to 4 in *S. hamata* treatment. However, the densities were significantly different across all the 15 treatments, as revealed by the ANOVA during rainy season (P <0.05) (Table 11a). Besides, the densities were also significantly different across tillage and organic amendment treatments between seasons (P <0.01), organic amendment (P <0.01), season and amendment interaction (P <0.01) and tillage treatments (P <0.05) (Table 10a). The densities were significantly different across the perennial ley treatments between seasons (P <0.01), season and treatment interaction (P <0.05) (Table 10b). ANOVA of the monthly data showed that the population densities of Sminthuridae were significantly different across all the treatments during July 1990 (P <0.05) (Table 12). Besides, the densities were also significantly different across the organic amendment during September 1989 and 1990 (P <0.01) across tillage x amendment interaction during August 1989 (P <0.05) (Table 13), and the perennial ley treatments during August 1989 (P <0.01) (Table 14).

Prostigmata: Its relative population densities across the 15 treatments presented in Fig. 24a revealed that the mean density was 0.3 in number in annual treatments compared to those of the perennial ley treatments (1.7). Under annual crop, in zero tillage treatments the densities ranged between 0.7 and 1.5, in shallow tillage treatments its densities were <1 and in deep tillage treatments its densities ranged between 0.4 and 1.5. In perennial ley treatments its density was <1 in *C. ciliaris* + *S. hamata* treatment which increased to 1.7 in pigeonpea treatment. The densities were significantly different across all the 15 treatments as revealed by the ANOVA during rainy season (P <0.01) (Table 11a). Besides, the densities were also significantly different across tillage and organic amendment treatments between seasons (P <0.01) (Table 10a). The densities were significantly different across the perennial ley treatments between seasons and season and treatment interaction (P <0.01) (Table 10b). ANOVA of the monthly data showed that the densities were significantly different across all the treatments during August 1989 (P <0.001), July, August, and September 1990 (P <0.01) (Table 12). Besides, the densities were significantly different across the organic amendment during September 1989, August and September 1990 (P <0.05), across tillage treatments during August and September 1990 (P <0.01) (Table 13) and the perennial ley treatment during July 1989 (P <0.05), August 1989 and April 1990 (P <0.01) and June 1990 (P <0.05) (Table 14).

Cryptostigmata: Its relative population densities across the 15 treatments presented in Fig. 24a revealed that the mean densities were <1 in both annual (0.67) and perennial (0.08) treatments. Under the annual treatments, its mean density ranged between 0.11 and 0.58 and in the perennial treatments, it ranged between 0.08 to 0.53. However, the densities were significantly different across all the 15 treatments, as revealed by the ANOVA during rainy season (*P* <0.05) (Table 11a). Besides, the densities were also significantly different across the tillage and organic amendment treatments between seasons (*P* <0.01) and seasons x tillage x amendment interaction (*P* <0.01) (Table 10a) and perennial ley treatments between seasons (*P* <0.01) (Table 10b). ANOVA of the monthly data showed that the population densities of Cryptostigmata were significantly different across all the treatments during August 1989 and 1990 (*P* <0.01) (Table 12). Besides, the densities were also significantly different across the tillage treatment during August 1989 (*P* <0.05) and organic amendment during August 1989 and 1990 (*P* <0.05) (Table 13) and the perennial ley treatments during August 1990 (*P* <0.05) (Table 14). **Mesostigmata:** Its relative population densities across the 15 treatments presented in Fig. 24a revealed that the mean density was significantly low (<1) in annual treatments compared to those of the perennial ley treatments (1.9). Under annual crop, in zero tillage treatments its mean density was low (<1) in farmyard manure amendment which increased (1.2) in rice-straw amendment. In shallow tillage treatments its mean density was <1 across the organic amendment treatment. In deep tillage and perennial treatments the densities showed very little variation ranging between <1 and 1.4 in the former, and between <1 and 1.9 in the latter treatments. Their densities showed significant difference across the tillage and organic amendment treatments, as revealed by the ANOVA between seasons ($P < 0.01$) and season and tillage interaction ($P < 0.05$) (Table 10a). Besides, the densities differed significantly across the perennial ley treatments between seasons ($P < 0.01$) (Table 10b). ANOVA of the monthly data showed that the densities were significantly different across all the treatments during December 1989 and September 1990 ($P < 0.05$) (Table 12). Besides, its densities were also different across the tillage treatment during August and September 1990 ($P < 0.05$) (Table 13) and the perennial ley treatments during December 1989 and October 1990 ($P < 0.05$) (Table 14). **Astigmata:** Its relative population densities across the 15 treatments presented in Fig. 24a revealed that the mean density was negligible in number (<1) in all the treatments. However, the densities were significantly differed across all the 15 treatments, as revealed by the ANOVA during rainy season ($P < 0.05$) (Table 11a). ANOVA of the monthly data showed that the population densities of Astigmata were significantly differed across all the treatments during August 1990 ($P < 0.05$) and September 1990 ($P < 0.01$) (Table 12). Besides, the densities were also significantly different across the tillage ($P < 0.01$) and organic amendment treatments ($P < 0.05$) (Table 13) during September 1990.

Diplopoda: Its relative population densities across the 15 treatments presented in Fig. 24a revealed that the population was negligible in number (<1) across the treatments. However, the densities were significantly different across the tillage and organic amendment treatments, as revealed by the ANOVA between seasons (P <0.05) (Table 10a). ANOVA of the monthly data of perennial ley treatments showed that the densities differed significantly across the treatments during November 1990 (P <0.01) (Table 14).

Carabidae: Its relative population densities across the 15 treatments presented in Fig. 24b revealed that the mean density was <1 ranging from 0.06 to 0.75. Under annual crop, in zero tillage treatments its densities ranged between 0.08 to 0.33, in shallow tillage treatments its densities ranged between 0.17 and 0.25 while in deep tillage treatments its densities ranged between 0.19 and 0.31. In perennial ley treatments its densities ranged between 0.06 and 0.75. However, their densities were significantly different across tillage and organic amendment treatments as revealed by the ANOVA between seasons (P <0.01) (Table 10a). ANOVA of the monthly data showed that the densities were significantly different across all the treatments during November 1990 (P <0.05) (Table 12). Besides, tillage (P <0.05) and tillage x amendment interaction (P <0.01) during November 1990 (Table 13). **Staphylinidae:** Its relative population densities across the 15 treatments presented in Fig. 24b revealed that the mean densities were <1 ranging from 0.06 to 0.28 and this did not show any significant response to treatments. ***Megalodicne*** Sp.: Its relative population densities across the 15 treatments presented in Fig. 24b revealed that the mean density was <1 ranging between 0.08 and 0.39. Under annual crop, in zero tillage treatments its density

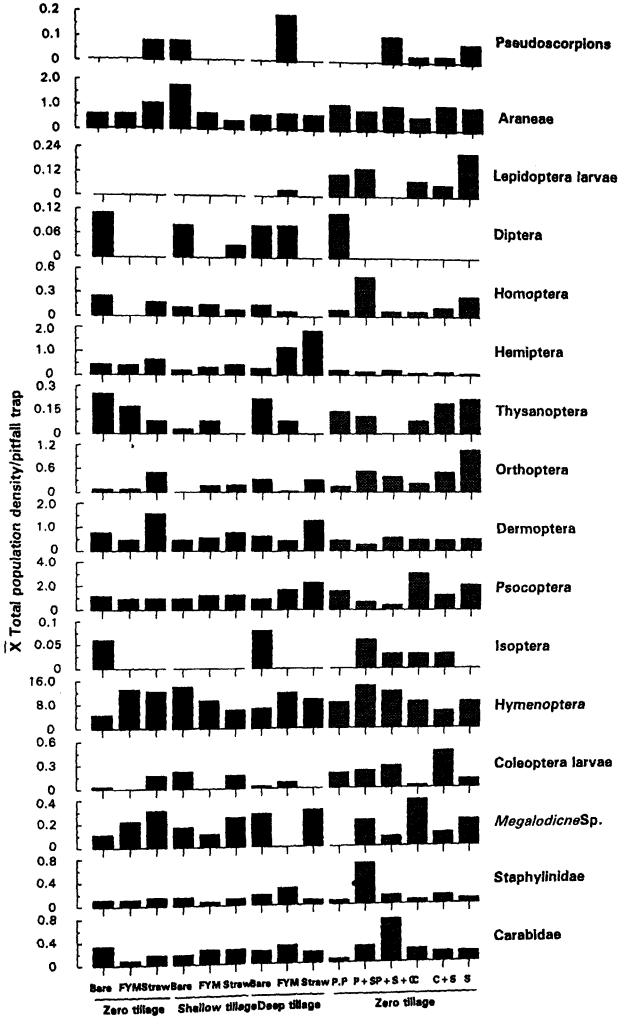

Figure 24b. Relative population densities of some of the soil surface arthropods across the fifteen soil management treatments.

ranged between 0.11 and 0.31, in shallow tillage treatments, the density ranged between 0.11 and 0.25, while in deep tillage treatments it ranged between 0.28 and 0.31. In perennial ley treatments, the density ranged between 0.08 and 0.39. However, their densities showed significant difference across the tillage and organic amendment treatments as revealed by the ANOVA between seasons (P <0.01) (Table 10a). ANOVA of the monthly data showed that the densities were significantly different across all the treatments during December 1989 and September 1990 (P <0.05) (Table 12) and organic amendment treatments during June 1990 (P <0.01) (Table 13). The densities were also different significantly across the perennial ley treatments during October 1989, September and November 1990 (P <0.05) (Table 14). **Coleoptera larvae:** Their relative population densities across the 15 treatments presented in Fig. 24b revealed that the mean density was negligible in number (<1) in all the treatments. However, their mean densities as revealed by the ANOVA differed across the 15 treatments significantly during rainy season (P <0.05) (Table 11b). Besides, their densities also differed significantly across the tillage and organic amendment treatments (P <0.05) (Table 10a) and perennial ley treatments between seasons (P <0.01), across the season and treatment interaction (P <0.01) (Table 10b). ANOVA of the monthly data showed on the mean population densities of Coleoptera larvae differed significantly across all the treatments during August 1989 (P <0.05) and August 1990 (P <0.01) (Table 12).

Hymenoptera: Its relative population densities across the 15 treatments presented in Fig. 24b revealed that the mean densities was 4.64 in annual treatments compared to those of the perennial ley treatments (16.42). Under annual crop, in zero tillage treatments, its mean density was 4.64 in bare amendment; it increased to 13.28 in farmyard manure treatment. In shallow tillage treatments its number was 6.31 in rice-straw amendment which increased to 14.1 in bare amendment. In deep tillage treatments its density was 6.8 in bare amendment and increased to 12 in farmyard manure amendment. In perennial ley treatments the density was 5.7 in *C. ciliaris* + *S. hamata* treatment and increased to 14.4 in pigeonpea + *S. hamata* treatment. ANOVA showed significant on its mean abundance differed across the tillage and organic amendment treatments significantly between seasons ($P < 0.01$) (Table 10a). Besides, the densities differed significantly across the perennial ley treatments between seasons ($P < 0.05$) (Table 10b). ANOVA of the monthly data showed that the population densities of Hymenoptera were significantly different across all the treatments during December 1989 ($P < 0.01$) and September 1990 ($P < 0.05$) (Table 12). Besides, their densities were also significantly different across the tillage treatments during December 1989 ($P < 0.01$), August 1990 ($P < 0.01$), and November 1990 ($P < 0.05$), and across the organic amendment treatments during December 1989 and August 1990 ($P < 0.01$), and across tillage x amendment interaction during December 1989 and August 1990 ($P < 0.05$) (Table 13). The densities were also significantly different across the perennial ley treatments during September 1990 ($P < 0.05$) (Table 14). **Isoptera:** Its relative population densities across the 15 treatments presented in Fig. 24b revealed that the mean densities were too few in number (<0.1) to show any distinct differences in between the treatments.

Psocoptera: Its relative population densities across the 15 treatments presented in Fig. 24b revealed that the mean density was <1 (i.e., 0.39) in number in pigeonpea + *S. hamata* + *C. ciliaris* treatment which increased to 3.0 in *C. ciliaris* treatment. Under annual crop, in zero and shallow tillage treatments its densities showed very little variation ranging between 0.9 and 1.2, and in deep tillage treatments, the densities ranged between 0.9 and 2.3. In perennial ley treatments its density was 0.4 in pigeonpea + *S. hamata* + *C. ciliaris* treatment which increased to 3.0 in *C. ciliaris* treatment. ANOVA showed that the densities of Psocoptera were significantly different in the tillage and organic amendment treatments together between seasons ($P < 0.01$) (Table 10a). ANOVA of the monthly data showed their densities were significantly different across all the treatments, during August 1990 ($P < 0.05$) (Table 12). Besides, its densities were also different across tillage significantly during December 1989 ($P < 0.05$), August, September, and November 1990 ($P < 0.01$), and across tillage x amendment interaction during September 1990 ($P < 0.01$) (Table 13). The densities were also different significantly across the perennial ley treatments during August 1989 ($P < 0.05$) and July 1990 ($P < 0.05$) (Table 14).

Dermaptera: Its relative population densities across the 15 treatments presented in Fig. 24b revealed that the mean density was significantly low (0.3) in number in perennial ley treatments compared to those of the annual treatments (1.58).

Under annual crop, in zero tillage treatments its density was <1 (i.e., 0.5) in farmyard manure amendment which increased to 1.6 in rice-straw amendment. In shallow tillage treatments its density showed very little variation ranging between 0.5 and 0.8. In deep tillage treatments the density was 0.4 in farmyard manure amendment which increased to 1.3 in rice-straw amendment. In perennial ley treatments its mean density showed very little variation ranging between 0.3 and 0.6. These densities differed significantly across the 15 treatments, as revealed by the ANOVA during rainy ($P < 0.01$) and postrainy season ($P < 0.05$) (Table 11b). Besides, the densities also differed significantly in between tillage and organic amendments between seasons ($P < 0.01$), and across season x amendment interaction ($P < 0.05$) (Table 10a) and across the perennial ley treatments between seasons ($P < 0.01$) (Table 10b). ANOVA of the monthly data showed that the mean densities significantly differed across all the 15 treatments during August 1990 ($P < 0.05$) (Table 12), across the tillage treatments during August 1990 ($P < 0.05$) and organic amendment during August 1989 ($P < 0.05$), September 1989 ($P < 0.01$), June ($P < 0.05$), July ($P < 0.01$), October ($P < 0.01$), and November 1990 ($P < 0.05$) (Table 13). **Orthoptera:** Its relative population density across the 15 treatments presented in Fig. 24b revealed that the mean density was significantly low in number (<1) in annual treatments compared to those of the perennial ley treatments (1.06). Under annual crop, in zero tillage treatments, the mean densities were <1, in shallow tillage treatments the densities showed very little variation ranging between 0.17 and 0.19 and in deep tillage treatments its densities ranged between 0.03 and 0.3. In perennial ley treatments its density was low (0.14) in pigeonpea treatment which increased to 1.0 in *S. hamata* treatment. Nevertheless, their densities showed significant difference across the tillage and organic amendment treatments between seasons (*P* <0.01) and across tillage (*P* <0.05) (Table 10a), and perennial ley treatments (*P* <0.01) (Table 10b). ANOVA of the monthly data showed that the population densities were significantly different across all the treatments during July 1990 (*P* <0.01) and September 1990 (*P* <0.05) (Table 12), across the organic amendment treatments during September 1990 (*P* <0.01) (Table 13), and the perennial ley treatments during July and September 1990 (*P* <0.05) (Table 14). **Thysanoptera:** Its relative population densities across the 15 treatments presented in Fig. 24b revealed that the mean density was very low (<0.1) in shallow tillage bare treatment which increased to 6.25 in zero tillage bare treatment, under the annual crop, in zero tillage treatments. In shallow tillage treatments its number was <0.1 while in deep tillage treatments and perennial ley treatments its density was <0.3. However, their densities were significantly different across the tillage and organic amendment treatments as revealed by the ANOVA between seasons (*P* <0.01) (Table 10a). ANOVA of the monthly data showed that the densities were also different across the tillage treatments during October 1990 (*P* <0.05) (Table 13). **Hemiptera:** Its relative population densities across the 15 treatments presented in Fig. 24b revealed that the mean density was very low (<0.1) in number in perennial ley treatments than to those of the annual treatments(1.86). Under annual crop, in zero tillage treatments its density ranged between 0.4 and 0.64, in shallow and deep tillage treatments and in perennial treatments the densities ranged between 0.06 and 1.9. However, the Hemiptera densities showed significant differences across the tillage and organic amendment treatments and perennial ley treatments as revealed by the ANOVA between seasons (*P* <0.01) (Tables 10a and b). **Homoptera:** Its relative population densities across the 15 treatments presented in Fig. 24b revealed that the mean density was very low ranged between 0.06 and 0.5. Under annual crop, in zero tillage treatments its density was low and showed very little variation ranging between 0.17 and 0.25, in shallow tillage and deep tillage treatments the density ranged between 0.06 and 0.14. In perennial ley treatments its density ranged between 0.06 and 0.5. However, the densities were significantly different across all the 15 treatments as revealed by the ANOVA during postrainy season (*P* <0.05) (Table 11b). Besides, the densities were also significantly different across tillage and organic amendment treatments between seasons (*P* <0.05) and season x amendment interaction (*P* <0.05) (Table 10a). The densities were significantly different across the perennial ley treatments between seasons (*P* <0.01) (Table 10b). ANOVA of the monthly data showed that the densities were significantly different across all the treatments during September 1990 (*P* <0.05) (Table 12).

Diptera: Its relative population densities across the 15 treatments presented in Fig. 24b revealed that the mean densities were very low, <0.2, and did not show any noticeable difference across the treatments. **Lepidoptera larvae:** Their relative population densities across the 15 treatments presented in Fig. 24b revealed that the mean densities were very low, <0.2. However, their densities showed significant differences across the perennial ley treatments (P <0.01) (Table 10b), particularly during October 1990 (P <0.05) (Table 14). **Araneae:** Its relative population densities across the 15 treatments presented in Fig. 24b revealed that the mean densities were low ranging between 0.4 and 1.8. Under annual crop, in zero tillage treatments, its density ranged between 0.6 and 1, in shallow tillage treatments its densities ranged between 0.4 and 1.8 while in deep tillage treatments, the density showed very little variation ranging between 0.6 and 0.7. In perennial ley treatments the density ranged between 0.6 and 1.1. The densities differed significantly across all the 15 treatments, as revealed by the ANOVA during rainy season (P <0.05) (Table 11b). Besides, the densities also differed significantly across the tillage and organic amendment treatments (Table 10a) and in perennial ley treatments (Table 10b) between seasons (P <0.01). ANOVA of the monthly data showed that the densities differed significantly across all the treatments during July 1990 (P <0.05) (Table 12), and across tillage and amendment interaction during July and September 1990 (P <0.05) (Table 13). **Pseudoscorpions:** Its relative population densities across the 15 treatments presented in Fig. 24b revealed that the mean density was recorded negligible in number (<1) in all the treatments. However, ANOVA revealed that the densities differed significantly across the tillage and organic amendment treatments between seasons (P <0.05) and season x tillage x amendment interaction (P <0.05) (Table 10a).

DISCUSSION

The soil surface arthropods collected across the 15 different soil management treatments belonged to 25 different arthropod taxa and Hymenoptera (Formicidae) was dominant taxa followed by Collembola and Acarina. Blumberg and Crossley (1983) collected arthropods belonging to 146 species from pitfall traps in conventional tillage and no-tillage systems in old field. Ao (1987) reported a collection of arthropods belonging to more than 30 different taxa of arthropods from the upland rice and maize ecosystems. Braman and Pendley (1993) reported a relative abundance of more than 203,000 predators, parasites, and decomposers in centipede grass, Carabidae and Hymenoptera being significantly more abundant.

In consistence to the present findings, Abbott et al (1979) recorded Hymenoptera often being higher in number in virgin soils and soils which had not been ploughed or stocked for seven years in Western Australia wheatbelt. Further, House and Stinner (1983) also reported that the Hymenoptera were higher in number in old-field pitfall traps from either of the two cropping systems — conventional tillage and no-tillage. Ao (1987) reported ants as the dominant group followed by Collembola in the upland rice and maize ecosystems. Braman and Pendley (1993) noted that Collembola were in large numbers in centipede grass. Prostigmata was most dominant taxa among Acarina followed by Mesostigmata, Cryptostigmata and Astigmata. In corroboration to these findings, Ao (1987) reported that Prostigmata being next to the Cryptostigmata followed by Astigmata and Mesostigmata. Braman and Pendley (1993) reported that higher number of Cryptostigmatid mites in centipede grass.

In the present study, three families of beetles were recorded of which Carabidae was dominant followed by Erotylidae (*Megalodicne* sp.) and Staphylinidae. However, the species composition and total numbers recorded during the present study is far less than the findings of Thiele (1977) who reported eight important Carabid species in the arable land of Europe. Holo Painen (1983) reported a total catch of 784 individuals of 32 species from cruciferous crops in organic and conventional forms in central Finland. Further, Hokkanen and Holopainen (1986) recorded 4541 Carabid beetles of 54 species from biologically and conventionally managed cabbage fields. Kromp (1989) reported a total of 12335 carabids belonging to 79 species from the biologically and conventionally farmed agroecosystems. Braman and Pendley (1993) recorded 21 species of carabids and 16 Staphylinid species in centipede grass as influenced by various management practices.

Other arthropods belonging to Pseudoscorpions, Diplopoda, Isoptera, Homoptera, Diptera, and Lepidoptera larvae were recorded in low numbers. This was in consistence to the findings of Ao (1987) that the Pseudoscorpions, Isoptera, Psocoptera, Dermaptera and Lepidopteran larvae were recorded in negligible numbers from rice and maize ecosystems. However, Araneae, Psocoptera, Dermaptera, Orthoptera and Hemiptera were collected in slightly higher numbers in the present investigation, as reported by Ao (1987). This is in consistence to the findings of Lobry de Bruyn (1993) that showed a high number of spiders on the soil surface in naturally vegetated sites.

The seasonal fluctuations in the mean relative population densities of soil surface inhabiting arthropods during the present investigation was most probably due to the changes in their activity in response to various abiotic factors (Reddy and Venkataiah, 1990) and to several other natural environmental or artificially induced factors and anthropogenic activities. The climatic factors such as temperature, relative humidity, rainfall and others effect to a greater extent, the activity of these arthropods and cause increase or decrease in their population size (Briggs, 1961; Duffey, 1962; Geiler, 1964; Greenslade, 1964; Mitchell, 1963a,b; Stein, 1965; Loser, 1972). Edwards et al (1975) and Hutson (1978) reported that temperature is one of the most important factors in dealing with the activities of the arthropods. Almost all the arthropods were affected by the fluctuation of temperature. These factors have to do with the type of crop(s) grown and management practices for the crop(s), on one hand and life history features and vagility of particular faunal taxa, on the other hand (Carter et al, 1985). Moreover, phenology frequently regulated the early or late season presence of arthropods which may explain some of the characteristics of their seasonal distribution. Arthropods during developmental stages being greatly affected by climatic factors may prefer vertical movement. Thus, many of them such as beetles and others in the larval stage live within the litter or rhizosphere-soil whereas their adults live away from the soil and litter sub-system. Such temporary soil animals form a considerable percentage of the soil surface arthropods. Thus, the populations of both the temporary and permanent soil surface dwelling arthropods may change in relation to the seasonal environmental factors, in responses to predators and conversely, to the cannibalism in response to starvation (Price and Shepard, 1977) leading to increase and decrease of the population densities. Besides, the seasonal activity of these arthropods may be influenced by many other factors which may not be uniformly applicable to all the species. Vegetational cover of crop may also influence the arthropod population as most of them are plant dependent (Jeschke, 1938; Duffey, 1972). Even the careless removal of the herbaceous layer near pitfall traps leads to either an increase or a decrease of the arthropod sample size (Greenslade, 1964).

The soil surface inhabiting arthropods during the present study were recorded in higher mean densities during the dry season followed by postrainy and rainy seasons. This was in consistence to the findings of Carter et al (1985) who reported that the arthropod fauna increased during the summer and autumn of 1981 and 1982, and it was as a consequence of immigration and natural increase. The ants were observed to be quite active throughout the year but were higher in densities during the postrainy season and lowest in the rainy season. This was in consistence to the findings of Majer (1981) and Major and Koch (1982) that the increase in ants in spring and summer was connected with high temperature and availability of food such as herbivore invertebrates, plant sap and seeds, and the reason for their low activity during other season may be the reduced availability of such resources. Observing the natural feeding rate of ants, Kajak et al., (1972) stated that their activity was correlated with availability of food. Ants, therefore, may be a good general indicator of the seasonal trends in overall biological activity. Ao (1987) reported that the ants were higher in number in winter in upland rice ecosystem. Lobry de Bruyn (1990) reported that the ants were more abundant in the warmer months (March and November) and was lower in the winter month (July). However, Abbott et al (1979) reported that the ant numbers in the summer samples were much lower than those in the winter samples.

The Collembola such as Poduridae, Sminthuridae and Isoptomitae were abundant during the rainy season, which may be probably due to the effects of rainfall, the most important climatic factor affecting the catches of Collembola (McColl 1975). This was in consistence to the findings of Wallace and Mackeras (1970) and McColl (1975) that more Collembola were captured during the rainy season. Ao (1987) reported that the Collembola were most abundant during summer with intermittent rains and decreased in the dry winter season. The decrease in Collembola population during the dry and postrainy seasons, is in consistence to the findings of Wallace and Mackeras (1970) and McColl (1975) that the Collembola were decreased towards the end of summer (February) which is attributable to the dry conditions. The mean population densities of Sminthuridae and Entomobryidae were recorded highest during rainy season followed by postrainy season and were very few in dry season.

The mean population densities of Acarina such as Prostigmata were higher during the dry winter season, followed by rainy season and postrainy season. Among the Acarina, Mesostigmata and Prostigmata were higher followed by Cryptostigmata and Astigmata. Mesostigmata were recorded higher in rainy season, followed by postrainy season and were not recorded during dry season. Cryptostigmata were recorded highest during the rainy season, followed by postrainy season. Favretto et al (1992) reported that the Prostigmatid and Cryptostigmatid mites were relatively abundant during dry periods (June 1989).

Coleoptera beetles such as Carabidae and Staphilinidae were recorded higher during the rainy season while they were not recorded during the dry season. This is in consistence to the findings of Ao (1987) that the population densities of Coleoptera were higher during the rainy season and were not recorded during the winter season. Further, Ostbye et al (1978) reported that the Coleoptera were higher during rainy season. Hokkanen and Holopainen (1986) reported that the total Carabid catches were higher in spring (1982) and autumn (1981). *Megalodicne* sp. (Erotylidae) were higher in number during postrainy season and not recorded during rainy and dry seasons. Ostbye et al (1978) reported that the Staphylinidae were higher number in summer season. Coleoptera larvae were higher in number during rainy season and not recorded during dry season. This may be because of soil moisture and availability of live roots as their food.

Psocoptera were higher in densities during the dry season followed by rainy and postrainy seasons, while Dermaptera and Orthoptera were higher during the postrainy season followed by rainy and dry seasons. In consistence to, Ao (1987) reported that the Orthoptera were maximum during rainy and postrainy seasons (June to October) and minimum during the winter season. Majer and Koch (1982) noted that the Orthoptera showed high levels of activity in spring, summer and in early autumn.

Intensive agricultural farming may cause adverse effects such as decrease in organic matter and nutrients in the soil by harvesting and erosion due to which populations of beneficial arthropods may decrease markedly, while those of pest organisms may increase concomitantly which may lead to marked deterioration of soil structure and soil compaction (Carter et al 1985). These effects may vary with soil type and slope, local climate and cropping systems and associated management practices. Adverse effects will be more serious if annual crops are grown regularly on the same land. Cultivation of undisturbed soil brings about a number of changes in community structure and activity of indigenous soil biota (Hendrix et al, 1990). In the present investigation it has been found that the most of the soil surface arthropods were higher in perennial ley treatments than the annual tillage treatments. This is in consistence to the findings of Braman and

Pendley (1993) that the soil arthropods in perennial cropping systems will experience less disturbances than the fauna under annual crops such as potatoes and barley. However, the effects of disturbances will vary according to taxa. Further, the less number of arthropods in annual tillage treatments was probably due to the effect of carbofuran insecticide applied at the beginning of the experiment to control sorghum shoot fly. Braman and Pendley (1993) reported that the soil arthropods were adversely affected by insecticide applications.

Among the tillage treatments they were higher in densities in zero tillage treatments than the deep and shallow tillage treatments. This was in consistence to the findings of House and Stinner (1983) that several major soil macroarthropods were higher in no-tillage than in conventional tillage systems. Similarly House and Parmelee (1985) reported that the soil arthropods were more abundant in no-tillage plots at Horse Shoe bend experimental site at Georgia (U.S.A.). Blumberg and Crossley (1983) showed that the no-tillage sorghum have the highest overall soil surface arthropod diversity than those of the conventional tillage. There were nearly 50% more individuals captured in no-tillage than in conventional tillage. There are larger catches in the habitats with denser vegetation and a litter layer. No-tillage indicated higher densities of arthropods than that in the habitat which allows unrestricted movement, conventional tillage. The soil surface arthropods were more numerous in no-tillage, probably because of the particular combination of properties derived from cropping and natural systems: the increased moisture retention, litter component and variety of plant species available in no-tillage paralleled conditions in a natural system while the crop, still an energy-subsidized system, provided an attractive nutrient-rich food source for herbivores. Moreover, the no-tillage systems are more stable than conventional tillage systems, providing not only advantages such as reduced erosion and increased soil moisture but also a system less susceptible to pest outbreaks (Blumberg and Crossley, 1983). Moore et al (1988), Dindal (1990) and Hendrix et al (1990) reported that the cultivation and the absence of mulch make the microclimate and the resource levels less favourable for soil mesofauna. Soil disturbances affect not only the detritus food web, but also the above-ground food webs. Further, Abbott et al (1979) observed that the ploughing, cropping and stocking altered the physical structure of the soil, and caused a reduction in the number of large soil arthropods. In addition, the decreased amount of organic matter following cultivation and cropping may also cause populations of large animals to decline.

Among the three tillages organic amendment treatments the arthropods particularly ants were higher in densities in farmyard manure treatment than the rice-straw and bare treatments. Their populations were significantly affected by all the treatments during December 1989 and September 1990; by tillage during December 1989 (P <0.01), August 1990 (P <0.01), and November 1990 (P <0.05), and by the organic amendment treatments during December 1989 and August 1990 (P <0.01), and by tillage x amendment interaction during December 1989 and August 1990 (P <0.05). The densities were also significantly affected by perennial ley treatments during September 1990 (P <0.05). It indicated that the soil management practices such as tillage, organic amendments and perennial crop covers have significantly affected the population structure of Formicidae. However, Favretto et al (1992) observed that the fertilizer practices did not influence the arthropod populations. The treatment effect on their population densities during the present findings revealed that Hymenoptera were highest in annual tillage treatments than in perennial ley treatments and among the tillage treatments, these were higher in zero tillage treatments than in the shallow and deep tillage treatments. This in consistence to the findings of House and Stinner (1983) who recorded higher number of ants in pitfall traps from no-tillage than from conventional tillage systems.

Collembola including Poduridae, Sminthuridae, Isotomidae and Entomobryidae were recorded higher mean densities in perennial ley crop treatments than the annual tillage treatments. This is in consistence to the findings of Michalak (1984) that the Collembolan densities were higher in the organically managed treatments than the conventional tillage systems. Reduction in their population densities in tillage treatments during the present study was most probably due to the effect of carbofuran that was applied at the beginning of the experiment to control sorghum shoot fly. This is in consistence to the findings of Braman and Pendley (1993) that the Collembolan population densities were adversely affected in the short-term by insecticide applications targeting the two lined spittle bug in centipede grass. Among the annual tillage treatments their densities were higher in zero tillage treatments than the deep and shallow tillage treatments and among the organic amendment treatments, they were higher in densities in farmyard manure amendments than the rice-straw and bare amendment treatments, which indicate the significant effect of these treatments on their population structure.

The Poduridae and Isotomidae were higher in the deep tillage treatments than the zero tillage and shallow tillage treatments while Sminthuridae were highest in the shallow tillage treatments than the zero and deep tillage treatments. Entomobryidae were higher in densities in the zero tillage treatment than the deep and shallow tillage treatments. Poduridae were higher in the farmyard manure amendments than the bare and rice-straw amendments while Sminthuridae and Isotomidae were higher in the rice-straw treatments than the farmyard manure and bare amendments. Entomobryidae densities were higher in the bare amendment than the farmyard manure and rice-straw amendments. The population densities of Sminthuridae were significantly affected by all the 15 treatments during rainy season ($P < 0.05$). Besides, the densities of Isotomidae, Sminthuridae and Poduridae were significantly affected by tillage and organic amendment treatments between seasons ($P < 0.01$), and Sminthuridae by organic amendment ($P < 0.01$), season and amendment interaction ($P < 0.01$) while densities of Isotomidae were significantly affected by season x tillage interaction ($P < 0.05$). The densities of Sminthuridae ($P < 0.01$) and Poduridae ($P < 0.05$) were significantly affected by the perennial ley treatments between seasons while

Sminthuridae densities by season and treatment interaction ($P < 0.05$). The population densities of Sminthuridae were significantly affected by all the treatments during July 1990 ($P < 0.05$) while that of Poduridae during August 1990 ($P < 0.05$). Sminthuridae densities were significantly affected during August 1989 ($P < 0.05$) and that of Poduridae during July 1990 ($P < 0.05$) across tillage x amendment interaction. Besides, the density of Isotomidae were significantly affected by tillage treatments during April, June and October, 1990 ($P < 0.05$) and that of densities of Isotomidae ($P < 0.01$) and Entomobryidae ($P < 0.05$) by the perennial ley treatments during June 1990, Sminthuridae ($P < 0.01$) during August 1989 and Poduridae ($P < 0.01$) during November 1990. These findings are in consistence to those of Favretto et al (1992) that the presence of the mulch and the consequent availability of organic matter mainly supported these populations. Because, soil invertebrate activity is linked with organic matter turnover and nutrient cycling, through interactions with the microbial population (Seastedt, 1984; Moore et al., 1988). Moreover, these materials constitute a conspicuous food base for the soil arthropods (Paoletti, 1987; Stinner and House, 1990).

Acari including Prostigmata and Mesostigmata were higher mean densities in the perennial ley treatments than the annual tillage treatments, which may be attributable to the vegetation cover that retained more soil moisture and had less soil disturbance than that of the tillage treatments. These findings are in consistence to the findings of Perdue and Crossley (1989) that the mite densities were more numerous in conventional tillage than the no-tillage agroecosystems during the first year. However, they were more abundant in no-tillage agroecosystem during the second year of the study. Among the annual tillage treatments Acarina densities including those of Mesostigmata were higher in the deep tillage treatments than the zero and shallow tillage treatments. Among the three tillages organic amendment treatments, Acarina densities including those of Mesostigmata were higher in the rice-straw amendment than the farmyard manure and bare amendments. However, Cryptostigmata and Astigmata were higher in mean densities in the annual tillage treatments than the perennial ley treatments. The population densities of Prostigmata (P <0.01), Cryptostigmata and Astigmata (P <0.05) were significantly affected by all the 15 treatments during rainy season. Besides, the population densities of Prostigmata, Cryptostigmata and Mesostigmata were also significantly affected by tillage and organic amendment treatments between seasons (P <0.01), while that of Cryptostigmata were significantly affected by the season x tillage x amendment interaction (P <0.01), and that of Mesostigmata by season x tillage interaction (P <0.05). The population densities of Prostigmata, Cryptostigmata and Mesostigmata were also significantly affected by the perennial ley treatments between seasons (P <0.01) and that of Prostigmata by season and treatment interaction (P <0.01). The population density of Prostigmata were significantly affected by all the treatments during August 1989 (P <0.001), July, August and September 1990 (P <0.01) and that of Cryptostigmata during August 1989 and 1990 (P <0.01), Mesostigmata during December 1989 and September 1990 (P <0.05), Astigmata during August (P <0.05) and September 1990 (P <0.01). Besides, the population density of Prostigmata were significantly affected by the organic amendment during September 1989, August and September 1990 ($P < 0.05$), and by tillage treatments during August and September 1990 ($P < 0.01$) and Cryptostigmata showed significant response to organic amendments during August 1989 and 1990 ($P < 0.05$) and tillage during August, 1989 ($P < 0.05$), Mesostigmata showed significant response to tillage during August and September 1990 ($P < 0.05$) and Astigmata to organic amendment ($P < 0.05$) and tillage treatments ($P < 0.01$) during September 1990. The perennial ley treatments showed significant effect on the population density of Prostigmata during July 1989 ($P < 0.05$), August 1989 and April 1990 ($P < 0.01$) and June 1990 ($P < 0.05$), while that of Cryptostigmata during August 1990 ($P < 0.05$), and Mesostigmata during December 1989 and October 1990 ($P < 0.05$).

Many authors reported that the Cryptostigmatid densities have increased over time in response to various agricultural practices, such as insecticide, herbicide, or fertilizer applications, partly in response to increased decaying organic matter or to a decrease in predators, or both (Wegorek and Trojanowski, 1986; Arnold and Potter, 1987; Turner et al, 1987; Vavrek and Niemczyk, 1990; and Braman and Pendley 1993). Among the annual tillage treatments, the densities of Cryptostigmata and Prostigmata were higher in the zero tillage treatment than the shallow and deep tillage treatments, while among the organic amendment treatments their densities were higher in the rice-straw treatment than the farmyard manure and bare treatments. This is in consistence to the findings of Favretto et al (1992) that the fluctuations in the populations of Cryptostigmata in the mulched plots were relatively abundant. Further, the rapid numerical increase in these mites, was probably due to the influence of potassium (Norton, 1990). Favretto et al (1992) reported that the Astigmatid mites were higher in cultivated soil in a vineyard farm and their varying sensitivity to different soil nutrients make them useful biological indicators in studying the effects of agricultural management (Dindal et al., 1977). Among the tillage treatments Astigmata were higher in the deep tillage treatments than the shallow tillage treatments and were absent in zero tillage treatments. Among the three tillages organic amendment treatments, they were higher in the farmyard manure amendments than the rice-straw and bare amendments.

The mean population densities of total Coleoptera including that of Carabidae and Staphylinidae and Coleoptera larvae were higher in perennial ley treatments than the annual tillage treatments. Among the tillage treatments they were higher in densities in deep tillage treatments than the shallow and zero tillage treatments. The population densities of Carabidae were significantly affected by tillage and organic amendment treatments (P <0.01). Besides, the densities of Carabidae were significantly affected by all the treatments during November 1990 (P <0.05). The densities of Carabidae were affected by tillage (P <0.05) and tillage x organic amendment interaction during November 1990 (P <0.01). These findings are consistence to those of Zender and Linduska (1987) that the adult densities of Colorado potato beetles were higher in conventional tillage plots than in no-tillage plots in rotated and non-rotated tomato fields. Further, Troxclair and Boethel (1984) reported that the beetle populations were found to be larger in soybean ecosystems under conventional tillage rather than in no-tillage culture. House and Stinner (1983) reported that the Staphylinidae were higher in numbers in no-tillage that in conventional tillage systems.

Among the organic amendment treatments, the densities of total Coleoptera were higher in rice-straw treatment than the bare and farmyard manure treatments. Heikki Hokkanen (per. comm.) recorded higher densities of carabid beetles in cabbage fields in Germany, which have been several years biodynamically managed than in conventionally managed fields, where insecticides were used regularly. Further, the carabid beetles were higher in densities as tillage is decreased (All, 1978; Raney, 1974; Stassart and Greoire Wibo, 1983). Greater abundance of these beetles was reported from conservation-tillage than from conventionally plowed soybeans (House and All, 1981). House and All (1981) found that carabid beetle number were often several times higher in no-tillage than in conventional tillage soybeans. The surface litter of no-tillage may have provided these predatory fauna with greater food resources and at the same time, protection from unfavourable climatic conditions. House and Stinner (1983) reported that the carabid beetles have occurred too frequently in higher numbers in no-tillage than in conventional tillage systems. House and Parmelee (1985) reported that the carabid beetles were higher in no-tillage than in plowed treatments. Further many authors have reported that the carabid beetles were higher in the biologically farmed agroecosystems than the conventional farmed fields (Dritschilo and Wanner, 1980; Kromp, 1989 and Hokkanen and Holopainen 1986). Carter et al (1985) reported that carabid beetles were predominated in annual crops in different agroecosystems.

Among the organic amendment treatments, the densities of Carabidae and Staphylinidae were higher in the farmyard manure treatments than the rice-straw treatments. This is in consistence to the findings of Dritschillo and Wanner (1980) that the carabid beetles were significantly higher in biologically managed corn fields with application of manure (1-7 t/ha), than the conventionally managed corn fields. Further, Pietraszko and de Clerq (1982) observed a higher total carabid density in potato and wheat fields where a manure (40 t/ha) was applied 2 years before the study period in contrast to untreated plots. Purvis and Curry (1984) observed that the application of farmyard manure (40 t/ha) increased the activity and density of carabid species early in the season in sugar beet ecosystems. Hokkanen and Holopinen (1986) observed that the amount of composed manure application in biologically managed fields, F1 and F3 was at the same level as in the studies of Purvis and Curry (1984) and Pietaszko and de Clerq (1982). In field F2 the application of manure was 80 t/ha, but the carabid numbers was smaller than in fields F1 and F3. Thus, the amount of manure application does not seem to be clearly associated with the higher carabid density in the biologically managed fields. However, a continuous input of organic material for over 10 years may have balanced the overall situation and favoured carabids in the biologically and conventionally managed fields.

Megalodicne sp. (Erotylidae) were higher in mean densities in annual tillage treatments than the perennial ley treatments. Among the tillage treatments they were higher in zero tillage than the deep and shallow tillage treatments, while their densities were higher in rice-straw amendments than the bare and farmyard manure treatments among the organic amendment treatments. Its population densities were significantly affected by tillage and organic amendment treatments (P <0.01), by all the treatments during December 1989 and September 1990 (P <0.05). The population densities of *Megalodicne* Sp. were significantly affected by the organic amendment treatments during June 1990 (P <0.01). Its densities were significantly affected by the perennial treatments during October 1989, and September and November 1990 (P <0.05).

The densities of Coleoptera larvae were higher in shallow tillage treatment than the zero and deep tillage treatments among the tillage treatments, while the organic amendment treatments they were higher in rice-straw amendment than the bare and farmyard manure amendments. The population densities of Coleoptera larvae were significantly affected by all the treatments particularly to the tillage and organic amendment treatments between seasons. The population densities of Coleoptera larvae were significantly affected by the perennial ley treatments across seasons (P <0.01), by the season and treatment interaction (P 0.01). Besides, the mean population densities of Coleoptera larvae were significantly affected by all the treatments during August 1989 (P <0.05) and August 1990 (P <0.01).

The mean population densities of Diplopoda were higher in densities in perennial ley treatments than the tillage treatments. The population densities of Diplopoda were significantly affected by tillage and organic amendment treatments across season (P <0.05). Besides, their densities were significantly affected by the perennial treatments during November 1990. This is in consistence to the findings of Carter et al (1985) that the densities of Diplopoda were severely affected and recorded in low populations under disturbed conditions. General observations of Ghilarov (1975) showed that millipedes are susceptible to perturbations caused by regular use of machinery and low food availability under such crops as potatoes. Further, Hokkanen and Klingauf (1986) reported that the millipedes were more abundant in biologically managed cabbage fields than the conventionally managed fields.

Although the population densities of Psocoptera, Isoptera, Orthoptera, Thysanoptera, Homoptera, Lepidoptera larvae, Araneae and Pseudoscorpions were in negligible numbers, they were in relatively more in number in perennial ley treatments than the tillage treatments. On the other hand, the number of Dermaptera, Hemiptera and Diptera were more in tillage treatments than the perennial ley treatments. Among the tillage treatments, Orthoptera, Hemiptera, Diptera, Psocoptera and Pseudoscorpions were more in number in deep tillage treatments while the number of Homoptera, Dermaptera, Araneae and Thysanoptera were more in zero tillage treatments and that of Isoptera and Lepidoptera larvae were more in deep tillage treatment. Among the organic amendments Dermaptera, Homoptera, Orthoptera, Psocoptera, Hemiptera and Araneae were more in number in rice-straw treatment. Thysanoptera, Isoptera and Diptera were more in number in bare treatment. Nevertheless, the population densities of Dermaptera (P <0.01) and Araneae (P <0.05) were significantly affected by all treatments during rainy season, and that of Dermaptera (P <0.05) during postrainy season. Besides, the densities of Psocoptera (P <0.01), Dermaptera (P 0.01), Orthoptera (P <0.01), Thysanoptera (P <0.01), Hemiptera (P <0.01), Homoptera (P <0.05), Pseudoscorpions (P <0.05) and Araneae (P <0.01) were significantly affected by tillage and organic amendments across seasons, and that Dermaptera and Homoptera were significantly effected by season x amendment interaction (P <0.05). The densities of Dermaptera were significantly affected by organic amendment treatments (P <0.01) and that of Orthoptera by the tillage (P <0.05), and Pseudoscorpions by season x tillage x amendment interaction (P <0.05).

The perennial ley treatments showed significant effect on the population densities of Dermaptera, Orthoptera, Hemiptera, Homoptera, Lepidoptera larvae and Araneae across seasons (P <0.01), while that of Homoptera were significantly affected by the treatments (P <0.01). Besides, the mean densities of Psocoptera and Dermaptera were significantly affected by all the treatments during August

1990 ($P < 0.05$), while that of Orthoptera ($P < 0.01$) and Araneae ($P < 0.05$) were significantly affected by the treatments during July 1990. Orthoptera and Homoptera were significantly affected during September 1990 ($P < 0.05$). The population densities of Psocoptera were significantly affected tillage treatments during December 1989 ($P < 0.05$), August, September, and November 1990 ($P < 0.01$), and by tillage x amendment interaction during September 1990 ($P < 0.01$), and that of Dermaptera were significantly affected by the tillage during August 1990 ($P < 0.05$) and organic amendments during August 1989 ($P < 0.05$), September 1989 ($P < 0.01$), June ($P < 0.05$), July ($P < 0.01$), October ($P < 0.01$), and November 1990 ($P < 0.05$). The densities of Orthoptera showed significant response to the organic amendment treatments during September 1990 ($P < 0.01$), and that Thysanoptera showed significant response to the tillage treatments during October 1990 ($P < 0.05$). The densities of Araneae were significantly affected by the tillage x amendment interaction during July and September 1990 ($P < 0.05$). The population densities of Psocoptera were significantly affected by the perennial ley treatments during August 1989 ($P < 0.05$) and July 1990 ($P < 0.05$) and Orthoptera during July and September 1990 ($P < 0.05$) and Lepidoptera larvae during October ($P < 0.05$). Paoletti (1987) observed that greater numbers of spiders in reduced tillage and no-tillage than in conventionally plowed corn systems. A similar trend was reported for corn systems in Ohio after 20 years of continuous treatment (Stinner et al, 1988). House and Stinner (1983) reported that the spiders, frequently occurred in higher numbers in no-tillage than in conventional tillage systems. No-tillage spatial heterogeneity and vegetational stratification may have promoted higher species diversity for some arthropod guilds (Murdoch et al, 1972). House and Stinner (1983) observed that the greater abundance of predatory foliage-inhabiting arthropods such as Hemiptera was found in no-tillage systems than in conventional tillage. Further, Troxclair and Boethel (1984) reported that the density of Hemiptera was higher in Louisiana no-tillage soybeans in some sites and lower in other locations, when compared to conventionally tilled systems. However, there is little information in the literature on these aspects of the above groups to compare with the findings of the present study.

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CHAPTER-III

MICROARTHROPOD POPULATION STRUCTURE

INTRODUCTION

Soil environment provides shelter for all forms of life, including, micro-, meso- and macro-arthropods. The soil arthropods depending on their body size, are divided into different groups such as mesofauna (2-10 mm) that includes all microarthropods and macrofauna (> 10 mm) which include larger arthropods and earthworms. Microarthropods are usually the most obvious of the mesofauna which live in soil pores and interstices, many of them are small and microscopic while some of the soil microarthropods spend a portion of their lives feeding in the soil. Some may spend much of their life above the soil; for instance, certain beetles which prey on aphids. Other soil arthropods spend their entire lives in the soil ecosystem. Since the soil is a highly specialised environment, it acts like a filter and only small animals which can cope with its peculiar conditions are able to survive in it (Kuhnelt, 1955 and Ghilarov, 1959). The soil floor has several layers which can be a habitat for even the smallest arthropods. However, the research on the ecology of soil microarthropods is difficult due to their habitat their delicate and small body size, sampling and taxonomic difficulties and experimental set-ups.

Microarthropods play a significant role in accelerating plant residue decomposition through their interactions with the microflora (Seastedt, 1984; Norton, 1985; Moore and Walter, 1988). The flow of energy and nutrients through the soil may be accelerated by microarthropods grazing on microflora, causing increased rates of microbial biomass turnovers. It is often felt that soil microarthropods are important to the process of decomposition (Macfadyen, 1963; Wallwork, 1976), because they comminute organic matter, making it more readily available for breakdown by smaller organisms. They also serve as a reservoir of nutrients that become available to plants when they die. They stimulate fungal growth by grazing, and disperse their spores. They improve soil aeration (Wallwork, 1970; Kuhnelt, 1976; Anonymous, 1982). Within the area of soil micromorphology many major mesofaunal influences are only just being discovered and acknowledged. Mesofaunal activity contributes to the overall soil-structural status of many soils and by considerably improving soil porosity through reorganisation. The ecological importance of soil microarthropods has been increasingly studied in the past 20 years but is still a subject of speculation. Extensive research on these aspects have been carried out in developed countries like USA and Canada.

Quite a good number of researchers like Bellinger (1954), Sheals (1957), Haarlov (1960), Dhillon and Gibson (1962), Milne (1962), Christiansen (1964) studied the qualitative and quantitative ecology of the Collembolan population in uncultivated fields. Prior to the 1950s virtually no research was conducted on microarthropods of agricultural land. Nearly all ecological investigations were conducted in old fields or forests (Dowday, 1944; Pearse, 1946; Strickland, 1947; Hairston & Byers, 1954; Haarlov, 1967). Since that time there has been increased interest on the effects of agricultural practices upon the soil fauna. The literature review on the effects of soil management on the population structure of soil microarthropods is scattered (Tischler, 1955; Anglade, 1975; Alejnikova & Utrobina, 1975; Edwards & Lofty, 1975). Soil microarthropods are adversely affected when soil is disturbed with various soil management practices such as tillage, which leads to sudden changes in the soil physico-chemical environment (Wallwork, 1976). With the increase of cultivation impacts, the more sensitive species and other beneficial arthropods decreased in abundances, only a less common species with high adaptability remained.

The attempts of agricultural research to provide more efficient and cost effective farming has resulted in many new tillage implements, methods and systems. The recent innovation, referred to "No-Till" has received considerable attention by researchers and farmers and failed in countries like Africa. No-Till is a method of growing crops on unplowed soil with the use of a special planter and herbicides. This method is acknowledged as having great potential production costs, fuel requirements and time (Phillips and Young, 1973). Many engineering, agronomic and economic aspects of No-Till crop production have been investigated, but there is relatively little information available on biological processes, especially those related to very small consumer and decomposer animal life. These invertebrates derive their food and energy from the decomposed organic matter.

Dhillon and Gibson (1962) studied the acarina and Collembola populations of agricultural soils. Musick and Collins (1971) studied the affect of tillage on Northern Corn rootworm. Ghilarov (1973) and Edwards and Lofty (1973) have studied and compared the Collembolan population of cultivated fields with those of natural soils. Edwards and Lofty (1969) reported on the influence of agricultural practice on soil microarthropod populations. Edwards and Lofty (1973) reported on the influence of cultivation on soil animal population. Ghilarov (1975) studied the general trends of changes in soil arthropod populations of arable land. Edwards (1977) investigated the influence of agricultural practice on soil arthropods. Aritajat et al (1977) studied the effects of compaction of agricultural soils on soil fauna. Cheshire and All (1979) investigated on feeding behaviour of lesser cornstalk borer larvae in simulations of no-tillage, mulched conventional-tillage and conventional-tillage corn cropping systems. Dindal (1980) reported soil biology as related to land use practices. Nakamura and Hakoishi (1981) investigated the crop system and abundance of soil arthropods, while Loring et al (1981) investigated the effects of three tillage practices on Acarina and Collembola populations. Shams et al (1981) and Boles and Oseto (1987) reported on the diversity of microarthropods and mesofaunal populations as related to no-till and conventional tillage methods. Andren and Lagerlof (1983) investigated soil microarthropods in agricultural cropping systems.

Berg and Pawluk (1984) has investigated soil mesofauna such as Acarina and Collembola distribution and diversity on a cultivated gray luvisol under seven different vegetative regimes. Moore et al (1984) reported the effects of different management practices on Acarina and Collembola in crop production systems. Emmanuel et al (1985) reported on the soil acarina of barley with different cultural treatments. Rickerl et al (1989) have investigated the effects of varying crop management systems on populations of Collembola.

Ruhendti (1982) reported the effect of tillage methods on the insect pests of grain legumes. Pike and Glazer (1982) recorded reduction of lepidoptera by using strip rotary tillage. Pike and Glazer (1982) reported the reduction of lepidoptera by using strip rotary tillage. Steen (1983) studied about 15 old field experiments with different crop rotations and manuring or fertilizing systems and the associated soil fauna. Sloder beck and Yeargen (1983) investigated on Green Cloverworm (lepidoptera : Natuidae) populations in conventional and double-cropped no-till soybeans. Troxclair and Boethel (1984) studied on the influence of tillage practices and row spacing on soybean insect populations. Brust et al (1986) investigated predation by soil inhabiting arthropods in intercropped and monoculture agroecosystems. Stinner et al (1986) reported on insecticide and tillage effects on pest and non-pest arthropods in corn agroecosystems. Landis et al (1987) studied the behaviour and survival of *Heliothis zea* (lepidoptera : Natuidae) prepupae in no-tillage and conventional tillage corn. Burton et al (1987) reported on damage by green bug (Homoptera) to grain sorghum as affected by tillage, surface residues and canopy. Stinner et al (1988) reported on soil and foliage arthropod communities in conventional, reduced and no-till corn systems. Nakamura (1988) studied on the effects of four contrasting soil management practices on soil fauna in an andosol cropped to upland rice and winter wheat. House and Alzugaray (1989) reported on the influence of cover cropping and no-tillage practices on community composition of soil arthropods. Winter et al (1990) investigated soil microarthropods in long-term no-tillage and conventional tillage corn production. Stinner and House (1990) reported the soil arthropods in conservation tillage agroecosystem. Perdue and Crossley (1990) measured soil mites t four depths under no-tillage and conventional tillage agroecosystems. Calgari et al (1991) studied the relationship between soil management and soil microarthropods in Romania. Reddy et al (1992) reported on soil management and seasonal community structure of soil microarthropods in a semi-arid tropical Alfisol.

Hazra and Choudhuri (1983) investigated on the population and seasonal distribution of Collembolan fauna of uncultivated and cultivated fields in relation to three major edaphological factors.

In India many researchers have investigated on the seasonal abundance and the qualitative and quantitative composition of different soil microarthropods in different agroecosystems such as Cotton (Trehan, 1945), wheat and floral gardens (Mukharji and Singh, 1967; Singh and Mukharji, 1971, 1973), Sugarcane (Avasthy, 1967; Singh and Mukharji, 1971, 1973; David, 1978; Reddy and Tiwary (unpublished), low land paddy (Bhattacharya and Joy, 1978; Pai and Prabhoo, 1980, 1981), fodder crop and citrus orchards (Singh and Pillai, 1981), upland paddy and maize (Ao, 1987), and other cultivated soils (Gupta and Mukharji, 1976a). Prabhoo (1976) and Reddy (1981) investigated the ecology of soil microarthropods in tea gardens. Gupta and Mukharji (1976b) and Hazra and Choudhuri (1983) compared the microarthropod densities of cultivated and uncultivated soils. The qualitative composition and ecology of Collembola was studied in cultivated fields (Choudhuri and Roy, 1967; Mitra et al, 1977, 1978) while Singh and Pillai (1975) and Joy and Bhattacharya (1981) reported the ecology of Acari in banana fields. Ghatak and Roy (1981) reported the seasonal abundance of Acari species in potato and jute fields.

Although considerable research work has been done on the effects of various soil management practices on soil arthropods in temperate agroecosystems, very little is known on these aspects in tropical and sub-tropical agroecosystems, particularly in India Reddy et al (1992) reported on soil management and seasonal community structure of soil microarthropods in semi-arid tropical Alfisols. During the present investigation attempts were made to investigate the effects of 15 different soil management practices on soil microarthropods across rainy, postrainy, and dry seasons in Alfisol sorghum agroecosystem.

MATERIALS AND METHODS

Population densities of soil inhabiting microarthropods in each experimental plot across the treatments were sampled using 10 cm core device of 4.5 cm diameter whose interior widened slightly to relieve compression of soil. Three random soil cores representing top, middle, and bottom position of each plot were taken on each sampling date in the morning hours in between 0730 to 0930 AM when the ambient temperature was conducive. Sample sites were selected in the central part of each plot to avoid possible edge effects. The soil cores of each plot were placed in plastic bags separately and labelled, taking as much care as possible to prevent spillage and brought to the laboratory. The soil cores were processed for extraction of microarthropods through Berlese-Tullgren funnel (Macfadyen, 1955). The heat and light source for each funnel was a 60-watt light bulb connected to a rheostat. Low settings were used so that the microarthropods would not be trapped inside the soil core due to rapid drying of soil. The extraction was continued for a minimum of three days. However, the period of extraction depended upon the soil water contents and varied from three to five days particularly during the rainy months. The arthropods were moved downward and finally out of the soil into a collecting phials containing 80% ethanol + 1% glycerol. These microarthropods were identified, grouped into various taxa and were enumerated with the help of a stereoscopic binocular microscope (Wild Heerbrug) at 60 magnification. Their numbers were converted into the number per metre square. The data of population densities of microarthropods across the treatments and seasons were processed by ANOVA using GENSTAT.

RESULTS

Qualitative Composition:

The soil inhabiting arthropods collected across the 15 soil management treatments such as different tillage and organic amendments with annual crop and perennial ley treatments belonged to 29 different arthropod taxa such as Araneae, Pseudoscorpions and Acarina — Prostigmata, Cryptostigmata, Mesostigmata and Astigmata; Diplopoda, Chilopoda and Symphyla, Protura, Thysanura, Diplura; Collembola — Entomobryidae, Isotomidae, Sminthuridae and Poduridae; Coleoptera — Carabidae, Staphylinidae, Tenebrionidae, *Megalodicne* Sp. and Coleoptera larvae; Hymenoptera, Isoptera, Thysanoptera, Hemiptera, Homoptera, Diptera and Lepidoptera larvae. The mean percentage composition of their taxa under the management treatments are presented in Figs. 25a and b.

Acarina: Acarina was dominant among the microarthropods, the mean percentage composition ranging between 41.7 to 71% across the treatments. In zero and shallow tillage treatments their mean percentage composition ranged from 64.3 and 61% in bare amendment to 67 and 68.6% in farmyard manure amendment. In deep tillage treatments their mean percentage composition ranged between 58.7% in bare amendment and 71% in rice-straw amendment. In perennial ley treatments their percentage composition ranged from 41.7% in pigeonpea + *S. hamata* treatment to 49.2% in pigeonpea + *S. hamata* + *C. ciliaris* amendment. **Prostigmata** being dominant taxa among the Acarina, its mean percentage

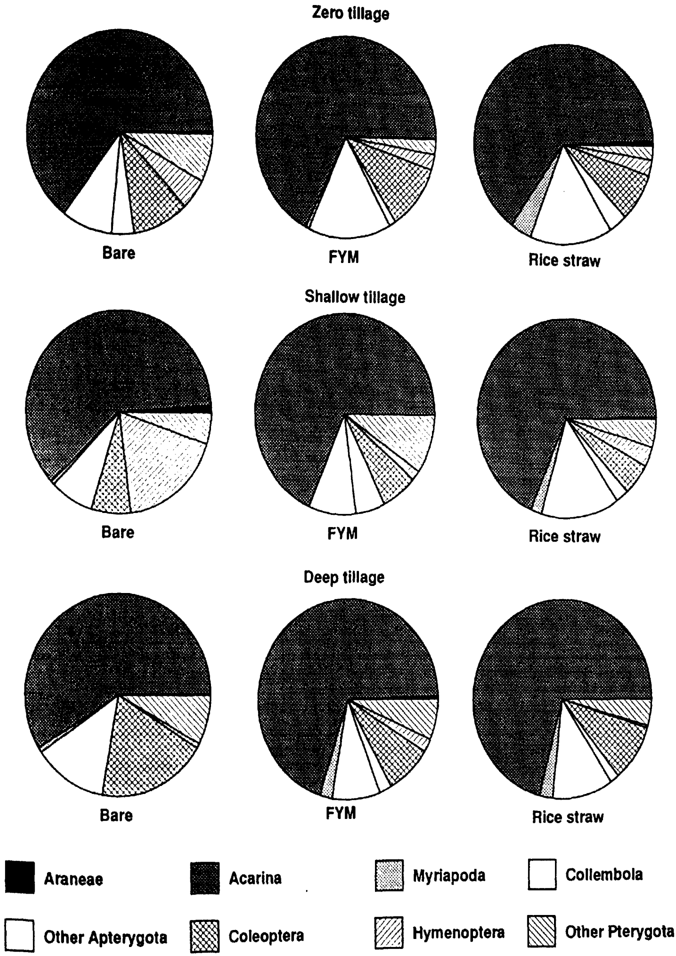

Figure 25a. Percentage composition of different soil inhabiting microarthropods across tillage and organic amendment treatments.

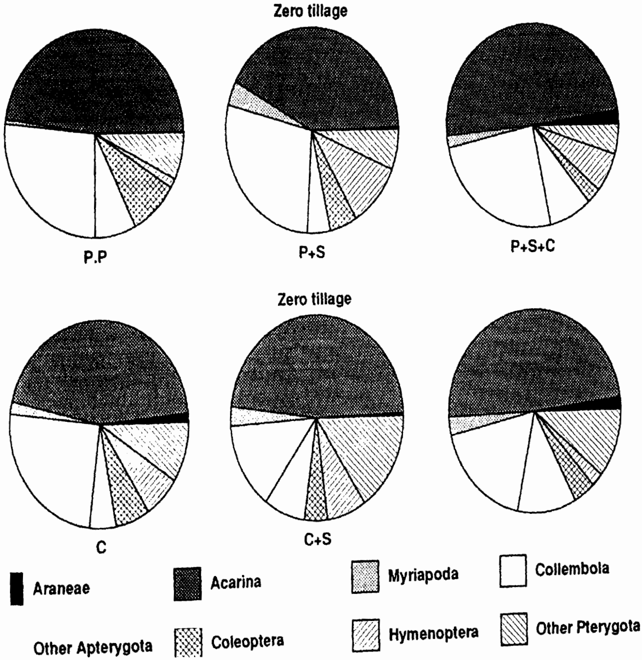

Figure 25b. Percentage composition of different soil inhabiting microarthropods across perennial ley crop treatments.

composition ranged between 13 and 43.4% across the 15 treatments. In zero tillage treatments its percentage composition ranged between 35% in bare amendment and 43.4% in rice-straw amendment. In shallow tillage treatments its percentage composition ranged from 29.2% in bare amendment to 39.4% in farmyard manure amendment. In deep tillage treatments its percentage composition ranged between 21.2% in farmyard manure amendment and 41.3% in bare amendment. In perennial ley treatments its percentage composition ranged from 13% in *S. hamata* treatment to 20% in pigeonpea treatment. **Astigmata**: Its percentage composition ranged between 8.1 and 31.5% across the 15 treatments. In zero tillage treatments its percentage composition ranged between 8.1% in bare amendment and 16.8% in farmyard manure amendment. In shallow tillage treatments its percentage composition ranged from 14.9% in bare and farmyard manure amendments to 16% in rice-straw amendment. In deep tillage treatments its percentage composition ranged between 11.9% in bare amendment and 31.5% in farmyard manure amendment. In perennial ley treatments its percentage composition ranged from 14.3% in pigeonpea + *S. hamata* treatment to 25.9% in *C. ciliaris* + *S. hamata* treatment. **Cryptostigmata**: Its mean percentage composition ranged between 4.7 and 19% across the 15 treatments. In zero tillage treatments its percentage composition ranged between 9.5% in rice-straw amendment and 18.7% in bare amendment. In shallow tillage treatments its percentage composition ranged from 14.4% in farmyard manure amendment to 19% in rice-straw amendment. In deep tillage treatments its percentage composition ranged from 5.6% in bare amendment to 18.4% in rice-straw amendment. In perennial ley treatments its percentage composition ranged from 4.7% in *C. ciliaris* + *S. hamata* treatment to 13.1% in pigeonpea + *S. hamata* + *C. ciliaris* treatment. **Mesostigmata**: Its mean percentage composition ranged between <1 and 2.5% across the 15 treatments. In zero tillage treatments its percentage composition ranged between 1% in rice-straw amendment and 2.5% in bare amendment. In shallow and deep tillage treatments it was recorded only in rice-straw amendment and comprised <1% (0.7 and 0.8%) and was not recorded in other treatments. In perennial ley treatments also it comprised of <1% (0.7%).

Collembola: It was the 2nd dominant taxa among the microarthropods and the percentage composition ranged between 7.5 and 28.1% across the 15 treatments. In zero tillage treatments their percentage composition ranged from 8.8% in bare amendment to 14.9% in farmyard manure amendment. In shallow tillage treatments the percentage composition ranged between 7.5% in bare amendment and 14.1% in rice-straw amendment. In deep tillage treatments the percentage composition ranged from 8.7% in farmyard manure amendment to 12.7% in bare amendment. In perennial ley treatments the percentage composition ranged from 13.8% in *C. ciliaris* + *S. hamata* treatment to 28.1% in pigeonpea + *S. hamata* treatment. **Isotomidae** being dominant taxa among the Collembola, its percentage composition ranged between <1 and 17.2% across the 15 treatments. In zero tillage treatments its percentage composition ranged between 1.4% in bare amendment and 8.9% in rice-straw amendment. In shallow tillage treatments its percentage composition ranged between 1.1% in farmyard manure amendment and 8.2% in rice-straw amendment. In deep tillage treatments its percentage composition ranged between <1% in bare amendment and 5.1% in rice-straw amendment. In perennial ley treatments its percentage composition ranged from 5.4% in *S. hamata* treatment to 17.2% in pigeonpea + *S. hamata* + *C. ciliaris* treatment. **Poduridae:** Its percentage composition ranged between <1 and 13.6% across the 15 treatments. In zero and shallow tillage treatments its percentage composition showed very little variation ranging from 1 to 3.7% across the amendments. In deep tillage treatments its percentage composition ranged between <1% in farmyard manure amendment and 7.1% in bare amendment. In perennial ley treatments its percentage composition ranged from 3.9% in *C. ciliaris* + *S. hamata* treatment to 13.6% in pigeonpea + *S. hamata* treatment. **Sminthuridae**: Its percentage composition ranged between 0.4 and 5.3% across the 15 treatments. In zero tillage treatments its percentage composition ranged between 3.1% in farmyard manure amendment and 5.3% in bare amendment. In shallow tillage treatments its percentage composition ranged between 2.6% in rice-straw amendment and 3.1% in bare amendment. In deep tillage treatments its percentage composition ranged between 2.4% in bare amendment and 4.3% in farmyard manure amendment. In perennial ley treatments its percentage composition ranged from <1% in *C. ciliaris* + *S. hamata* treatment to 3.8% in *C. ciliaris* treatment. **Entomobryidae:** Its percentage composition ranged between 0.3 and 2.7% across the 15 treatments. In zero tillage treatments its percentage composition ranged between <1% in rice-straw amendment and 1.1% in bare amendment. In shallow tillage treatments its percentage composition ranged from <1% in rice-straw amendment to 1.1% in farmyard manure amendment. In deep tillage treatments its percentage composition ranged between 2.4% in bare amendment and 2.7% in farmyard manure and rice-straw amendments. In perennial ley treatments its percentage composition ranged from <1% in pigeonpea + *S. hamata* + *C. ciliaris* treatment to 2.4% in *C. ciliaris* treatment. **Other Apterygota**: The percentage composition of other Apterygota, of which composed of **Protura, Thysanura,** and **Diplura** ranged between 1.2 and 11.1% across the 15 treatments. In zero tillage treatments their percentage composition ranged from 1.2% in farmyard manure amendment to 3.9% in bare amendment. In shallow and deep tillage treatments their percentage composition ranged from 2.3 and 1.6% in rice-straw amendment to 5.3 and 2.2% in farmyard manure amendment, respectively. In perennial ley treatments their percentage composition ranged from 4.3% in pigeonpea + *S. hamata* treatment to 11.1% in *S. hamata* treatment. Among the other Apterygota, **Protura** being dominant taxa, its percentage composition ranged between <1 and 9.5% across the 15 treatments. In zero tillage treatments its percentage composition ranged between <1% in rice-straw amendment and 1.1% in bare amendment. In shallow tillage treatments it was not recorded. In deep tillage treatments it was recorded only in rice-straw amendment, and its percentage composition comprised of <1 (0.8%) and was not recorded in other treatments. In perennial ley treatments its percentage composition ranged from <1% in pigeonpea + *S. hamata* + *C. ciliaris* treatment to 9.5% in *S. hamata* treatment. **Thysanura**: Its percentage composition ranged <1 and 5.3% across the 15 treatments. In zero tillage treatments its percentage composition ranged between <1% in farmyard manure amendment and 1.6% in rice-straw amendment. In shallow and deep tillage treatments its percentage composition ranged from 2.3 and 0.4% in rice-straw amendment to 5.3 and 2.2% in farmyard manure amendment respectively. In perennial ley treatments its percentage composition ranged between 0.3% in *S. hamata* treatment and 3% in *C. ciliaris* + *S. hamata* treatment. **Diplura**: Its percentage composition ranged between 0.4 and 6.1% across the 15 treatments. In zero tillage treatments its percentage composition ranged between 1.3% in rice-straw amendment and 2.1% in bare amendment. In shallow tillage treatments it was not recorded. In deep tillage treatments it was recorded in rice-straw amendment, and comprised of 0.4% and not recorded in other two amendments. In perennial ley treatments its percentage composition ranged between 1.3% in *C. ciliaris* + *S. hamata* and *S. hamata* treatments to 6.1% in pigeonpea + *S. hamata* + *C. ciliaris* treatment.

Myriapoda: The percentage composition of Myriapoda, which comprised of **Symphyla, Diplopoda,** and **Chilopoda** ranged between 0.6 and 3.9% across the 15 treatments. In zero tillage treatments their percentage composition ranged between 0.6% in farmyard manure amendment and 3.9% in rice-straw amendment. In shallow and deep tillage treatments their percentage composition ranged from 0.6 and 0.8% in bare amendment to 2 and 2.4% in rice-straw amendment respectively. In perennial ley treatments their percentage composition ranged between <1% in pigeonpea treatment and 3.8% in pigeonpea

+ *S. hamata* amendment. **Symphyla** being dominant taxa among the Myriapoda, its percentage composition ranged between 0.5 and 3.6% across the 15 treatments. In zero tillage treatments it was recorded only in rice-straw amendment, and comprised of 3.6%. In shallow tillage treatments its percentage composition ranged between <1% in bare amendment and 1% in rice-straw amendment. In deep tillage treatments its percentage composition ranged from 1.2% in rice-straw amendment to 1.6% in farmyard manure amendment. In perennial ley treatments its percentage composition ranged from 0.5% in *C. ciliaris* treatment to 3.3% in pigeonpea + *S. hamata* treatment. **Diplopoda**: Its percentage composition ranged between <1 and 1.4% across the 15 treatments. In zero tillage treatments its percentage composition was <1%. In shallow tillage treatments it was recorded only in rice-straw amendment, and comprised 1%. In deep tillage treatments its percentage composition ranged between 0.5% in farmyard manure amendment and 1.2% in rice-straw amendment. In perennial ley treatments its percentage composition ranged from <1% in pigeonpea + *S. hamata* treatment to 1.4% in *C. ciliaris* treatment. **Chilopoda**: Its percentage composition was too low to show any distinct variation among the 15 different soil management treatments.

Coleoptera: The percentage composition of Coleoptera, which comprised of ***Megalodicne*** Sp., **Staphylinidae, Tenebrionidae, Carabidae,** and **Coleoptera larvae,** ranged between 2.6 and 19% across the 15 treatments. In zero tillage treatments their percentage composition ranged from 7.9% in rice-straw amendment to 10.6% in farmyard manure amendment. In shallow tillage treatments their percentage composition ranged between 5.2% in rice-straw amendment and 6.8% in bare amendment. In deep tillage treatments their percentage composition ranged between 8.2% in farmyard manure amendment and 19% in bare amendment. In perennial ley treatments their percentage composition ranged from 2.6% in pigeonpea + *S. hamata* + *C. ciliaris* treatment to 8.9% in pigeonpea treatment. **Carabidae** being dominant taxa among the Coleoptera, its percentage composition ranged between <1 and 8.7% across the 15 treatments. In zero tillage treatments its percentage composition ranged between 4.6% in rice-straw amendment and 8.7% in farmyard manure amendment. In shallow tillage treatments its percentage composition ranged from 1.6% in farmyard manure amendment to 3.1% in bare amendment. In deep tillage treatments its percentage composition ranged between 6.3% in rice-straw amendment and 7.9% in bare amendment. In perennial ley treatments its percentage composition ranged from <1% in *C. ciliaris* + *S. hamata* treatment to 7.4% in pigeonpea treatment.

Coleoptera larvae: Their percentage composition ranged between <1 and 3.6% across the 15 treatments. In zero tillage treatments the percentage composition was <1%. In shallow tillage treatments its percentage composition ranged between 2% in rice-straw amendment and 3.2% in farmyard manure amendment. In deep tillage treatments its percentage composition ranged between <1% in farmyard manure amendment and 2.4% in bare amendment. In perennial ley treatments its percentage composition ranged from 1.3% in pigeonpea + *S. hamata*

+ *C. ciliaris* and *S. hamata* treatments to 3.6% in pigeonpea + *S. hamata* treatment. **Staphylinidae:** Its percentage composition ranged between <1 and 6.3% across the 15 treatments. In zero tillage treatments its percentage composition ranged between 1.2% in farmyard manure amendment and 2.8% in bare amendment. In shallow tillage treatments its percentage composition ranged between <1% in bare amendment and 1% in rice-straw amendment. In deep tillage treatments its percentage composition ranged from <1% in rice-straw amendment to 6.3% in bare amendment. In perennial ley treatments its percentage composition ranged <1% in *C. ciliaris* + *S. hamata* treatment to 2.4% in *C. ciliaris* treatment. The percentage composition of **Megalodicne** Sp. and **Tenebrionidae** was too low to show any distinct variation in their percentage composition among the 15 treatments.

Hymenoptera: Their percentage composition ranged between <1 and 18% across the 15 treatments. In zero and shallow tillage treatments its percentage composition ranged from 2.5 and 1.6% in farmyard manure amendment to 4.9 and 18% in bare amendment respectively. In deep tillage treatments its percentage composition ranged between <1% in rice-straw amendment and 2.2% in farmyard manure amendment. In perennial ley treatments its percentage composition ranged between 1.5% in pigeonpea treatment and 10.2% in pigeonpea + *S. hamata* treatment. **Other pterygota**: The percentage composition of other pterygota, which included **Psocoptera, Isoptera, Thysanoptera, Hemiptera, Homoptera, Diptera,** and **Lepidoptera larvae** ranged between 2.3 and 15.9%

across the 15 treatments. In zero tillage treatments their percentage composition ranged between 2.3% in rice-straw amendment and 7.8% in bare amendment. In shallow tillage treatments their percentage composition ranged between 4.6% in rice-straw amendment and 9.6% in farmyard manure amendment. In deep tillage treatments their percentage composition ranged between 4.3% in rice-straw amendment and 7.9% in bare amendment. In perennial ley treatments their percentage composition ranged from 4.8% in pigeonpea + *S. hamata* + *C. ciliaris* treatment to 15.9% in *C. ciliaris* + *S. hamata* treatment. **Psocoptera** being dominant taxa among the Other Pterygota, its percentage composition ranged between <1 and 9.2% across the 15 treatments. In zero tillage treatments it was not recorded. In shallow and deep tillage treatments its percentage composition ranged from 2.1 and 1.1% in farmyard manure amendment to 2.5 and 2.4% in bare amendment respectively. In perennial ley treatments its percentage composition ranged from <1% in pigeonpea + *S. hamata* + *C. ciliaris* treatment to 9.2% in *S. hamata* treatment. **Isoptera**: Its percentage composition ranged between <1 and 6.9% across the 15 treatments. In zero tillage treatments its percentage composition is 4.9% in bare amendment and not recorded in other two amendments. In shallow tillage treatments it was not recorded. In deep tillage treatments its percentage composition was <1 across the organic amendments. In perennial ley treatments its percentage composition ranged from <1% in pigeonpea treatment to 6.9% in *C. ciliaris* + *S. hamata* treatment.

Thysanoptera: Its percentage composition ranged between 0.3 and 5.3% across the

15 treatments. In zero tillage treatments its percentage composition ranged between <1% in farmyard manure amendment and 1.6% in rice-straw amendment. In shallow and deep tillage treatments its percentage composition ranged from 2.9 and <1% in rice-straw amendment to 5.3 and 2.2% in farmyard manure amendments respectively. In perennial ley treatments its percentage composition ranged from <1% in *S. hamata* treatment to 3.3% in *C. ciliaris* treatment. **Hemiptera**: Its percentage composition ranged between <1 and 1.9% across the 15 treatments. In zero tillage treatments its percentage composition ranged from <1 in bare amendment to 1.9% in farmyard manure amendment. In shallow tillage treatments it was recorded only in bare amendment, and comprised 1.9% in each of other treatments. In deep tillage treatments its percentage composition showed very little variation ranging from <1 (0.8%) in bare and rice-straw amendments to 1.1% in farmyard manure amendment. In perennial ley treatments, its percentage composition also showed very little variation ranging from <1% in pigeonpea + *S. hamata* and pigeonpea + *S. hamata* + *C. ciliaris* treatments to 1% in *C. ciliaris* treatment. The percentage composition of **Homoptera, Diptera,** and **Lepidoptera larvae** were too low to show any distinct variation among the 15 different soil management treatments.

Araneae: The percentage composition of Araneae, which included **Thanatus** Sp., and **Pseudoscorpions** ranged between <1 and 2.2% across the 15 treatments. In zero tillage treatments their percentage composition was <1% among the organic amendment treatments. In shallow tillage treatments their percentage composition showed very little variation ranging from <1% in rice-straw amendment to 1.2% in bare amendment. In deep tillage treatments they were recorded in farmyard manure amendment comprising <1%. In perennial ley treatments their percentage composition ranged between 0.3% in pigeonpea + *S. hamata* treatment to 2.2% in pigeonpea + *S. hamata* + *C. ciliaris* treatment. **Thanatus** Sp., being dominant taxa among the Araneae, its percentage composition ranged between <1 to 1.6% across the 15 treatments. In zero tillage treatments it was not recorded. In shallow and deep tillage treatments its percentage composition was <1%. In perennial ley treatments its percentage composition showed very little variation ranging from <1% in *C. ciliaris* treatment to 1.6% in pigeonpea + *S. hamata* + *C. ciliaris,* and *S. hamata* treatments. **Pseudoscorpions**: Its percentage composition ranged between <1 and 1% across the 15 treatments. In zero, shallow and deep tillage treatments its percentage composition was <1%. In perennial ley treatments its percentage composition showed very little variation ranging from <1% in pigeonpea + *S. hamata* and *S. hamata* treatments to 1% in *C. ciliaris* treatment.

Temporal Variation:

Total soil microarthropods: The seasonal fluctuation in their population densities across the 15 soil management treatments presented in Fig. 26 revealed that the mean density was 70 m^{-2} in shallow-tillage rice-straw and *S. hamata* treatments, and increased to nine folds higher (630 m^{-2}) in zero-tillage rice-straw amendment 10 days after sowing during the crop season (July, 1989). The density was 70 m^{-2}

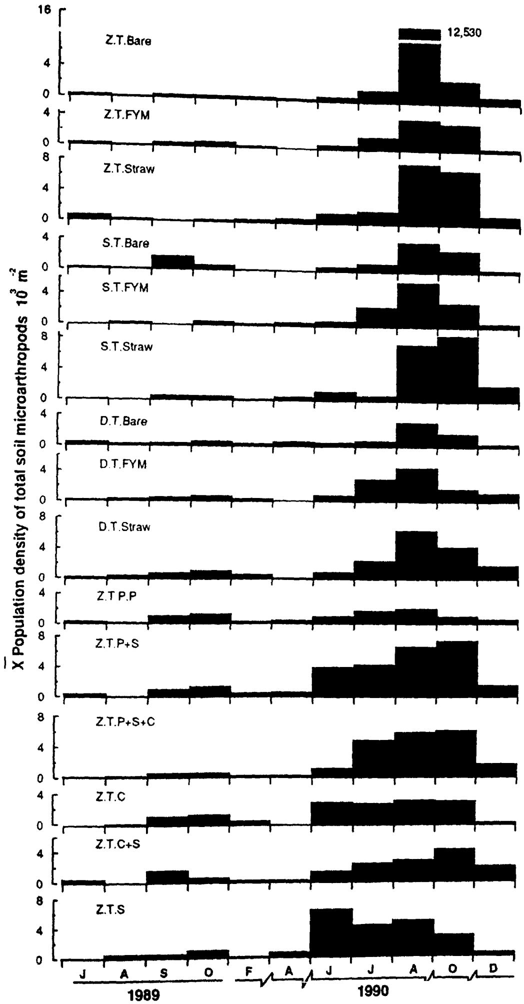

Figure 26. Seasonal fluctuation in the population densities of total soil microarthropods m^{-2} across the fifteen soil management treatments.

in zero-tillage bare and farmyard manure, shallow-tillage bare, pigeonpea + *S. hamata*, *C. ciliaris* and *C. ciliaris* + *S. hamata* treatments and increased to eight folds higher (560 m^{-2}) in *S. hamata* treatment 30 days after sowing (August, 1989). It was 70 m^{-2} in zero-tillage rice-straw amendment and increased to twenty four folds higher (1680 m^{-2}) in shallow tillage bare treatment, followed by *C. ciliaris* + *S. hamata* treatment (1610 m^{-2}) 60 days after sowing (September, 1989), while it was 210 m^{-2} in zero-tillage rice-straw amendment and increased to more than six folds higher (1330 m^{-2}) in pigeonpea + *S. hamata* treatment, followed by pigeonpea and *C. ciliaris* treatments (1260 m^{-2}) 90 days after sowing (October, 1989). During the following fallow period, the mean density was 70 m^{-2} in shallow-tillage bare treatment and increased to seven folds higher (490 m^{-2}) in deep tillage rice-straw and pigeonpea + *S. hamata* treatments, followed by *C. ciliaris* treatment (420 m^{-2}) 90 days after harvesting the crop (February, 1990). It was 70 m^{-2} in deep tillage rice-straw amendment and increased to ten folds higher (700 m^{-2}) in *S. hamata* treatment, followed by pigeonpea + *S. hamata* treatment (630 m^{-2}) 150 days after harvesting (April, 1990). It was 490 m^{-2} in zero tillage farmyard manure and deep tillage bare amendments and increased to more than thirteen folds higher (6440 m^{-2}) in *S. hamata* treatment 210 days after harvesting (June, 1990).

During the 2nd crop season, the mean density was 630 m^{-2} in shallow-tillage rice-straw amendment and increased to more than seven folds higher (4830 m^{-2}) in pigeonpea + *S. hamata* + *C. ciliaris* treatment 10 days after sowing during the crop (July, 1990). It was 1960 m^{-2} in pigeonpea treatment and increased to more than six folds higher (12530 m^{-2}) in zero-tillage bare treatment 60 days after sowing (August, 1990). It was 910 m^{-2} in pigeonpea treatment and increased more than nine folds higher (8540 m^{-2}) in shallow-tillage rice-straw amendment 90 days after sowing (October, 1990). During the following fallow period, it was 210 m^{-2} in *C. ciliaris* treatment and increased to more than nine folds higher (2030 m^{-2}) in shallow tillage rice-straw and *C. ciliaris* + *S. hamata* treatments 30 days after harvesting the crop (December, 1990).

The seasonal fluctuation in the population densities of **Araneae** presented in Fig. 27a and that of **Pseudoscorpions** presented in Fig. 27b revealed that their mean densities were too few to show any significant seasonal differences.

Prostigmata: The seasonal fluctuation in its population densities across the treatments presented in Fig. 28a revealed that the mean densities were too few to show any distinct variation till 30 days after sowing (August, 1989). It was 70 m^{-2} in zero tillage farmyard manure, shallow tillage rice-straw and *S. hamata* treatments and increased to six folds higher (420 m^{-2}) in *C. ciliaris* + *S. hamata* treatment, followed by deep tillage rice-straw amendment (350 m^{-2}) 60 days after sowing (September, 1989). It was 70 m^{-2} in pigeonpea + *S. hamata* + *C. ciliaris* and *C. ciliaris* treatments which increased to five folds higher (350 m^{-2}) in *S. hamata* treatment, followed by deep tillage rice-straw amendment (280 m^{-2}) 90 days after sowing (October, 1989). During the following fallow period, the density was too few to show any distinct variation till 150 days after harvesting (April, 1990). It

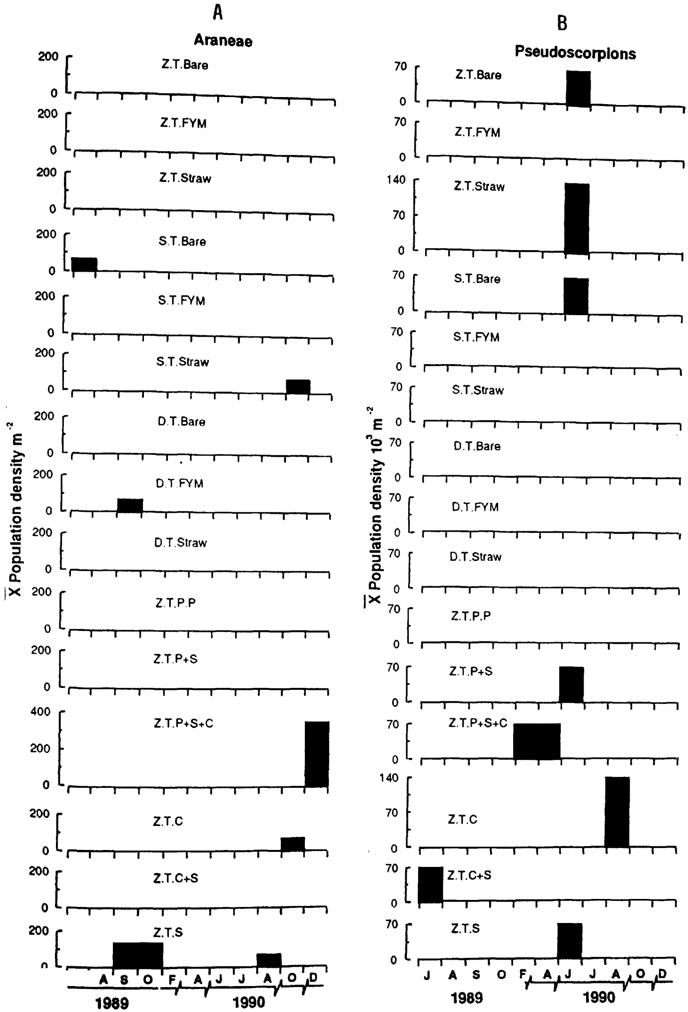

Figure 27. Seasonal fluctuation in the population densities of Araneae m^{-2} (A) and that of Pseudoscorpions m^{-2} (B) across the fifteen soil management treatments.

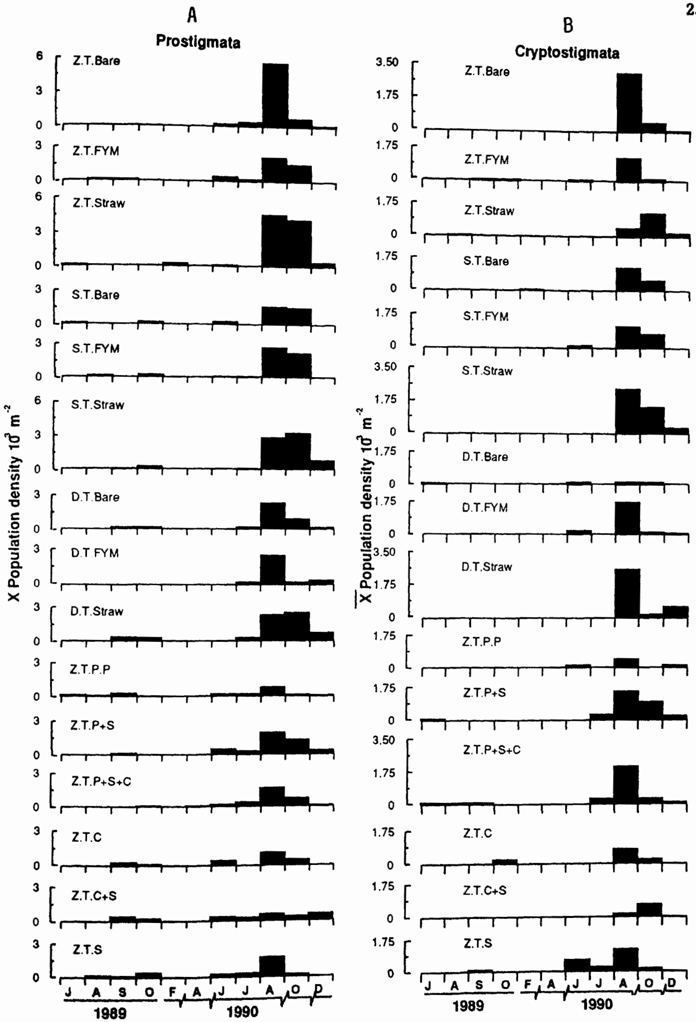

Figure 28. Seasonal fluctuation in the population densities of Prostigmata m^{-2} (A) and that of Cryptostigmata m^{-2} (B) across the fifteen soil management treatments.

was 70 m^{-2} in zero tillage rice-straw and shallow tillage farmyard manure amendments and increased to seven folds higher (490 m^{-2}) in pigeonpea + *S. hamata* treatment 210 days after harvesting (June, 1990).

During the 2nd crop season, the density was 70 m^{-2} in shallow tillage farmyard manure and rice-straw, and deep tillage farmyard manure amendments and increased to five folds higher (350 m^{-2}) in zero tillage bare and pigeonpea + *S. hamata* + *C. ciliaris* treatments, followed by deep tillage rice-straw, pigeonpea + *S. hamata*, *C. ciliaris* + *S. hamata* and *S. hamata* treatments (280 m^{-2}) 10 days after sowing during the crop (July, 1990). It was 560 m^{-2} in *C. ciliaris* + *S. hamata* treatment and increased to more than nine folds higher (5530 m^{-2}) in zero tillage bare treatment, followed by zero tillage rice-straw amendment (4480 m^{-2}) 60 days after sowing (August, 1990). It was 70 m^{-2} in deep tillage farmyard manure amendment and increased to fifty eight folds higher (4060 m^{-2}) in zero tillage rice-straw amendment, followed by shallow tillage rice-straw amendment (3150 m^{-2}) 90 days after sowing (October, 1990). During the following fallow period, the density was 70 m^{-2} in pigeonpea and pigeonpea + *S. hamata* + *C. ciliaris* treatments and increased to eleven folds higher (770 m^{-2}) in shallow tillage rice-straw amendment, followed by deep tillage rice-straw amendment (700 m^{-2}) 30 days after harvesting the crop (December, 1990).

ANOVA revealed that the population densities of Prostigmata were more than three folds higher in tillage and organic amendment treatments during rainy season, than that of dry season, the difference being statistically significant (Table 15). Besides, its density showed significant variation across perennial ley treatments among the seasons. Its density was more than five folds higher during the rainy and postrainy seasons than that of the dry season, the differences being statistically significant (Table 15).

Cryptostigmata: The seasonal fluctuation in its population densities across the treatments presented in Fig. 28b revealed that the mean densities were too few to show any distinct temporal variation till 150 days after harvesting (April, 1990). It was 70 m^{-2} in zero and shallow tillage farmyard manure amendments and increased to nine folds higher (630 m^{-2}) in *S. hamata* treatment 210 days after harvesting (June, 1990).

During the 2nd crop season, the mean density showed very little variation ranging from 210 to 280 m^{-2} in *S. hamata*, pigeonpea + *S. hamata* and pigeonpea + *S. hamata* + *C. ciliaris* treatments and was not recorded in other treatments till 10 days after sowing during the crop (July, 1990). It was 140 m^{-2} in deep tillage bare and *C. ciliaris* + *S. hamata* treatments which increased to more than twenty two folds higher (3150 m^{-2}) in zero tillage bare treatment, followed by deep tillage rice-straw amendment (2590 m^{-2}) 60 days after sowing (August, 1990). It was 140 m^{-2} in zero tillage farmyard manure, deep tillage bare, farmyard manure, rice-straw and *S. hamata* treatments and increased to ten folds higher (1400 m^{-2}) in shallow tillage rice-straw amendment, followed by zero tillage rice-straw

Table 15. Significant responses in soil microarthropods m^{-2} to 15 treatments during 1989-1990.

Arthropod taxa	Tillage and organic amendment treatments: Rainy	Post-rainy	Dry	At 1% LSD	Perennial ley treatments: Rainy	Post-rainy	Dry	At 1% LSD
Acarina:								
Prostigmata	237.2	155.6	66.1	143.3	418.1	400.6	70.0	249.8
Cryptostigmata	531.5	723.3	11.7	461.3	338.3	264.4	5.8	228.5
Mesostigmata	274.8	230.7	3.9	189.4	-	-	-	-
Myriapoda:								
Symphyla	25.9	2.6	-	20.8*	56.4	11.7	-	40.3
Apterygota:								
Thysanura	-	-	-	-	3.9	62.2	-	34.7*
Isotomidae	51.8	121.8	7.8	83.3	56.4	548.3	-	272.6
Poduridae	-	-	-	-	229.4	101.1	5.8	175.5
Pterygota:								
Carabidae	47.9	129.6	46.7	78.1*	-	-	-	-
Coleoptera larvae	-	-	-	-	33.1	73.9	-	38.4
Hymenoptera	37.6	116.6	-	70.2	-	-	-	-

* Significant at (P <0.05).

amendment (1260 m^{-2}) 90 days after sowing (October, 1990). During the following fallow period, the density was 70 m^{-2} in zero tillage bare, deep tillage farmyard manure and pigeonpea + *S. hamata* + *C. ciliaris* treatments and increased to eight folds higher (560 m^{-2}) in deep tillage rice-straw amendment and was not recorded in other treatments 30 days after harvesting the crop (December, 1990).

ANOVA revealed that the population densities of Cryptostigmata were more than sixty one folds higher in tillage and organic amendment treatments during postrainy season and more than one fold higher in density during postrainy season than that of rainy season, the differences being statistically significant (Table 15). Besides, its population density showed significant variation across perennial ley treatments among the seasons. Its density was more than fifty eight folds higher during the rainy season than that of dry season, and more than one fold higher in density during rainy season than that of postrainy season, the differences being statistically significant (Table 15).

Mesostigmata: The seasonal fluctuation in its population densities across the treatments presented in Fig. 29a revealed that their mean densities were very few in number and did not show any distinct temporal variation. However, ANOVA revealed that the Mesostigmata population densities were more than seventy folds higher in density in tillage and organic amendment treatments during rainy season than that of dry season, and more than one fold higher in density during rainy season than that of postrainy season, the differences being statistically

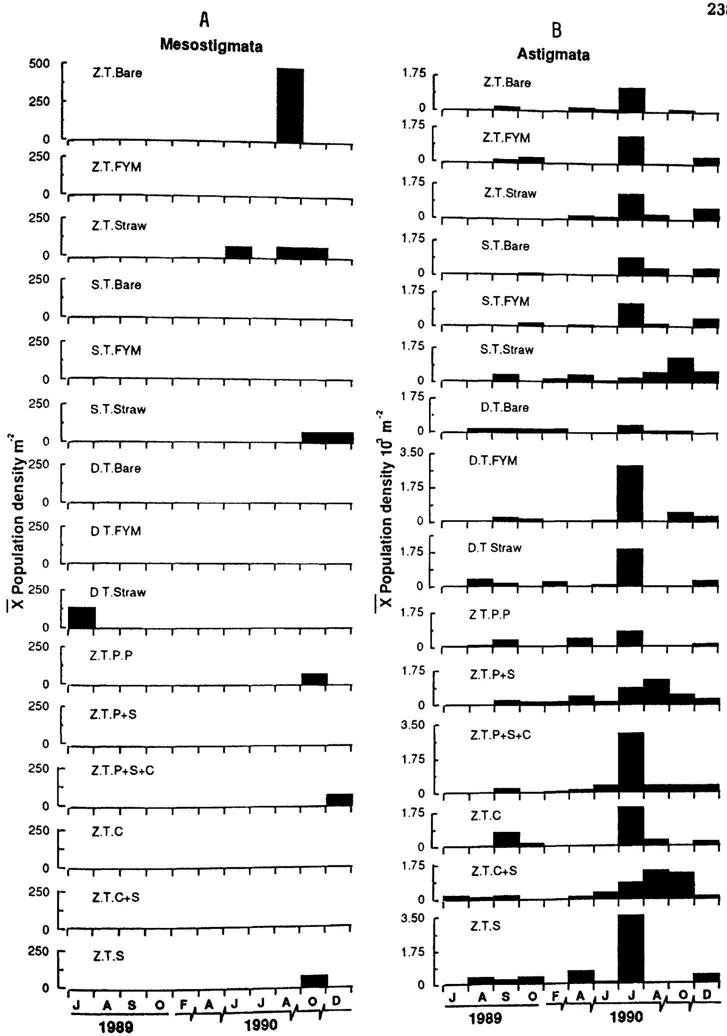

Figure 29. Seasonal fluctuation in the population densities of Mesostigmata m^{-2} (A) and that of Astigmata m^{-2} (B) across the fifteen soil management treatments.

significant (Table 15).

Astigmata: The seasonal fluctuation in its population density across the treatments presented in Fig. 29b revealed that the density was 140 m^{-2} only in *C. ciliaris* + *S. hamata* treatment, and not recorded in other treatments 10 days after sowing during the crop season (July, 1989). The density was 70 m^{-2} in pigeonpea and *C. ciliaris* + *S. hamata* treatments which increased to five folds higher (350 m^{-2}) in deep tillage rice-straw and *S. hamata* treatments 30 days after sowing (August, 1989). It was 70 m^{-2} in zero tillage farmyard manure amendment and increased to ten folds higher (700 m^{-2}) in *C. ciliaris* treatment 60 days after sowing (September, 1989). It was 70 m^{-2} in shallow tillage bare treatment and increased to five folds higher (350 m^{-2}) in *S. hamata* treatment 90 days after sowing (October, 1989). During the following fallow period, the density was 70 m^{-2} in pigeonpea + *S. hamata* + *C. ciliaris* treatment and increased to three folds higher (210 m^{-2}) in deep tillage rice-straw amendment, followed by shallow tillage rice-straw, deep tillage bare and pigeonpea treatments (140 m^{-2}), and were not recorded in other treatments 90 days after harvesting the crop (February, 1990). It was 70 m^{-2} in shallow tillage farmyard manure and *C. ciliaris* + *S. hamata* treatments and increased to nine folds higher (630 m^{-2}) in *S. hamata* treatment 150 days after harvesting (April, 1990). It was 70 m^{-2} in zero tillage bare and rice-straw, shallow tillage rice-straw, deep tillage farmyard manure and rice-straw and *S. hamata* treatments and increased to five folds higher (350 m^{-2}) in pigeonpea + *S. hamata* + *C. ciliaris* treatment, followed by *C. ciliaris* + *S. hamata* treatment (280 m^{-2}) 210 days after harvesting (June, 1990).

During the 2nd crop season, the density was 210 m^{-2} in shallow tillage rice-straw amendment and increased to more than sixteen folds higher (3500 m^{-2}) in *S. hamata* treatment 10 days after sowing the crop (July, 1990). It was 70 m^{-2} in deep tillage bare treatment and increased to twenty folds higher (1400 m^{-2}) in *C. ciliaris* + *S. hamata* treatment 60 days after sowing (August, 1990). It was 70 m^{-2} in zero and deep tillage bare treatments and increased to eighteen folds high (1260 m^{-2}) in shallow tillage rice-straw and *C. ciliaris* + *S. hamata* treatments 90 days after sowing (October, 1990). During the following fallow period, the density was 70 m^{-2} in *C. ciliaris* + *S. hamata* treatment and increased to eight folds higher (560 m^{-2}) in zero and shallow tillage rice-straw amendments 30 days after harvesting the crop (December, 1990).

The seasonal fluctuation in the population densities of **Diplopoda** (Fig. 30a) and **Chilopoda** (Fig. 30b) revealed that their mean densities were very few in number and did not show any distinct temporal variation. **Symphyla:** The seasonal fluctuation in its mean population densities across the treatments presented in Fig. 31a revealed that the densities were recorded in very few numbers and did not show any significant temporal variation. However, the ANOVA revealed that its population density was more than nine folds higher in tillage and organic amendment treatments during rainy season than that of postrainy season, the difference being statistically significant, whereas its density

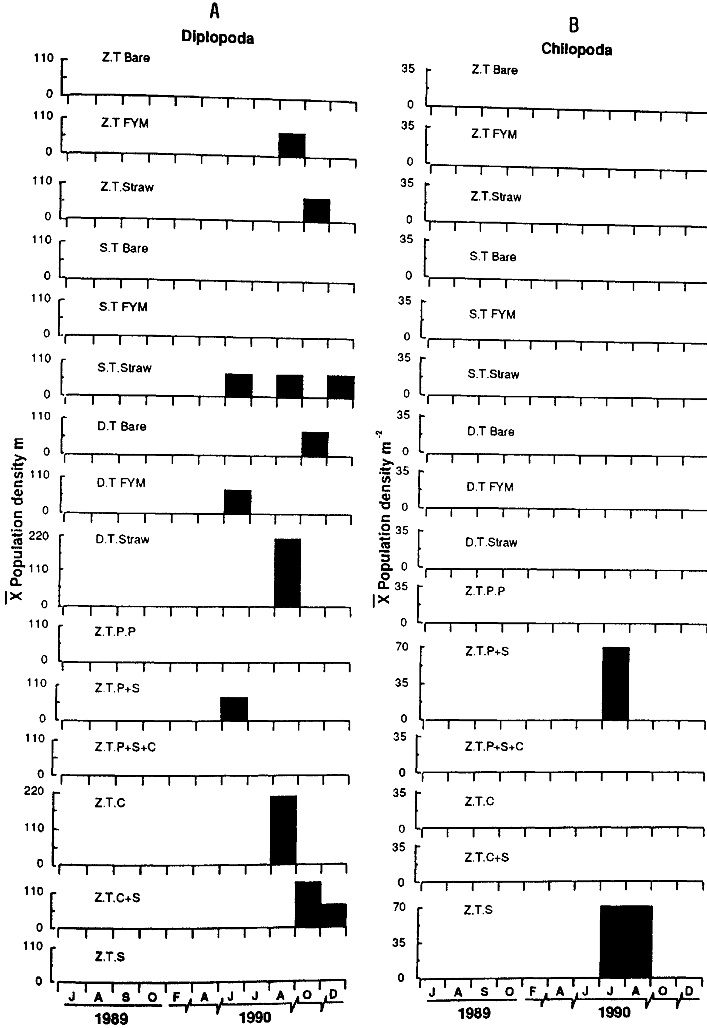

Figure 30. Seasonal fluctuation in the population densities of Diplopoda m^{-2} (A) and that of Chilopoda m^{-2} (B) across the fifteen soil management treatments.

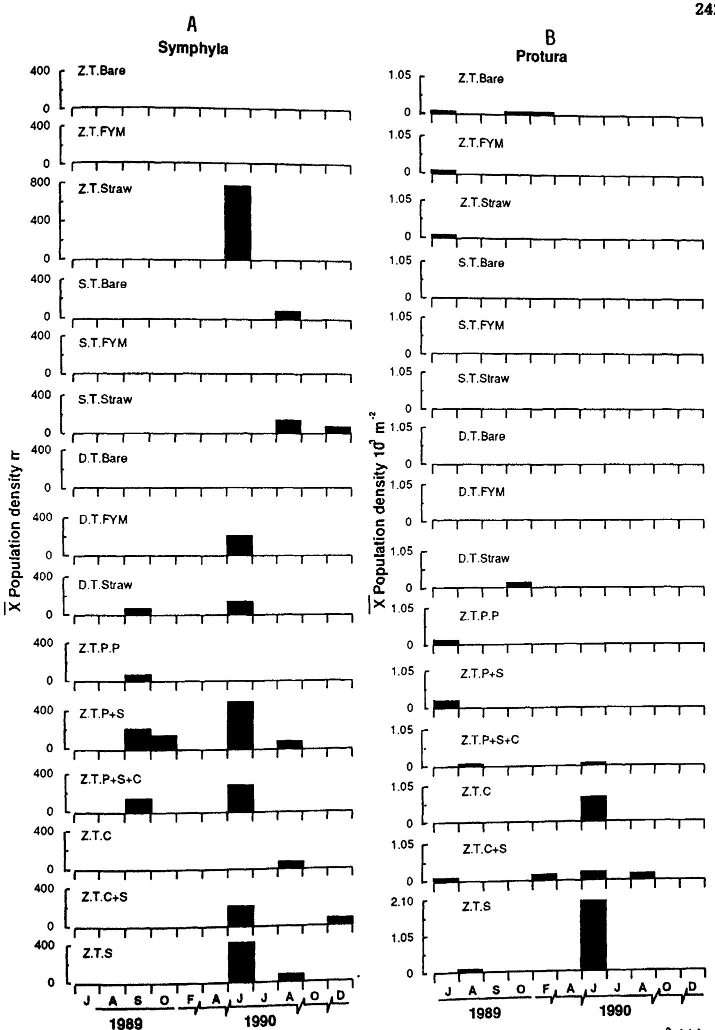

Figure 31. Seasonal fluctuation in the population densities of Symphyla m^{-2} (A) and that of Protura m^{-2} (B) across the fifteen soil management treatments.

was absent during dry season (Table 15). Besides, their population density showed significant variation across perennial ley treatments among the seasons. Its density was more than four folds higher during the rainy season, than that of the postrainy season, the difference being statistically significant, whereas its density was absent during dry season (Table 15).

Protura: The seasonal fluctuation in its population density across the treatments presented in Fig. 31b revealed that the mean densities were very few in number and did not show any significant temporal variation. **Thysanura:** The seasonal fluctuation in its population density across the treatments presented in Fig. 32a revealed that the mean densities were very few in number and did not show any significant variation till 150 days after harvesting the crop (April, 1990). It was 70 m^{-2} in deep tillage farmyard manure amendment and increased to five folds higher (350 m^{-2}) in shallow tillage rice-straw amendment 210 days after harvesting (June, 1990).

During the 2nd crop season, it was not recorded in any treatment till 10 days after sowing during the crop (July, 1990). It was 70 m^{-2} in zero tillage farmyard manure, shallow tillage rice-straw, pigeonpea + *S. hamata* and *S. hamata* treatments and increased to eight folds higher (560 m^{-2}) in shallow tillage farmyard manure amendment 60 days after sowing (August, 1990). It was 70 m^{-2} in shallow and deep tillage rice-straw amendments, and was not recorded in other treatments 90 days after sowing (October, 1990). During the following

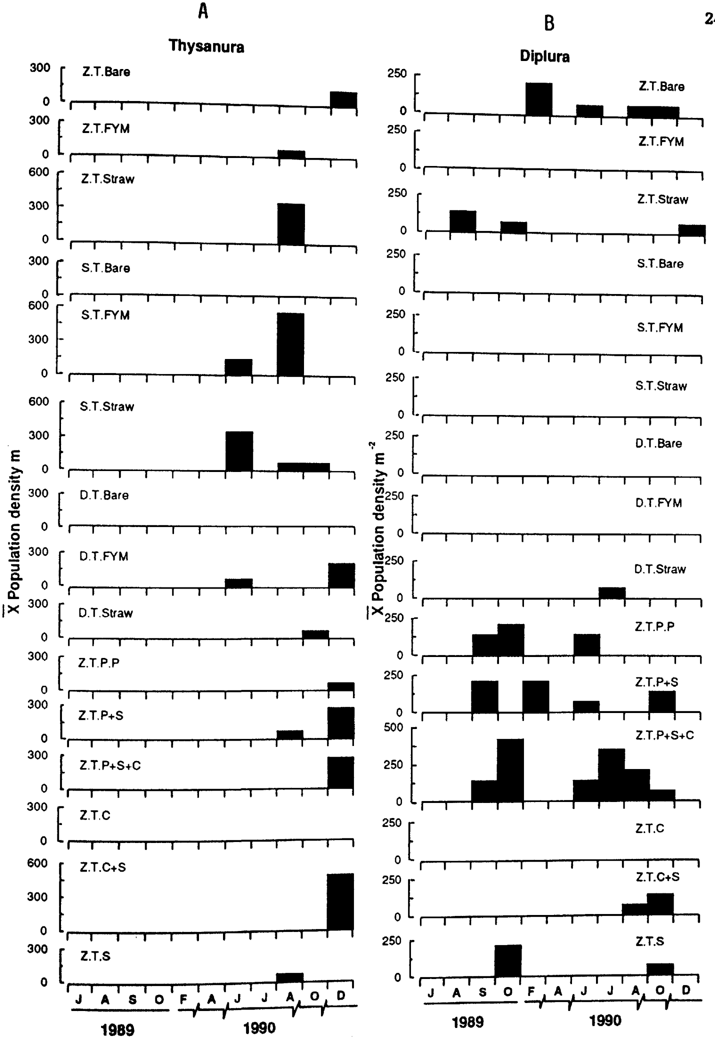

Figure 32. Seasonal fluctuation in the population densities of Thysanura m^{-2} (A) and that of Diplura m^{-2} (B) across the fifteen soil management treatments.

fallow period, the density was 70 m^{-2} in pigeonpea treatment and increased to seven folds higher (490 m^{-2}) in *C. ciliaris* + *S. hamata* treatment 30 days after harvesting the crop (December, 1990).

ANOVA revealed that its density was more than fifteen folds higher in density in perennial ley treatments during postrainy season, than that of rainy season, the difference being statistically significant, whereas its density was absent during dry season (Table 15).

Diplura: The seasonal fluctuation in its population density across the treatments presented in Fig. 32b revealed that the mean densities were very few in number and did not show any significant variation till 60 days after sowing (September, 1989). It was 70 m^{-2} in zero tillage rice-straw amendment and increased to six folds higher (420 m^{-2}) in pigeonpea + *S. hamata* + *C. ciliaris* treatment 90 days after sowing (October, 1989). During the following fallow period, its mean densities were too few to show any distinct variation, and during the 2nd crop season, the mean density was 70 m^{-2} in deep tillage rice-straw amendment and increased to five folds higher (350 m^{-2}) in pigeonpea + *S. hamata* + *C. ciliaris* treatment and not recorded in other treatments till 10 days after sowing during the crop (July, 1990). They were too few to show any distinct temporal variation till 30 days after harvesting the crop (December, 1990).

Entomobryidae: The seasonal fluctuation in its population density across the treatments presented in Fig. 33a revealed that the mean densities were too few to show any significant temporal variation. **Isotomidae:** The seasonal fluctuation in its population density across the treatments presented in Fig. 33b revealed that the mean densities were too few to show any significant temporal variation till 60 days after sowing (September, 1989). It was 420 m^{-2} in pigeonpea + *S. hamata* treatment and increased to more than one fold higher (560 m^{-2}) in pigeonpea treatment and was not recorded in other treatments 90 days after sowing (October, 1989). During the following fallow period, the densities were too few to show any significant temporal variation and during the 2nd crop season, the density was 70 m^{-2} in pigeonpea treatment and increased to two folds higher (140 m^{-2}) in shallow tillage farmyard manure amendment 10 days after sowing during the crop (July, 1990). It was 140 m^{-2} in *C. ciliaris* treatment and increased to more than eight folds higher (1190 m^{-2}) in zero tillage rice-straw amendment 60 days after sowing (August, 1990). It was 70 m^{-2} in zero tillage bare treatment and increased to forty five folds higher (3150 m^{-2}) in pigeonpea + *S. hamata* + *C. ciliaris* treatment 90 days after sowing (October, 1990). During the following fallow period, the densities were too few to show any significant temporal variation.

ANOVA revealed that the Isotomidae density was more than fifteen folds higher in density in tillage and organic amendment treatments during postrainy season, than that of dry season, and more than two folds higher in density in postrainy season, than that of the rainy season, the differences being statistically

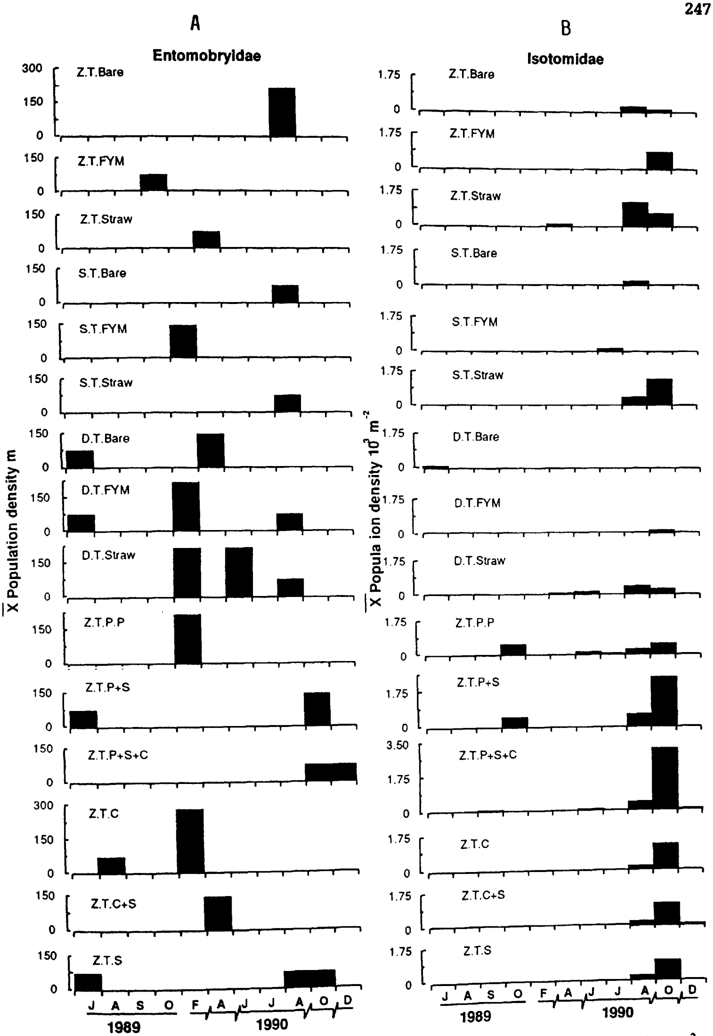

Figure 33. Seasonal fluctuation in the population densities of Entomobryidae m^{-2} (A) and that of Isotomidae m^{-2} (B) across the fifteen soil management treatments.

significant (Table 15). Besides, their population density showed significant variation across perennial ley treatments among the seasons. Its density was more than nine folds higher during the postrainy season, than that of the rainy season, the difference being statistically significant, whereas its density was absent during dry season (Table 15).

Sminthuridae: The seasonal fluctuation of its population density across the treatments presented in Fig. 34a revealed that the mean densities were too few to show any significant temporal variation till 60 days after sowing (September, 1989). It was 140 m^{-2} in zero tillage farmyard manure amendment and increased to more than two folds higher (350 m^{-2}) in deep tillage farmyard manure amendment and was not recorded in other treatments 90 days after sowing (October, 1989). During the following fallow period, they were not recorded in any treatments till 90 and 150 days after harvesting the crop (February and April 1990), respectively. It was 70 m^{-2} in zero tillage rice-straw, shallow tillage farmyard manure, pigeonpea + *S. hamata* and *C. ciliaris* + *S. hamata* treatments and increased to five folds higher (350 m^{-2}) in shallow tillage rice-straw and *C. ciliaris* treatments 210 days after harvesting (June, 1990).

During the 2nd crop season, they were not recorded in any treatments till 10 days after sowing during the crop (July, 1990). The density was 70 m^{-2} in deep tillage bare, farmyard manure and *C. ciliaris* treatments and increased to fifteen folds higher (1050 m^{-2}) in zero tillage bare treatments 60 days after sowing

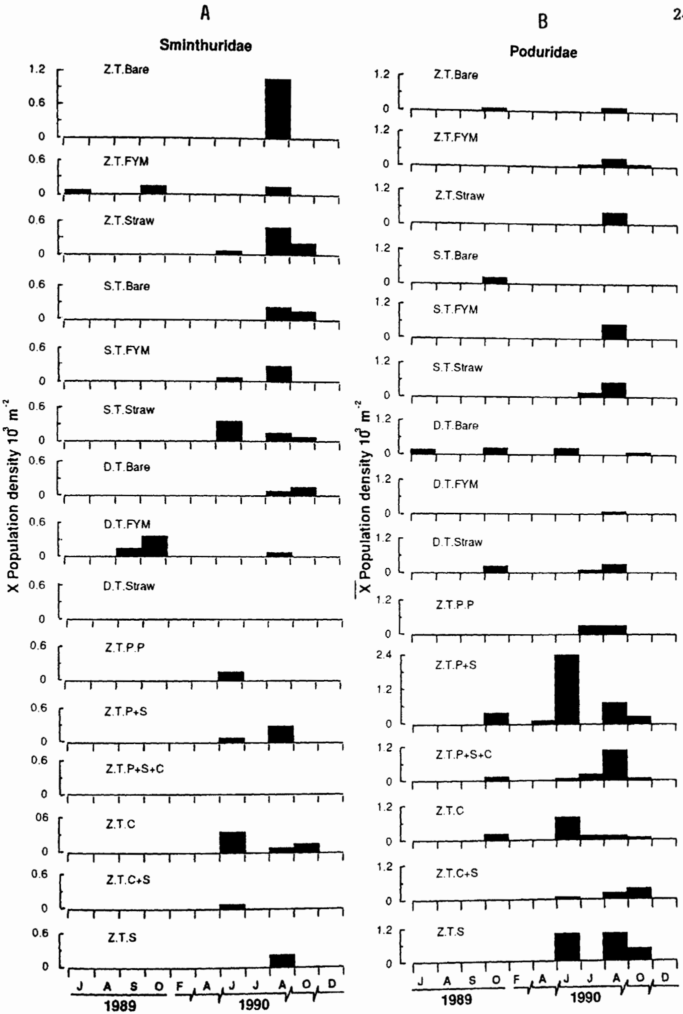

Figure 34. Seasonal fluctuation in the population densities of Sminthuridae m^{-2} (A) and that of Poduridae m^{-2} (B) across the fifteen soil management treatments.

(August, 1990). It was 70 m^{-2} in shallow tillage rice-straw amendment and increased to three folds higher (210 m^{-2}) in zero tillage rice-straw amendment, followed by shallow and deep tillage bare amendments and C. *ciliaris* (140 m^{-2}) treatments and not recorded in other treatments till 90 days after sowing (October, 1990). During the following fallow period, they were not recorded in any treatment till 30 days after harvesting the crop (December, 1990).

Poduridae: The seasonal fluctuation in its population density across the treatments presented in Fig. 34b revealed that the mean densities were too few in number and did not show any significant variation till 60 days after sowing (September, 1989). The density was 70 m^{-2} in zero tillage bare treatment and increased to five folds higher (350 m^{-2}) in pigeonpea + *S. hamata* treatment 90 days after sowing (October, 1989). During the following fallow period, the densities were very few in number and did not show significant temporal variation till 150 days after harvesting (April, 1990). It was 70 m^{-2} in pigeonpea + *S. hamata* + *C. ciliaris* and *C. ciliaris* + *S. hamata* treatments and increased to thirty four folds higher (2380 m^{-2}) in pigeonpea + *S. hamata* treatment 210 days after harvesting (June, 1990).

During the 2nd crop season, the mean density was 70 m^{-2} in zero tillage farmyard manure amendment and increased to four folds higher (280 m^{-2}) in pigeonpea treatment, followed by pigeonpea + *S. hamata* + C. *ciliaris* (210 m^{-2}) treatment 10 days after sowing during the crop (July, 1990). It was 70 m^{-2} in deep tillage farmyard manure amendment and increased to fifteen folds higher (1050 m^{-2}) in pigeonpea + *S. hamata* + *C. ciliaris* treatment, followed by *S. hamata* treatment (980 m^{-2}) 60 days after sowing (August, 1990). It was 70 m^{-2} in zero tillage farmyard manure, deep tillage bare, pigeonpea + *S. hamata* + *C. ciliaris* and *C. ciliaris* treatments and increased to six folds higher (420 m^{-2}) in *S. hamata* treatment, followed by *C. ciliaris* + *S. hamata* treatment (350 m^{-2}) 90 days after sowing (October, 1990). During the following fallow period, they were not recorded in any treatments till 30 days after harvesting the crop (December, 1990).

ANOVA revealed that the Poduridae density was more than thirty nine folds higher in density in perennial ley treatments during rainy season, than that of the dry season, the difference being statistically significant (Table 15).

Carabidae: The seasonal fluctuation in its population density across the treatments presented in Fig. 35a revealed that the mean density was 70 m^{-2} in zero tillage bare, farmyard manure, shallow tillage rice-straw, deep tillage bare, farmyard manure and pigeonpea + *S. hamata* + *C. ciliaris* treatments and increased to five folds higher (350 m^{-2}) in zero tillage rice-straw amendment and was not recorded in other treatments till 10 days after sowing during the crop season (July, 1989). They were very few in number and did not show any significant variation till 90 days after sowing (October, 1989) and during the following fallow period till 210 days after harvesting (June, 1990).

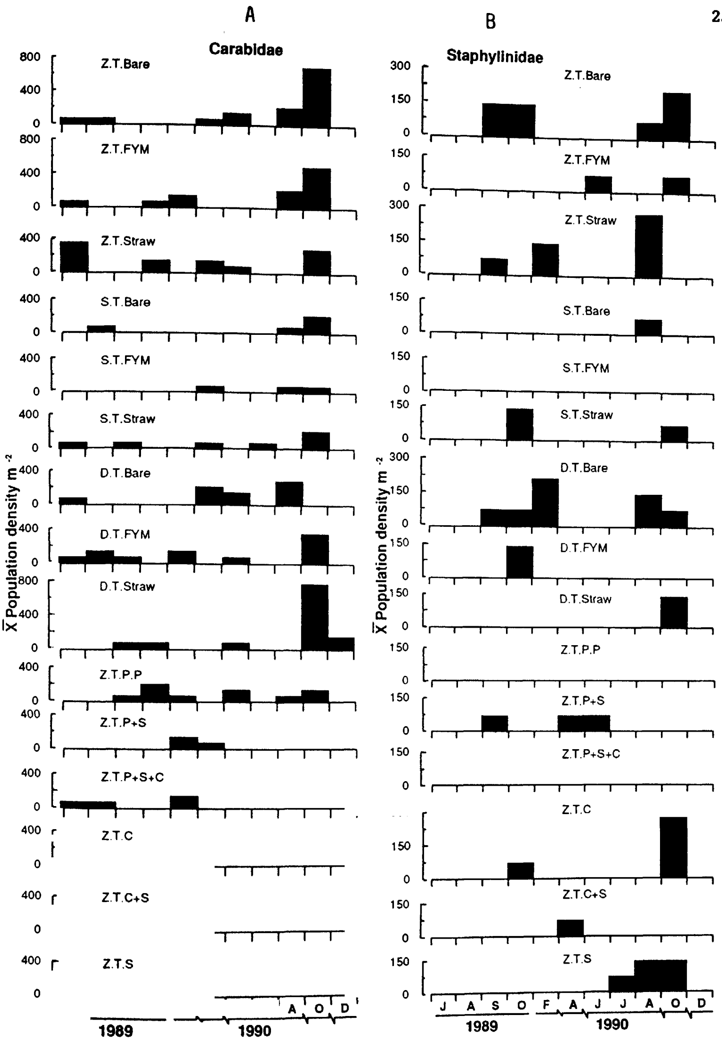

Figure 35. Seasonal fluctuation in the population densities of Carabidae m^{-2} (A) and that of Staphylinidae m^{-2} (B) across the fifteen soil management treatments.

During the 2nd crop season, the density was 70 m^{-2} in shallow tillage rice-straw amendment and they were not recorded in other treatments 10 days after sowing during the crop (July, 1990). It was 70 m^{-2} in shallow tillage bare, farmyard manure and pigeonpea treatments and increased to four folds higher (280 m^{-2}) in deep tillage bare treatment, followed by zero tillage bare and farmyard manure amendments (210 m^{-2}) and was not recorded in other treatments 60 days after sowing (August, 1990). It was 70 m^{-2} in shallow tillage farmyard manure amendment and increased to eleven folds higher (770 m^{-2}) in deep tillage rice-straw amendment, followed by zero tillage bare treatment (700 m^{-2}) 90 days after sowing (October, 1990). During the following fallow period, the densities were very few in number and did not show any distinct temporal variation.

ANOVA revealed that the Carabidae density was more than two folds higher in density in tillage and organic amendment treatments during postrainy season than that of rainy and dry seasons, the difference being statistically significant (Table 15).

The seasonal fluctuation in the population densities of Staphylinidae (Fig. 35b), **Tenebrionidae** (Fig. 36a) and *Megalodicne* Sp. (Fig. 36b) across the treatments showed that their densities were too few to show any significant temporal variation.

Coleoptera larvae: The seasonal fluctuation in their population density across the

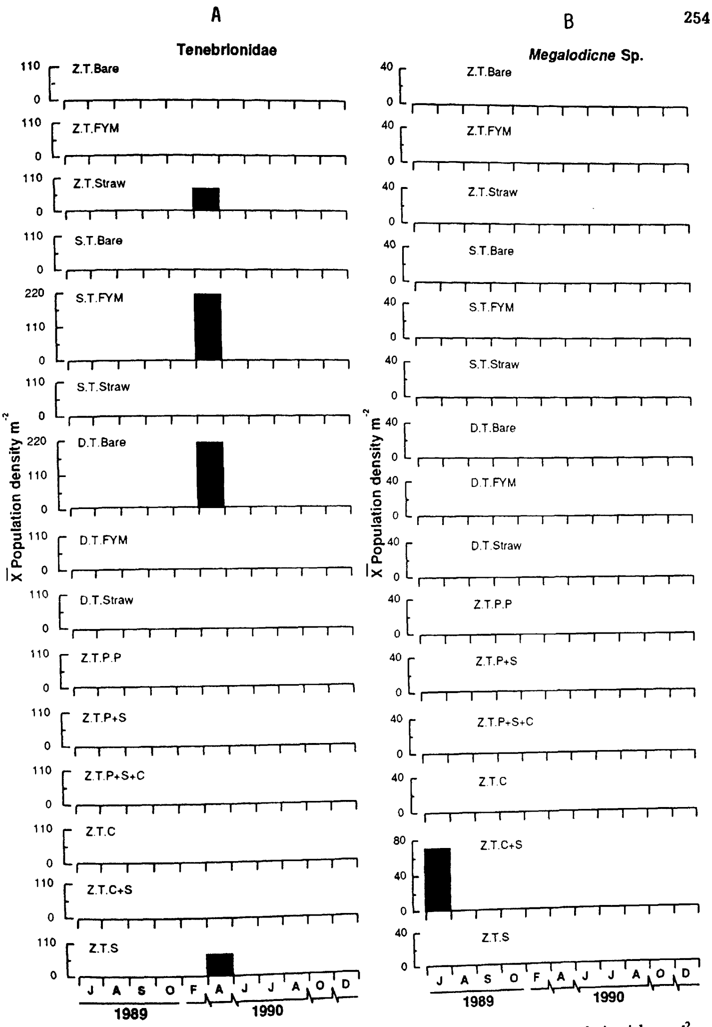

Figure 36. Seasonal fluctuation in the population densities of Tenebrionidae m^{-2} (A) and that of *Megalodicne* Sp. m^{-2} (B) across the fifteen soil management treatments.

treatments presented in Fig. 37 revealed that the mean densities were too few to show any significant temporal variation till 90 days after sowing (October, 1989) and during the following fallow period.

During the 2nd crop season, their mean density was 70 m^{-2} in shallow tillage farmyard manure, rice-straw, pigeonpea and *S. hamata* treatments which increased to two folds higher (140 m^{-2}) in pigeonpea + *S. hamata* + *C. ciliaris* treatment and they were not recorded in other treatments 10 days after sowing the crop (July, 1990). It was 70 m^{-2} in zero tillage bare, shallow tillage bare, rice-straw, pigeonpea + *S. hamata* + *C. ciliaris* and *S. hamata* treatments and increased to five folds higher (350 m^{-2}) in deep tillage rice-straw amendment 60 days after sowing (August, 1990). It was 70 m^{-2} in zero tillage farmyard manure, rice-straw, shallow and deep tillage farmyard manure, pigeonpea + *S. hamata* + *C. ciliaris*, *C. ciliaris* + *S. hamata* and *S. hamata* treatments and increased to eleven folds higher (770 m^{-2}) in pigeonpea + *S. hamata* treatment 90 days after sowing (October, 1990). During the following fallow period, their mean densities were too few to show any significant temporal variation.

ANOVA, however, revealed that the Coleoptera larvae density was more than two folds higher in density in perennial ley treatments during postrainy season, than that of rainy season, the difference being statistically significant, whereas its density was absent during dry season (Table 15).

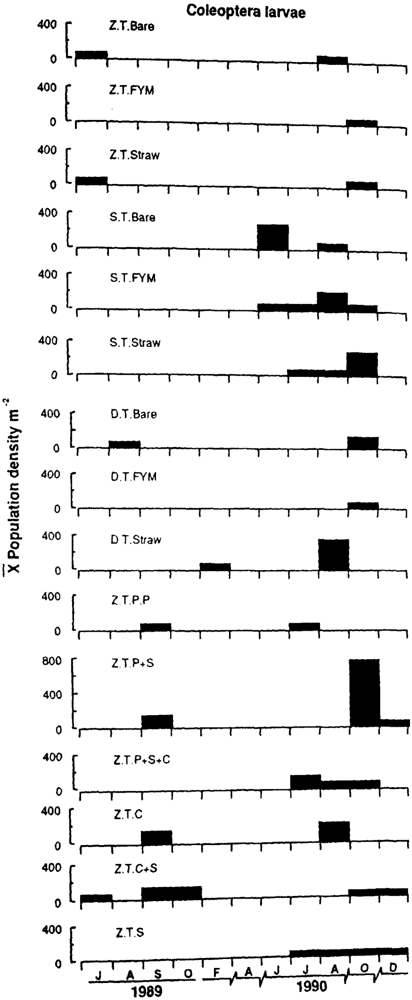

Figure 37. Seasonal fluctuation in the population densities of Coleoptera larvae m^{-2} across the fifteen soil management treatments.

Hymenoptera: The seasonal fluctuation in their population densities across the treatments presented in Fig. 38a revealed that their mean densities were too few in number and did not show any significant temporal variation till 30 days after sowing (August, 1989). Their density was 70 m^{-2} in pigeonpea treatment and increased to twenty four folds higher (1680 m^{-2}) in shallow tillage bare treatment 60 days after sowing (September, 1989). It was not recorded in all the treatments 90 days after sowing (October, 1989). During the following fallow period, they were not recorded in any treatments 90, 150, and 210 days after harvesting the crop (February, April, and June, 1990), respectively.

During the 2nd crop season, their mean density was 140 m^{-2} in shallow tillage farmyard manure amendment and increased to more than thirteen folds higher (1890 m^{-2}) in pigeonpea + *S. hamata* treatment 10 days after sowing during the crop (July, 1990). They were not recorded in any treatments till 60 days after sowing (August, 1990). The density was 70 m^{-2} in shallow tillage farmyard manure, deep tillage bare and rice-straw amendments and increased to eighteen folds higher (1260 m^{-2}) in pigeonpea + *S. hamata* + *C. ciliaris* treatment 90 days after sowing (October, 1990). During the following fallow period, the density was 70 m^{-2} in pigeonpea and *C. ciliaris* + *S. hamata* treatments and increased to six folds higher (420 m^{-2}) in zero tillage bare treatment 30 days after harvesting the crop (December, 1990).

ANOVA revealed that the Hymenoptera density was more than three folds

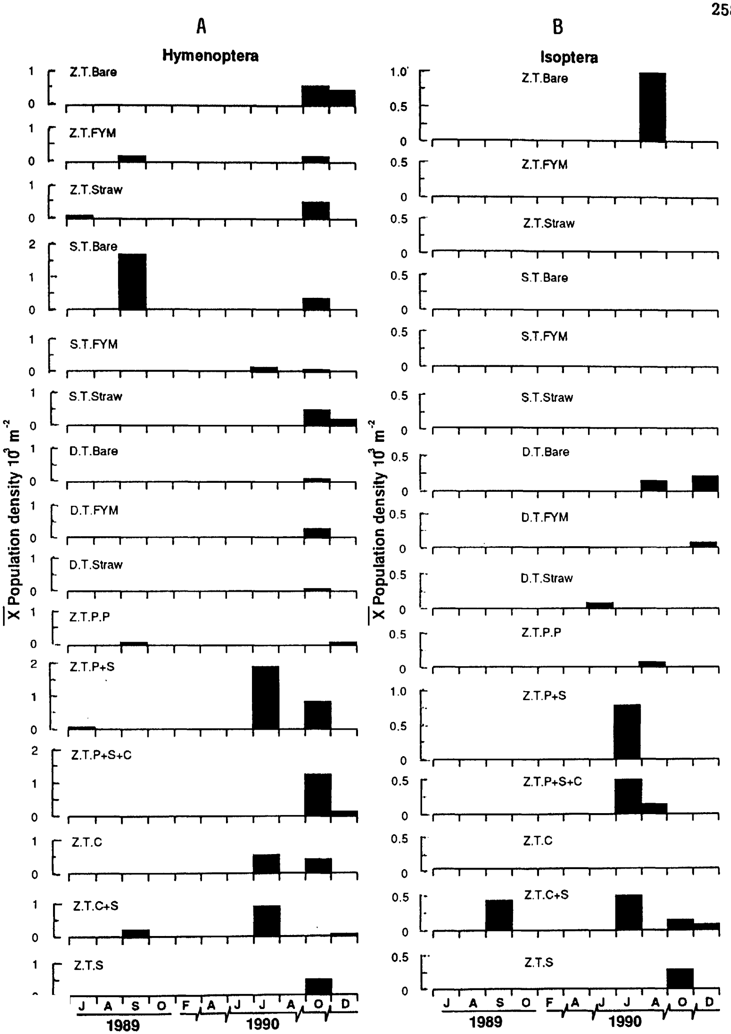

Figure 38. Seasonal fluctuation in the population densities of Hymenoptera m^{-2} (A) and that of Isoptera m^{-2} (B) across the fifteen soil management treatments.

higher in tillage and organic amendment treatments during postrainy season, than that of rainy season, the difference being statistically significant, whereas its density was absent during dry season (Table 15).

Isoptera: The seasonal fluctuation in its population density across the treatments presented in Fig. 38b revealed that the mean densities were too few to show any significant temporal variation till 30 days after sowing during the crop season (August, 1989). The density was 420 m^{-2} and recorded only in *C. ciliaris* + *S. hamata* treatment, and they were not recorded in other treatments 60 days after sowing (September, 1989), and in any of the treatments till 90 days after sowing (October, 1989). During the following fallow period, the mean densities were too few to show any significant temporal variation.

During the 2nd crop season, the mean density was 490 m^{-2} in pigeonpea + *S. hamata* + *C. ciliaris* and *C. ciliaris* + *S. hamata* treatments and increased to more than one fold higher (770 m^{-2}) in pigeonpea + *S. hamata* treatment and they were not recorded in other treatments till 10 days after sowing during the crop (July, 1990). It was 70 m^{-2} in pigeonpea treatment and increased to fourteen folds higher (980 m^{-2}) in zero tillage bare treatment 60 days after sowing (August, 1990). They were recorded very few in number and did not show any significant temporal variation till 30 days after harvesting the crop (December, 1990).

Psocoptera: The seasonal fluctuation in its population density across the treatments presented in Fig. 39a revealed that the mean densities were too few to show any significant temporal variation till 90 days after sowing (October, 1989) and during the following fallow period, the mean densities were in very few numbers till 150 days after harvesting the crop (April, 1990). It was 70 m^{-2} in pigeonpea + *S. hamata* + *C. ciliaris* treatment and increased to twenty nine folds higher (2030 m^{-2}) in *S. hamata* treatment 210 days after harvesting the crop (June, 1990). During the 2nd crop season, the mean densities were too few to show any significant temporal variation.

Thysanoptera: The seasonal fluctuation in its population density across the treatments presented in Fig. 39b revealed that they were not recorded in any treatments till 60 days after sowing during the crop season (September, 1989). The density was 140 m^{-2} in shallow tillage rice-straw amendment and increased to more than three folds higher (490 m^{-2}) in *C. ciliaris* treatment and was not recorded in other treatments 90 days after sowing (October, 1989). During the following fallow period, they were not recorded in any treatments till 150 days after harvesting the crop (February and April, 1990), respectively. It was 70 m^{-2} in deep tillage farmyard manure amendment and increased to five folds higher (350 m^{-2}) in shallow tillage rice-straw amendment 210 days after harvesting the crop (June, 1990).

During the 2nd crop season, the density was 70 m^{-2} in zero tillage farmyard manure, shallow tillage rice-straw, pigeonpea + *S. hamata* and *S. hamata* treatments

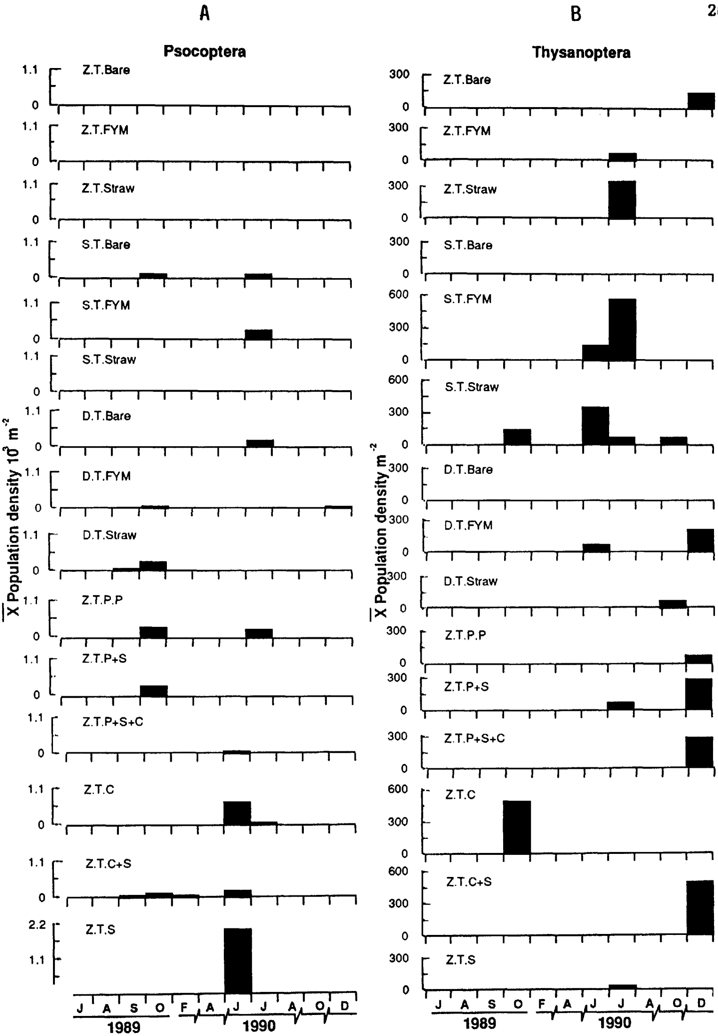

Figure 39. Seasonal fluctuation in the population densities of Psocoptera m^{-2} (A) and that of Thysanoptera m^{-2} (B) across the fifteen soil management treatments.

which increased to eight folds higher (560 m^{-2}) in shallow tillage farmyard manure amendment 10 days after sowing during the crop (July, 1990). The mean densities were too few to show any significant temporal variation till 90 days after sowing (October, 1990). During the following fallow period, the density was 70 m^{-2} in pigeonpea treatment and increased to seven folds higher (490 m^{-2}) in *C. ciliaris* + *S. hamata* treatment 30 days after harvesting the crop (December, 1990).

The seasonal fluctuation in the population densities of **Hemiptera** (Fig. 40a), **Homoptera** (Fig. 40b), **Diptera** (Fig. 41a) and **Lepidoptera larvae** (Fig. 41b) across the treatments showed that their mean densities were too few to show any significant temporal variation.

Treatment Effect:

Total soil microarthropods: The population densities of total soil (inhabiting) microarthropods across the 15 different soil management treatments presented in Fig. 42a revealed that the mean density was significantly low in annual treatments (815 m^{-2}) compared to those of the perennial ley treatments (2475 m^{-2}). Under annual crop, in zero tillage treatments the mean density was low in farmyard manure amendment (1018 m^{-2}), while it was high in rice-straw amendment (1935 m^{-2}). In shallow and deep tillage treatments they were lower in number in bare amendment (1025 m^{-2} and 815 m^{-2}) and high in rice-straw amendment (1909 m^{-2} and 1597 m^{-2}), respectively. In perennial ley treatments the density was low in pigeonpea treatment (878 m^{-2}) and about three times higher in pigeonpea + *S.*

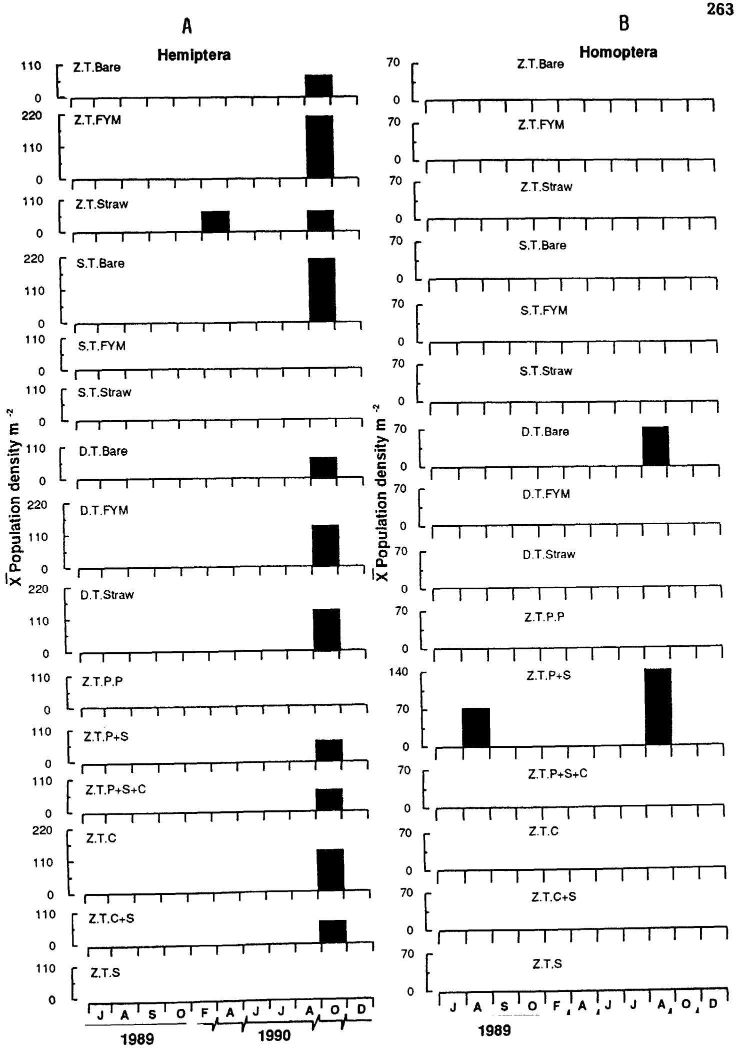

Figure 40. Seasonal fluctuation in the population densities of Hemiptera m^{-2} (A) and that of Homoptera m^{-2} (B) across the fifteen soil management treatments.

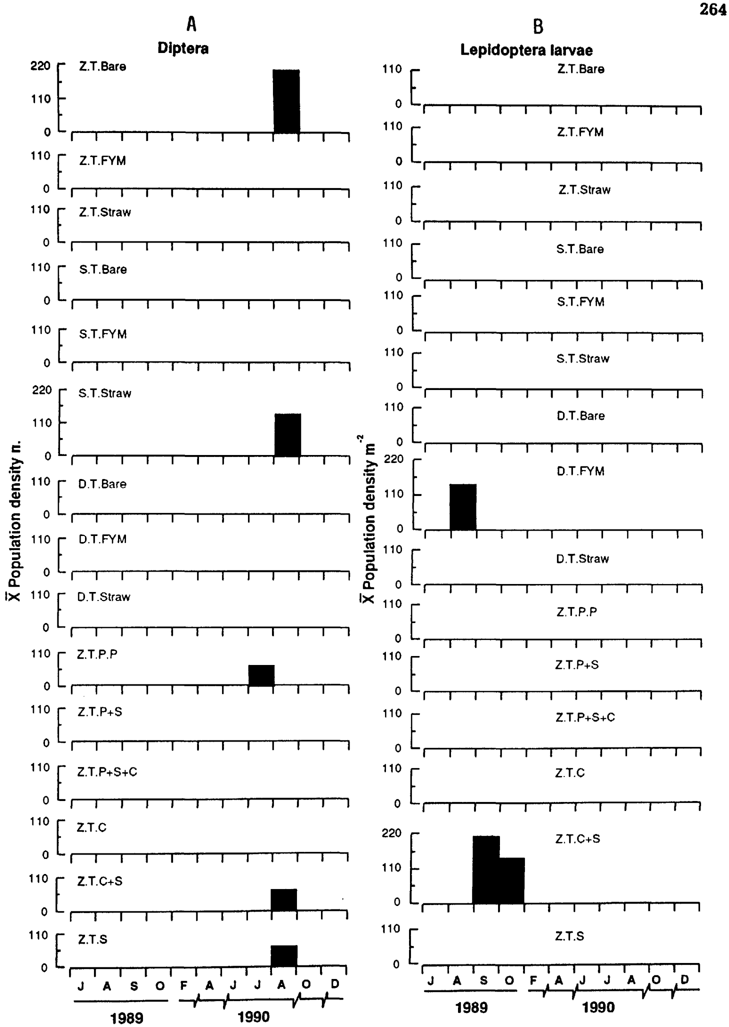

Figure 41. Seasonal fluctuation in the population densities of Diptera m^{-2} (A) and that of Lepidoptera larvae m^{-2} (B) across the fifteen soil management treatments.

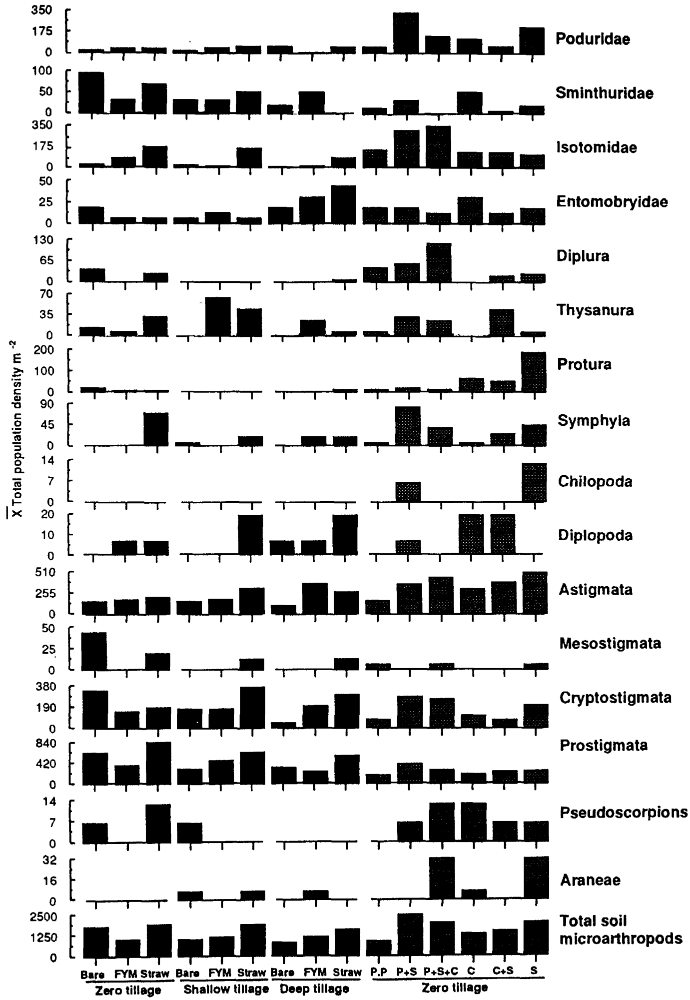

Figure 42a. Population densities of some of the soil-inhabiting microarthropod groups m^{-2} across the fifteen soil management treatments.

hamata treatment (2475 m^{-2}).

Araneae: Its population densities across the treatments presented in Fig. 42a revealed that the mean density was low in shallow tillage bare, rice-straw, deep tillage farmyard manure and *C. ciliaris* treatments (6.4 m^{-2}) and five folds higher in pigeonpea + *S. hamata* + *C. ciliaris* and *S. hamata* treatments (32 m^{-2}) and they were not recorded in other treatments. The densities of Araneae were not significantly different across all the 15 treatments (Table 16) and the tillage and organic amendments (Table 17) and perennial ley treatments (Table 18) as revealed by the ANOVA. However, their monthly densities were significantly different across the treatments during October 1989 (P <0.01) (Table 19), whereas they did not differ significantly across the tillage and organic amendments (Table 20), and perennial ley treatments (Table 21) during any month of the study period.

Pseudoscorpions: Its population densities across the treatments presented in Fig. 42a revealed that the mean density was low in zero, shallow tillage bare, pigeonpea + *S. hamata*, *C. ciliaris* + *S. hamata* and *S. hamata* treatments (6.4 m^{-2}) and two folds higher in zero tillage rice-straw, pigeonpea + *S. hamata* + *C. ciliaris* and *C. ciliaris* treatments (13 m^{-2}) and they were not recorded in other treatments. The densities did not differ significantly across all the 15 treatments (Table 16) and the tillage and organic amendments (Table 17) and perennial ley treatments (Table 18) as revealed by the ANOVA. However, ANOVA of their monthly

Table 16. Analysis of variance (mean squares) of the data on population densities of different groups of soil microarthropods across the 15 soil management treatments during different seasons – 1989-1990.

	SOURCE OF VARIATION				
Seasons	Blocks (Ignoring treatments)	Entries (Eliminating blocks)	Within entries errors	F (14, 21)	Mean abundance
Isotomidae					
Rainy	12599	7711	4346	1.8	54
Postrainy	204391	248670	101425	2.4*	292
Dry	504	417	509	0.8	5
Prostigmata					
Rainy	212482	99594	35851	2.8*	301
Postrainy	98696	216743	84474	2.6*	254
Dry	26086	10117	12689	0.8	68
Diplura					
Rainy	1857	3974	1395	2.8*	20
Postrainy	1606	7733	2836	2.7*	33
Dry	3981	4245	4494	0.9	14
Coleoptera larvae					
Rainy	1900	960	2157	0.4	30
Postrainy	8445	13617	3708	3.7**	45
Dry	279	218	248	0.9	2
Lepidoptera larvae					
Rainy	276	283	186	1.5	4
Postrainy	224	367	105	3.5**	3
Dry	-	-	-	-	-

* Significant at P <0.05; ** Significant at P <0.01.

Table 17. Analysis of variance (mean squares) of the data on population densities of different groups of soil microarthropods across the tillage and organic amendment treatments (number in parentheses represent degrees of freedom).

Arthropod taxa	SOURCE OF VARIATION								MEAN ABUND-ANCE
	SEAS (2)	AMM (2)	SEAS x AMM (4)	TILL-AGE (2)	SEAS x TILL (4)	TILL x AMM (4)	SxT x A (8)	ERROR (46)	
Prostigmata	197769**	54626	44281	43601	7995	9630	79852*	38027	153
Cryptostigmata	3660678**	1026021	761557	231676	176755	193686	76861	393833	422
Mesostigmata	570623**	115604	77402	36795	32825	42705	55635	66386	170
Symphyla	5505*	3917	2647	469	968	1282	1716	1432	10
Diplura	197	1921	1308	5187*	330	1463	1229	1700	9
Isotomidae	89349**	105456**	30413	21158	11653	22583	28122*	12847	61
Sminthuridae	23819**	181	1815	4219	7214	5410	5149	4445	32
Poduridae	18390**	1467	5686*	741	1966	1236	1989	2164	28
Carabidae	60993*	2374	8386	36039	6798	8269	19933	20182	75
Staphylinidae	3917	6095	106	5278	786	2371	5822*	2684	25
Tenebrionidae	6669*	544	544	544	544	408	3607	2154	9
Hymenoptera	95747**	24243	11857	26965	20160	102	24402**	9133	51
Psocoptera	2964*	15	650	2964*	1694	941	1830*	842	11
Hemiptera	9180**	15	560	560	287	1146	1331	1822	13

* Significant at $P < 0.05$; ** Significant at $P < 0.01$.

Table 18. Analysis of variance (mean squares) of the data on population densities of different groups of soil microarthropods across the perennial ley treatments (number in parentheses represent degrees of freedom).

	SOURCE OF VARIATION				
Arthropod taxa	SEAS (2)	TREATMENT (5)	SEAS x TRT (10)	ERROR (28)	MEAN ABUNDANCE
Prostigmata	692148**	97701	221312**	73705	296
Cryptostigmata	548687**	82960	27544	61679	203
Mesostigmata	238625**	13840	41700*	18961	128
Symphyla	15948**	4274	1901	1924	23
Protura	57325**	11682	17200	12474	38
Thysanura	21868**	6531	4392	6165	22
Diplura	12454	14059*	5730	5031	43
Isotomidae	1637575**	125977	116125	69572	202
Sminthuridae	5376*	1693	747	1205	14
Poduridae	226648**	81211	22753	36410	112
Coleoptera larvae	24659**	5026*	12191**	1743	36
Thysanoptera	46006**	10517	4900	7194	31
Hemiptera	2269**	351	309	389	7
Homoptera	204	152	204**	75	2
Lepidoptera larvae	295*	-	295**	78	5

* Significant at $P < 0.05$; ** Significant at $P < 0.01$.

Table 19. Analysis of variance (mean squares) of the date on population densities of different groups of soil microarthropods across the 15 soil management treatments during different months – 1989-1990.

Year & month	Arthropod taxa	SOURCE OF VARIATION				Mean abundance
		Blocks (Ignoring treatments)	Entries (Eliminating blocks)	Within entries (Errors)	F (14, 21)	
1989, October	Araneae	1769	3360	1015	3.3**	9.3
1990, August	Pseudoscorpions	1524	3504	1024	3.4**	9.3
1989, September	Prostigmata	21288	41572	17015	2.4*	65.3
1990, August	"	6433291	2902450	1259309	2.3*	1470
1989, September	Cryptostigmata	71023	55874	22846	2.4*	117
1989, October	Mesostigmata	4383	9292	3781	2.4*	19
1989, October	Symphyla	2014	3147	1052	3*	9.3
1990, October	Isotomidae	1606219	2093429	836681	2.5*	854
1989, October	Poduridae	37539	41113	17636	2.3*	93
1989, September	Coleoptera larvae	4464	10403	3565	2.9*	33
1990, October	"	75705	93654	25239	3.7**	112
1989, September	Hymenoptera	433405	443965	127278	3.5**	140
1989, October	Thysanoptera	18293	44103	15678	2.8*	42
1989, September	Lepidoptera larvae	5145	7428	2923	2.5*	14
1989, October	"	2014	3301	949	3.5**	9.3

* Significant at $P < 0.05$; ** Significant at $P < 0.01$.

Table 20. Analysis of variance (mean squares) of the data on population densities of different groups of soil microarthropods across tillage and organic amendment treatments during different months - 1989-1990 (number in parentheses represent degrees of freedom).

Year & month		Arthropod taxa	SOURCE OF VARIATION Amendment (A) (2)	Tillage (T) (2)	T x A (4)	Error (10)	Mean abundance
1989,	September	Prostigmata	31033	80033**	23275	12577	54
"	"	Cryptostigmata	34300	58800*	25725	12250	70
"	October	"	21233	84933**	35525*	8657	109
1990,	August	Symphyla	4900	14700*	3675	3430	23
"	October	Isotomidae	1187433*	354433	44225	243857	366
1989,	October	Sminthuridae	80033*	31033	18375	20417	54
"	September	Hymenoptera	868933*	868933	651700	214947	202

* Significant at $P < 0.05$; ** Significant at $P < 0.01$.

Table 21. Analysis of variance (mean squares) of the data on population densities of different groups of soil microarthropods across perennial ley treatments during different months – 1989-1990 (number in parentheses represent degrees of freedom).

Year & month		Arthropod taxa	SOURCE OF VARIATION Treatment (T) (5)	Error (4)	Mean abundance
1990,	July	Prostigmata	95466*	14805	140
"	"	Cryptostigmata	173901*	24255	233
1989,	October	Mesostigmata	20286*	2205	35
"	"	Poduridae	77301**	5355	117
1990,	"	Coleoptera larvae	98301**	8505	163
1989	"	Thysanoptera	108486**	2205	82

* Significant at $P < 0.05$; ** Significant at $P < 0.01$.

densities showed that the population densities differed significantly across all the 15 treatments during August, 1990 (P <0.01) (Table 19), whereas they did not show any significant difference across tillage and organic amendments (Table 20) and perennial ley treatments (Table 21) during any month.

Prostigmata: Its population densities across the treatments presented in Fig. 42a revealed that the mean density was significantly low in number in perennial ley treatments (172 m^{-2}) compared to those of the annual treatments (840 m^{-2}). Under annual crop, in zero tillage treatments, the density was low in farmyard manure amendment (376 m^{-2}) which was two times higher in rice-straw amendment (840 m^{-2}). In shallow tillage treatments it was low in bare amendment (299 m^{-2}) which increased to two folds higher in rice-straw amendment (636 m^{-2}). In deep tillage treatments it was low in farmyard manure amendment (248 m^{-2}) and about two folds higher in rice-straw amendment (573 m^{-2}). In perennial ley treatments its mean density was low in pigeonpea treatment (172 m^{-2}) and more than two folds higher in pigeonpea + *S. hamata* treatment (401 m^{-2}).

The population densities differed significantly across the 15 treatments as revealed by ANOVA during rainy (P <0.05) and postrainy seasons (P 0.05) (Table 16). Besides, the densities also showed significant difference across tillage and organic amendment treatments between seasons (P <0.01) and season x tillage x amendment interaction (P <0.05) (Table 17), also across the perennial ley treatments between seasons (P <0.01) and season x treatment interaction (P <0.01)

(Table 18). The monthly population densities showed significant difference across all the treatments during September 1989 ($P < 0.05$) and August 1990 ($P < 0.05$) (Table 19), and across the tillage treatments during September 1989 ($P < 0.01$) (Table 20) and perennial ley treatments during July 1990 ($P < 0.05$) (Table 21).

Cryptostigmata: Its population densities across the treatments presented in Fig. 42a revealed that the mean density was low in deep tillage bare treatment (45 m^{-2}) and was eight folds higher in shallow tillage rice-straw amendment (369 m^{-2}). Under annual crop, in zero tillage treatments its mean density was low in farmyard manure amendment (146 m^{-2}) while it was more than two times higher in bare amendment (337 m^{-2}). In shallow tillage treatments it was low in bare and farmyard manure amendments (172 m^{-2}) and two folds higher in rice-straw amendment (369 m^{-2}). In deep tillage treatments it was low in bare amendment (45 m^{-2}) and more than six folds higher in rice-straw amendment (299 m^{-2}). In perennial ley treatments its mean density was low in pigeonpea and *C. ciliaris* + *S. hamata* treatments (70 m^{-2}) and four folds higher in pigeonpea + *S. hamata* treatment (280 m^{-2}).

The population densities differed significantly across the tillage and organic amendment treatments ($P < 0.01$) (Table 17) and the perennial ley treatments between seasons ($P < 0.01$) (Table 18) as revealed by the ANOVA. The monthly densities showed significant difference across all the treatments during September, 1989 ($P < 0.05$) (Table 19), across the tillage treatments during September 1989 (P

<0.05), and October 1989 (P <0.01) and tillage treatment x organic amendment treatments interaction (P <0.05) (Table 20). Their densities also differed significantly across the perennial ley treatments during July 1990 (P <0.05) (Table 21).

Mesostigmata: Its population densities across the treatments presented in Fig. 42a revealed that the mean density was significantly low in number in perennial ley treatments (6.4 m^{-2}) compared to those of the annual treatments (45 m^{-2}). Under annual crop, in zero tillage treatments its mean density was low in rice-straw amendment (19 m^{-2}) while it was more than two folds higher in bare amendment (45 m^{-2}). In shallow and deep tillage treatments it was recorded in rice-straw amendment (13 m^{-2}) and was not recorded in other two amendments. In perennial ley treatments its mean density was recorded in pigeonpea, pigeonpea + *S. hamata* + *C. ciliaris* and *S. hamata* treatments (6.4 m^{-2}) and not recorded in other treatments.

The population densities differed significantly across the tillage and organic amendment treatments as revealed by ANOVA, between seasons (P <0.01) (Table 17). Besides, the densities also differed significantly across the perennial ley treatments between seasons (P <0.01) and the season x treatment interaction (P <0.05) (Table 18). ANOVA of the monthly data showed that the population density differed significantly across all the treatments during October 1989 (P <0.05) (Table 19), whereas they did not show any significant difference across the tillage and organic amendment treatments during any month (Table 20). However, the population densities differed significantly across the perennial ley treatments during October, 1989 (P <0.05) (Table 21).

Astigmata: Its population densities across the treatments presented in Fig. 42a revealed that the mean density was significantly low in number in annual treatments (96 m^{-2}) compared to those of the perennial ley treatments (503 m^{-2}). Under annual crop, in zero and shallow tillage treatments its mean density was low in bare amendment (146 m^{-2} and 153 m^{-2}) while it was high in rice-straw amendment (204 m^{-2} and 312 m^{-2} respectively). In deep tillage treatments it was low in bare amendment (96 m^{-2}) and more than three folds higher in farmyard manure amendment (369 m^{-2}). In perennial ley treatments its mean density was low in pigeonpea treatment (159 m^{-2}) and three folds higher in *S. hamata* treatment (503 m^{-2}).

The population densities did not differ significantly across the tillage and organic amendment treatments (Table 17) and perennial ley treatments (Table 18) as revealed by the ANOVA. Besides, ANOVA of the monthly data showed that their population did not differ significantly across all the treatments (Table 19), and tillage and organic amendments (Table 20) and perennial ley treatments (Table 6) during any month.

Diplopoda: Its population densities across the treatments presented in Fig. 42a revealed that the mean density was low in number in zero tillage farmyard manure, rice-straw, deep tillage bare, farmyard manure and pigeonpea + *S. hamata* treatments (6.4 m^{-2}) and more than two folds higher in shallow and deep tillage rice-straw, *C. ciliaris* and *C. ciliaris* + *S. hamata* treatments (19 m^{-2}) and they were not recorded in other treatments.

The population densities of Diplopoda did not differ significantly across the tillage and organic amendment treatments (Table 17) and perennial ley treatments (Table 18) as revealed by the ANOVA. Besides, ANOVA of the monthly data showed that their population did not differ significantly across all the treatments (Table 19), and tillage and organic amendments (Table 20) and perennial ley treatments (Table 21) during any month.

Chilopoda: Its population densities across the treatments presented in Fig. 42a revealed that the mean density was low in number in pigeonpea + *S. hamata* treatment (6.4 m^{-2}) which increased to two folds higher in *S. hamata* treatment (13 m^{-2}) and they were not recorded in other treatments.

The population densities did not differ significantly across the tillage and organic amendment treatments (Table 17) and perennial ley treatments (Table 18) as revealed by the ANOVA. Besides, ANOVA of the monthly data showed that their densities did not differ significantly across all the treatments (Table 19), and tillage and organic amendments (Table 20) and perennial ley treatments (Table 21) during any month.

Symphyla: Its population densities across the treatments presented in Fig. 42a revealed that the mean density was low in number in shallow tillage bare, pigeonpea and *C. ciliaris* treatments (6.4 m^{-2}) and increased to more than twelve folds higher in pigeonpea + *S. hamata* treatment (83 m^{-2}). Under annual crop, in zero tillage treatments its mean density was 70 m^{-2} in rice-straw amendment and not recorded in other two amendments. In shallow tillage treatments its number was low in bare amendment (6.4 m^{-2}) and more than two folds higher in rice-straw amendment (19 m^{-2}). In deep tillage treatments it was 19 m^{-2} in farmyard manure and rice-straw amendments and not recorded in bare amendment. In perennial ley treatments its mean density was low in pigeonpea and *C. ciliaris* treatments (6.4 m^{-2}) which increased to more than twelve folds higher in pigeonpea + *S. hamata* treatment (83 m^{-2}).

The population density differed significantly across the tillage and organic amendment treatments (P <0.05) (Table 17), and the perennial ley treatments between seasons (P <0.01) (Table 18) as revealed by ANOVA. Their monthly densities showed significant difference across all the treatments during October, 1989 (P <0.05) (Table 19), across the tillage treatments during August, 1990 (P <0.05) (Table 20), whereas they did not differ significantly across perennial ley treatments (Table 21) during any month.

Protura: Its population densities across the treatments presented in Fig. 42a revealed that the mean density was significantly low in annual treatments (6.4 m^{-2}) compared to those of the perennial ley treatments (191 m^{-2}). Under annual crop, in zero tillage treatments it was low in farmyard manure and rice-straw amendments (6.4 m^{-2}) while it increased to more than two folds higher in bare amendment (19 m^{-2}). It was not recorded in shallow tillage treatments. In deep tillage treatments it was 13 m^{-2} in rice-straw amendment and not recorded in other two amendments. In perennial ley treatments its mean density was low in number in pigeonpea and pigeonpea + *S. hamata* + *C. ciliaris* treatments (13 m^{-2}) which increased to more than fourteen folds higher in *S. hamata* treatment (191 m^{-2}).

The population densities were not significantly different across the tillage and organic amendment treatments (Table 17) as revealed by the ANOVA. However, their densities were significantly differed across the perennial ley treatments between seasons (P <0.01) (Table 18). ANOVA of the monthly data showed that their population densities did not differ significantly across all the treatments (Table 19), and tillage and organic amendments (Table 20) and perennial ley treatments (Table 21) during any month of the study period.

Thysanura: Its population densities across the treatments presented in Fig. 42a revealed that the mean density was low in number in zero tillage farmyard manure, deep tillage rice-straw, pigeonpea and *S. hamata* treatments (6.4 m^{-2}) and increased to ten times higher in shallow tillage farmyard manure amendment (64 m^{-2}). Under annual crop, in zero tillage treatments its mean density was low in farmyard manure amendment (6.4 m^{-2}) which increased to five times higher in rice-straw amendment (32 m^{-2}). In shallow and deep tillage treatments its number was low in rice-straw amendment (45 m^{-2} and 6.4 m^{-2}) and was slightly higher in farmyard manure amendment (64 m^{-2} and 26 m^{-2} respectively). In perennial ley treatments its mean density was low in number in pigeonpea and *S. hamata* treatments (6.4 m^{-2}) which increased to seven folds higher in *C. ciliaris* + *S. hamata* treatment (45 m^{-2}).

The population densities did not differ significantly across the tillage and organic amendment treatments (Table 17) as revealed by the ANOVA. However, their population densities differed significantly across perennial ley treatments between seasons (P <0.01) (Table 18). ANOVA of the monthly data showed that their densities did not differ significantly across all the treatments (Table 19) and tillage and organic amendment treatments (Table 20) and perennial ley treatments (Table 21) during any month.

Diplura: Its population densities across the treatments presented in Fig. 42a revealed that the mean density was significantly low in number in annual treatments (6.4 m^{-2}) compared to those of the perennial ley treatments (121 m^{-2}). Under annual crop, in zero tillage treatments its mean density was low in rice-straw amendment (26 m^{-2}) which slightly increased in bare amendment (38 m^{-2}).

It was not recorded in shall tillage treatments. In deep tillage treatments it was 6.4 m^{-2} in rice-straw amendment and not recorded in other two amendments. In perennial ley treatments its mean density was low in *C. ciliaris* + *S. hamata* treatment (19 m^{-2}) which increased to more than six times higher in pigeonpea + *S. hamata* + *C. ciliaris* treatment (121 m^{-2}).

The population densities differed significantly across all the 15 treatments as revealed by the ANOVA during rainy (P <0.05) and postrainy seasons (P <0.05) (Table 16). Besides, their densities also showed significant difference across the tillage and organic amendment treatments (P <0.05) (Table 17) and perennial ley treatment (P <0.05) (Table 18). ANOVA of the monthly data showed that their population densities did not differ significantly across all the treatments (Table 19), and tillage and organic amendment (Table 20) and perennial ley treatments (Table 21) during any month.

Entomobryidae: Its population densities across the treatments presented in Fig. 42a revealed that the mean density was significantly low in zero tillage farmyard manure, rice-straw, shallow tillage bare and rice-straw amendments (6.4 m^{-2}) which increased to seven times higher in deep tillage rice-straw amendment (45 m^{-2}). Under annual crop, in zero tillage treatments it was low in farmyard manure and rice-straw amendments (6.4 m^{-2}) which increased to more than two folds higher in bare amendment (19 m^{-2}). In shallow tillage treatments its number was low in bare and rice-straw amendments (6.4 m^{-2}) and increased to two times higher in farmyard manure amendment (13 m^{-2}). In deep tillage treatments its number was low in bare amendment (19 m^{-2}) and more than two folds higher in rice-straw amendment (45 m^{-2}). In perennial ley treatments its mean density was low in pigeonpea + *S. hamata* + *C. ciliaris* and *C. ciliaris* + *S. hamata* treatments (13 m^{-2}) and increased to more than two times higher in *C. ciliaris* treatment (32 m^{-2}).

The population densities did not differ significantly across the tillage and organic amendments (Table 17) and perennial ley treatments (Table 18) as revealed by ANOVA. ANOVA of the monthly data showed that their population densities did not differ significantly across all the treatments (Table 19), and tillage and organic amendments (Table 20) and perennial ley treatments (Table 21) during any month.

Isotomidae: Its population densities across the treatments presented in Fig. 42a revealed that the mean density was significantly low in number in annual treatments (6.4 m^{-2}) compared to those of the perennial ley treatments (344 m^{-2}). Under annual crop, in zero tillage treatments its mean density was low in bare amendment (25.5 m^{-2}) which increased to more than six folds higher in rice-straw amendment (172 m^{-2}). In shallow tillage treatments its number was low in farmyard manure amendment (13 m^{-2}) and increased to twelve folds higher in rice-straw amendment (159 m^{-2}). In deep tillage treatments its number was low in bare amendment (6.4 m^{-2}) and about thirteen folds higher in rice-straw amendment (83 m^{-2}). In perennial ley treatments its mean density was low in *S.*

hamata treatment (108 m^{-2}) and increased to three folds higher in pigeonpea + *S. hamata* + *C. ciliaris* treatment (344 m^{-2}).

The population densities differed significantly across all the 15 treatments as revealed by the ANOVA during postrainy season ($P < 0.05$) (Table 16). Besides, their population densities also differed significantly across the tillage and organic amendment treatments between seasons ($P < 0.01$) and amendment ($P < 0.01$) and season x tillage x amendment interaction ($P < 0.05$) (Table 17) and the perennial ley treatments between seasons ($P < 0.01$) (Table 18). ANOVA of the monthly data showed that the population densities differed significantly across all the treatments during October, 1990 ($P < 0.05$) (Table 19) and organic amendment during October 1990 ($P < 0.05$) (Table 20), whereas the population densities did not differ significantly across perennial ley treatments during any month (Table 21).

Sminthuridae: Its population densities across the treatments presented in Fig. 42a revealed that the mean density was significantly low in number in perennial ley treatments (6.4 m^{-2}) compared to those of the annual treatments (95 m^{-2}). Under annual crop, in zero tillage treatments its mean density was low in farmyard manure amendment (32 m^{-2}) which increased to more than two folds higher in bare amendment (95 m^{-2}). In shallow tillage treatments its number was low in bare and farmyard manure amendments (32 m^{-2}) and was slightly high in rice-straw amendment (51 m^{-2}). In deep tillage treatments its number was low in bare amendment (19 m^{-2}) and increased to more than two folds higher in farmyard manure amendment (51 m^{-2}). In perennial ley treatments its mean density was low in *C. ciliaris* + *S. hamata* treatment (6.4 m^{-2}) which increased to about eight folds higher in *C. ciliaris* treatment (51 m^{-2}).

The population densities differed significantly across the tillage and organic amendment treatments ($P < 0.01$) (Table 17), and the perennial ley treatments between seasons ($P < 0.05$) (Table 18). ANOVA of the monthly data showed that their population densities did not differ significantly across all the treatments during any month (Table 19). However, the population densities differed significantly across the organic amendment treatment during October 1989 ($P < 0.05$) (Table 20), whereas the densities did not show any significant difference across the perennial ley treatments (Table 21) during any month.

Poduridae: Its population densities of Poduridae across the treatments presented in Fig. 42a revealed that the mean density was significantly low in number in annual treatments (6.4 m^{-2}) compared to those of the perennial ley treatments (337 m^{-2}). Under annual crop, in zero tillage treatments its density was low in bare amendment (19 m^{-2}) which increased to two times higher in farmyard manure, rice-straw amendments (38 m^{-2}). In shallow tillage treatments its number was low in bare amendment (19 m^{-2}) and increased to three folds higher in rice-straw amendment (57 m^{-2}). In deep tillage treatments its mean density was low in farmyard manure amendment (6.4 m^{-2}) and increased to about nine folds higher in bare amendment (57 m^{-2}). In perennial ley treatments its mean density was low in pigeonpea treatment (51 m^{-2}) which increased to more than six folds higher in pigeonpea + *S. hamata* treatment (337 m^{-2}).

The population densities differed significantly across the tillage and organic amendment treatments between seasons (P <0.01) and season x amendment interaction (P <0.05) (Table 17), and the perennial ley treatments between seasons (P <0.01) (Table 18). ANOVA of the monthly data showed that the population density of Poduridae differed significantly across all the treatments during October 1989 (P <0.05) (Table 19), whereas the densities did not show any significant difference across the tillage and organic amendments during any month (Table 20). However, their population densities differed significantly across the perennial ley treatments during October, 1989 (P <0.01) (Table 21).

Carabidae: Its population densities across the treatments presented in Fig. 42b revealed that the mean density was significantly low in number in perennial ley treatments (6.4 m^{-2}) compared to those of the annual treatments (115 m^{-2}). Under annual crop, in zero tillage treatments its mean density was low in farmyard manure and rice-straw amendments (89 m^{-2}) while it was slightly high in bare amendment (115 m^{-2}). In shallow tillage treatments its number was low in farmyard manure amendment (19 m^{-2}) and more than two folds higher in rice-straw amendment (45 m^{-2}). In deep tillage treatments its number was low in bare amendment (64 m^{-2}) which increased to 102 m^{-2}. In perennial ley treatments its mean density was low in *C. ciliaris* + *S. hamata* amendment (6.4 m^{-2}) and increased

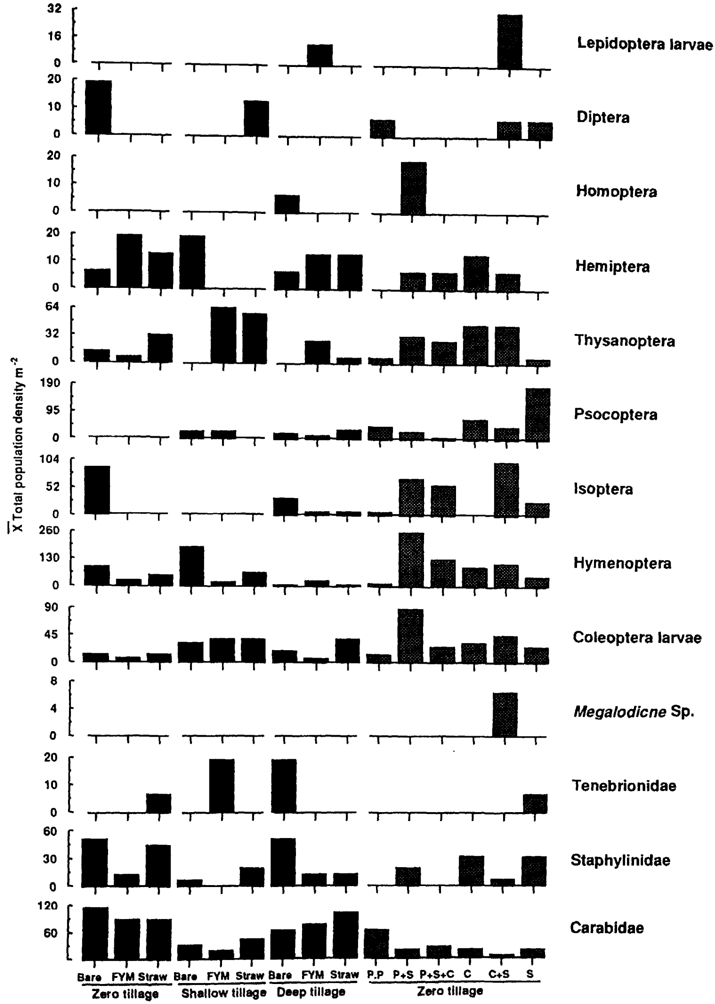

Figure 42b. Population densities of some of the soil-inhabiting microarthropod groups m^{-2} across the fifteen soil management treatments.

to ten folds higher in pigeonpea treatment (64 m^{-2}).

The population densities differed significantly across the tillage and organic amendment treatments between seasons (P <0.05) (Table 17) as revealed by the ANOVA. However, the densities did not differ significantly across the perennial ley treatments (Table 18). ANOVA of the monthly data showed that the population densities did not differ significantly across all the treatments (Table 19), and tillage and organic amendment treatments (Table 20) and perennial ley treatments (Table 21) during any month.

Staphylinidae: Its population densities across the treatments presented in Fig. 42b revealed that the mean density was significantly low in number in shallow tillage bare and *C. ciliaris* + *S. hamata* treatments (6.4 m^{-2}) which increased to more than eight folds higher in zero and deep tillage bare treatments (51 m^{-2}). Under annual crop, in zero tillage treatments its mean density was low in farmyard manure amendment (13 m^{-2}) and increased to about four folds higher in bare amendment (51 m^{-2}). In shallow tillage treatments its number was low in bare amendment (6.4 m^{-2}) and three times higher in rice-straw amendment (19 m^{-2}). In deep tillage treatments its number was low in farmyard manure and rice-straw amendments (13 m^{-2}) and about four folds higher in bare amendment (51 m^{-2}). In perennial ley treatments its mean density was low in *C. ciliaris* + *S. hamata* treatment (6.4 m^{-2}) which increased to five folds higher in *C. ciliaris* and *S. hamata* treatments (32 m^{-2}).

The population densities differed significantly across the tillage and organic amendment treatments between season x tillage x amendment interaction (P <0.05) as revealed by the ANOVA (Table 17), whereas their population densities did not differ significantly across the perennial ley treatments (Table 18). ANOVA of the monthly data showed that their densities did not differ significantly across all the treatments (Table 19), and tillage and organic amendment treatments (Table 20), and perennial ley treatments (Table 21) during any month.

Tenebrionidae: Its population densities across the treatments presented in Fig. 42b revealed that the mean density was significantly low in number in zero tillage rice-straw and *S. hamata* treatments (6.4 m^{-2}) which increased to about three times higher in shallow tillage farmyard manure and deep tillage bare amendments (19 m^{-2}) and not recorded in other treatments.

The population densities differed significantly across the tillage and organic amendment treatments between seasons (P <0.05) (Table 17) as revealed by the ANOVA. However, their densities did not differ significantly across the perennial ley treatments (Table 18). ANOVA of the monthly data showed that their densities did not differ significantly across all the treatments (Table 19), and tillage and organic amendment treatments (Table 20) and perennial ley treatments (Table 21) during any month.

Megalodicne Sp.: Its population densities across the treatments presented in Fig. 42b revealed that the mean density was negligible in number and was 6.4 m^{-2} only in *C. ciliaris* + *S. hamata* treatment and they were not recorded in other treatments.

The population densities did not differ significantly across the tillage and organic amendments (Table 17) and perennial ley treatments (Table 18) as revealed by the ANOVA. ANOVA of the monthly data showed that their densities did not differ significantly across all the treatments (Table 19), and tillage and organic amendment treatments (Table 20) and perennial ley treatments (Table 21) during any month.

Coleoptera larvae: Its population densities across the treatments presented in Fig. 42b revealed that the mean density was significantly low in number in annual treatments (6.4 m^{-2}) compared to those of the perennial ley treatments (89 m^{-2}). Under annual crop, in zero tillage treatments its mean density was low in farmyard manure amendment (6.4 m^{-2}) which increased to two times higher in bare and rice-straw amendments (13 m^{-2}). In shallow tillage treatments its number ranged between 32 to 38 m^{-2} across the organic amendments. In deep tillage treatments its number was low in farmyard manure amendment (6.4 m^{-2}) which increased to about six times higher in rice-straw amendment (38 m^{-2}). In perennial ley treatments its mean density was low in pigeonpea treatment (13 m^{-2}) and increased to more than six folds higher in pigeonpea + *S. hamata* treatment

(89 m^{-2}).

The population densities differed significantly across all the 15 treatments as revealed by the ANOVA during postrainy season (*P* <0.01) (Table 16). However, the densities did not differ significantly across the tillage and organic amendment treatments (Table 17), whereas their densities differed significantly across the perennial ley treatments between seasons (*P* <0.01), and season x treatment interaction (*P* <0.01) (Table 18). ANOVA of the monthly data showed that their population densities differed significantly across all the treatments during September 1989 (*P* <0.05) and October 1990 (*P* <0.01) (Table 19), whereas their densities did not differ significantly across the tillage and organic amendment treatments (Table 20) during any month. However, their densities differed significantly across the perennial ley treatments during October 1990 (*P* <0.01) (Table 21).

Hymenoptera: Its population densities across the treatments presented in Fig. 42b revealed that the mean density was significantly low in number in annual treatments (6.4 m^{-2}) compared to those of the perennial ley treatments (255 m^{-2}). Under annual crop, in zero and shallow tillage treatments its mean density was low in farmyard manure amendments (26 m^{-2} and 19 m^{-2}) while it was high in bare amendments (89 m^{-2} and 185 m^{-2} respectively). In deep tillage treatments its number was low in bare and rice-straw amendments (6.4 m^{-2}) and increased to four times higher in farmyard manure amendment (26 m^{-2}). In perennial ley treatments its mean density was low in number in pigeonpea treatment (13 m^{-2}) which increased to more than nineteen folds higher in pigeonpea + *S. hamata* treatment (255 m^{-2}).

The population densities differed significantly across the tillage and organic amendment treatments between seasons (P <0.01) and season x tillage x amendment interaction (P <0.01) (Table 17) as revealed by the ANOVA, whereas their densities did not differ significantly across the perennial ley treatments (Table 18). ANOVA of the monthly data showed that the population densities differed significantly across all the treatments during September 1989 (P <0.01) (Table 19), and tillage (P <0.05) and organic amendment (P <0.05) during September 1989 (Table 20), while they did not show any significant difference across the perennial ley treatments (Table 21) during any month.

Isoptera: Its population densities across the treatments presented in Fig. 42b revealed that the mean density was significantly low in number in deep tillage farmyard manure, rice-straw and pigeonpea treatments (6.4 m^{-2}) which increased to fifteen times higher in *C. ciliaris* + *S. hamata* treatment (102 m^{-2}). Under annual crop, in zero tillage treatments its mean density was 89 m^{-2} in bare amendment and not recorded in other two amendments. They were not recorded in shallow tillage treatments. In deep tillage treatments its mean density was low in farmyard manure and rice-straw amendments (6.4 m^{-2}) and increased to five folds higher in bare amendment (32 m^{-2}). In perennial ley treatments its mean density was low in pigeonpea treatment (6.4 m^{-2}) which increased to about sixteen folds higher in *C. ciliaris* + *S. hamata* treatment (102 m^{-2}).

The population densities were not significantly different across the tillage and organic amendment treatments (Table 17) and perennial ley treatments (Table 18) as revealed by the ANOVA. ANOVA of the monthly data showed that their population densities did not differ significantly across all the treatments (Table 19), and the tillage and organic amendment treatments (Table 20) and perennial ley treatments (Table 21) during any month.

Psocoptera: Its population densities across the treatments presented in Fig. 42b revealed that the mean density was significantly low in number in pigeonpea + *S. hamata* + *C. ciliaris* treatment (6.4 m^{-2}) which increased to about twenty nine folds higher in *S. hamata* treatment (185 m^{-2}). Under annual crop, they were not recorded in zero tillage treatments. In shallow tillage treatments its mean density was 26 m^{-2} in bare and farmyard manure amendments and not recorded in rice-straw amendment. In deep tillage treatments its mean density was low in farmyard manure amendment (13 m^{-2}) which increased to more than two times higher in rice-straw amendment (32 m^{-2}). In perennial ley treatments its mean density was low in pigeonpea + *S. hamata* + *C. ciliaris* treatment (6.4 m^{-2}) and increased to about twenty nine folds higher in *S. hamata* treatment (185 m^{-2}).

The population densities differed significantly across the tillage and organic amendment treatments between seasons (P <0.05), tillage (P <0.05) and season x tillage x amendment interaction (P <0.05) (Table 17) as revealed by the ANOVA, while they did not show any significant difference across the perennial ley treatments (Table 18). ANOVA of the monthly data showed that the population densities of Psocoptera did not differ significantly across all the treatments (Table 19), and the tillage and organic amendment treatments (Table 20) and perennial ley treatments (Table 21) during any month.

Thysanoptera: Its population densities across the treatments presented in Fig. 42b revealed that the mean density was significantly low in number in zero tillage farmyard manure, deep tillage rice-straw, and pigeonpea and *S. hamata* treatments (6.4 m^{-2}) which increased to ten folds higher in shallow tillage farmyard manure amendment (64 m^{-2}). Under annual crop, in zero tillage treatments its mean density was low in farmyard manure amendment (6.4 m^{-2}) while it was five folds higher in rice-straw amendment (32 m^{-2}). In shallow and deep tillage treatments its mean density was low in rice-straw amendments (57 m^{-2} and 6.4 m^{-2}) which was slightly higher in farmyard manure amendments (64 m^{-2} and 26 m^{-2} respectively). In perennial ley treatments its mean density was low in pigeonpea and *S. hamata* treatments (6.4 m^{-2}) and increased to seven folds higher in *C. ciliaris* + *S. hamata* treatment (45 m^{-2}).

The population densities did not differ significantly across the tillage and organic amendment treatments (Table 17) as revealed by the ANOVA, while their population densities differed significantly across the perennial ley treatment between seasons (P <0.01) (Table 18). ANOVA of the monthly data showed that their densities were significantly different across all the treatments during October, 1989 (P <0.05) (Table 19), whereas they did not differ significantly across the tillage and organic amendment treatments (Table 20) during any month. However, their monthly densities were significantly different across the perennial ley treatment during October, 1989 (P <0.01) (Table 21).

Hemiptera: Its population densities across the treatments presented in Fig. 42b revealed that the mean density was significantly low in number in zero, deep tillage bare, pigeonpea + *S. hamata*, pigeonpea + *S. hamata* + *C. ciliaris* and *C. ciliaris* + *S. hamata* treatments (6.4 m^{-2}) which increased to about three folds higher in zero tillage farmyard manure and shallow tillage bare amendments (19 m^{-2}). Under annual crop, in zero tillage treatments its mean density was low in bare amendment (6.4 m^{-2}) and increased to about three folds higher in farmyard manure amendment (19 m^{-2}). In shallow tillage treatments it was 19 m^{-2} only in bare amendment and not recorded in other two amendments. In deep tillage treatments its number was low in bare amendment (6.4 m^{-2}) and increased to two folds higher in farmyard manure and rice-straw amendments (13 m^{-2}). In perennial ley treatments its mean density was low in number in pigeonpea + *S. hamata*, pigeonpea + *S. hamata* + *C. ciliaris* and *C. ciliaris* + *S. .hamata* treatments (6.4 m^{-2}) which increased to two folds higher in *C. ciliaris* treatment (13 m^{-2}).

The population densities differed significantly across the tillage and organic amendment treatments (P <0.01) (Table 17) and perennial ley treatments between seasons (P <0.01) (Table 18) as revealed by the ANOVA. ANOVA of the monthly data showed that their population densities did not differ significantly across all the treatments (Table 19) and tillage and organic amendment treatments (Table 20) and perennial ley treatments (Table 21) during any month.

Homoptera: Its population densities across the treatments presented in Fig. 42b revealed that the mean density was low in number in deep tillage bare amendment (6.4 m^{-2}) which increased to about three folds higher in pigeonpea + *S. hamata* treatment (19 m^{-2}) and not recorded in other treatments.

The population densities did not differ significantly across the tillage and organic amendment treatments (Table 17) as revealed by the ANOVA, while their population densities differed significantly across the perennial ley treatments between season x treatment interaction (P <0.01) (Table 18). ANOVA of the monthly data showed that their population densities did not differ significantly across all the treatments (Table 19), and tillage and organic amendment treatments (Table 20) and perennial ley treatments (Table 21) during any month.

Diptera: Its population densities Diptera across the treatments presented in Fig. 42b revealed that the mean density was significantly low in number in pigeonpea, *C. ciliaris* + *S. hamata* and *S. hamata* treatments (6.4 m^{-2}) and increased to about three folds higher in zero tillage bare amendment (19 m^{-2}) followed by shallow tillage rice-straw amendment (13 m^{-2}) and was not recorded in other treatments.

The population densities did not differ significantly across the tillage and organic amendment treatments (Table 17) and perennial ley treatments (Table 18) as revealed by the ANOVA. ANOVA of the monthly data showed that their densities did not differ significantly across all the treatments (Table 19), and tillage and organic amendment treatments (Table 20) and perennial ley treatments (Table 21) during any month.

Lepidoptera larvae: Its population densities across the treatments presented in Fig. 42b revealed that the mean density was low in number in deep tillage farmyard manure amendment (13 m^{-2}) which increased to more than two folds higher in *C. ciliaris* + *S. hamata* treatment (32 m^{-2}) and was not recorded in other treatments.

The population densities differed significantly across the 15 treatments as revealed by the ANOVA during postrainy season (P <0.01) (Table 16), while their population densities did not differ significantly across the tillage and organic amendment treatments (Table 17). However, their densities differed significantly across the perennial ley treatments between seasons (P <0.05) and season x treatment interaction (P <0.01) (Table 18). ANOVA of the monthly data showed that the population densities differed significantly across all the treatments during

September, 1989 (*P* <0.05) and October 1989 (*P* <0.01) (Table 19), whereas their densities did not differ significantly across the tillage and organic amendment treatments (Table 20) and perennial ley treatments (Table 21) during any month.

DISCUSSION

The microarthropods were identified only upto higher taxa levels such as Araneae, Pseudoscorpions and Acarina (Arachnida), Diplopoda, Chilopoda and Symphyla (Myriapoda), Protura, Thysanura, Diplura and Collembola (Apterygota: Insecta), Coleoptera, Hymenoptera, Isoptera, Psocoptera, Thysanoptera, Hemiptera, Homoptera, Diptera and Lepidoptera larvae (Pterygota : Insecta). Different studies in soil arthropod ecology revealed a considerable variation in the description, and structural components of arthropod populations. Therefore, it is difficult to assess whether or not the results reported by different authors are due to the treatment differences and due to the techniques used. However, the variety of the fauna collected in the present study areas and the relatively dense populations recorded suggest that the extraction technique used was efficient. The extraction of small and delicate microarthropods such as Prostigmata, Protura and Psocoptera attest to the efficiency of the extraction procedure used during the present investigation (Price, 1973) because of the difficulties in determining their genus and species. A mean total density of 2,49,550 m^{-2} microarthropods belonging to 29 taxa were recorded across fifteen soil management treatments. Berg and Pawluk (1984) reported that the total microarthropods ranged from 13,000 to 1,22,000 m^{-2} under different vegetative regimes in north Central Alberta, Canada. Ao (1987) reported microarthropods of 2,45,545 m^{-2} and 2,04,491 m^{-2} belonging to 22 different taxa under upland rice and maize ecosystems in north-east India.

Acarina was dominant among the microarthropods, and their mean density was 1,43,080 m^{-2}. These estimates are nearer to those of Salt et al (1948) who recorded 1,64,363 m^{-2} in pasture soil. However, Ao (1987) recorded less number, 74,284 m^{-2} in upland rice and 63,207 m^{-2} in maize ecosystems. Wallwork (1967) reported that the Acarina was dominant in different habitats. The probable reason for their dominance may be the environmental factors and availability of their requirements like food and shelter in the habitat. Moore et al (1984) and Emmanuel et al (1985) recorded Acarina as the most dominant group from barley ecosystem. Among the Acarina, Prostigmata was dominant and represented 65,450 m^{-2}. Price (1973) recorded the dominance of Prostigmata with an estimated density of 74,981 m^{-2}, while Emmanuel et al, (1985) reported that the group was at the highest mean level of abundance in barley ecosystem. The reason for the dominance of Prostigmata is not known and it was suggested that they are mostly small in size and delicate which are more easily overlooked or may not be as readily obtained by the Tullgren or floatation methods (Gill, 1969, and Price, 1973). Their dominance in the experimental area may be further attributed to their physiological or behavioural adaptations which makes them, as a group, more tolerant to the dry environmental conditions (Loots and Ryke, 1967). Mesostigmata were relatively low in numbers across the treatments. Madge (1965) and Ao (1987) found that the Mesostigmata were low in numbers in agroecosystems. The low abundance of Mesostigmata may be due to the competitive exclusion effect caused by the large numbers of predatory arthropods.

Collembola maintained the second position in abundance. The average density of Collembola was 41,300 m^{-2}. This is in consistence to Ao (1987) also reported Collembola maintaining the second position in abundance in upland rice-ecosystem (7699 m^{-2}) while in maize field they were maximum in abundance (7411 m^{-2}). Among Collembola, Isotomidae was dominant followed by Poduridae, Sminthuridae and Entomobryidae. This is in consistence to the findings of Ao (1987) that Isotomidae was dominant among Collembola, in upland rice and maize ecosystem. Shams et al (1981) reported that the Isotomidae were higher in densities (two to four times greater) than the numbers of other Collembolan species under the effects of no-tillage corn production methods. Besides Acarina and Collembola, the other taxa of microarthropods were recorded low in numbers. In accordance with the present findings Ao (1987) reported that the average density of different arthropod taxa of microarthropods such as Psocoptera, Diplopoda, Diplura, Pseudoscorpionidae, Hymenoptera, Coleoptera and Isoptera, which are very less.

Among Coleoptera, Carabidae, Coleoptera larvae and Staphylinidae were higher in numbers. The presence of these arthropods particularly Carabidae and Staphylinidae may be attributed to their nature as predators on other insects in the soil litter sub-system. Prabhoo (1981) reported that the numbers of several taxa of Coleoptera such as Carabidae, Staphylinidae and Tenebrionidae as predators of insects and arthropods in the soil. *Megalodicne* Sps. and Tenebrionidae were recorded in poor numbers.

Many researchers have reported that the Acari and Collembola were predominant among the soil microarthropods and constituting 58.2% and 15.8%, respectively. Winter et al (1990) reported that the Acarina and Collembola comprised 93 to 89% of total faunal numbers in long-term no-tillage and conventional tillage corn production. In some cases the former are more numbers than the latter, in others, vice versa (Mani and Singh, 1955; Choudhuri and Roy, 1967; Mukharji and Singh, 1967, 1970; Singh and Mukharji, 1971; Bhattacharya and Joy, 1978; Veeresh and Reddy, 1978; Reddy, 1981; Prabhoo, 1981).

The seasonal variation in mean population densities of the total soil microarthropods across the soil management practices showed two peaks of abundances, the larger one being during the postrainy season, preceded by a smaller one rainy season. Their densities were low during the dry season. These findings are consistence to those of Bhattacharya (1971) that the higher densities of arthropod populations occurred during the post-monsoon period. Further, Singh and Mukharji (1971) also reported that the total microarthropods reached their maximum densities during monsoon and minimum during summer season. Singh (1977) recorded a maximum abundance of microarthropods during monsoon and a minimum during post-monsoon seasons. Loring et al (1981) reported reduced densities of soil arthropods during late July and August when the temperature was high. Ao (1987) recorded the larger peak of abundance of microarthropods during the post-monsoon season, preceded by monsoon and minimum in winter in the maize ecosystem.

Seasonal fluctuation in the mean population densities of soil microarthropods tended to follow seasonal pattern and was higher during rainy season particularly towards post-monsoon period, and decreased during the dry summer season across the treatments. Most probably rainfall and soil moisture, soil temperature and food resources had a favourable influence on soil microarthropod population densities (Sheals, 1957; Reddy, 1984).

The mean population densities during 1989 were small, and were distinctly different from those of the following year 1990. This is mainly because of ecotoxicological effects of Carbofuran, and the herbicides applied from time to time to the treatment plots. Many researchers have reported the reduced population structure of soil microarthropods because of insecticide and herbicide treatments (Ingham et al 1985; House et al 1987; Reddy, 1989). The population densities slowly recovered from the pesticide stress by the following rainy season in 1990. Moreover, during the initial months of the rainy season in these two years, the microarthropod mean densities were smaller in size compared to the following months of the growing season which may be because of disturbances caused by tillage operations practiced during that period. The development of an environmental mosaic (i.e., soil stabilization and undisturbedness, and favourable environment) in the following months probably have induced reestablishment and recolonisation of the microarthropods leading to their increased population densities. Such an initial decrease in microarthropod mean population density followed by an increase towards the end of the growing season is an accordance with the findings of Stinner and Crossley (1980) and Loring et al (1981).

The temporal variation of Acarina such as Prostigmata and Cryptostigmata showed the higher peaks of their mean abundance during the rainy season, followed by postrainy season and minimum during the dry season across the treatments. This is in consistence to the findings of Choudhuri and Banerjee (1975) that single peak of abundance of Acari in monsoon with minimum in number in summer season. Prabhoo (1976) reported that the numbers of Acari were recorded highest single peaks during the monsoon. Singh and Mukharji (1971) and Singh (1977) recorded highest number of mites in monsoon and minimum number during post-monsoon and summer. Mitra et al (1981) recorded maximum numbers of Acari during monsoon and minimum in post-monsoon. Banerjee and Roy (1981) reported population peaks for Acari during the monsoon which decreased during summer season. Ao (1987) reported the highest peak of Acarina during the monsoon and post-monsoon which decreased during the winter in upland rice and maize ecosystems. Studies in temperate conditions showed maximum abundance of Acarina in July (Bellinger, 1954; Madge, 1965). Perdue and Crossley (1990) recorded largest number of Prostigmata during the winter-spring (December through April) in conventional and no-tillage agricultural systems.

Prabhoo (1976) reported that the greater number of Cryptostigmatid mites were recorded during monsoon and least in summer season. Further, Sanyal (1981a, b, 1982) and Sanyal and Bhadhuri (1982) recorded two peaks of Cryptostigmatid populations, one in pre-monsoon and the other in the beginning of the winter season, with minimal numbers towards the end of the winter season. Ghatak and Roy (1981) also recorded highest peak in monsoon, when jute crop was in the field which decreased in number in middle of summer season. Joy and Bhattacharya (1981) reported that the Cryptostigmata reached highest peak in post-monsoon and decreased in pre-monsoon. However, Ao (1987) reported that the population abundance of Cryptostigmata reached its peak during monsoon in the maize field, while it was high during summer and minimum during monsoon in the upland rice ecosystem. Many European investigations have speculated that the spring and autumn may be the periods of high Cryptostigmatid activity owing to the favourable conditions (Ford, 1937, 1938; Evan et al, 1961). The autumn and winter population peaks were largely produced by the appearance of larval and protonymphal stages (Wallwork, 1967).

The temporal variation of Mesostigmata indicated their mean densities being higher during the postrainy season and lower during rainy season, while they were not recorded during the summer across the treatments. They were less abundant among the acarina, during postrainy and rainy seasons. Prabhoo (1976) reported greater number of Mesostigmata during monsoon which decreased in number during summer season. In consistence, Ao (1987) reported that the Mesostigmata were less in abundance in their population number; she observed the peak abundance during monsoon and minimum during winter. Reduction in their population density was reported by Madge (1965), which was attributed to the availability of their prey. Astigmata was recorded highest peak of its mean densities during rainy season followed by postrainy and minimum in dry season. Ao (1987) reported the Astigmata population densities being higher during early winter in maize ecosystem.

The Collembola, during the present study, showed the higher peak of their mean abundance during the postrainy season preceded by rainy season while their mean densities were minimum during dry season across the treatments. This was due to the climatic and vegetational differences. Singh and Mukharji (1971) recorded maximum densities of Collembola during monsoon and post-monsoon seasons and minimum during summer. In consistence, Mitra et al (1977, 1981) reported that the Collembola showed two distinct peaks of abundances, one during monsoon and the other in post-monsoon seasons. Hazra and Choudhuri (1983) who reported that the Collembola were maximum during rainy season followed by postrainy season and very low during summer season. However, Choudhuri and Roy (1972) and Choudhuri and Banerjee (1975, 1977) observed only single peak of Collembola abundance which occurred during rainy season. Prabhoo (1976) recorded higher densities of Collembola during rainy season, which decreased during summer months. Ao (1987) reported that the total collembola of the maize ecosystem showed the highest peak of abundance during the monsoon and post-monsoon seasons and minimum during the winter while in the rice ecosystem she recorded the highest peak of abundance during the monsoon and minimum during the winter. Rickerl et al (1989) reported that the Collembola population tended to follow seasonal patterns (Broadhead and Wapshere, 1966) and to be higher during spring and fall seasons than summer season. Further, Berg and Pawluk (1984) reported that the Collembola were highest in fall, and they appear to move to perennial vegetation site in the fall before the onset of winter. Higher populations could also be the result of species multiplication in response to food abundance. Bellinger (1954) reported that the Collembola were maximum during spring. They are very sensitive to dry conditions and will actively move to moisture areas (Loring 1981; Joosse and Verhoef 1974).

The mean population densities of other miscellaneous groups such as Araneae, Diplopoda and Thysanoptera were too few to show the seasonality. However, their mean densities were recorded highest peak during postrainy season and minimum during rainy season, while it was not recorded during the dry season; that of the Pseudoscorpions was higher during rainy season and minimum during dry season, while it was not observed during postrainy season. Chilopoda and Symphyla were in higher peak of their mean densities during the rainy season while it was not recorded during the postrainy and dry seasons. Symphyla was minimum during the postrainy season, while it was not recorded during the dry season. Protura was recorded higher peak of its mean abundance during the rainy season followed by the dry season. In consistence to, Prabhoo

(1976) reported that the Symphyla and Protura were higher during monsoon season. Diplura was higher peak of its mean abundance during the postrainy season, followed by rainy season and were low during the dry season.

Coleoptera such as Carabidae and Staphylinidae were in higher mean densities during the postrainy season, followed by dry season and were low during the rainy season. In consistence, Dutta and Gupta (1981) reported that the Staphylinidae were higher during the dry season. Tenebrionidae were higher during the dry season and were not recorded during the rainy and postrainy seasons. *Megalodicne* sps. were recorded highest peak during the rainy season and were not recorded during postrainy and dry seasons. Coleoptera larvae were recorded highest peak of its mean abundance during the postrainy season, followed by rainy season and were low during the dry season. Hymenoptera and Thysanoptera were in higher mean densities during the postrainy season and minimum during rainy season, while it was not recorded during the dry season. In consistence, Ao (1987) reported that the densities of Hymenoptera were higher during the November, 1983. The other groups were too few to show any distinct seasonality.

The mean population densities of total soil microarthropods were higher in perennial ley treatments than the annual tillage and organic amendment treatments. This is in consistence to the findings of Persson and Lohm (1977) and Persson et al (1980) that the arthropods were lower in the arable soils than in uncultivated permanent grassland soils and forest soils in Sweden. Regular disturbances through ploughing, harrowing and sowing of the fields creates a less favourable environment for most soil arthropods than an undisturbed natural biotype. Small, mobile, omniphaghous species are favoured. Short generation time and resting stages are also characteristic properties of arable soil dwellers (Steen, 1983). It is well known that perennial grass crops in rotations are of great importance to soil fauna. The plant cover provides shelter for many species of litter dwellers. Such crops built up a large root biomass which along with the litter dropped from above ground parts, provide food for these arthropods. Besides, perennial cropping systems allow time for many fauna to recover from the effects of disturbances, e.g., annual ploughing. Thus, the perennial ley crops have higher densities of many faunal groups (Steen, 1983). Among the perennial cover crops, higher densities of microarthropods were recorded in the treatments with pigeonpea + *S. hamata, S. hamata* and pigeonpea + *S. hamata* + *C. ciliaris* compared to that of only sole pigeonpea. This may be because of the formation and subsequent arrangement of microhabitats available under a specific vegetational regime (Berg and Pawluk, 1984). Bhattacharya and Joy (1978) found maximum abundance of soil microarthropods in a fallow grassland than the fodder crop paddy fields.

The reduction of soil microarthropods in tillage plots may be due to the tillage effect and effects of pesticides spraying to kill the pests such as insects and weeds which may be the cause of depletion of the beneficial non-target soil fauna.

In consistence, Steen (1983) reported that some pesticides when used regularly can cause a permanent reduction of the soil fauna. Among the tillage treatments they were higher in the zero tillage treatments, followed by shallow and deep tillage treatments. These findings are in consistence with those of Loring et al (1981) that the population levels were declined dramatically in tillage plots than the no-till plots. Similarly, Nakamura (1988) reported low densities of microarthropods in the previous 4 years before and after beginning of the experiment which may be mainly due to the impact of tillage and partly to the effect of pesticide application. Tillage (mouldboard ploughing, harrowing, etc.) generally decreased the abundance of soil animals (Ghilarov, 1975; Stinner and Crossley, 1980). The direct detrimental effects of tillage are partly caused by abrasive damage to the animals and partly to trapping of animals in the soil when it is inverted and the existing system of cracks and pores is destroyed (Nakamura, 1988). The indirect effects of tillage, such as drying of the uppermost part of the soil or removal of litter from the soil surface are probably also of importance in decreasing the microarthropod densities (Gill, 1969; Wallwork, 1976; Andren and Lagerlof, 1980; Lal and De Vle eschauwer, 1982). House and Parmelee (1985) reported more number of soil arthropods in no-tillage treatment.

The present results are also in accordance with the findings of House and Alzugaray (1989) that tillage has a more consistent effect on soil arthropod community composition than no-tillage treatment. This is because tillage induced sudden changes in the soil environment, such as mechanical disturbances, changes in soil temperature and humidity, redistribution of plant residues, and disruption of access to their food resources (Wallwork, 1976; Andren and Lagerlof, 1980). On the other hand, no-tillage practices minimised soil disturbances; plant residues are deposited on the soil surface where they serve to reduce moisture loss and offer a concentration of food resources to the soil biota including the microarthropods. Among the three tillage amendments, the microarthropod densities were higher under the rice-straw than the bare and farmyard manure treated plots. It is in consistence to the findings of Edwards and Lofty (1969), Andren and Lagerlof (1983) and Nakamura (1988) that the organic mulch treated plots received larger number of soil arthropods than the no-treated mulch plots. It indicated that organic mulch is beneficial for soil animals, as mulch decreased the value of soil hardness and increased soil pH.

Acarina population mean densities were higher in the tillage treatments than the perennial ley treatments. In consistence, Pillai and Singh (1980) reported that the Acari was most abundant in the banana and citrus crops than the fodder crop and fallow land. Further, Boles and Oseto (1987) reported that the total mite populations were higher under conventional tillage than the no-tillage with 57 percent of the population occurring under conventional tillage and 43 percent occurring under no-till. However, Winter et al (1990) reported that the total Acarina were higher in the no-till corn than the conventional tillage corn. Singh and Mukharji (1971, 1973) reported that the abundance of Acari were higher in uncultivated system than the rose gardens and sugarcane fields. Further, Shams et al (1981) reported that the Acarina were higher in the no-till plots than the ploughed plots. Tillage significantly reduced their numbers. The surface litter on the no-till plots apparently represented a particular favourable habitat at the time of sampling. In the present study there was no big difference in Acarina population across the tillage treatments although they were slightly higher in the zero tillage treatment. In consistence, Loring et al (1981) reported that there was virtually no difference in Acarina composition between differently tilled plots. However, Nakamura (1988) reported that the Acarina were reduced in numbers in conventional tillage treatments than the direct drilling treatments. Among the three tillage organic amendment treatments, their population densities were higher in the rice-straw treatments than the farmyard manure and bare treatments. This is in consistence to the findings of Nakamura (1988) who reported that the Acarina were significantly higher in number in organic mulch treated plots than the without mulch treatment.

Among the Acarina, the mean densities of Prostigmata, followed by that of Cryptostigmata and Mesostigmata were higher in the tillage treatments than the perennial ley treatments. The population densities of Prostigmata were significantly affected by all the 15 treatments, during rainy and postrainy seasons ($P < 0.05$). Besides, the densities of Prostigmata, Cryptostigmata and Mesostigmata mites were significantly affected by tillage and organic amendment treatments between seasons ($P < 0.01$) while Prostigmata was significantly affected by season x tillage x organic amendment interaction ($P < 0.05$). The densities of Prostigmata, Cryptostigmata and Mesostigmata were also significantly affected by the perennial ley treatments between seasons (P <0.01), while Prostigmata (P <0.01) and Mesostigmata (P <0.05) were significantly affected by the season x treatment interaction. The population densities of Prostigmata and Cryptostigmata were significantly affected by all the treatments during September 1989 (P <0.05), that of Prostigmata during August 1990 and Mesostigmata during October 1989 (P <0.05). Besides, the population densities of Prostigmata (P <0.01) and Cryptostigmata (P <0.05) were significantly affected by the tillage treatments during September 1989, and that of Cryptostigmata across the tillage x amendment interaction during October 1989 (P <0.05). The population densities of Prostigmata and Cryptostigmata were significantly affected across the perennial ley treatments during July 1990 (P <0.05) and that of Mesostigmata during October 1989 (P <0.05). In consistence, Loring et al (1981) reported that the Prostigmata were higher in numbers in tilled plots than the no-tilled plots, and these mites can apparently well adapt to cultivated conditions and attain a considerable population size. Further, Boles and Oseto (1987) reported that the Prostigmatid mites were the dominant suborder with the highest numbers occurred under conventional tillage than the no-tillage. Among the tillage treatments the population densities of Prostigmata and Mesostigmata were higher in the zero tillage treatments than the shallow and deep tillage treatments while Cryptostigmata densities were higher in the shallow tillage treatments than the zero and deep tillage treatments. This is in consistence to the findings of Winter et al (1990) that the Prostigmata were higher in the no-till corn than the conventional tillage. Among the three tillage organic amendment treatments, the population densities of these groups were higher in the rice-straw treatments than the bare and farmyard manure treatments. Soil and surface organic residues were the apparent main source for colonization by the Prostigmatids during the growing crop (Emmanuel 1985). Bhattacharya et al (1981) reported that the population density of Cryptostigmata being maximum in the banana fields than the grassland. Winter et al (1990) reported that the Cryptostigmata and Mesostigmata were higher in the no-tillage corn than the conventional tillage corn. Astigmata were higher in the perennial ley treatments than the tillage treatments. Among the tillage treatments they were higher in the deep tillage treatments than the shallow and zero tillage treatments. This is in consistence to the findings of Winter et al (1990) that the Astigmata were higher in the conventional tillage than the no-till corn ecosystems.

The mean population densities of Collembola such as Isotomidae, Entomobryidae and Poduridae were higher in the perennial ley treatments than the tillage treatments. The population densities of Isotomidae were significantly affected by all the 15 treatments during postainy season ($P < 0.05$). Besides, the densities of Isotomidae, Sminthuridae and Poduridae were significantly affected by tillage and organic amendment treatments between seasons ($P < 0.01$), Isotomidae was significantly affected by organic amendment treatments ($P < 0.01$) and season x tillage x amendment interaction ($P < 0.05$), and Poduridae were significantly affected across season x amendment interaction ($P < 0.05$). The densities of Isotomidae (P <0.01); Sminthuridae (P <0.05) and Poduridae (P <0.01) were significantly affected by the perennial ley treatments between seasons. The population densities of Isotomidae were also significantly affected by all the treatments during October 1990 (P <0.05) while that of Poduridae were affected during October 1989 (P <0.05). Besides, the densities of Isotomidae were significantly affected by the organic amendment treatments during October 1990 (P <0.05) while that of Sminthuridae were significantly affected during October 1989 (P <0.05), the population densities of Poduridae were significantly affect by the perennial ley treatments during October 1989 (P <0.01). Edwards and Lofty (1969) reported that the Collembola were significantly more abundant in unploughed fields than in conventionally tilled soil of silty clay loam treated with herbicide, paraquat. Further, Hazra and Choudhuri (1983) reported that the total Collembolan populations were significantly higher in uncultivated fields than the cultivated fields. Similar results were obtained by Ghilarov (1973) and Edwards and Lofty (1973). According to Ghilarov (1973) when the uncultivated virgin soil was tilled the upper layers were destroyed the litter and other plant debris disappeared from the surface horizon; as a result all arthropods living in the litter layers found no suitable place after cultivation and obviously disappeared. Andren and Lagerlof (1983) that the Collembolans were significantly more abundant under grass plots than under oats crop. These data may reflect the fact that many of the Collembolans are surface feeders and respond directly to increases in organic matter (Steen, 1983). The reduced densities of Collembola under tillage treatments compared to perennial ley treatments probably was due to the effects of tillage and carbofuran may have reduced the populations. These findings are in consistence to those of Edwards (1970) and Popovici et al (1977) who reported that the pesticide reduced the numbers of Collembola. Among the tillage treatments the population densities of Isotomidae and Sminthuridae were higher in the zero tillage treatments than the shallow and deep tillage treatments. Boles and Oseto (1987) reported that the Collembola were higher in the no-tillage systems than the conventional tillage systems. The moisture content of the soil was probably the main factor affecting the distribution of Collembola. Collembolans were favoured by minimum tillage practices (Emmanuel et al., 1985). Farror and Crossley (1983) and Rickerl et al (1989) reported that the Collembola were more in no-till than tilled plots. Others have also reported greater number of Collembola in grass rooted plants or woodlands than in cultivated, tap-rooted crops (Cragg, 1961). Winter et al., (1990) observed that the Collembola were higher in the no-till corn than the conventional till corn fields. However, Shams et al (1981) reported that the no-till plots received higher *Isotoma* populations than the ploughing plots. The high number in no-till plots was probably due to the high organic matter concentrations and the low bulk density values. He further reported that ploughing whether by chisel or by moldboard, greatly reduces the *Isotoma* populations. Winter et al (1990) reported that the Isotomidae were higher in the no-till corn than the conventional till corn production. Shams et al (1981) reported that the *Isotoma* populations were high in the plots in which the crop residues are left on the soil surface, and was probably due to the available sources of moisture and energy. During the present study the Collembolan population did not differ much between three tillage practices. This is in consistence to the findings of Loring et al (1981) that there was virtually no difference in Collembolan composition between different tilled treatments. Among the three tillage organic amendment treatments, the densities of Isotomidae, Entomobryidae and Poduridae were higher in the rice-straw treatments than the farmyard manure and bare treatments. In consistence, Nakamura (1988) reported that the Collembola were significantly larger in number in the organic mulch treated plots compared to unmulch treated plots. This indicates that organic mulch is beneficial for soil arthropods (Edwards and Lofty 1969; Andren and Lagerlof, 1983). The reduced densities of Collembola recorded in bare treatments than the other two treatments was probably due to the fact that the treatment was without manure and mulch and exposed to the sunlight throughout the sampling period (Nakamura, 1988).

The population densities of Entomobryidae and Poduridae were recorded highest in the deep tillage treatments than the zero and shallow tillage treatments. Sminthuridae were higher in the tillage treatments than the perennial ley treatments. Winter et al (1990) reported that the Sminthuridae and Poduridae were higher in the no-till corn than the conventional till corn production. Among the three tillage amendment treatments they were higher in the bare treatments than the rice-straw and farmyard manure treatments.

The mean population densities of total Coleoptera, Carabidae, Staphylinidae and Tenebrionidae were higher in the tillage treatments than the perennial ley treatments. The population densities of Coleoptera larvae were significantly affected by all the 15 treatments during postrainy season ($P < 0.01$). Besides, the population densities of Carabidae and Tenebrionidae were also significantly affected by tillage and organic amendment treatments between seasons ($P < 0.05$), while that of Staphylinidae was affected by season x tillage x amendment interaction ($P < 0.05$). Nakamura (1988) reported that the Staphylinidae were higher in conventional tillage plots than the direct drilled plots under four cropping systems. However, *Megalodicne* sp. and the Coleopteran larvae were higher in perennial ley treatments than the tillage treatments. Among the tillage treatments, Carabidae and Staphylinidae were higher in the zero tillage treatment than the deep and shallow tillage treatments. The population densities of Tenebrionidae and Coleoptera larvae were higher in the shallow and deep tillage treatments than the zero tillage treatment. Among the three tillage organic amendment treatments total Coleoptera, Carabidae and Coleoptera larvae were higher in the rice-straw treatment than the bare and farmyard manure treatments. The population densities of Staphylinidae and Tenebrionidae were higher in the bare amendment treatment than the rice-straw and farmyard manure treatments. The densities of Coleoptera larvae were significantly affected by the perennial ley treatments ($P < 0.05$) between seasons ($P < 0.01$) and season x treatment interaction ($P < 0.01$). The densities of Coleoptera larvae were significantly affected by all the treatments during September 1989 ($P < 0.05$) and October 1990 ($P < 0.01$), while the perennial ley treatments affected their densities during October 1990 (P <0.01). These findings are in consistence to those of Nakamura (1988) that the Coleoptera were higher in the mulch treated plots than the without mulch treated plots under four soil management systems.

Araneae, Pseudoscorpions, Diplopoda, Chilopoda, Symphyla, Protura and Diplura mean densities were too few in number. However, their mean densities were recorded higher in the perennial ley treatments than the tillage treatments. The population densities of Diplura were significantly affected by all the 15 treatments during rainy and postrainy seasons (P <0.05). Besides, the densities of Symphyla were significantly affected by tillage and organic amendment treatments between seasons (P <0.05) while that of Diplura were affected by tillage (P <0.05). The densities of Symphyla, Protura and Thysanura were significantly affected by the perennial ley treatments between seasons (P <0.01). The population densities of Araneae (P <0.01) and Symphyla (P <0.05) were significantly affected by all the treatments during October 1989, while that of Pseudoscorpions during August 1990 (P <0.01). The population densities of Symphyla were significantly affected by tillage during August 1990 (P <0.05). Among the tillage treatments Araneae were higher in the shallow tillage treatment than the deep tillage treatment while they were not recorded in the zero tillage treatment. The Pseudoscorpions were higher in the zero tillage treatment than the shallow tillage treatment. The Symphyla, Protura and Diplura population densities were higher in zero tillage treatment than the deep tillage and shallow tillage treatments. Nakamura (1988) reported that the Symphyla were recorded only in direct drilling treatments and were not recorded in conventional tillage treatments under four soil management practices. Among the three tillage amendments Pseudoscorpions and Diplura were higher in the bare treatments than the rice-straw treatment. The Protura were higher in the bare and rice-straw treatments than the farmyard manure treatments. Among the tillage treatments, the Diplopods were higher in the deep tillage treatment than the shallow and zero tillage treatments. Among the three tillage organic amendment treatments Diplopoda and Symphyla were higher in the rice-straw treatment than farmyard manure and bare treatments. These findings are in consistence to those of Nakamura (1988) that the Diplopoda were higher in the mulch treated plots than the without mulch treated plots under four soil management practices. He further, reported that the Chilopoda were higher in the direct drilling plots than the conventional tillage treatments in four soil management practices. Thysanura mean densities were higher in the tillage treatments than the perennial ley treatments. Among the tillage treatments they were higher in the shallow tillage treatment than the zero and deep tillage treatments. Among the amendments they were higher in the farmyard manure treatment than the rice-straw and bare treatments.

The mean population densities of Hymenoptera, Isoptera, Psocoptera, Homoptera, Thysanoptera and Lepidoptera larvae were higher in the perennial ley treatments than the tillage treatments. The densities of Hymenoptera (*P*

< 0.01), Psocoptera ($P < 0.05$) and Hemiptera ($P < 0.01$) were significantly affected by tillage and organic amendment treatments between seasons, while Hymenoptera ($P < 0.01$) and Psocoptera ($P < 0.05$) were significantly affected by season x tillage x amendment interaction and Psocoptera by tillage ($P < 0.05$). The densities of Thysanoptera ($P < 0.01$), Hemiptera ($P < 0.01$) and Lepidoptera larvae ($P < 0.05$) were significantly affected across the perennial ley treatments between seasons, while that of Homoptera and Lepidoptera larvae were significantly affected by the season x treatment interaction ($P < 0.01$). The population densities of Hymenoptera ($P < 0.01$) and Lepidoptera larvae ($P < 0.05$) were significantly affected by all the treatments during September 1989, and Thysanoptera ($P < 0.05$) and Lepidoptera larvae were significant during October 1989. The perennial ley treatments significantly affected the population densities of Thysanoptera during October 1989 ($P < 0.01$). Among the tillage treatments the Hymenoptera and Thysanoptera populations were higher in the shallow tillage treatment than the zero and deep tillage treatments, while Isoptera populations were higher in the zero tillage treatment than the deep tillage treatment. The Psocoptera populations were higher in the deep tillage treatment than the shallow tillage treatment. Among the three tillage organic amendment treatments the population densities of Isoptera and Psocoptera were higher in the bare treatment than the farmyard manure and rice-straw treatments. Hymenoptera populations were higher in bare treatment than the rice-straw and farmyard manure treatments, while that of Thysanoptera were higher in farmyard manure treatment than the rice-straw and bare treatments.

Hemipteran and dipteran mean population densities were higher in the tillage treatments than the perennial ley treatments. Among the tillage treatments they were higher in the zero tillage treatment than the deep and shallow tillage treatments. Nakamura (1988) reported higher populations of these arthropods in conventional tilled plots than the direct drilled plots under four soil management systems. Among the three tillage organic amendment treatments they were higher in the bare treatment than the farmyard manure and rice-straw treatments. Among the tillage treatments, Homoptera and Lepidoptera larvae populations were recorded only in the deep tillage treatment, while among the organic amendment treatments Homoptera were recorded only in the bare treatment and Lepidoptera larvae were recorded in the farmyard manure treatment.

This indicated that the soil management practices had significantly affected the community structure of the soil microarthropods particularly during the rainy and postrainy seasons. However, during the dry season, there was no significant effect of these management practices on the microarthropod population densities as their densities were in reduced numbers because of the unfavourable and weather conditions.

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CHAPTER-IV

TERMITE POPULATION STRUCTURE

INTRODUCTION

Termites commonly known as "white ants" belonging to the order Isoptera, are small, and whitish to yellow and blackish-brown soft-bodied insects. They are called "Kashra harika" (wood feeding) in ancient Sanskrit literature. They are polymorphic social insects which live in self constructed nests which serve to house and protect the colony, store food material and maintain an optimum environment inside. The functioning of the termite colony is based on its self-regulated behaviour of individuals and there is a division of labour among them based on which they are differentiated into groups known as Castes within the colony. The individuals in a colony of termites are divided of three main castes such as workers, soldiers, and reproductives (a royal pair) (the so-called Kings (males) and Queens (females), which are morphologically distinguishable and perform separate functions.

Out of about 2500 different species of termites hitherto known in the world, some 270 species occur in Indian region. The classification of termites recognises nearly six families, of which five families are collectively known as the lower termites and the sixth one includes most of higher termites that are included in the family that is known as Termitidae. It includes 75 percent of the known species of higher termites. Of the 2500 species of termites we known world wide, about 300 species have been recorded as potential pests of agricultural crops, stored crops, forests and fruit trees, and gardens.

Termites are subterranean, and are one of the important groups of the soil macrofauna. They occur almost every where except in permanently waterlogged places and temperate higher cold climatic conditions. They are present throughout the tropics and semi-arid tropics other than the very high altitude zones. In some temperate regions, they occur at a lesser degree. Zimmerman et al (1982) reported that 70% of land being occupied by the termites in tropical and worm temperate areas of the world. Few species of termites such as *Odontotermes* spp. can maintain nests in cultivated fields. Foraging, however, takes place everywhere if left undisturbed for a few years (M.V. Reddy and V.R. Reddy, unpublished data). Subterranean termites are one of the most important diggers in the soil because of their habit of construction of foraging tunnels and soil sheetings, and play a significant role in the development of soil structure.

They make burrows that are prominent features of soil profiles and enhance the soil porosity. Thus, they may have a significant effect on macro-porosity. However, little is known of their effects on the hydraulic characteristics of soils (Lal, 1987). The construction of mounds and tunnels by termites involves the translocation of large quantities of soil. Part of the translocated soil is deposited at the surface in the form of mounds and earthen sheets which composed of excreta or of soil particles cemented together with excreta or saliva (Lee and Wood, 1971). The earthen sheet covers the foraging trails that lead to concentrated sources of food (plant litter, lags grass, dung pads). Sheetings probably serve to protect the foraging termites against desiccation, predators (notably ants) and competitors. The significance of termites in soils is related to their numbers and the effects they have in transporting and transforming the mineral and organic components of soils.

They contribute to the flow of energy and nutrients, as both herbivores and decomposers in the ecosystem (Ferrar and Watson, 1970; Watson and Gay, 1970; Wood and Sands, 1978; Spain and McIvor, 1988). Grass, litter- and humus-feeding termites would significantly influence the rate of decomposition of organic matter in certain grass lands such as tropical and sub-tropical savannas, and the dung of grazing animals is a significant source of organic matter and its decomposition is strongly influenced by termites (Ferrar and Watson, 1970).

The possible beneficial effects of termites on soils by movement of soil profiles, and enhanced water penetration are receiving attention in recent years (Sands, 1977; Lal, 1987). They play an important role in nutrient cycling in tropical ecosystems (Holt and Coventry, 1990). They modify soil characteristics through energy and nutrients redistribution, and soil aeration and drainage (Lobry de Bruyn and Conacher, 1990). Termites affect nutrient availability by transporting soil and organic matter to mounds from which they are redistributed. They affect root growth through their influences on soil structure, pore space, permeability, water-holding capacity and stability of soil aggregates.

The magnitude of the ecological role of termites, as with other organisms, is largely a function of population density and biomass (Lee and Wood, 1971). Wood et al (1977) investigated the ecology and importance of termites in crops and pastures. Abbott et al (1979) studied on the changes in the abundance of large soil animals and physical properties of soils following cultivation. Abensperg-traun (1991) studied on the seasonal changes in activity of subterranean termite species in Western Australian wheatbelt habits. Since the 1950s, contribution of the termites to soil formation and their effects on soil fertility have been widely discussed (Adamson, 1943; Grasse, 1950; Hesse, 1955; Nye, 1955; Boyer, 1956; Maldague, 1959). Sands (1977) studied the role of termites in tropical agriculture. Wood and Johnson (1978) investigated on the abundance and vertical distribution in soil of *microtermes* in savanna woodland and agricultural ecosystem at Mokwa. Black and Wood (1989) investigated on the effects of cultivation on the vertical distribution of *microtermes* spp. in soil at Mokwa, Nigeria. In 1980s investigations were carried out on species diversity and densities of termites under different types of land use (Wood et al, 1977; 1982) and on the consumption of litter by termites (Buxton, 1981; Collins, 1981a, 1981b).

Research on the effects of different soil management practices such as tillage and stubble residue management strategies on soils has mainly concentrated on physical and chemical aspects. Studies on the effects of these agricultural management practices on termite density and diversity are very few and very much scattered (Douglas, 1987; Black and Wood, 1989). The termite population densities are severely depressed by tillage (Abbott et al, 1979; Clarke and Russell, 1977; Robertson et al, 1993). Unfortunately, very little information is available on the effect of different soil management practices such as tillage, organic amendments and other cover crops on population densities of termites in semi-arid tropics (Reddy et al, 1994). Therefore, the present investigation was carried out aiming at assessing the effects of different soil management practices upon the relative population densities of termites (trapped by toilet rolls) in a semi-arid tropical Alfisol.

MATERIALS AND METHODS

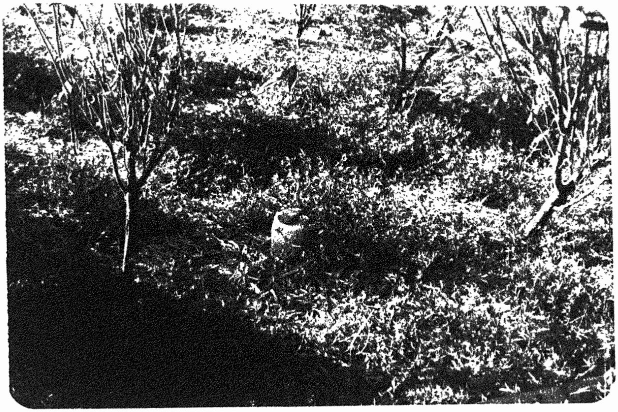
The species composition and the relative population densities of termites trapped by toilet rolls across the 15 soil management treatments were monitored by trapping using the toilet rolls by Haverty et al. 1974. Termites were sampled from the toilet rolls placed at three places in each plot, in every month across three different seasons i.e., rainy (June to September), postrainy (October to January), and dry season (February to May). Thus, they were collected for eleven months during the study period, i.e., on September, October, and December of 1989 and January to August of 1990. The toilet rolls were inserted in a wide mouthed plastic containers measuring about 12.5 cm high with a diameter of 8.8 cm at the mouth, and were installed in a inverted position on the soil surface so that the rim of the container and the toilet roll were flushed (touch) with the soil surface. On each sampling occasion the toilet rolls in each plot were retrieved and transferred immediately to in a enamel tray and the termites attacking the toilet roll (Plate-IXa) were separated by shaking and hand sorting method, the accuracy of which was checked by a soil washing and floatation technique (Raw 1955) and found satisfactory. Any toilet roll that had been completely eaten by termites were replaced every month and the toilet rolls which were not attacked were left as such (Plate-IXb). The collected termites were instantly preserved in 80% ethanol in plastic containers. In the laboratory these plastic containers were emptied in large petry dishes and termites were identified, separated and grouped into soldiers and workers. They were identified approximately, sent for species level identification to Zoological Survey of India (Calcutta).

The data on the relative population densities of soldiers and workers of different species of termites across the soil management treatments and seasons were analysed by ANOVA using GENSTAT package.

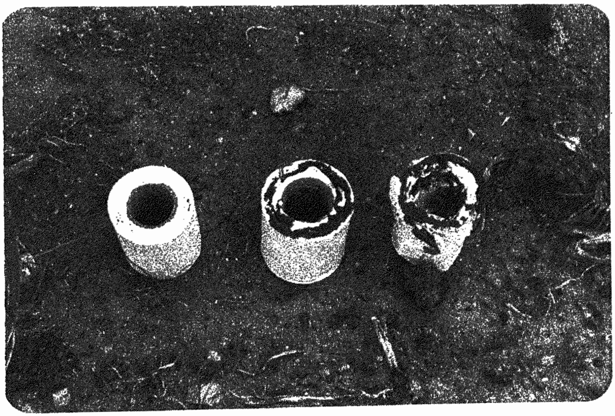
PLATE-IX

(a) A termite-trap, toilet roll covered by plastic container in the Zero tillage perennial ley (pigeonpea and *S. hamata*) treatment, and (b) Toilet rolls without and with termite attack

PLATE - IX



a



b

RESULTS

Qualitative Composition:

The termites sampled across the 15 soil management treatments such as different tillage and organic amendment treatments and perennial ley crop treatments belonged to two species *Odontotermes obesus* (Rambur) and *Microtermes obesi* Holmgren (Termitidae), the latter being dominant. The mean percentage composition of their soldiers and workers across the soil management treatments presented in Fig. 43 showed that the percentage composition of the soldiers of *O. obesus* ranged from 1.02 to 12.1%. In zero and shallow tillage treatments, their percentage composition ranged from 1.02% and 6.3% under farmyard manure amendments to 3.8% and 9.5% under bare amendments, respectively. In deep tillage treatments their percentage composition ranged between 4.3% in rice-straw amendment and 6.2% in bare amendment. In perennial ley treatments their percentage composition ranged from 3.3% in pigeonpea + *S. hamata* + *C. ciliaris* treatment to 12.1% in pigeonpea + *S. hamata* treatment.

The percentage composition of the workers of *O. obesus* ranged between 1.8 and 10.4% across the treatments. In zero tillage treatments their percentage composition ranged between 1.8% in farmyard manure amendment and 5.3% in bare amendment. In shallow tillage treatments their percentage composition ranged between 6% in bare amendment and 10% in rice-straw amendment. In deep tillage treatments the percentage composition ranged from 3.9% in farmyard

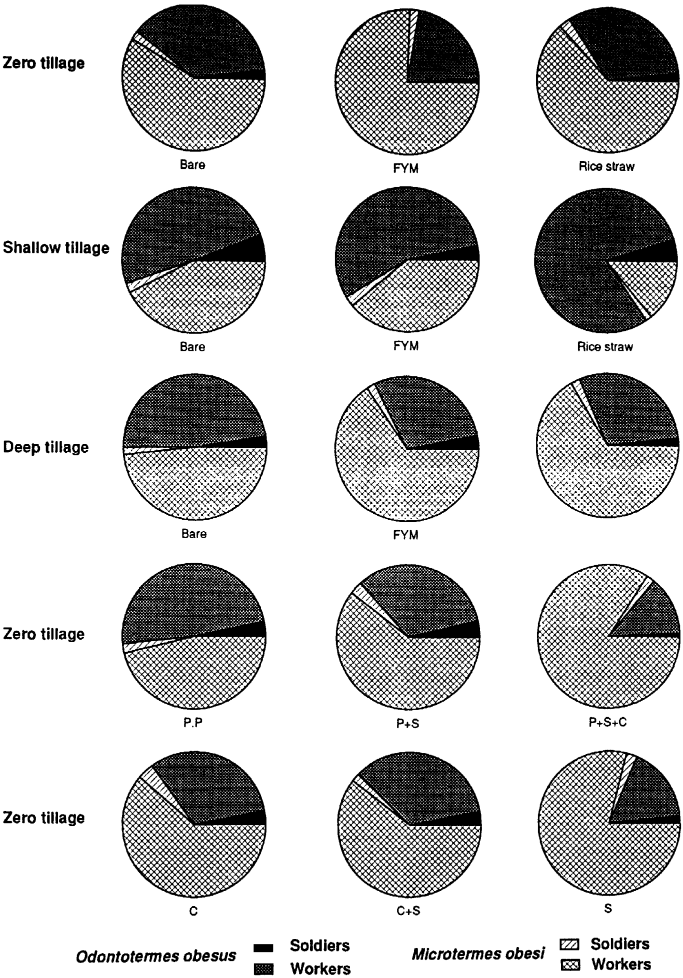


Figure 43. Percentage composition of soldiers and workers of the *Odontotermes obesus* and *Microtermes obesi* across the fifteen soil management treatments.

manure amendment to 9% in bare amendment. In perennial ley treatments the percentage composition ranged from 4% in pigeonpea + *S. hamata* + *C. ciliaris* treatment to 10.4% in *C. ciliaris* + *S. hamata* treatment.

The percentage composition of the soldiers of *M. obesi* ranged between 2.7 and 17% across the treatments. In zero tillage treatments their percentage composition ranged from 2.8% in farmyard manure amendment to 6% in rice-straw amendment. In shallow tillage treatments their percentage composition ranged from 2.7% in rice-straw amendment to 5.2% in farmyard manure amendment. In deep tillage treatments their percentage composition ranged from 3.9% in farmyard manure amendment to 5.9% in rice-straw amendment. In perennial treatments their percentage composition ranged from 4.9% in pigeonpea treatment to 17% in *C. ciliaris* treatment.

The percentage composition of the workers of *M. obesi* ranged from 1 to 14.9% across the treatments. In zero tillage treatments their percentage composition ranged from 3.7% in farmyard manure amendment to 5.4% in rice-straw amendment. In shallow tillage treatments the percentage composition ranged from 1% in rice-straw amendment to 3.3% in farmyard manure amendment. In deep tillage treatments the percentage composition ranged from 5% in farmyard manure amendment to 7.1% in rice-straw amendment. In perennial ley treatments the percentage composition ranged from 4.1% in pigeonpea treatment to 14.9% in pigeonpea + *S. hamata* + *C. ciliaris* treatment.

Temporal Variation:

Total termites: The seasonal fluctuation in the mean relative population densities of total soldiers of both *O. obesus* and *M. obesi* across the 15 soil management treatments presented in Figs. 44 a and b revealed that the mean density of soldiers was very meagre in number in zero tillage bare amendment which increased to eighteen folds higher (22.1) in pigeonpea + *S. hamata* treatment 50 days after sowing towards the end of the rainy season (September, 1989). The density was <1 in number in shallow tillage farmyard manure amendment and increased to thirty seven folds higher (29.3) in *C. ciliaris* + *S. hamata* treatment 90 days after sowing during the postrainy season (October, 1989). During the following fallow period, it was <1 in number in zero tillage farmyard manure amendment which increased to more than four hundred folds higher (44.3) in *C. ciliaris* treatment 40 days after harvesting the crop during the postrainy season (December, 1989). The mean density was <1 in number in zero tillage bare amendment and increased to more than three hundred folds higher (34.6) in *C. ciliaris* treatment 75 days after harvesting the crop towards the end of the postrainy season (January, 1990), and did not show much variation across the treatments 100 to 180 days after harvesting the crop during the dry season (February to May 1990). It was 1.4 in zero tillage farmyard manure amendment and increased to nineteen folds higher (26.8) in shallow tillage farmyard manure amendment 230 days after harvesting the crop during the beginning of the rainy season (June, 1990). During the 2nd crop season, the mean density was 2.8 in zero tillage bare amendment and increased to eleven folds higher (30.6) in *S.*

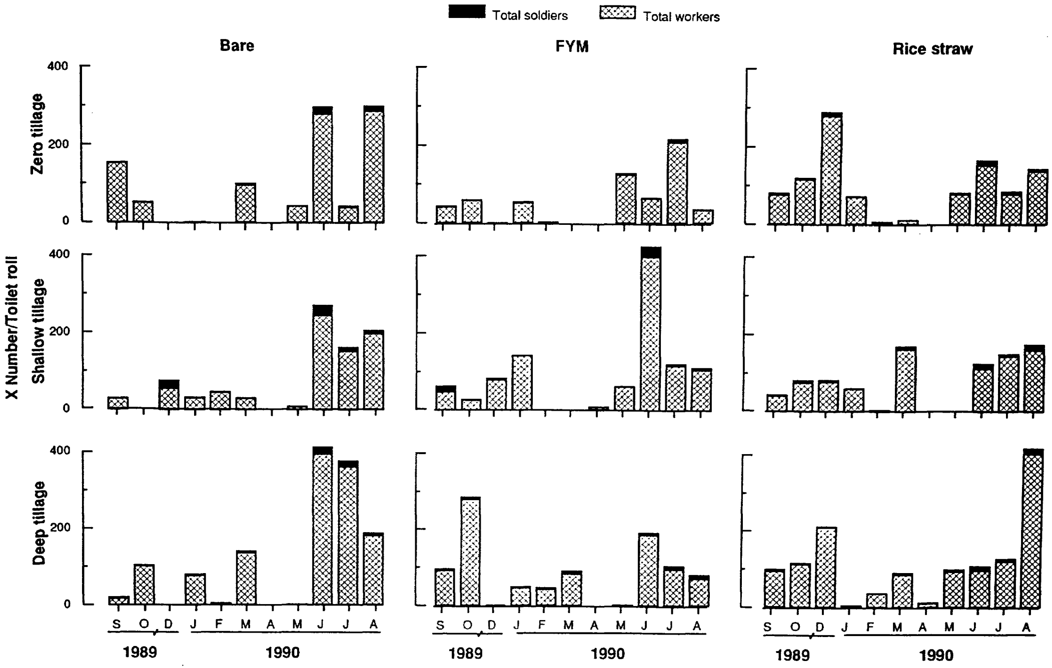


Figure 44a. Seasonal fluctuation in the relative population densities of total soliders and total workers of the *Odontotermes obesus* and *Microtermes obesi* termites across tillage and organic amendment treatments.

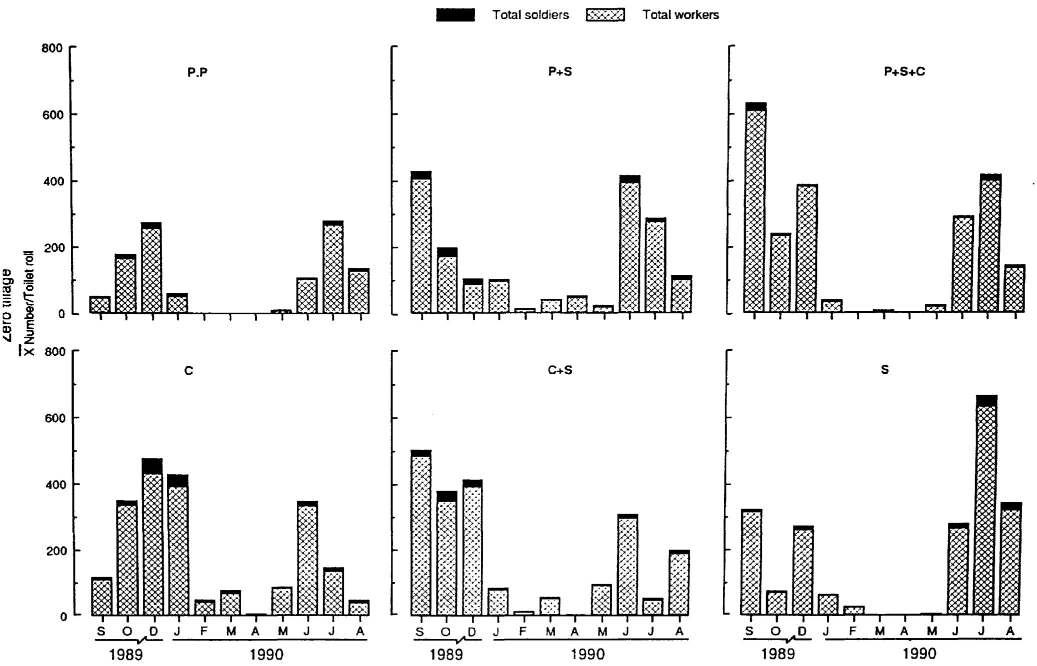


Figure 44b. Seasonal fluctuation in the relative population densities of total soliders and total workers of the *Odontotermes obesus* and *Microtermes obesi* termites under perennial ley crop treatments.

hamata treatment 5 days after sowing during the rainy season (July, 1990), and was 1.3 in zero tillage farmyard manure amendment and increased to fifteen folds higher (20) in *S. hamata* treatment 40 days after sowing during the rainy season (August, 1990).

The mean relative population density of total workers of *O. obesus* and *M. obesi* across the 15 soil management treatments presented in Figs. 44 a and b revealed that the density was 17 in number in deep tillage bare amendment and increased to thirty six folds higher (608) in pigeonpea + *S. hamata* + *C. ciliaris* treatment 50 days after sowing towards the end of the rainy season (September, 1989). It was 26 in shallow tillage farmyard manure amendment and increased to thirteen folds higher (347) in *C. ciliaris* + *S. hamata* treatment 90 days after sowing during the beginning of the postrainy season (October, 1989). During the following fallow period, it was <1 in number in deep tillage farmyard manure amendment which increased to more than two thousand folds higher (431) in *C. ciliaris* treatment 40 days after harvesting the crop during the postrainy season (December, 1989), and was 1.7 in zero tillage bare amendment and increased to more than two hundred folds higher (393) in *C. ciliaris* treatment 75 days after harvesting the crop towards the end of the postrainy season (January, 1990). It was 3 in zero tillage farmyard manure amendment and increased to about fifteen folds higher (46) in shallow tillage bare amendment 100 days after harvesting the crop during the beginning of the dry season (February, 1990), and was 4.7 in pigeonpea + *S. hamata* + *C. ciliaris* treatment which increased to thirty four folds higher (162) in shallow tillage rice-straw amendment 130 days after harvesting the crop during the dry season (March, 1990). It was <1 in *C. ciliaris* + *S. hamata* treatment and increased to more than one hundred fifty folds higher (46) in pigeonpea + *S. hamata* treatment 160 days after harvesting the crop during the middle of the dry season (April, 1990), and was <1 in deep tillage bare amendment and increased to more than hundred fifty folds higher (125) in zero tillage farmyard manure amendment 180 days after harvesting the crop towards the end of the dry season (May, 1990). It was 63.3 in zero tillage farmyard manure amendment and increased to six folds higher (398) in shallow tillage farmyard manure amendment 230 days after harvesting the crop during the beginning of the following rainy season (June, 1990). During the 2nd crop season, their mean density was 38.2 in zero tillage bare amendment and increased to about seventeen folds higher (632) in *S. hamata* treatment 5 days after sowing during the middle of the rainy season (July, 1990). It was 33.2 in zero tillage farmyard manure amendment and increased to about twelve folds higher (403) in deep tillage rice-straw amendment 40 days after sowing during the rainy season (August, 1990).

O. obesus: The mean relative population density of soldiers of *O. obesus* across the 15 soil management treatments presented in Figs. 45a and 46a revealed that the density was <1 in zero tillage farmyard manure amendment and increased to sixty folds higher (18) in pigeonpea + *S. hamata* treatment 50 days after sowing towards the end of the rainy season (September, 1989). It was <1 in pigeonpea

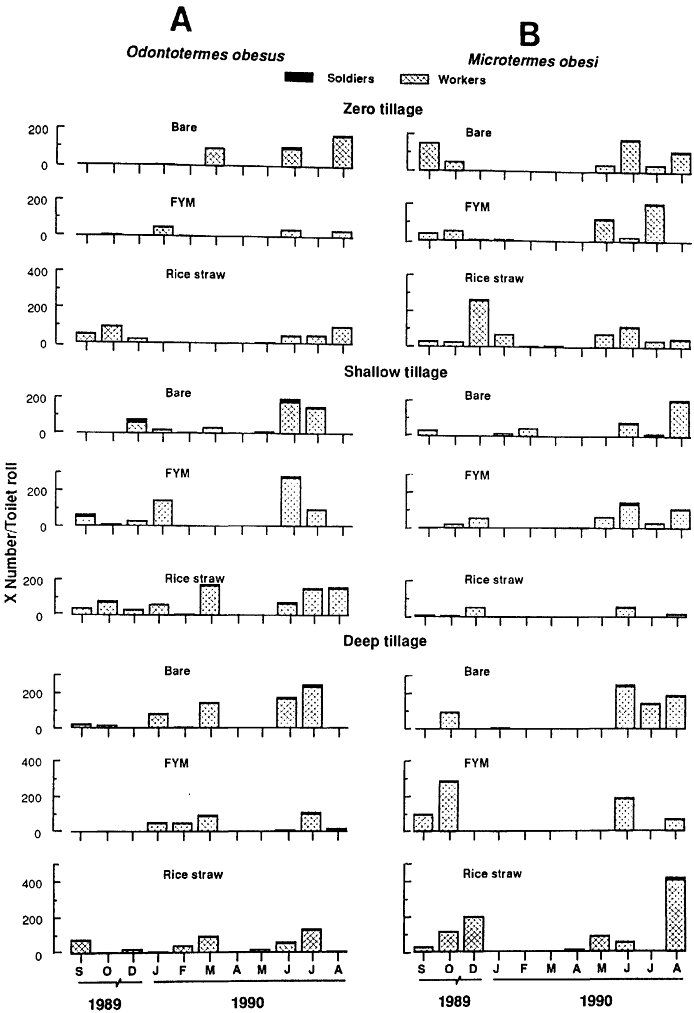


Figure 45. Seasonal fluctuation in the relative population densities of soldiers and workers of *Odontotermes obesus* (A) and that of *Microtermes obesi* (B) across tillage and organic amendment treatments.

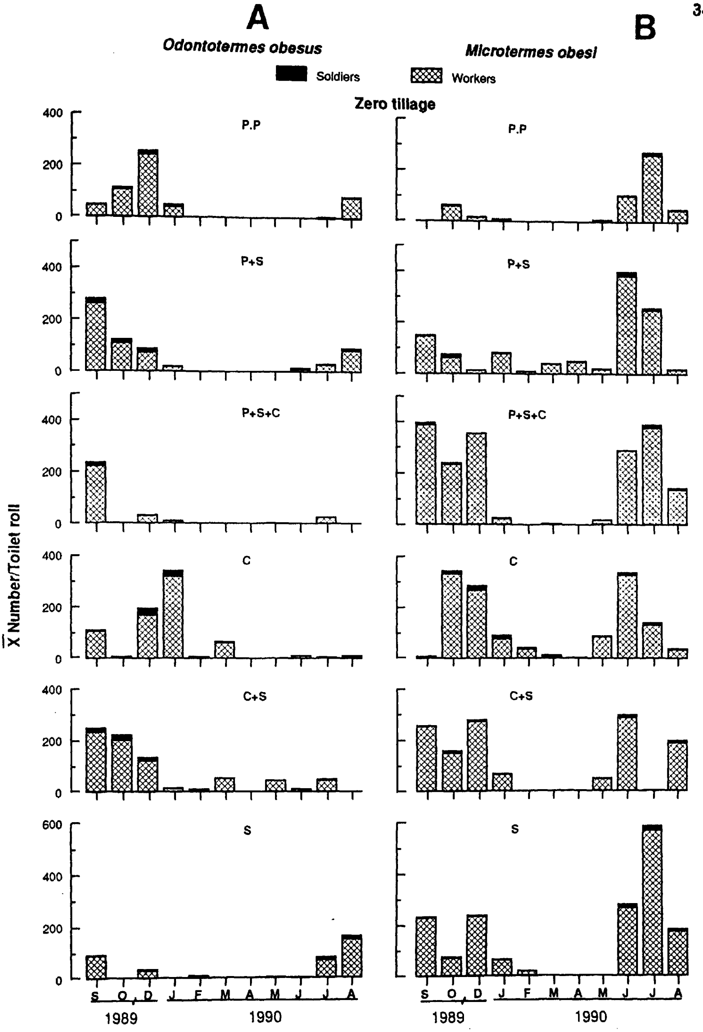


Figure 46. Seasonal fluctuation in the relative population densities of soldiers and workers of *Odontotermes obesus* (A) and that of *Microtermes obesi* (B) under perennial ley crop treatments.

+ *S. hamata* + *C. ciliaris* and *C. ciliaris* treatments and increased to more than hundred folds higher (22) in *C. ciliaris* + *S. hamata* treatment 90 days after sowing during the beginning of the postrainy season (October, 1989). During the following fallow period, it was <1 in deep tillage farmyard manure amendment and increased to more than one hundred thirty folds higher (27.4) in *C. ciliaris* treatment 40 days after harvesting the crop during the postrainy season (December, 1989). It was <1 in zero tillage bare amendment and increased to more than two hundred folds higher (22) in *C. ciliaris* treatment 75 days after harvesting the crop during the end of the postrainy season (January, 1990). The density did not show much variation across the treatments 100 to 180 days after harvesting the crop during the dry season (February to May 1990). It was <1 in deep tillage farmyard manure and *S. hamata* treatments and increased to ninety five folds higher (19) in shallow tillage bare amendment 230 days after harvesting the crop at the beginning of the following rainy season (June, 1990). During the 2nd crop season, it was <1 in *C. ciliaris* treatment and increased to fifteen folds higher (12.3) in deep tillage bare amendment 5 days after sowing during the rainy season (July, 1990), and was <1 in deep tillage rice-straw amendment and increased to about sixty four folds higher (12.8) in *S. hamata* treatment 40 days after sowing during the rainy season (August, 1990).

ANOVA revealed that the *O. obesus* soldiers were more or less same in number in tillage and organic amendment treatments during rainy, postrainy, and dry seasons, the differences among the seasons being not significant (Table 22),

Table 22. Response of relative population densities of termites to 15 soil management treatments during 1989-1990.

Termite measurement	Tillage and organic amendment treatments: Rainy	Post-rainy	Dry	At 1% LSD	Perennial ley treatments: Rainy	Post-rainy	Dry	At 1% LSD
O. obesus:								
Soldiers	4.8	4.7	3.6	5.3	0.9	18.3	2.4	13.9
Workers	67.5	50.8	76.6	62.9	25.7	166.3	11.2	104.2
M. obesi:								
Soldiers	3.8	2.9	0.7	2.7	8.4	15.0	4.4	8.5
Workers	82.8	135.5	18.5	93.8	255.7	412.9	88.4	199.6

whereas their densities showed significant variation under perennial ley treatments across the seasons. They were more than twenty folds higher during the postrainy season than that of the rainy season and they were more than seven folds higher during the postrainy season than that of dry season, these differences being statistically significant (Table 22).

The population density of workers of *O. obesus* across the 15 soil management treatments presented in Figs. 45a and 46a revealed that their mean density was 1.6 in number in zero tillage farmyard manure amendment and increased to more than one hundred sixty folds higher (262) in pigeonpea + *S. hamata* treatment 50 days after sowing towards the end of the rainy season (September, 1989). It was <1 in deep tillage farmyard manure amendment and increased to more than three hundred folds higher (199) in *C. ciliaris* + *S. hamata* treatment 90 days after sowing during the beginning of the postrainy season (October, 1989). During the following fallow period, the density was 14.8 in number in deep tillage rice-straw amendment and increased to sixteen folds higher (242) in pigeonpea treatment 40 days after harvesting the crop during the postrainy season (December, 1989), and was <1 in *S. hamata* treatment and increased to more than a thousand five hundred folds higher (317) in *C. ciliaris* treatment 75 days after harvesting the crop towards the end of the postrainy season (January, 1990). It was <1 in pigeonpea + *S. hamata* treatment and increased to about seventy folds higher (42) in deep tillage farmyard manure amendment 100 days after harvesting the crop during the beginning of the dry season (February, 1990), and was 30 in shallow tillage bare amendment and increased to five folds higher (162) in shallow tillage rice-straw amendment 130 days after harvesting the crop during the dry season (March, 1990). The density was very meagre across the treatments 160 days after harvesting the crop during the dry season (April, 1990). It was <1 in deep tillage bare amendment and increased to fifty five folds higher (44) in *C. ciliaris* + *S. hamata* treatment 180 days after harvesting the crop towards the end of the dry season (May, 1990). It was 1.3 in *S. hamata* treatment and increased to more than two hundred folds higher (260) in shallow tillage farmyard manure amendment 230 days after harvesting the crop during the beginning of the following rainy season (June, 1990). During the 2nd crop season, it was <1 in zero tillage farmyard manure amendment and increased to more than three hundred seventy folds higher (227) in deep tillage bare amendment 5 days after sowing during the rainy season (July, 1990), and was 1.3 in shallow tillage farmyard manure and deep tillage rice-straw amendments and increased to more than one hundred thirty folds higher (174) in zero tillage bare amendment 40 days after sowing during the rainy season (August, 1990).

ANOVA revealed that the workers of *O. obesus* were more or less same in number in tillage and organic amendment treatments during rainy, postrainy, and dry seasons, the differences among the seasons being not significant (Table 22), whereas, their population densities showed significant variation across perennial ley treatments among the seasons. They were more than six folds higher during the postrainy season than that of the rainy season and were more than fourteen folds higher during the postrainy season than that of the dry season, the differences being statistically significant (Table 22).

M. obesi: The population density of soldiers of *M. obesi* across the 15 soil management treatments presented in Figs. 45b and 46b revealed that the mean density was <1 in number in deep tillage rice-straw treatment and increased to fourteen folds higher (8.6) in pigeonpea + *S. hamata* + *C. ciliaris* treatment 50 days after sowing towards the end of the rainy season (September, 1989). The density was <1 in shallow tillage rice-straw amendment and increased to more than forty folds higher (12.3) in pigeonpea + *S. hamata* treatment 90 days after sowing during the beginning of the postrainy season (October, 1989). During the following fallow period, it was <1 in number in zero tillage farmyard manure amendment and increased to one hundred seventy folds higher (17) in *C. ciliaris* treatment 40 days after harvesting the crop during the postrainy season (December, 1989), and was <1 in zero tillage farmyard manure amendment and increased to more than one hundred twenty folds higher (12.7) in *C. ciliaris* treatment 75 days after harvesting the crop towards the end of the postrainy season (January, 1990). The density was represented in small numbers ranging from <1 to 5 across the treatments during 100 to 180 days after harvesting the crop during the beginning of the dry season (February to May 1990). It was 0.6 in zero tillage farmyard manure amendment and increased to twenty five folds higher (15) in shallow tillage farmyard manure and pigeonpea + *S. hamata* treatments 230 days after harvesting the crop during the beginning of the following rainy season (June, 1990). During the 2nd crop season, the mean density was 0.3 in *C. ciliaris* + *S. hamata* treatment and increased to sixty five folds higher (20) in *S. hamata* treatment 5 days after sowing during the middle of the rainy season (July, 1990). It was 1.9 in pigeonpea + *S. hamata* treatment and increased to about more than six folds higher (12.4) in deep tillage rice-straw amendment 40 days after sowing during the rainy season (August, 1990).

ANOVA revealed that the *M. obesi* soldiers were more than five folds higher in number in tillage and organic amendment treatments during postrainy season compared to those of the dry season, the difference being statistically significant (Table 22). Besides, their population densities showed significant variation under perennial ley treatments across the seasons. They were more than three folds higher during the postrainy season than those of the dry season, the difference being statistically significant (Table 22).

The population density of workers of *M. Obesi* across the 15 soil management treatments presented in Figs. 45b and 46b revealed that the mean density was <1 in number in shallow tillage farmyard manure amendment and increased to more than nine hundred sixty folds higher (387) in pigeonpea + *S. hamata* + *C. ciliaris* treatment 50 days after sowing towards the end of the rainy season (September, 1989). The density was 5.1 in shallow tillage rice-straw amendment and increased to sixty five folds higher (329) in *C. ciliaris* treatment

90 days after sowing during the beginning of the postrainy season (October, 1989). During the following fallow period, it was <1 in number in deep tillage farmyard manure amendment and increased to more than one thousand folds higher (353) in pigeonpea + *S. hamata* + *C. ciliaris* treatment 40 days after harvesting the crop during the postrainy season (December, 1989). It was <1 in deep tillage farmyard manure amendment and increased to eighty eight folds higher (79) in pigeonpea + *S. hamata* treatment 75 days after harvesting the crop towards the end of the postrainy season (January, 1990). It was 3.6 in zero tillage rice-straw amendment and increased to about twelve folds higher (42.4) in shallow tillage bare amendment 100 days after harvesting the crop during the beginning of the dry season (February, 1990), and was 4.7 in pigeonpea + *S. hamata* + *C. ciliaris* treatment and increased to eight folds higher (38) in pigeonpea + *S. hamata* treatment 130 days after harvesting the crop during the dry season (March, 1990). It was <1 in *C. ciliaris* + *S. hamata* treatment and increased to more than one hundred fifty folds higher (46.2) in pigeonpea + *S. hamata* treatment 160 days after harvesting the crop during the dry season (April, 1990), and was <1 in shallow tillage bare amendment and increased to more than four hundred folds higher (125) in zero tillage farmyard manure amendment 180 days after harvesting the crop towards the end of the dry season (May, 1990). It was 25 in zero tillage farmyard manure amendment and increased to fifteen folds higher (384) in pigeonpea + *S. hamata* treatment 230 days after harvesting the crop during the beginning of the following rainy season (June, 1990). During the 2nd crop season, the density was <1 in deep tillage farmyard manure and rice-straw amendments

and increased to more than one thousand eight hundred folds higher (563) in *S. hamata* treatment 5 days after sowing during the middle of the rainy season (July, 1990), and was 13 in shallow tillage rice-straw amendment and increased to more than thirty folds higher (401) in deep tillage rice-straw amendment 40 days after sowing during the middle of the rainy season (August, 1990).

ANOVA revealed that the population densities of workers of *M. obesi* were more than seven folds higher in number in tillage and organic amendment treatments during postrainy season compared to that of dry season, the difference being statistically significant (Table 22). Besides, their population densities showed significant variation under perennial ley treatments among the seasons. They were more than four folds higher during the postrainy season than that of the dry season, the difference being statistically significant (Table 22).

Treatment Effect:

Total termites: The mean relative population densities of total soldier termites (*O. obesus* + *M. obesi*) across the 15 soil management treatments presented in Fig. 47 revealed that the mean density was significantly low in the annual treatments (1.7) compared to that of the perennial ley treatments (12.8). Under annual crop in zero tillage treatment, their density was low in the farmyard manure amendment (1.7), which was slightly higher in rice-straw amendment (4.2); in shallow tillage treatments the densities ranged between 5.1 and 6.3 whereas in deep tillage treatments their number ranged between 4.2 and 4.9. In perennial ley

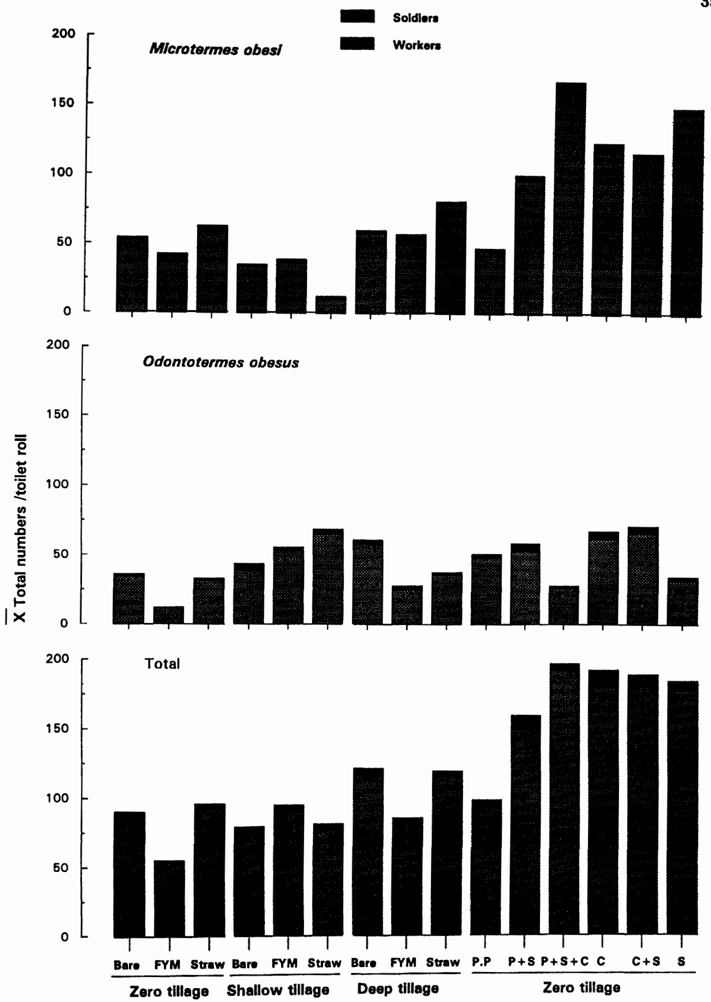


Figure 47. Relative population densities of soliders and workers of the *Odontotermes obesus* and *Microtermes obesi* across the fifteen soil management treatments.

treatments their densities ranged from 5.2 in pigeonpea + *S. hamata* + *C. ciliaris* treatment to 12.8 in *C. ciliaris* treatment.

The mean relative population density of total worker termites (*O. obesus* + *M. obesi*) recorded across the 15 soil management treatments presented in Fig. 47 revealed that their density was 53.1 in the annual treatments compared to that of the perennial ley treatments (191.3). Under annual crop, in zero tillage treatments their density ranged from 53.1 in the bare amendment to 91.2 in rice-straw amendment. In shallow tillage treatments the densities ranged from 72.4 to 89.2 while in deep tillage treatments their number ranged between 81 and 116. In perennial ley treatments their densities were in low in pigeonpea treatment (93) which increased to 191.3 in pigeonpea + *S. hamata* + *C. ciliaris* treatment.

O. obesus: The mean relative population density of soldiers of *O. obesus* across the 15 soil management treatments presented in Fig. 47 revealed that the mean density was significantly low in the annual treatments (<1) compared to that of the perennial ley treatments (5.9). Under annual treatments, in zero, shallow and deep tillage treatments its density showed very little variation ranging from <1 to 1.8, 3 to 4.6, and 2 to 3 in numbers, respectively. In perennial ley treatments their number ranged from 1.6 in pigeonpea + *S. hamata* + *C. ciliaris* treatment to 5.9 in pigeonpea + *S. hamata* treatment.

The population densities of soldiers of *O. obesus* significantly differed across the tillage treatments (P <0.05), as revealed by the ANOVA (Table 23). Besides, their densities also differed significantly across the perennial treatments between the seasons (P <0.01) (Table 24). ANOVA of the monthly data showed that the population densities of soldiers differed across all the different treatments during January and June 1990 (P <0.05) (Table 25). Their densities did not differ significantly across the tillage and organic amendment treatments (Table 26). However, the densities differed significantly across the perennial ley treatments during January 1990 (P <0.01) and February 1990 (P <0.05) (Table 27).

O. obesus: The population densities of workers of *O. obesus* across the 15 soil management treatments presented in Fig. 47 revealed that the mean density was significantly low in the annual treatments (11.7) compared to that of the perennial ley treatments (65.6). Under annual crop, in zero tillage treatments its density was low in the farmyard manure amendment (11.7) which increased more than three folds in bare amendment (33.8). In shallow tillage treatments the density was lower in bare amendment (38.9) and increased to 64.4 in rice-straw amendment. In deep tillage treatments it was low in farmyard manure amendment (25) and increased to more than two folds in bare amendment (57.6). In perennial ley treatments the density was 26 in pigeonpea + *S. hamata* + *C. ciliaris* treatment which increased to more than two folds in *C. ciliaris* + *S. hamata* treatment (65.6).

The population densities of workers of *O. obesus* differed significantly across all the 15 treatments as revealed by the ANOVA, during dry season (P

Table 23. Analysis of variance (mean squares) of relative population densities of termites across the tillage and organic amendment treatments (number in parentheses represent degrees of freedom).

Termite taxa	Seasons (S) (2)	Amend-ment (A) (2)	SxA (4)	Til-lage (T) (2)	SxT (4)	TxA (4)	SxTxA (8)	Error (46)	Mean abund-ance
	SOURCE OF VARIATION								
O. obesus:									
Soldiers	12	36	20	160*	87	56	57	52	4
Workers	4611	11092	2895	11683	11552	6665	5966	7348	65
M. obesi:									
Soldiers	72**	14	15	5	5	10	9	14	3
Workers	92650**	12676	30921	39023	20984	4771	7048	16322	79

* Significant at $P < 0.05$; ** Significant at $P < 0.01$.

Table 24. Analysis of variance (mean squares) of relative population densities of termites across the perennial ley treatments (number in parentheses represent degrees of freedom).

	SOURCE OF VARIATION				
Termite taxa	Seasons (S) (2)	Treatment (T) (5)	SxT (10)	Error (28)	Mean abundance
O. obesus:					
Soldiers	2237**	362	214	229	9
Workers	158022**	30175	22418	12842	96
M. obesi:					
Soldiers	511**	246*	90	86	8
Workers	474167**	140566*	61340	47080	198

* Significant at $P < 0.05$; ** Significant at $P < 0.01$.

Table 25. Analysis of variance (mean squares) of relative population densities of termites across the 15 soil management treatments during different months, 1989-90.

Year & Month		SOURCE OF VARIATION: Blocks (Ignoring treatments)	Entries (Eliminating blocks)	Within entries (Errors)	F (14, 21)	Mean abundance
O. obesus:						
Population density of soldiers						
1989		(The mean squares of different months of 1989 were not significant)				
1990	January	87	73	32	2.3*	3
	June	65	100	46	2.2*	5
Population density of workers:						
1989		(The mean squares of different months of 1989 were not significant)				
1990	January	27146	13636	5598	2.4*	53
	June	12659	15475	7555	2.1*	61
M. obesi:						
Population density of soldiers:						
1989		(The mean squares of different months of 1989 were not significant)				
1990	April	2	3	1	2.4*	0.4
Population density of workers:						
1989	October	19271	31275	13246	2.4*	102
1990		(The mean squares of different months of 1990 were not significant)				

* Significant at $P < 0.05$.

Table 26. Analysis of variance (mean squares) of relative population densities of termites across the tillage and organic amendment treatments during different months, 1989-1990 (number in parentheses represent degrees of freedom).

		SOURCE OF VARIATION				
Year &	Month	Amendment (2)	Tillage (2)	Till x AMM (4)	Error (10)	Mean abundance
O. obesus:						
Population density of soldiers:						
1989		(The mean squares of different months of 1989 were not significant)				
1990		(The mean squares of different months of 1990 were not significant)				
Population density of workers:						
1989		(The mean squares of different months of 1989 were not significant)				
1990		(The mean squares of different months of 1990 were not significant)				
M. obesi:						
Population density of soldiers:						
1989	October	2	22*	2	4	1.4
1990		(The mean squares of different months of 1990 were not significant)				
Population density of workers:						
1989	October	14839	55828*	9377	11762	70
1990		(The mean squares of different months of 1990 were not significant)				

* Significant at $P < 0.05$.

Table 27. Analysis of variance (mean squares) of relative population densities of termites across the perennial ley treatments during different months, 1989-1990 (number in parentheses represent degrees of freedom).

Year & Month		SOURCE OF VARIATION Treatment (5)	Error (4)	Mean abundance
O. obesus:				
Population density of soldiers:				
1989		(The mean squares of different months of 1989 were not significant)		
1990	January	153**	6	6
	February	1*	0.1	0.3
Population density of workers:				
1989		(The mean squares of different months of 1989 were not significant)		
1990	January	26958*	4346	67
	March	1864*	200	18
	May	1753**	4	8
M. obesi:				
Population density of soldiers:				
1989	December	262**	8	5
1990		(The mean squares of different months of 1990 were not significant)		
Population density of workers:				
1989		(The mean squares of different months of 1989 were not significant)		
1990		(The mean squares of different months of 1990 were not significant)		

* Significant at $P < 0.05$; ** Significant at $P < 0.01$.

<0.05) (Table 28). Their densities also showed significant differences across the perennial ley treatment between the seasons (*P* <0.01) (Table 24). ANOVA of the monthly data showed that the population density of workers of *O. obesus* differed significantly across all the treatments during January and June 1990 (*P* <0.05) (Table 25). Their densities also differed significantly across the perennial ley treatment during January and March 1990 (*P* <0.05) and May 1990 (*P* <0.01) (Table 27).

M. obesi: The mean relative population densities of soldiers of *M. obesi* recorded across the 15 soil management treatments presented in Fig. 47 revealed that the mean density was significantly low in the annual treatments (1.1) compared to that of the perennial ley treatments (7.1). Under annual treatments, its densities ranged between 1 and 2.5 in number in between the organic amendments of zero, shallow and deep tillage treatments. In the perennial ley treatments the density was low in pigeonpea treatment (2.1) which reached more than three folds in *C. ciliaris* treatment (7.1).

Its mean population densities significantly differed across the tillage and organic amendment between the seasons (*P* <0.01) as revealed by the ANOVA (Table 23). Besides, the densities also differed significantly across the perennial treatment (*P* <0.05) and between seasons (*P* <0.01) (Table 24). ANOVA of the monthly data on the population densities differed significantly across all the treatments during April 1990 (*P* 0.05) (Table 25), across the tillage treatments

Table 28. Analysis of variance (mean squares) of relative population densities of *Odontotermes obesus* workers across the 15 soil management treatments during different seasons, 1989-1990.

	SOURCE OF VARIATION				
Seasons	Blocks (Ignoring treatments)	Entries (Eliminating blocks)	Within entries (Errors)	F (14, 21)	Mean abund-ance
Rainy	14145	16040	8247	1.9	130
Postrainy	529	531	326	1.6	12
Dry	42591	37899	15901	2.4*	111

* Significant at $P < 0.05$.

during October 1989 (P <0.05) (Table 26), and the perennial treatments during December 1989 (P <0.01) (Table 27).

M. obesi: The mean relative population densities of workers of *M. obesi* recorded across the 15 soil management treatments presented in Fig. 47 revealed that the density was significantly low in the annual treatments (11.3) compared to that of the perennial ley treatments (165.3). Under annual treatments in zero tillage the density was 41.4 in the farmyard manure amendment which increased to 60.3 in rice-straw amendment. In shallow tillage treatments the density was 11.3 in rice-straw amendment which increased to more than three folds in farmyard manure amendment (36.8). In deep tillage treatments the density was 56 in farmyard manure amendment which increased to 79 in rice-straw amendment. In perennial ley treatments its density was 45.5 in pigeonpea treatment which increased to more than three folds in pigeonpea + *S. hamata* + *C. ciliaris* treatment (165.3).

Its densities differed significantly across the tillage and organic amendment between seasons (P <0.01) as revealed by the ANOVA (Table 23). Besides, the densities also differed significantly across the perennial treatments (P <0.05) between the seasons (P <0.01) (Table 24). ANOVA of the monthly data showed that the densities differed significantly across all the 15 treatments during October, 1989 (P <0.05) (Table 25), across the tillage treatments during October 1989 (P <0.05) (Table 26).

DISCUSSION

Termites collected across the 15 different treatments belonged to two species, *M. obesi* and *O. obesus.* There was no variation in the species diversity across the treatments. Reddy et al (1994) reported four species viz., *M. obesi, O. obesus, Nasutitermes* sp. and *Odontotermes* sp. across the soil management treatments at the same site. The number of species of termites may vary according to the size of the geographical area and the number of habitats with different types of vegetation in it. The area sampled across the 15 treatments may be too small to have variation in species diversity of termites. Kooyman and Onck (1987) reported seventeen species of termites under different agricultural practices in Kisii District, Kenya. Holt and Coventry (1988) reported six species of mound building termites in the woodland and two species in the introduced plots in North Queensland. Black and Wood (1989) reported four species of termites from the secondary woodland and maize fields over a two-year period in soils at Mokwa, Nigeria. Abensperg-Traun and de Boer (1990) reported a total of thirty six species of termites comprising eleven genera within the surface soil layer of three western Australian wheatbelt habitats. Abensperg-Traun (1991) reported ten species of subterranean termites in woodland and eight species in western Australian wheatbelt habitats. Holt et al (1993) reported five species of subterranean termites in tillage and stubble residue management practices from the central Queensland Vertisols.

Among the termite taxa *M. obesi* was dominant comprising of 62.8% (workers: 60.6% and soldiers: 2.2%) across the 15 soil management treatments. *O. obesus* comprised

37.2% (workers: 34.5% and soldiers: 2.7%). Reddy et al (1994) reported *M. obesi* damaging more number of plants which varied from 9.5 to 14% while *O. obesus* damaged 1 to 2.5% of plants. These results indirectly support the present findings that the *M. obesi* is more frequent than the *O. obesus*. The mean densities of *M. obesi* were higher in perennial ley treatments than the annual tillage treatments. This may be because of the fact that the *M. obesi* preferred an undisturbed soil with perennial vegetation. Black and Wood (1989) reported that the *microtermes* spp. are mainly surface-foraging termites so their predominance is seen in the top 50 cm of soil in uncultivated plots.

The seasonal fluctuations in the population densities of termites during this investigation was most probably due to the variation in their activity in relation to changes in various abiotic environmental factors. In corroboration, Black and Wood (1989) reported that the temporal changes in termite species abundance and distribution in cultivated and perennial ley treatments are due to fundamental environmental changes, artificially induced factors and anthropogenic activities. The climatic factors such as temperature, relative humidity, rainfall and others may have affected the seasonal variation in their densities.

It has been found that the mean densities of total termites particularly the workers were higher during the rainy season followed by postrainy and dry seasons. Most of the termites being crop pests and feeding on plants may have preferred the rainy and postrainy seasons for their activity. This is in consistence to the findings of Roonwal

(1981) that the attack of termites occurred both in pre- and post-monsoon periods. However, Abensperg-Traun (1991) reported occurrence of high species richness only during autumn and spring, presumably because environmental conditions were favourable and termites were very active. In the western Australian wheatbelt, soil moisture determined termite activity, and a moisture content of less than 3.5% caused a marked decline in activity levels (Abensperg-Traun and de Boer, 1990). At such times (summer and late spring), the termite fauna consisted of six or fewer species per habitat. All species were affected by low soil moisture and that may be the reason for their less abundant during summer.

The mean densities of soldiers and workers of *O. obesus* and *M. obesi* were in higher peak of abundance during the rainy season followed by postrainy season and were low in densities during the dry summer season. This is in consistence to the findings of Wood and Johnson (1978) that the densities of *Microtermes* spp. were recorded very low during the dry season. Further, Black and Wood (1989) reported total *Microtermes* spp. population being greater in the wet season than the dry season.

The mean densities of termites were higher in the perennial ley treatments than the annual tillage treatments. Moreover, the less mean number of termites in annual tillage treatments during the present study may be due the effect of carbofuran applied at the beginning of the experiment to control sorghum shoot fly. It may also be due to the fact that under cultivated condition, there was a decrease in their food materials in the form of roots than that of perennial systems (Wood et al, 1980). Kooyman and Onck

(1987) reported that the under natural conditions (i.e., without cultivation), the species composition is governed by climate, vegetation and soil properties which may increase their population, but in cultivated land it is affected by tillage operations and crop characteristics due to which the densities may decrease. The distribution and abundance of termites appeared to be influenced by characteristics of vegetation and their food (Abensperg-Traun and de Boer, 1990). Further, Brouwer et al (1991) reported that the tillage has decreased the termite activity. In addition, Holt et al (1993) reported that the tillage experiments at Mt. Murchison and Biloela R.S. showed that four subterranean termites being relatively common in zero tillage, but rarely found in conventionally cultivated treatments.

Among the three tillage treatments the densities of termites were higher in deep tillage treatments than the shallow and zero tillage treatments. However, Holt et al (1993) reported that the deep tillage plots has no termites which may suggest that tillage operations have negative effect on termite activity, most probably because of the frequent physical disruption of their habitat. Further, from baiting trials, they have reported that there may have been more termite activity in the reduced tillage than the zero tillage treatments at Biloela R.S.

Among the three tillage organic amendment treatments total termites were higher in rice-straw treatments than the bare and farmyard manure treatments. These treatments showed significant effect on the densities of workers of *M. obesi* during October 1989, and on that of soldiers during April 1989. The tillage treatments showed significant effect on the workers and soldiers population densities during October 1989 while the perennial treatment on the densities of soldiers during December 1989. This is in consistence to the findings of Holt et al (1993) that there was higher termite activity in stubble retained treatment than the without stubble treated plots. However, he further recorded no differences in termite activity between the with stubble and without stubble treated plots by baiting method. The higher number of termites in the rice-straw treated plots was probably because of rice-straw being good source of food for the termites.

Tillage and organic amendment treatments, and the perennial treatments showed significant effect on the population densities of *M. obesi* across the seasons ($P < 0.01$). The less mean number of *Microtermes* spp. in the annual tillage treatments was supported by the findings of Wood et al (1980) that the cultivation of top soil removed the food sources of many of the species of termites and destroyed the nests of epigeal and top-soil. The diffused nests of *microtermes* occur throughout the top 2 m of soil and consist of chambers, each containing a single fungus comb, linked by a network of galleries (Bigger, 1966; Josens, 1971, 1972; Wood and Johnson, 1978). These nests, therefore, are disturbed by cultivation. As soon as a site is cultivated, a number of species of termites disappear. The intensity of tillage partly depends on the type of crop growth. Fields with bananas, coffee, tea or trees are not tilled as frequently as fields with annual crops like maize, beans and sorghum etc. Therefore, fields under perennial crops harbour more species. Only *Microtermes* spp. thrive in intensely tilled fields; crops influence the density of termite populations through their annual litter production and the litter palatability. In cultivated plots, they are by far the most common termites.

The mean densities of *O. obesus* particularly the workers were higher in densities in annual tillage treatments than the perennial ley treatments. Kooyman and Onck (1987) reported that the *Odontotermes* spp. are susceptible to cultivation. Among the tillage treatments they were higher in shallow tillage treatments than the deep and zero tillage treatments and three tillage amendments they were higher in bare amendment than the rice-straw and farmyard manure treatments. The population densities of workers of *O. obesus* were significantly affected by all the 15 treatments during the dry season ($P < 0.05$). Besides the densities of soldiers of *O. obesus* were significantly affected by the annual tillage treatment ($P < 0.05$), and that of the workers and soldiers were significantly affected by the perennial ley treatments between seasons ($P < 0.01$). The population densities of *O. obesus* workers and soldiers were significantly affected across all the 15 treatments during January and June 1990 ($P < 0.05$) respectively; while the perennial ley treatments significantly affected the population densities of *O. obesus* workers during January, March ($P < 0.05$) and May 1990 ($P < 0.01$) and that of soldiers during January ($P < 0.01$) and February 1990 ($P < 0.05$). Kooyman and Onck (1987) reported that the *Odontotermes* species are also affected by intensive cultivation, although to a lesser extent. However, there is little information on the literature on the densities of soldiers and workers populations in relation to the termite trapping and activity in annual cereal fields to compare with the present results.

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GENERAL DISCUSSION

Soil management includes a variety of practices such as tillage (conservation and conventional), organic amendments (crop residue and organic manure), cover crops (leguminous and non-leguminous) and application of various agrochemicals (pesticides and fertilizers), and these practices affect the biotic and abiotic components of the soil environment (Fig. 1). Changes in the abiotic environment such as physical and chemical factors, of soil leads to the alteration in the activities of beneficial soil organisms. However, most of the agricultural practices alter more than one of these factors at a time and thus it is difficult to single out the cause and effect relationships. The effects of soil management on endogeic and epigeic soil macroorganisms such as earthworms and arthropods were very much distinct in relation to season during the present investigation. These organisms showed a distinct temporal variation in the field reaching higher peaks of abundance during rainy and postrainy seasons, and lower densities during dry season while some of the arthropods active on the soil surface, such as Hymenoptera were in higher densities during dry season. These variations are mainly related to the seasonal fluctuation in abiotic environmental variables.

The application of carbofuran and herbicides showed significant synergetic effect reducing the population densities of earthworms, soil inhabiting microarthropods and termites drastically in the annual treatments while the epigeic i.e., soil surface inhabiting arthropods showed very little response to these pesticides. The endogeic fauna was very sensitive both to the fallout from foliar-applied to surface applied biocides. Thus the abundance of earthworms, and soil inhabiting microarthropods showed discernible reduction in the annual tillage treatments compared to the perennial ley treatments.

The perennial crop covers are well known to increase vegetational cover, habitat conditions and resource availability in time and space and to increase the species diversity of cropping systems thereby affecting the habitat for the soil invertebrates. The increased densities of these invertebrates in some of the perennial treatments such as leguminous crop covers (treatment with *S. hamata* or *S. hamata* + pigeonpea) compared to that of non-leguminous crop cover (with *C. ciliaris*) indicated their preference to the soils having higher nitrogen levels. These observations may be helpful in increasing the capabilities of "husbandry" of soil organisms in a semi-arid tropics. Introduction of many of the soil invertebrates such as earthworms and predator arthropods have been proven successful in increasing soil structure and fertility (Lee, 1985; Reddy et al, 1994), and controlling a variety of insect and weed pests (Piemental et al, 1986).

Some of the annual tillage treatments such as tillage known to alter the soil physico-chemical conditions, change the habitat conditions and resource availability often and reduce the species diversity but may increase abundance of some groups (Hendrix, 1987). Nevertheless, Hymenoptera, and Cryptostigmata and Astigmata mites active on the soil surface were recorded higher in tillage treatment compared to the perennial ley treatments. Zero tillage conditions were preferred to other tillage conditions by the endogeic fauna, although some of the groups of arthropods such as termites preference tilled conditions (deep tillage). Mulching with rice-straw provided shelter to most of them compared to farmyard manure treatments. It has been proved for the first time during the present study that different soil management practices have significantly influenced at specific levels of herbivores, predators and decomposer invertebrates in the semi-arid tropical Alfisol agroecosystem in India, although such effects have already been reported by some of the investigators in western temperate ecosystems (Stinner and House, 1990).

It is incredible that we have made a beginning in the impact study on soil management and ecosystem-structure of soil fauna, earthworm and soil arthropod populations in the semi-arid tropical Alfisol agroecosystem, and we have a long way to cover to explicitly put down our understanding on various aspects of functioning of these beneficial invertebrates in response to soil management across different ecosystems in the semi-arid tropical region in India particularly in Andhra Pradesh. The present investigation has raised many pertinent and interesting questions which are yet to be answered to further our insight into various aspects of modern soil management and related agroecological problems and use such insight in ameliorating the productivity of the semi-arid tropical marginal farm-land.

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Stinner, B.R. and House, G.J. 1990. Arthropods and other invertebrates in conservation-tillage agriculture. Ann. Rev. Entomol. 35: 299-318.

APPENDIXES

List of Research Publications of the Candidate

YEAR	AUTHORS	TITLE OF THE PAPER AND JOURNAL
1990	**V. RAVINDER REDDY** AND M. VIKRAM REDDY	Response of population structure and biomass of earthworms to conventional tillage in a semi-arid tropical grassland. Journal of Soil Biology and Ecology. Vol. 10(2): 73-78.
1991	D.F. YULE, M. VIKRAM REDDY, **V. RAVINDER REDDY**, P.J. GEORGE AND A.L. COGLE	Effects of soil management on population abundance and biomass of earthworms in a semi-arid tropical Alfisol. 12th Int. Conf. Soil Tillage and Agricultural Sustainability, 8-12 July, 1991 ISTRO, IITA, Ibadan, Nigeria, 63-71 pp.
1992	M. VIKRAM REDDY AND **V. RAVINDER REDDY**	Effects of organochlorine, organophosphorus and carbamate insecticides on the population structure and biomass of earthworms in a Semi-Arid Tropical Grassland. Soil Biology and Biochemistry. Vol. 24(12): 1733-1738.
1992	M. VIKRAM REDDY, D.F. YULE, **V. RAVINDER REDDY** AND P.J. GEORGE	Attack on pigeonpea (*Cajanus cajan* (L.) Mill sp.) by *Odontotermes obesus* (Rambur) and *Microtermes obesi* Holmgren (Isoptera: Microtermitinae). Tropical Pest Management, Vol. 38(3): 239-240.
1992	M. VIKRAM REDDY, **V. RAVINDER REDDY**, V.P. KIRAN KUMAR, D.F. YULE AND A.L. COGLE	Soil management and seasonal community structure of soil microarthropods in semi-arid tropical Alfisols. Int. Conf. Problems in Modern soil management, Aug 31-Sept 5, 1992, Brno (Czechoslovakia), 204-218 pp.
1994	M. VIKRAM REDDY, **V. RAVINDER REDDY**, D.F. YULE, A.L. COGLE AND P.J. GEORGE	Decomposition of straw in relation to tillage, moisture and arthropod abundance in semi-arid tropical Alfisol. Biology and Fertility of Soils. Vol. 17(1): 45-50.
1994	M. VIKRAM REDDY, **V. RAVINDER REDDY**, D.F. YULE AND K. VIDYASAGAR RAO	Influence of tillage and microarthropod abundance on some nutrients during decomposition of rice-straw mulch in a semi-arid tropical Alfisol. Tropical Agriculture (Trinidad)[Communicated]
1994	M. VIKRAM REDDY, V.P. KIRAN KUMAR, **V. RAVINDER REDDY**, P. BALA SHOURI, D.F. YULE, A.L. COGLE AND L.S. JANGAWAD	Earthworm biomass response to soil management in semi-arid tropical Alfisol agroecosystems. Biology and Fertility of soils. [Communicated]

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Response of Population Structure and Biomass of Earthworms to Conventional Tillage in a Semi-arid Tropical Grassland

V RAVINDER REDDY AND M VIKRAM REDDY

Environmental Biology Laboratory Department of Zoology Kakatiya University Warangal 506009 Andra Pradesh

Abstract

Investigations on the effects of conventional tillage on the population abundance and biomass of earthworms in a grassland revealed that three species viz., *Drawida willsi* Michaelsen *Lampito mauritii* Kinberg, *Barogaster* sp. inhabit the grassland the former being predominant and constituting > 99% of the total A week before tillage the total population was 128.00 ± 17.36 m^{-2} of which 30% were adults. The biomass was 48.00 ± 8.5 mg m^{-2} (wet weight) One day after tillage the earthworm population in the top 15 cm of soil had increased to 144.00 ± 44.4 m^{-2} with the adults constituting about 75% and a biomass of 68.8 ± 17.4 mg m^{-2} Two days after tillage the population decreased but after 10 days, it had increased again reaching a more or less similar population as that existed prior to tillage 26 days after first tillage a second tillage operation was performed One day after the second tillage the earthworm population and total biomass decreased again but 24 days after the second tillage the earthworm population had increased reaching 122.00 ± 49.08 m^{-2} adults constituting 64% and the biomass reaching 50.40 ± 25.62 mg m^{-2} 80 days after the second tillage the population of the 15 cm top soil had increased still further mainly because of newly hatched juveniles Therefore total biomass slightly decreased 110 days after tillage as the soil started drying, the earthworm population (both number and biomass) decreased

Introduction

Vast areas of natural grassland are subjected to the effects of various afforestation practices such as different types of mechanical tillage with the introduction of afforestation programmes all over the world, particularly in tropics to counteract various environmental problems such as greenhouse effects etc, (Evans, 1982) These practices invert the soil thereby expose beneficial soil organisms like earthworms to the attack by various predators Also, many of them may die of body damage caused by tractor implements and drying and desiccation of the exposed soil (Gerard and Hay, 1979) It may take a long time for the grassland to recover such losses of fauna Although some information is available on the effects of tillage practices on earthworm community in different agroecosystems in the temperate areas (Edwards and Lofty, 1977 and Lee, 1985) unfortunately no information is available on how the mechanical tillage affects the earthworm population of grasslands under semi-arid tropical conditions The present investigation is a case study on the effects that tillage practices can have no earthworm population in a tropical semi-arid natural grassland in Telangana of Andhra Pradesh (India)

Material and Methods

Study area

The present investigation was conducted about 20 days after the commencement of rains in an area of 60 ha in the grassland part of the Kakatiya University campus in Warangal (Lat 18° 31", long 79° 29' 5" and altitude of 263 7 m above MSL) in Telangana region of Andhra Pradesh. The grass cover of the grassland was dominated by *Dimeria sp.* The grassland has scattered herbs, shrubs and trees of different species viz., *Zornia gibbosa*, *Asystesia* sp., *Alysicarpus* sp., *Jatropha gossypiifolia*, *Calotropis procera*, *Butea monosperma*, *Canthium parviflorum* and *Randia candolleana* The surface soil of the grassland was light brown in colour and of fine sandy loam type. It was alkaline in nature and poor in organic matter and phosphorus. It has little litter layer

The climate of the area was semi-arid with a monthly rainfall ranging from 1 to 18 4 cm, > 80% of the rain falling during the rainy season, June to September Winter season extended from October to February and summer from March to May with the temperature shooting up to 43-45°C during the peak summer *i e*, in May

Experimental set-up and sampling

60 ha of the grassland was ploughed to a depth of 15 cm by a tractor on 8t July 1989 The earthworms were sampled a week prior to and soon after 24 hour two days and 10 days after the first tillage The grassland was tilled for the secon time on 4th August 1989 and earthworms were sampled after one, 24, 80 and 11 days after the second ploughing On each sampling date, the earthworms were han sorted from eight pits randomly distributed throughout the grassland, each pit measurin 25 x 25 x 15 cm and being apart from the other by a distance of 5 m, during th morning hours (6 to 8 a m) The earthworms of each pit were collected in a polythe bag along with a little of moist parent soil and were brought to the laboratory The were slowly narcotised with 100% ethanol and sorted into various age- groups su as juveniles and adults which were identified into different species Their number w enumerated and the fresh wet biomass was determined by weighing the narcotis animals They were treated with 5% formalin overnight, and stored in 80% ethan In case of damaged worms, the heads and tails were separately counted, and t highest number was chosen

Results and Discussion

The earthworms of the grassland belonged to three species viz, *Drawida w* Michaelsen, *Lampito mauritii* Kinberg and *Barogaster*sp, the former being m predominant, constituting > 99% of the number/biomass, before and after tillage ‹ the *L mauritii* recorded < 1% of the total *Barogaster* sp appeared very rarely *D w* was an hypogeic species (Lavelle, 1983)

The number of earthworms, categorised into juveniles and adults are presented all the sampling occasions in Fig 2a Prior to tillage the total earthworm abundai was 128 00 ± 17 36 m^{-2} of which about 30% consisted of the adults Earthwc abundance in the top 15 cm of the soil increased to 144 00 ± 44 40 m^{-2} in one (after tillage, the adults constituting 75 55% of the total On the second day, numb

TABLE I

Calculated 't' values of 'student' t-test between the population abudance of adult, juvenile and total earthworms and their biomass before and after ploughing the grassland

Comparison of samples	Adult earthworms	Juvenile earthworms	Total earthworms	Biomass (mg.,wet wt)
Before ploughing X one day after 1st ploughing	2.40*	2.91**	0.392	1.19
Before ploughing X 2 days after 1st ploughing	2.80**	1.88	2.77*	3.52**
Before ploughing X 10 days after 1st ploughing	0.78	0.937	0.39	0.847
Before ploughing X one day after 2nd ploughing	1.203	2.298*	2.397*	3.157***
Before ploughing X 24 days after 2nd ploughing	2.108*	3.26***	0.244	0.194
Before ploughing X 80 days after 2nd ploughing	2.40*	0.945	2.694**	0.972
Before ploughing X 110 days after 2nd ploughing	2.58*	2.628*	0.169	1.412

Level of significance: $P<0.05$*; $P<0.02$**; $P<0.01$***

The changes in the biomass of earthworms in response to two tillage operations presented in Fig. 2B showed a more or less similar pattern of fluctuation as that of the earthworm number. However, the only significant difference between after and before tillage were found shortly after the two tillage operations (Table I). This was mainly because both juveniles and adults were present in significantly lower numbers than before tillage started.

These results showed that the ploughing has perturbed the earthworms population of the grassland. The population soon a day after tillage increased, decreased two days after and increased 10 days after the first tillage. Similarly the earthworm population although decreased soon a day after the 2nd ploughing, increased thereafter. Conventional mechanical tillage such as ploughing, rotary hoeing and harrowing have been reported to reduce the earthworm populations by many investigators. In contrast, some investigations have reported increase in population number with tillage (Lee, 1985)

The reduction in earthworm population number and biomass two days after the first tillage and immediately after second tillage may be due to the action of the tillage implements, which have been assumed to be the major cause of worm mortality (Lee, 1985). The plough cutting slice of the earth and the tines shattering the soil may have damaged many earthworms and thus reducing their the appearance of pale sub-soil at the soil surface (Fig.1), causing the reduction in the number and biomass

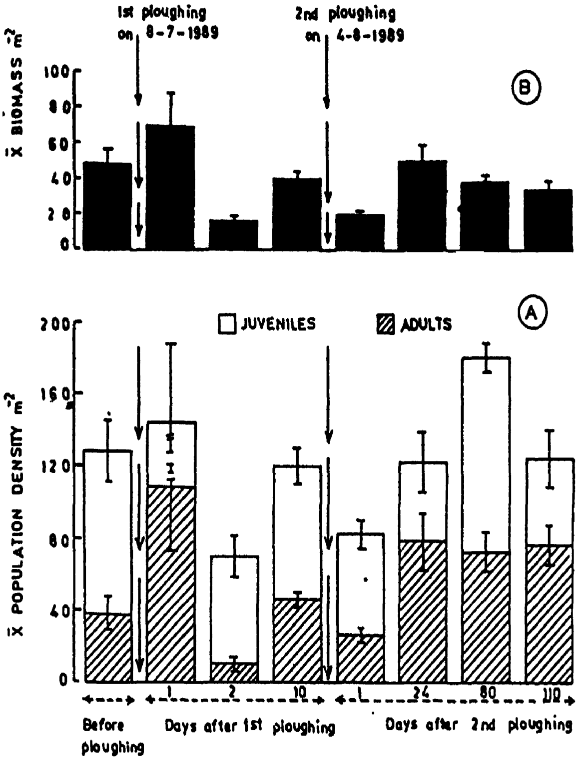

Fig 2: Changes in population of juvenile and adult, and total earthworms (A) and their wet biomass (B) in response to ploughing in the grassland.

of earthworms (Gerard and Hay, 1979). Edwards and Lofty (1978) stated that the exposed tilth after tillage resulted in reduction in earthworm populations by a combination of mechanical injury and exposure of earthworms to various predators such as birds However, these appear to be the unlikely causes for differences in worm population according to Rovira *et al.*, (1987), who stated that the tillage with a scarifier does not thin the soil over and thus it is less likely that the worms are exposed to predation.

The gradual increase in population number after 24 and 80 days of second tillage particularly after the later date with huge number of juveniles, may be because of the fact that when the established grassland was ploughed a large quantity of plant material which previously existed above the ground and unavailable to the decomposer system, was mixed into the soil by tillage and became available as a substrate to decomposer organisms including earthworms. It was expected that the earthworms whose primary source of food was partially decomposed plant tissue could flourish well as a result, and continued to flourish along with the other decomposer organisms until the flush of food provided by the ploughing in one of the plants was exhausted (Edwards and Lofty, 1977). However, the decline of population abundance and biomass 110 days after second ploughing was probably due to the exhaust of the flush of food provided by the ploughing in one of the decomposed plant materials well as the soil drying due to the seasonal difference in soil moisture (Lee, 1985).

These results showed that the earthworms of the natural grasslands when disturbed by human activities such as ploughing recovered both in adult population and biomass 10 days after first tillage and 24 days after second ploughing to a stage more or less similar to that which was seen prior to tillage. Nevertheless, it may be stated that even after second tillage the earthworm population recovered within a month, both in number and biomass of juveniles and adults.

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EFFECTS OF SOIL MANAGEMENT ON POPULATION ABUNDANCE AND BIOMASS OF EARTHWORMS IN A SEMI-ARID TROPICAL ALFISOL

D.F. Yule[*], M.V. Reddy[**], V.R. Reddy[**], P.J. George[*] and A.L. Cogle[*]

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EFFECTS OF SOIL MANAGEMENT ON POPULATION ABUNDANCE AND BIOMASS OF EARTHWORMS IN A SEMI-ARID TROPICAL ALFISOL

D.F. Yule*, M.V. Reddy**, V.R. Reddy**, P.J. George* and A.L. Cogle*

* Resource Management Program, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), P.O. Patancheru 502 324, A.P., India.

** Environmental Biology Laboratory, Department of Zoology, Kakatiya University, Warangal 506 009, A.P., India

INTRODUCTION

Conservation tillage, reduced tillage and no tillage systems for agriculture have been widely researched and adopted in temperate climates (Blevins, 1984). The key elements of these systems are a reduction in the number, depth and severity of the tillage operations and the retention of crop residues on the soil surface. These systems have lead to improved soil quality as evidenced by increased soil organic matter content (Blevins et al., 1983) and reduced runoff and soil erosion (Salloway et al., 1990). In contrast, conventional tillage systems typically involve removal or burning of the crop residues and inverting tillage which incorporates crop residues.

No tillage agroecosystems were found to have higher densities of soil inhabiting animals than conventional tillage systems in U.S.A. (House and Parmelee, 1985). Earthworms comprise a large portion of animal biomass in soils and their activities have ameliorative effects on soil physico-chemical properties, soil fertility and plant growth (Atlavinyte and Zimkuviene, 1985; Lee, 1985; Reddy, 1988). Soil management practices, such as tillage and crop residue management, alter both soil physico-chemical properties and soil faunal activity (Andren and Lagerloef, 1983, House and Parmelee, 1985) but reduced tillage systems are generally less harmful (Robertson, 1989; Haukka, 1988, Rovira et al., 1987). Tillage damages earthworms and their burrows and reduces the food supply by burying plant residues while farm yard manure and organic mulches increase the food supply. Pastures both increase the food supply and decrease disturbance and mechanical damage due to lack of cultivation (Edwards and Lofty, 1977; Lee, 1985).

Many investigations have studied the effects of soil management on soil animals, particularly earthworms in temperate climates (House and Parmelee, 1985; Andersen, 1987; Haukka, 1988; Parmelee et al., 1990) but Lal and Vleeschauwer (1981) report one of the few similar studies in tropical soils. We know of no reports of studies of the effects of soil management on earthworms in Alfisols in semi-arid tropical climates. The earthworm study reported here was conducted within an experiment which aims to quantify the effects of management on soil physical properties and processes. A wide range of treatments had been established and large effects were measured on runoff (Yule et al., 1990). The treatments included tillage, amendments of farm yard manure or rice straw and perennial pastures. These soil managements should affect earthworm populations and biomass. The aim of the earthworm study was to measure the population dynamics and biomass of earthworms in response to soil management.

MATERIALS AND METHODS

The core experiment is conducted on a shallow to medium depth Alfisol (Patancheru Series, Udic Rhodustralf) in field RM19B at ICRISAT, near Hyderabad, India. The soil is hardsetting and very prone to surface sealing and crusting. The climate is monsoonal semi-arid tropical with average annual rainfall of 764 mm and 80% of rain occurring from June to early October. The core experiment combines two balanced incomplete block designs, one a 3 x 3 factorial arrangement of tillage x amendment with annual cropping, the other involving six treatments with perennial species. The fifteen treatment combinations are listed in Table 1. There are three replications and the plot size is 22m long x 5 m wide. The core experiment was established in 1988 and treatments are maintained in the same plot each year. The tillage X amendment treatments are imposed after initial rains in early June. Tilled plots initially receive a shallow tine with duckfoot tillage (0.05-0.07 m depth) to break the surface crust and to control weeds. After further rains, typically 10

Table 1. Treatments applied in soil management study on an Alfisol at ICRISAT, India. The annual crops have been millet (1988), sorghum (1989) and sorghum (1990). The perennial species are perennial pigeonpea (*Cajanus cajan*), *Stylosanthes hamata* and *Cenchrus ciliaris*

	Tillage	X	Amendment
Annual crops	Zero (T0)		Bare (B)
	10 cm depth (T10)		FYM[1] (F)
	20 cm depth (T20)		Straw[2] (S)
Perennial crops	Perennial pigeonpea (PP)		
	PP + *S. hamata* (PP+S)		
	PP + *S. hamata* + *C. ciliaris* (PP+S+C)		
	C. ciliaris (C)		
	C. ciliaris + *S. hamata* (C+S)		
	S. hamata (S)		

[1] FYM = farm yard manuare, 15 t ha^{-1} (air dry)
[2] Straw = rice straw, 5 t ha^{-1} (air dry)

to 14 days, a second tillage is imposed using narrow tines at 50 cm spacing to the treatment depth. Planting by hand follows 10 to 14 days later. The amendments are applied (15 t ha^{-1} farmyard manure (FYM), 5 t ha^{-1} rice straw) in three equal increments after each of these cultural operations. Rice straw is removed to facilitate tillage and then replaced. Herbicides (glyphosate, paraquat, diquat) are applied pre-planting as required. One or two hand weedings are carried out during crop growth. In 1989, carbofuran insecticide granules (40 kg ha^{-1}) were applied to the soil in the planting furrow to control shoot fly (*Atherigona soccata*). In 1990, about 5 kg ha^{-1} carbofuran granules were applied in the whorls of the seedlings for shoot fly control. Fertilizer applied was 100 kg ha^{-1} diammonium phosphate at planting and 200 kg ha^{-1} urea by side dressing. The annual crop is harvested in October.

The *S. hamata* and *C. ciliaris* plots are harvested twice per year and the cut material removed. The perennial pigeonpea (PP) was pruned for grain harvesting once or twice in each year and also pruned in 1989 to control growth. In 1990, the perennial pigeonpea (PP) were replanted because wilt (*Fusarium udum*), termites (*Odontotermes bellatiunisensis* and *Microtermes obesi*) and drought had decimated the population (Reddy *et al.*, unpub.). Considerable leaf fall occurs from perennial pigeonpea. Much of this is retained in the PP + S and PP + S + C plots but it is blown away from PP plots which consequently have generally bare soil throughout the year. The *S. hamata* produces a thick cover up to 0.3 cm high during the rainy season while *C. ciliaris* plots have complete projected foliage cover but grass tufts are separated by bare soil areas.

Two observational plots of the same dimensions were established prior to the rainy season in 1990 in a 10 years old pasture area on a similar Alfisol about 800 m away. This pasture had a complete cover, was composed of mixed grasses and legumes and had been ungrazed but occasionally mown. Cuttings were left in place so that a thick organic mulch had developed.

The earthworms were sampled in each plot by the hand sorting method, every month during July to September, 1989 and June to October, 1990. The soil of an area measuring 0.25 m x 0.25 m was removed to a depth of 0.15 m, placed in an enamel tray and carefully searched for adult and juvenile earthworms. In 1989, two randomly selected areas and in 1990 three areas in each plot were sampled. The earthworms of each plot were collected in separate polythene bags with a little amount of moist soil and brought to the laboratory. They were counted and washed of the adhered soil particles, soaked with filter paper to remove the water attached to their outer body wall, and weighed.

Examination of the earthworm data showed that the populations were much higher in the perennial species treatments compared to the treatments with annual cropping. Consequently a least squares analysis of variance was done separately for each group to obtain adjusted treatment means which were compared statistically using Duncan's k-ratio t test.

RESULTS AND DISCUSSION

The species of earthworm found in plots of the core experiment were predominantly Ochochaetona philleti (67%), Lampito mauritti (31%) and occasionally Drawida sp (2%). These are relatively small sized species living mostly in the surface soil (0-0.15 m depth). In the long term pasture area the dominant species was Barogaster sp., a relatively larger and deeper burrowing species which deposits large castings on the soil surface. O. philleti and Drawida sp. were also recorded in small numbers.

Table 2. Adjusted treatment means and significant responses ($k < 100$) in juvenile earthworms, total number of earthworms and earthworm biomass to treatments in 1989 and 1990.

a) Annual crops

Earthworm measurement	Date	T_0	T_{10}	T_{20}	k-ratio LSD
Juveniles (counts m^{-2})	Jun 1990	11.3^a	0.6^b	4.7^b	5.9
Totals (counts m^{-2})	Jun 1990	16.9^a	0.9^b	7.1^b	8.8
Biomass (g m^{-2})	Jul 1989	9.1^{ab}	14.9^a	4.7^b	7.5
	Jun 1990	1.1^a	0.1^b	0.5^{ab}	0.7

b) Perennial crops

Earthworm measurement	Date	PP	PP+S	PP+C+S	C	C+S	S	k-ratio LSD
Juveniles (counts m^{-2})	Jun 1990	4.3^{bc}	20.0^a	6.7^b	0^c	5.3^b	6.4^b	4.7
Totals (counts m^{-2})	Jun 1990	6.4^{bc}	30.0^a	10.0^b	0^c	8.0^b	9.6^b	7.0
	Jul 1990	19.0^b	19.8^b	6.4^c	42.4^a	10.4^c	39.2^a	7.2
Biomass (g m^{-2})	Sep 1989	8.7^c	12.4^{bc}	3.2^d	12.2^{bc}	16.2^{ab}	18.9^a	4.9
	Jun 1990	0.4^{bc}	2.0^a	0.7^b	0^c	0.4^{bc}	0.8^b	0.6

Few significant responses in earthworm population or biomass were measured to the individual treatments (Table 2). A general response was measured in June, 1990 when tillage and perennial species produced significant responses for juvenilles and total biomass. The response to treatments for juveniles, total and biomass were the same with zero tillage having the most earthworms among the annually cropped treatments and treatments with S. hamata and having generally more earthworms than the plots which had less cover (PP) Also these responses were not generally similar to the responses in June, 1990. The effect of amendments on earthworms was not significant at all sampling dates and the tillage x amendment interaction was significant for biomass at one sampling date (August, 1989). We conclude that the response of earthworms to the individual treatments within either annual cropping or perennial cropping has been small and inconsistent.

The adjusted treatment means were combined for perennial crops and the mean values are compared in Figure 1 with the data from the long term pasture plots. Very large differences are apparent between the treatment groups in both values and trends during the season. Although the annual group and the perennial group had similar values at our initial sampling in July 1989 the changes during the season were in marked contrast. The plots with perennial species either maintained or increased population and biomass but in the plots with sorghum earthworm population rapidly declined to virtually zero.

In June 1990, small numbers of juveniles were present in the annually and perennially cropped plots of the core experiment but numbers in the annually cropped plots declined over time to near zero, compared to steady increases in numbers of both juveniles and adults in perennial plots. In the long term pasture plots earthworms numbers also increased through the season but the total numbers present were much larger and a relatively large number of adults were already present at the initial sampling at this site in June, 1990.

The earthworm populations in the long term pasture are generally within the ranges reported by Edwards and Lofty (1977) for temperate pastures and more than they report in tropical soils. The June, 1989 populations in the core experiment are also within the ranges reported for arable soils in Europe (Edwards and Lofty, 1977) and in sub-tropical Queensland, Australia (Robertson, 1989). While the pasture plots show the expected trends of higher populations with longer time under pasture and increasing populations during the wet season, the plots cropped to sorghum consistently show unexpected seasonal trends (decrease of earthworms to near zero) and little or no response to the applied treatments. The most likely explanation for these responses is that the carbofuran applications for insect pest control also killed the earthworms. Carbofuran is toxic to earthworms and takes some time to completely reduce the population (Parmelee et al., 1990). Figure 1 shows a population decline over two months to September 1989. The reappearance of juvenile earthworms in these plots in June 1990 was probably due to emergence from cocoons or migration from border areas. Negligible numbers of juveniles and adults were subsequently found indicating further toxic effects due to either residual carbofuran from 1989 or the small additional application of carbofuran in 1990. This decline in the population completely masked any possible tillage or amendment treatment effects although the few differences found did favour reduced tillage as expected (Table 2).

We plan to continue this experiment without applying soil insecticides to the annual crop to follow longer term effects on population and biomass. We will also remove the perennial pastures in the core experiment and study the population dynamics under subsequent annual cropping. The long term pasture area will be retained for comparative purposes. The data from the July, 1989 sampling suggest that cultivation systems without soil applied insecticides may maintain reasonable populations of earthworms. We therefore consider a survey of fields with known histories of both insecticide use and cultivation would clarify the effects of these managements on earthworms.

CONCLUSIONS

Semi-arid Alfisols under pasture support relatively high populations of earthworms and populations increase with time under a pasture phase.

Any response to soil management treatments for annual cropping in our experiment was masked by decimation of the population by insecticidal application.

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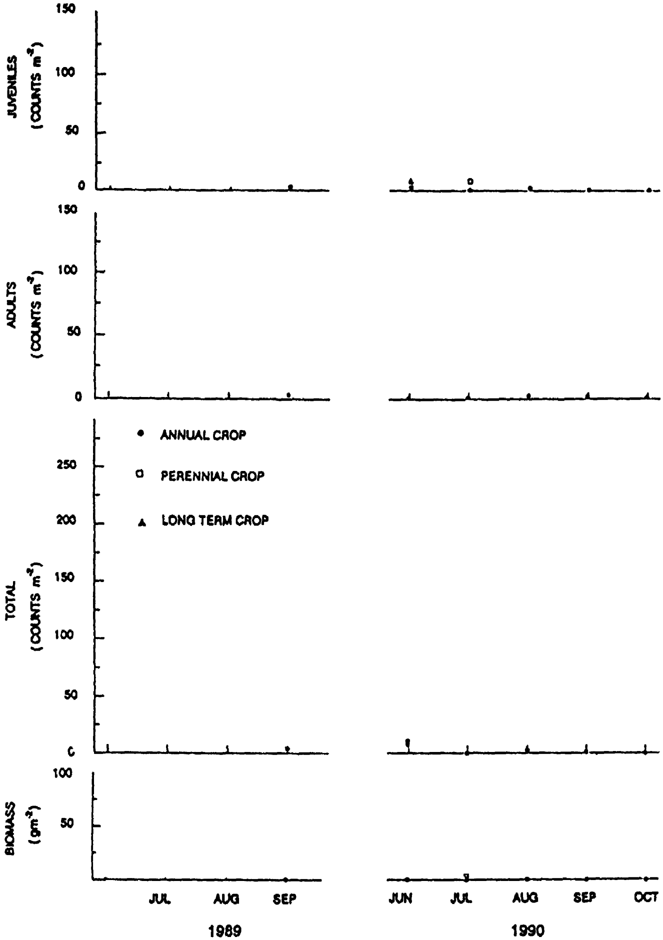

Figure 1. Temporal changes in earthworm population and biomass for three management on alfisols at ICRISAT during 1989 and 1990

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EFFECTS OF ORGANOCHLORINE, ORGANOPHOSPHORUS AND CARBAMATE INSECTICIDES ON THE POPULATION STRUCTURE AND BIOMASS OF EARTHWORMS IN A SEMI-ARID TROPICAL GRASSLAND

M VIKRAM REDDY and V RAVINDER REDDY
Environmental Biology Laboratory Department of Zoology Kakatiya University
Warangal 506 009 India

Summary—Effects of normal (1 ml of endosulfan 35% E C 0 66 ml of methyl parathion 50% E C and 4 16 g of carbaryl (Sevin 50% W D P) each dissolved in 1 litre of water and applied to 5 × 5 m plot) and high doses (3 times the normal dose) of endosulfan methyl parathion and carbaryl on the population structure and biomass (wet) of earthworms of a semi-arid tropical grassland were investigated The earthworm population and biomass (wet wt) were highest in the untreated control plots No earthworm was recorded in plots treated with the high dose of endosulfan until 80 days after treatment while the earthworm adundance was reduced significantly in the plots treated with the normal dose The adults juveniles and total population reduced by 52 58% after 40 days of treatment with the high dose of methyl parathion and by 15 52% with the normal dose However the numbers of adults increased after 60 and 80 days of treatment at the high dose and the juvenile population reduced by 28% after 60 days and by >70% after 80 days of treatment ($P < 0\ 05$) The number of adults increased after 60 days and reduced after 80 days of treatment with the normal dose of methyl parathion The adults juveniles and total population was reduced by 15 50% after 40 days of treatment with high dose of carbaryl However the number of adults increased after 40 days of treatment with the normal dose and after 60 and 80 days of treatment with the high dose The biomass of the earthworms was significantly reduced with treatment of either dose by each of the insecticides

INTRODUCTION

Earthworms play a significant role in soil biological processes enhancing the mixing of soil and residues of plant litter, by ameliorating soil fertility, aeration and drainage of soil (Satchell, 1967) Any chemical which is harmful to earthworms and their activity may therefore influence the process of pedogenesis (Lee, 1985) New pesticide compounds often organophosphorus and carbamate compounds are being registered for use in agriculture The partial ban of chlorinated hydrocarbon insecticides in many countries has led to the greater use of organophosphorus and more recently of carbamate insecticides to control pests They are not being tested sufficiently for their effect on non-target organisms like earthworms in the environment (Lee, 1985)

The majority of the research work on the effects of various insecticides on soil invertebrates has dealt with the changes in their numbers Effects on earthworms were reviewed by Davey (1963) and Edwards and Thompson (1973) who commented that very little is known of the effect of pesticides Later, some more investigations on effects of various pesticides on the number of biomass of earthworms were made in pastures and grasslands (Thompson, 1971, Tomlin and Gore, 1974, Edwards and Brown, 1982) Although Reddy and Goud (1988) made observations on the effects of different pesticides on earthworm populations of wet-land rice fields, no information is available on the responses of field population of earthworms to different insecticides in tropical grassland ecosystems Therefore, the present investigation was carried out to evaluate the ecological effects of organochlorine, organophosphorus and carbamate insecticides on the population abundance and biomass (wet) of earthworms in a semi-arid tropical Savanna

MATERIALS AND METHODS

Study area

The present investigation was made during July to September 1989 in a 50 × 50 m area of the undisturbed grassland of the savanna inside the campus of Kakatiya University, Warangal (lat 18 0 31 , long 79°29 5 and altitude of 263 7 m a m s l) in Telangana, the semi-arid region of Andhra Pradesh (India) The grass cover of the savanna was dominated by *Dimeria* sp The savanna has scattered herbs, shrubs and trees of different species viz , *Zornia gibbosa*, *Asystesia* sp , *Alysicarpus* sp , *Jatropha gossypiifolia*, *Calotropis procera*, *Butea monosperma*, *Canthium parviflorum* and *Randia candolleana* The surface soil of the savanna was light brown and of fine sandy loam type It was alkaline in nature and poor in organic matter and phosphorus It has little litter layer

The climate of the area was semi-arid with a monthly rainfall ranging from 0 to 18 4 cm, >80% of the rain falling during the rainy season, June to September Winter season extended from October to February and summer from March to May with the temperature shooting up to 43–45 C during the peak summer, i e in May

Experimental procedure

The experiment was set up on 8 July 1989 Three blocks each measuring 25 × 10 m, one for treatment with organochlorine insecticide, endosulfan 35% E C , the other for treatment with the organophosphorus compound, methyl parathion 50% E C and another for treatment with a carbamate compound, carbaryl (Sevin) 50% W D P , being separated from each other by a distance of 5 m, were marked out Each block was divided into 10 equal sized plots each measuring 5 × 5 m area Of the 10 plots, three were selected randomly and treated with the normal dose (each plot being treated with 1 ml of endosulfan, 0 66 ml of methyl parathion and 4 16 g of carbaryl, each dissolved in 1 litre of water) as recommended for use by farmers, of the insecticide and another 3 randomized plots were treated with the high dose, three times that of the normal dose and the other three were left untreated as control plots Thus, each insecticide treatment was replicated three times

The earthworms were sampled prior to the treatment of insecticides in the plots, and after 40, 60 and 80 days The earthworms were sampled by handsorting from an area of 25 × 15 × 10 cm during the morning hours (06 00–08 00 a m) The earthworms of each plot were collected in a polythene bag with a little amount of parent soil and were brought to the laboratory These were sorted into various age-groups such as juveniles and adults and different species were identified They were counted and weighed (fresh wt) They were treated with 5% formalin overnight, and stored in 80% ethanol

The data of population abundance of earthworms of the pre-spraying samples and those of the treated and untreated control plots were statistically analyzed by student's t-test at the 5 and 1% levels of significance

RESULTS

Earthworms recorded from the plots during the pre-spraying and post-spraying period, belonged to two species, *Drawida willsi* Michaelson and *Lampito mauritii* Kinberg The former was dominant constituting >99% of the total and the latter was recorded in meagre number The individuals of *D willsi* were small and active, and inhabited the surface soil

Many dead and dying individuals were recorded on the surfaces of the endosulfan treated plots The abundance of earthworms both juveniles and adults, and the total population in different plots treated with both high and normal doses of endosulfan, methyl parathion and carbaryl (Sevin), and that of pre-spraying sample presented in Fig 1 revealed that, prior to insecticide spraying, the earthworms were 128 00 ± 17 36 m ^{2}, the adults constituting 29 7% of the total The earthworm abundances in the control plots, after the insecticide treatment, although showing variation from one plot to another, were more or less equal to that in the pre-spraying period The high dose of endosulfan completely eradicated the earthworms from the plots until day 80 after its application, and the adult population showed significant differences ($P < 0\ 05$) and the juveniles and total population showed highly significant differences from those of pre-spraying samples ($P < 0\ 01$), while the adults, juveniles and total population showed similar significant differences from those of the untreated control plots ($P < 0\ 001$) after 40 and 60 days However, at the 80th days, only the juveniles and total populations were significantly different from those of the pre-spraying samples ($P < 0\ 02$) and the adults, juveniles and total population were highly significantly different from those of the control ($P < 0\ 001$) Even in plots treated with normal doses of endosulfan, the adult earthworms were completely absent until day 40 However, the adults appeared in meagre numbers (26 6 ± 14 617 m ^{2}) after 60 days but had disappeared by 80 days The juveniles, after 40 days were reduced by 90 0% being 10 0% of the control, by 82 0% being 30 0% of the control after 60 days and by 76 6% being 56 7% of the control after 80 days Nevertheless, the total population reduced by 93 8% being 6 8% of the control after 40 days, by 66 7% constituting 38 1% of the control after 60 days and by 83 3% constituting 22 2% of the control after 80 days The adult numbers were significantly different from those of the pre-spraying samples ($P < 0\ 05$) after 40 days, while the juveniles and total population were highly significantly different from them after 60 days ($P < 0\ 001$) and 80 days ($P < 0\ 02$) Moreover, the adult, juvenile and total populations were highly significantly different from those of the control after 40 days ($P < 0\ 01$), after 60 days (for adult and juvenile—$P < 0\ 02$ and for total populations—$P < 0\ 01$), and after 80 days, except the juveniles (adults—$P < 0\ 001$ and total population—$P < 0\ 01$)

The adults and juveniles were reduced by 57 8 and 52 5% constituting 40 0 and 66 6% of the control, respectively, and the total population was reduced by 54 1% constituting 56 4% of the control after 40 days with the high dose of methyl parathion The juveniles and total population were significantly different from those of the pre-spraying samples ($P < 0\ 05$), while the adults were highly significantly different from those of the control ($P < 0\ 01$) However, the adults

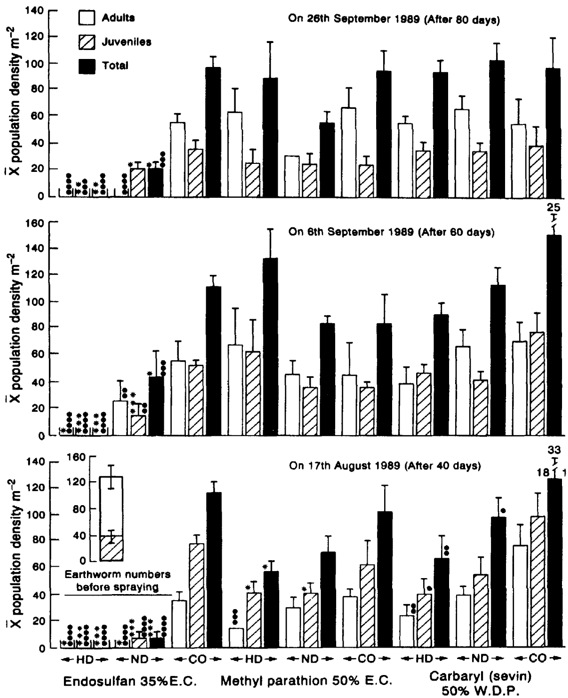

Fig. 1. Effects of normal and high doses on endosulfan, methyl parathion and carbaryl on adult, juvenile and total earthworm populations after 40, 60 and 80 days. HD: high dose; ND: normal dose; Co: control. Significant difference from pre-treatment samples: *$P < 0.05$; **$P < 0.02$; ***$P < 0.01$; and significant difference from control: ˙$P < 0.05$; ˙˙$P < 0.02$; ˙˙˙$P < 0.01$; ˙˙˙˙$P < 0.001$.

and total population increased by 82.4 and 4.7% constituting 144.4 and 156.2% of the control, respectively, while the juveniles were enhanced by 28.8% constituting 171.4% of the control after 60 days. The adults increased by 68.4% constituting 92.3% of the control while the juveniles were reduced by 70.3%, being equal in number to those of the control plots, and significantly different from those of the pre-spraying samples ($P < 0.05$), after 80 days. However, the total population reduced by 29.2% constituting 94.4% of the control. The adults, juveniles and total population were reduced by 15.8, 52.6 and 41.7% constituting 80.0, 66.7 and 71.8% of the control, respectively, after 40 days with the normal dose. The adults increased by 26.3% while the juveniles and total populations reduced by 58.5 and 33.3%, respectively, all of them being equal in number to those of the control plots after 60 days. The adults, juveniles and total earthworm populations decreased by 15.8, 70.4 and 54.6% respectively after 80 days. The former and latter constituted 46.2 and 61.1% of the control, respectively, and the juveniles were equal in number to those of the control. The juveniles were significantly different from those of the pre-spraying samples after 40 days and 80 days ($P < 0.05$).

After 40 days of treatment with the high dose of carbaryl, the adults, juveniles and total earthworm populations were reduced by 29.8, 52.6 and 15.8% constituting 33.3, 42.1 and 38.2% of the control, respectively, and were significantly different from those of the control (adults and total population—$P < 0.02$ and juveniles $P < 0.05$). The adults increased by 12.3% constituting 57.2% of the control while the juveniles and total population reduced by 43.7 and 27.1% constituting 63.3 and 60.3% of the control, respectively after 60 days. After 80 days, the adults increased by 54.4% being equal in number to those of the control plots while in the juvenile and total populations reduced by 58.5 and 25.0% constituting 87.5 and 94.7% of the control, respectively. The adults increased by 12.3% constituting 53.3% of the control, while the juveniles and total populations reduced by 34.8 and 20.8% constituting 57.9 and 58.9% of the control respectively, the latter being significantly different from those of the control ($P < 0.05$) after 40 days of treatment of its normal dose. After 60 days, the adult population increased by 82.4% constituting 92.9% of the control while the juveniles and the total population reduced by 49.6 and 10.5% and constituted 56.7 and 74.1% of the control, respectively. After 80 days, the adult population increased by 82.4% constituting 118.2% of the control, while the juvenile and total populations decreased by 58.5 and 16.7% and constituted 87.5 and 105.3% of the control, respectively. However, the differences between adult, juvenile and total populations of treated plots and those of the pre-spraying samples were statistically insignificant.

The biomass of earthworms in response to both the high and normal doses of the insecticides in presented in Fig. 2. It showed that there was no earthworm biomass in the plots treated with high dose of endosulfan being significantly different from that of the pre-spraying sample, after 40 and 60 days ($P < 0.01$) and after 80 days ($P < 0.05$). The biomass also showed highly significant differences from that of the control ($P < 0.001$). In the plots treated with the normal dose, the biomass reduced by 97.2, 83.3 and 77.8% and constituted 4.7, 30.0 and 46.5% of the control after 40, 60 and 80 days, respectively. The biomass showed significant differences from that of the pre-spraying sample, after 40 days ($P < 0.01$), 60 days ($P < 0.02$) and 80 days ($P < 0.05$). It was also highly significantly different from that of the control after 40 days ($P < 0.001$), 60 days ($P < 0.001$) and 80 days ($P < 0.002$).

In the plots treated with the high dose of methyl parathion, the biomass was reduced by 63.9, 20.0 and 40.0% constituting 72.3, 147.0 and 98.2% of the control after 40, 60 and 80 days, respectively. It showed a significant difference from that of the pre-spraying sample after 40 days ($P < 0.05$), while in the plots treated with the normal dose, the biomass was reduced by 52.8, 43.3 and 58.9% and constituted 94.5, 104.1 and 67.3% of the control, after 40, 60 and 80 days, respectively.

In the plots treated with the high dose of carbaryl, the biomass was reduced by 52.8, 51.1 and 50.0% constituting 39.5, 54.3 and 91.8% of the control after 40, 60 and 80 days, respectively and showed a significant difference from that of the control after 40 days ($P < 0.05$). While in the plots treated with the normal dose the biomass was reduced by 33.3, 29.4 and 27.8% and constituted 55.8, 78.4 and 132.7% of the control, after 40, 60 and 80 days, respectively.

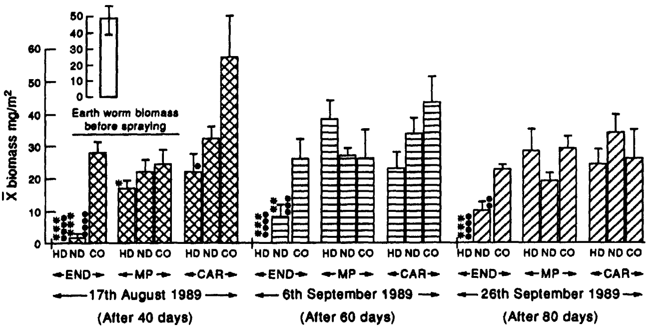

Fig. 2. Effects of normal and high doses of endosulfan, methyl parathion and carbaryl on biomass of earthworms after 40, 60 and 80 days of treatment. HD: high dose; ND: normal dose; Co: control; END: endosulfan; MP: methyl parathion; CAR: carbaryl (Sevin). Significant difference from pre-treatment samples: *$P < 0.05$; **$P < 0.02$; ***$P < 0.01$. Significant difference from untreated control samples: ˙$P < 0.05$; ˙˙$P < 0.02$; ˙˙˙$P < 0.01$; ˙˙˙˙$P < 0.001$.

DISCUSSION

The earthworms move on the soil during the nights to collect food, and while doing so they might have come in contact with the surface deposits of the insecticide through the skin and ingested the contaminated food, which might have killed them. Kring (1969) recorded many dead and dying individuals on the soil surface after treatment with Box and Carbofuran. However, Edwards and Brown (1982) reported that the earthworms may reduce their exposure to pesticides by entering a state of quiescence and diapause or by moving into the deeper layers of soil. We did not find any such stage of quiescence and diapause nor their presence in deeper layers of the soil, during the present study, although the dead and dying worms were recorded on the plots treated with endosulfan.

The results indicated that there were significant effects of both the high and normal doses of endosulfan on adults, juveniles and total population of earthworms until day 40 of treatment. The normal dose did not have any significant effect on adults after 60 days and both the high and normal doses did not show any significant effect on the adults after 80 days. Besides, the normal dose did not show any significant effect on juveniles after 80 days as there was no significant difference with that of the control. Both the doses of methyl parathion showed significant effect only on juveniles after 40 and 80 days and its high dose had a significant effect on adults after 40 days. Carbaryl did not have any effect on the adults, and juveniles and thus, on the total population until 40 days of treatment of normal dose. Its high dose showed significant effect on them while its normal dose showed such effect on the total population only after 40 days.

The data from most of the plots treated with methyl parathion and carbaryl, unlike those of endosulfan, showed insignificant differences between the treated and untreated plots, with occasional large significant differences between them. It suggested that endofulfan had significant effects on earthworm abundance. However, Dursban, DDT and fenitrothion had been reported to have no effect on the numbers of earthworms (Edwards *et al.*, 1968; Thompson, 1971; Edwards and Thompson, 1973; Martin, 1976).

DDT had a deleterious effect on earthworms at high dosage (Davey, 1963: Edwards and Thompson, 1973), but may not be harmful when applied at normal dose (Gallaher and Evans, 1961; Martin, 1976). Thompson (1971) reported moderate effects of endrin and carbaryl, which reduced the earthworm numbers by 52.0 and 59.1% respectively. Heungens (1966) reported carbaryl as the most efficient of 10 insecticides. Phorate when applied at normal agricultural doses, may eliminate earthworms and no other organophosphorus insecticide had been reported to have such a great effect on earthworms (Kelsey and Arlidge, 1968; Edwards *et al.*, 1968; Way and Scopes, 1968). Thompson (1971) showed that the initial effects of Dosanit, carbofuran, and N-2596 were as great as those of phorate. Tomlin and Gore (1974) reported benomyl and carbofuran G to be highly toxic to earthworms. However, Martin (1986) found *Lumbricus terrestris* to be less sensitive to carbofuran than fensulfothion and phorate.

The present findings also showed recovery of earthworm population by day 80 of insecticide treatment, to a level more or less nearer to that of the control plots and those of the pre-spraying sample. The endosulfan did not show any significant effect on adults even with a high dose after 60 days and at its high and normal doses at 80 days. In some treatments of methyl parathion and carbaryl, the total earthworm population particularly the adults increased well above the level of those of control plots and the pre-spraying sample, which may be due to their immigration from the neighboring plots and from the outside. The variations in sensitivity of earthworms to the toxicity of these insecticides may explain these responses. Moreover, these responses may also be explained by their speed of recruitment once the pesticide residues fall below the lethal threshold (Edwards and Brown, 1982).

Thompson (1971) stated that number of earthworms alone does not indicate a true record of the insecticide effect; its biomass is more important as it can be used in calculation of physiological requirements of the tissues, and the cycling of mineral nutrients. The population reductions are generally correlated to biomass reduction. The biomass was reduced in the plots wherever there was a significant reduction in numbers due to the effect of insecticide. The insecticides (particularly endosulfan) significantly reduced the earthworm biomass. The high and normal doses of endosulfan showed significant effects on earthworm biomass until 80 days except the insignificant effect of its normal dose after 80 days, while the high dose of methyl parathion showed a significant effect and that of carbaryl showed significant effect after 40 days. This is consistent with the findings of Thompson (1971) who reported that fensulfothion caused a greater reduction in earthworm biomass. Martin (1976) reported that the earthworm population decreased in number and biomass in plots treated with DDT, fenitrothion, fensulfothion and carbamate. Of the three insecticides, endosulfan was most deleterious to earthworm population followed by methyl parathion and carbaryl. Keeping in view the deleterious effects of endosulfan, it should be used only when no alternative insecticides are available. As alternatives, methyl parathion and carbaryl (Sevin) which were relatively less toxic even at high doses should be used in agricultural pest control operations.

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Attack on pigeonpea (*Cajanus cajan* (L.) Millsp.) by *Odontotermes obesus* (Rambur) and *Microtermes obesi* Holmgren (Isoptera: Microtermitinae)*

(*Keywords:* termite damage, pigeonpea, semi-arid tropics, India)

M. VIKRAM REDDY†, D. F. YULE‡, V. RAVINDER REDDY† and P. J. GEORGE§

† *Environmental Biology Laboratory, Kakatiya University, Warangal, Andhra Pradesh 506 009*
§ *Resource Management Programme, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru PO, AP 502324, India*
‡ *Land Management Research Branch, QDPI, PO Box 6014, Rockhampton, Qld 4702, Australia*

Abstract. Damage is caused by *Odontotermes obesus* (Rambur) and *Microtermes obesi* Holmgren to perennial pigeonpea (*Cajanus cajan* (L.) Millsp.) in south India. *O. obesus* attacked the root, stem and some branches under an earthen sheet. *M. obesi* damaged the root and pith, making irregular, soil-filled cavities, which were indicated by cracked bark near the stem base. The two species were sometimes associated. Termite damage increased after the rainy season until the end of summer. 2-year-old plants were killed by the combined effects of root disease, termite attack and drought.

1. Introduction

Pigeonpea (*Cajanus cajan* (L.) Millsp.) is a major drought-resistant perennial grain legume of the semi-arid tropics. It is used for food, animal feed and buildings. About 200 species of insect pests have been associated with pigeonpea (Sithanantham, 1987) but only one subterranean insect, i.e. the termite, *Odontotermes parvidens* Holmgren and Holmgren, has been reported to damage the crop seriously (Chhotani, 1980; Sithanantham, 1987; Lateef and Reed, 1990). Singh *et al.* (1978) reported considerable damage caused by *Allodontermes, Ancistrotermes* and *Microtermes* sp. to pigeonpea in Kenya. Reed *et al.* (1989) described the symptoms of the damage caused by some unknown species of *Odontotermes* spp. and *Microtermes* spp. in pigeonpea. *Microtermes* sp. has been reported as a pest on pigeonpea in East Africa and Nigeria (cf. Lateef and Reed, 1990). This report describes the damage caused by two species of termites—*Odontotermes obesus* (Rambur) and *Microtermes obesi* Holmgren belonging to Termitidae—to perennial pigeonpea. The observations were made in an Alfisol field at the International Crops Research Institute for Semi-Arid Tropics (ICRISAT), Hyderabad, where pigeonpea is one of the mandate crops (Davies and Lateef, 1978). While this is the first report of damage to pigeonpea by these species of termites, they have been found in different states of South India as pests of a wide range of crops, on dead trees and on dried cow dung (Bose, 1984; Sudhakar and Veeresh, 1985; Sen-Sarma, 1986).

2. Nature of damage

O. obesus attacked the roots of the plants, a few centimetres below the ground. It hollowed out the root and the basal portion of the stem irregularly and filled them with soil. In some cases it covered the stem and branches with earthen sheet up to a height of more than 60 cm from the soil surface, ate the bark and portions of the stem, and engraved irregular cavities and filled them with soil. Reed *et al.* (1989) reported that the stem surfaces of some large pigeonpea plants were fed upon by *Odontotermes* spp. beneath the earthen sheet. This termite attacked the root, stem and a few branches under the cover of the earthen sheet, and consequently these plants wilted. This termite builds mounds and, near the experimental plots where damage to pigeonpea plants was recorded, sub-conical mounds with a broad base and a few holes were found.

Attack of *M. obesi* remained unnoticed from the outside except for the appearance of cracks on the bark at the basal portion of the stem. A closer observation of the cracked bark showed soil inside. Removal of the bark revealed damage to the pith, with irregular cavities moving upwards to the branches and filled with soil. In some cases it was associated with *O. obesus* showing the phenomenon of inquilinism. Reed *et al.* (1989) reported that *Microtermes* spp. made a hole in the stem just below the soil surface, resulting in wilting and death.

The termite damage was observed towards the end of the rainy season and increased gradually as winter approached. By the end of January, 24% of the plants were dead (Table

Table 1. Percentage of termite-affected, dead pigeonpea plants in the experimental plots at ICRISAT Centre, Patancheru, India

Dates of observation	Plots								
	I	II	III	IV	V	VI	VII	VIII	IX
31 Jan 1990	29·3	14·1	26·0	29·3	29·3	27·1	22·8	26·0	13·0
1 May 1990	92·3	98·9	54·3	63·0	70·6	48·9	55·4	68·4	44·5

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1). By the end of the summer that followed, the proportion of dead plants increased to >66% (Table 1). No rainfall was recorded during this period. The fungal disease, wilt (*Fusarium udum*), is endemic to this area, and as a result of combined root disease, termite attack and drought, 2-year-old pigeonpea plants dried up and died. However, the relative contributions of wilt, termite and drought to the death of the plant are not known.

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Soil Management and Seasonal Community Structure of Soil Microarthropods in Semi-Arid Tropical Alfisols

M. Vikram Reddy[1,*], V. Ravinder Reddy[1], V.P. Kiran Kumar[1], D.F. Yule[2,3] and A.L. Cogle[2]

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1). By the end of the summer that follow of dead plants increased to >66% (Table recorded during this period. The fun (*Fusarium udum*), is endemic to this are of combined root disease, termite att 2-year-old pigeonpea plants dried up and relative contributions of wilt, termite and d of the plant are not known.

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Soil Management and Seasonal Community Structure of Soil Microarthropods in Semi-Arid Tropical Alfisols

M. Vikram Reddy[1,*], V. Ravinder Reddy[1], V.P. Kiran Kumar[1], D.F. Yule[2,3] and A.L. Cogle[2]

Environmental Biology Laboratory, Department of Zoology, Kakatiya University, Warangal 506 009, Andhra Pradesh, India.

Resource Management Program, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India.

Queensland Department of Primary Industries, Land Management Research Branch, P.O. Box 6014, Rockhampton, Qld. 4702, Australia.

siting Scientist (Under the Rockefeller Foundation Environmental esearch Fellowship in International Agriculture), Resource Management Program, RISAT.

respondence: M. Vikram Reddy, Resource Management Program, ICRISAT.

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Summary

Response of the soil microarthropod community was monitored across different soil management treatments with annual and perennial crops in semi-arid tropical Alfisols Annual crop management treatments included zero, shallow and deep tillage either bare or with application of 15 t ha^{-1} farm-yard manure or 5 t ha^{-1} rice-straw Perennial crop treatments were *Stylosanthes hamata*, *Cenchrus ciliaris* and pigeonpea either alone or in combination Microarthropods, across all the treatments, included Collembola, Acarina Araneae, Pseudoscorpiones, Pauropods, Symphyla, Diplura, Dermaptera, Psocoptera Isoptera, Thysanoptera, Homoptera, Hymenoptera and Coleoptera adults and larvae The number of Collembola and Acarina together constituted > 62% of the total microarthropods The population densities of all microarthropods showed a more or less similar pattern of temporal variations under all treatments They were higher during the rainy season of 1990 and 1991 in bare plots under zero-tillage treatment followed by plots under rice-straw treatment However, densities during rainy months of 1989 were low compared to those of 1990 because of the high dose of carbofuran treatment Population densities showed significant treatment differences during some months indicating significant impact of soil management practices on microarthropod community structure

Materials and Methods

Experimental site and treatments:

This experiment was conducted using plots 28 m long (2% slope) and 5 m wide on a shallow to medium depth Alfisol (Patancheru Series, Udic Rhodustalf) at ICRISAT farm (Long. 78° 17' 0'E, Lat. 17° 28' 58N") near Hyderabad in south India. The soil is hard setting and very prone to surface sealing and crusting. The experimental design was an incomplete randomised block with an embedded factorial. There were 15 treatments each with three replicates. Annual crops were grown on nine treatments which included three tillage options [no or zero-tillage, shallow-tillage (10 cm deep) and deep-tillage (20 cm deep)] and three amendments (no amendment or bare, 15 t ha^{-1} farm-yard manure, and 5 t ha^{-1} rice straw), in the factorial. The remaining tratments were with perennial pigeonpea, Cenchrus ciliaris and Stylosanthes hamata alone or in combination. Full details of the experimental design are given in Smith et al. (1992).

The experiment was established in 1988 and the treatments were maintained in the same plot each year. The tillage treatments and amendments were imposed afte initial rains every year. In June 1989, carbofuran insecticide granules (40 kg ha^{-1}) were applied to the soil in the planting rows to control shoot fly (Atherigona soccata Rond. Again, during August 1990, carbofuran granules (5 kg ha^{-1}) were applied to whorls of th seedlings for shoot fly control. No insecticide was applied during 1991 and 199 Paraquat (4 l ha^{-1}) was applied to all plots on June 29 and July 20, 1989 and to no t mulch on July 5, 1990.

Tillage plots received a shallow cultivation to break the crust, and then, about a week later a tyne cultivation (50 cm spacing) to the treatment depth. Amendments were added in three equal increments after each tillage operation and after planting. Millet was grown with the treatments in July 1988. In 1989 and 1990, sorghum was sown in mid July after imposing the treatments in late June - early July. In 1991, maize was grown after applying the treatments in June.

Soil microarthropod sampling

Each plot was sampled for soil microarthropod population density with the help of an iron soil core sampler of 5 cm diameter and 10 cm depth. Sampling was carried out in the morning hours between 0730 and 0930 when the ambient temperature was low, monthly from July to October 1989, February to December 1990, May to December 1991, and February and March 1992. Three soil core samples were taken randomly in the central area of each plot leaving 2 m from each side in order to avoid edge effects. The soil samples were processed through Tullgren funnel apparatus for 72 hours and the soil microarthropods were extracted in 80% alcohol. They were identified into major taxa, enumerated and data were converted into densities m^{-2}.

Statistical analysis (analysis of variance) of the data was accomplished within the factorial to show the effect of tillage depth and mulch, or within the randomised block to compare all treatments, using GENSTAT package.

Results and Discussion

Because of difficulties in determining the genus and species of these microarthropods, they were identified to higher taxa only (e.g., Prostigmata, Mesostigmata, Cryptostigmata and Astigmata in Acarina, Isotomidae, Entomobryidae, Hypogastruridae, Onychiuridae and Sminthuridae in Collembola, and Araneae, Pseudoscorpiones, Pauropods, Symphyla, Diplura, Dermaptera, Psocoptera, Isoptera, Thysanoptera, Homoptera, Hymenoptera, and Coleoptera adults). Acarina on average comprised > 34%, Collembola comprised 28%, and the miscellaneous arthropods, which included all arthropods other than Collembola and Acarina, comprised of > 37% of the total number of microarthropods across the treatments over the study period.

Among the tillage treatments, higher numbers of soil microarthropods were associated with zero tillage bare treatment (mean $\pm$ S.E. density for the study-period: 2493.3 $\pm$ 722.4 m^{-2}) and with zero tillage rice-straw treatment (2396.7 $\pm$ 575.9 m^{-2}) compared to farm-yard manure treatment (1870.0 $\pm$ 421.7 m^{-2}) ($P < 0.05$) (Fig. 1a). In shallow and deep tillage treatments, the microarthropod densities were more in rice-straw treatment (2356.7 $\pm$ 514.4 m^{-2} in shallow tillage and 1933.3 $\pm$ 440.2 m^{-2} in deep tillage) than in farm-yard manure treatment (1943.3 $\pm$ 448.6 m^{-2} in shallow tillage and 1736.7 $\pm$ 410.8 m^{-2} in deep tillage) ($P < 0.05$) (Fig. 1b and 1c). This indicates that the zero-tillage bare, and rice straw mulch conditions are more favourable for soil microarthropods (Nakamura, 1988). House and Parmelee (1985) recorded higher numbers of soil arthropods in no-tillage treatment at the Horseshoe Bend research site in Clarke county near Athens in Georgia (USA). The present results are also in accordance with the findings of House et al. (1989) that tillage has a more consistent effect on soil arthropod community composition than no-tillage treatment. This is because tillage induced sudden changes in the soil environment, such as mechanical disturbances, changes in soil temperature and humidity, redistribution of plant residues, and disruption of access to their food resources (Wallwork, 1976; Andren and Lagerlof, 1980). In contrast, no-tillage practices minimise soil disturbance; plant residues are deposited on the soil surface where they serve to reduce moisture loss and offer a concentration of food resources. The direct detrimental effects of tillage are, in part, due to abrasive damage to these arthropods and in part, due to trapping of arthropods in the soil during inversion when the existing systems of cracks and animal-pores are damaged (Nakamura, 1988).

Under the perennial cover crops, higher densities of microarthropods were recorded in zero-tillage pigeonpea + *S. hamata* treatment (2516.7 $\pm$ 464.1 m^{-2}) and with pigeonpea + *S. hamata* + *C. ciliaris* treatment (2193.3 $\pm$ 477.1 m^{-2}) compared to that of only pigeonpea treatment (1496.7 $\pm$ 262.0 m^{-2}) ($P < 0.05$) (Fig. 2a). Higher numbers of microarthropods were also recorded in zero-tillage with *S. hamata* treatment (2936.7 $\pm$ 576.4 m^{-2}) followed by that with *C. ciliaris* + *S. hamata* treatment (2790.0 $\pm$ 540.7 m^{-2}) and with only *C. ciliaris* (2778.3 $\pm$ 526.5 m^{-2}) (Fig. 2b). This may be a result of the formation and subsequent arrangement of microhabitats available under a specific vegetational regime (Berg and Pawluk, 1984). It indicated that the microarthropod densities over the years, across all treatments, were much higher in zero-tillage particularly with *S. hamata* treatment followed by zero-tillage with *C. ciliaris* + *S. hamata* treatment and with *C. ciliaris* treatment.

The microarthropod population densities showed significant treatment differences during July and August (variance ratio: $P < 0.05$) and October 1989 (variance ratio: $P < 0.01$), February and July 1990 (variance ratio: $P < 0.05$), June (variance ratio: $P < 0.01$)

and July 1991 (variance ratio: $P < 0.05$) and February 1992 (variance ratio: $P < 0.01$). This indicated that the soil management practices had significant effects on the community structure of the microarthropods. However, during the other months, there was no significant effect of these management practices on the microarthropod population densities which was probably because of wide variations in the population densities among the replicate plots of each treatment. This is possibly because of the nature of non-randomised distribution of soil microarthropods; and the most likely cause of such non-randomness is the patchy distribution of either food resources or soil water (Usher, 1976; Farrar and Crossley, 1983). Thus, the microarthropod populations sampled may contain biased samples of clumped individuals. Farrar and Crossley (1983) found microarthropod aggregations higher in no-tillage soybean systems than those in conventionally tilled soybean systems.

The population densities of soil microarthropods showed temporal variations and fluctuated irregularly across the season. During 1990 and 1991, their abundance tended to follow a similar seasonal pattern and was higher during rainy season than the preceding and following dry summer and winter seasons. Most probably rainfall and soil moisture had a favourable influence on soil microarthropod population densities (Reddy, 1984). However, during 1989 the population densities were low, and were distinctly different from those of the year 1990, and 1991, except in July 1990 (Figs. 1 and 2). This is attributable to the ecotoxicological effects of higher dose of carbofuran granules, and herbicides applied from time to time. Application of carbofuran granules at a lower dose (5 kg ha^{-1}) to the whorls of the seedling had little effect on soil microarthropod densitie during 1991. Many researchers have reported the reduced population structure of soil microarthropods because of higher doses of insecticide and herbicide treatments (Reddy, 1989). The population densities slowly recovered from the stress of the insecticide and herbicides by the rainy season in 1990. However, during the initial months of the rainy season in these two years the microarthropod densities were lower compared to the following months (Figs. 1 and 2) which may be because of disturbance caused by tillage operation practiced during that period. The development of an environmental mosaic (i.e., soil stabilization and undisturbedness, and favourable environment) in the following months probably induced reestablishment and recolonisation of the microarthropods leading to their increased population densities. Such an initial decrease in microarthropod population density followed by an increase towards the end of the growing season corroborates the findings of Stinner and Crossley (1988) and Loring et al. (1981).

Soil microarthropods have been reported as good bioindicators of impact of modern agricultural management practices (Paoletti et al. 1991). These arthropods ameliorate the soil structure and soil fertility (Lee and Foster, 1991). Therefore, it is beneficial to maintain a good number of soil microarthropods in crop fields by different soil management practices such as zero tillage, mulching with crop residue and sowing cover crops (Lal, 1991). The present findings indicated higher microarthropod densities under perennial crop covers, zero-tillage and rice-straw mulched conditions. Such management practices may be useful in sustainable agriculture and enhance the productivity.

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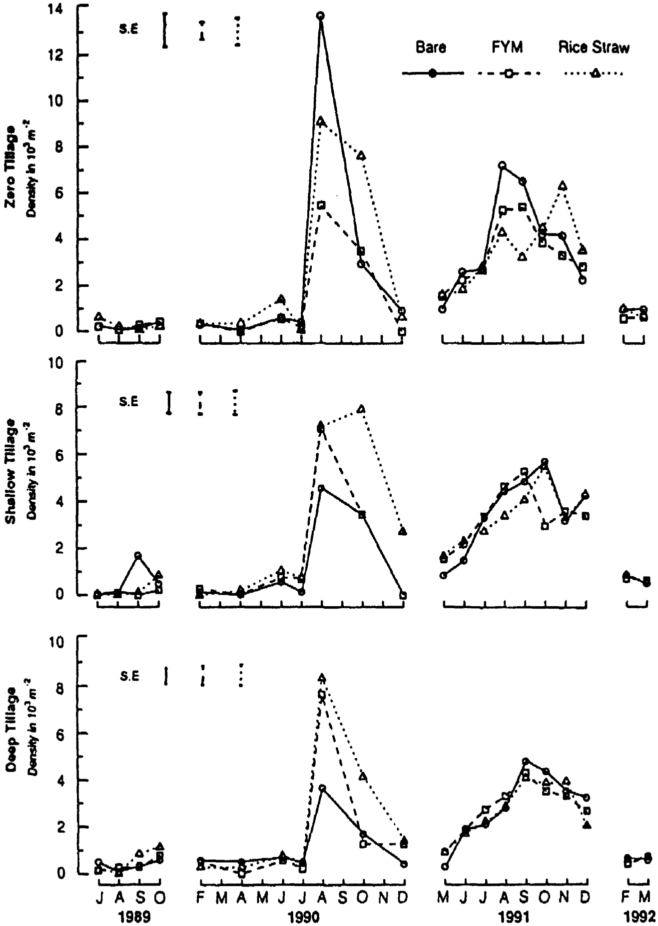


Fig. 1. Population densities of soil microarthropods across tillage treatments with different organic amendments.

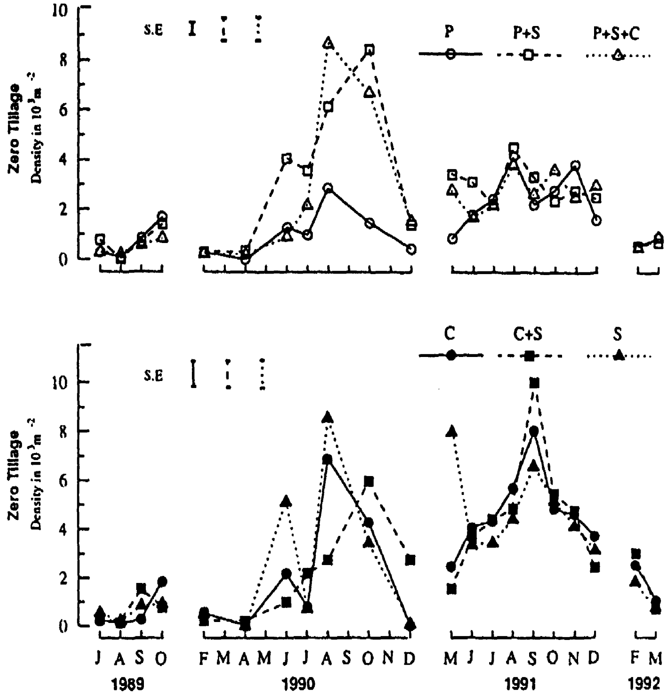


Fig. 2. Population densities of soil microarthropods across treatments of zero-tillage with pigeonpea (P), *Stylosanthes hamata* (S) and *Cenchrus ciliaris* (C) alone and in combination.

ated with a lower faunal abundance while a distinct increase in plant-residue decomposition was associated with a reduced tillage intensity. Other studies have been conducted on the impacts of tillage and cultivation on soil invertebrates associated with decomposition processes (Hendrix et al. 1986; Andrén et al. 1990). However, there is very little information on the effects of soil arthropods on the decomposition of straw and other crop residues in relation to different soil management practices in tropical agroecosystems (Lekha et al. 1989). In the present investigation, therefore, we analysed the rate of mass loss of rice straw in relation to the abundance of soil arthropods and different types of tillage and soil management practices in Alfisols in the semi-arid tropics.

Materials and methods

Site description

This experiment was conducted between August 1989 and July 1990 within a long-term soil management trial on an experimental shallow-to-medium depth Alfisol field (Patancheru series, Udic Rhodustalf) at the International Crops Research Institute for the Semi-Arid Tropics, near Hyderabad, India. The long-term core experiment was conducted with 15 treatments (three tillage×three amendments+six ley crops) and three replications in a balanced incomplete randomized block design with 28-m long and 5-m wide plots (Smith et al. 1992).

This experiment was conducted in three treatments of the core experiment, comprising mulch (5 t ha^{-1} rice, *Oryza sativa* L. straw) with zero tillage (no tillage), mulch with tillage to 10 cm in depth (shallow tillage), and mulch with tillage to 20 cm in depth (deep tillage). Tillage was done in late June to early July, when all plots were given a shallow cultivation with duckfeet tine to break the crust and, 6 days later, a chisel-tine cultivation (50 cm spacing) to the treatment depth. Sorghum (cv. CSH 9) was sown on 19 July. Mulch was added in three equal splits after each soil cultivation operation and after sowing.

Paraquat (1 kg a.i. ha^{-1}) was applied to all plots on 29 June and 20 July 1989, and to the no-till mulch on 5 July 1990. One or two hand-weedings were carried out during the crop growth in both years. In June 1989, carbofuran insecticide granules (1.3 kg a.i. ha^{-1}) were applied to the soil in the planting furrows to control shoot fly (*Athrigona soccata* Rond.). In June 1990, carbofuran granules were applied at about 5 kg ha^{-1} to the whorls of the seedlings for shoot-fly control. Fertilizer was applied as 18 kg N ha^{-1} and 46 kg P ha^{-1} (diammonium phosphate) at planting and 90 kg N ha^{-1} (urea) by side dressing. In both years, sorghum was harvested by hand in November by cutting the stalks about 5 cm above ground level and removing them (Yule et al. 1993).

Decomposition measurement technique

To study the decomposition and disappearance of rice straw in relation to arthropod abundance and tillage practices, nylon mesh bags of two mesh sizes, coarse (7 mm) and fine (1 mm), each measuring 10×6 cm wre prepared, mainly to prevent large macroarthropods from entering the fine-mesh bags. The bags were filled with 10 g air-dried rice straw and six bags of each mesh size were placed randomly on the soil surface and covered with a thin layer of straw in the plots on 8 August 1989. One bag of each mesh size was recovered at random from each plot 30, 60, 120, 180, 240, and 330 days later. Each bag was collected separately in a polyethylene bag after removing the adhering particles with a fine-haired brush, taking as much care as possible to prevent spillage. These bags were brought to the laboratory, weighed and placed on Tullgren funnels for 72 h for extraction of the associated soil arthropods, within 1 h of collection. The extracted arthropods were collected in 80% alcohol, identified, classified into various taxonomic groups with the help of a stereoscopic binocular microscope (Wild M3 Heerbrugg), and enumerated. The mass loss and moisture content of straw at each sampling were determined by the method of Curry (1969).

The termites could not be sampled accurately by sampling the litter bags because of their high mobility. Their foraging activity on straw was therefore assessed qualitatively and indirectly by visual observation based on their earthern sheet coverage on the straw.

The data were statistically analysed using the GENSTAT package. The effects of the abundance of different groups of arthropods, tillage, and moisture content of straw on mass loss of straw over the period of study were estimated by multiple linear regression analysis.

Results and discussion

In the rainy season, particularly in September, a high abundance of arthropods, comprising Acarina, Collembola, and other miscellaneous arthropods such as termites, Coleoptera and their larvae, Psocoptera, Dermaptera, Blattidae, Homoptera, Pseudoscorpiones, Pauropoda, and Thysanura, were recorded across the tillage treatments in the straw of both the coarse- and fine-mesh bags (Fig. 1), although the population densities of soil arthropods were suppressed by carbofuran treatment during the study period (Reddy et al. 1993). On other sampling occasions, although the arthropods were only represented in small numbers, the foraging activity of termites was obvious in the field. At most times more arthropods were present in the coarse-mesh bags than in the fine-mesh bags (significantly more in no-tillage in September 1989), most probably due to the larger mesh size providing easy entrance to the macroarthropods. The abundance of microarthropods was significantly affected ($P<0.01$) by the tillage treatments and the season (Table 1). In September 1989, there were significantly more

Table 1 Summary table of analysis of variance of data on arthropod abundance, mass loss, and moisture of decomposed straw in relation to tillage over the seasons

Sources of variation	Degrees of freedom	Mean square		
		Arthropod abundance	Mass loss	Moisture
Coarse-mesh bags				
Tillage (T)	2	6335.20[a]	22.96	33.18
Season-days (S)	4	65130.87[a]	5860.22[a]	807.89[a]
T×S	8	6646.15[a]	91.54	58.53
Error	28	1288.05	237.66	45.25
Fine-mesh bags				
Tillage (T)	2	1933.96[a]	125.62	18.59
Season-days (S)	4	26031.40[a]	2884.08	849.80
T×S	8	2036.71[a]	203.76	23.66
Error	28	355.38	211.38	52.62

[a] $P<0.01$

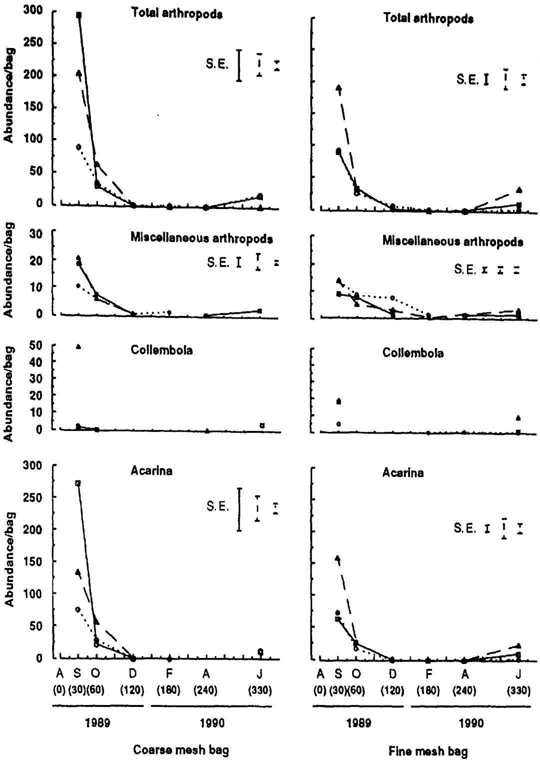


Fig. 1 Arthropod abundance in straw-filled nylon bags of coarse and fine mesh across tillage treatments (*numbers in parentheses* represent days). –□– Zero tillage; ---△--- 10-cm tillage; ···○··· 29-cm tillage

arthropods in the no-tillage and 10-cm tillage than in 20-cm tillage treatment. This is in accord with the findings of Friebe and Henke (1991) that a greater tillage intensity was associated with a lower faunal abundance.

Acarina were the most abundant arthropods in litter bags of both mesh sizes across the tillage treatments, comprising more than 70% of the total arthropods. In particular, Acarina were more abundant in coarse-mesh bags in the no-tillage treatment in September 1989 (Fig. 1). The Collembola, mostly represented by *Lepidocyrtus* sp. (Entomobryidae), were least abundant in the straw of both mesh sizes under the no-tillage and 20-cm tillage treatment (Fig. 1). Among the Acarina, Prostigmata were dominant during July and September 1989, while Cryptostigmata dominated during October and December 1989. This is in accord with a study by Whitford and Parker (1989) who concluded that Acarina are the most numerous and important arthropods in semi-arid regions and that among Acarina, the Cryptostigmata are dominant in surface litter.

Termites, particularly *O. obesus*, dominated the miscellaneous groups of arthropods associated with the decomposing straw. *O. obesus* was very active and foraged along with *M. obesi*, on the straw, under the cover of a thin earthern sheet across the tillage treatments. The foraging activities of both the termites, *O. obesus* and *M. obesi*, started about 8 – 10 days after the straw was placed in the field but numbers were very low during the rainy months and gradually increased during the dry season extending from October to May. Termite activity was much

Fig. 2 Moisture content of straw in coarse- and fine-mesh bags across tillage treatments. For further explanations, see Fig. 1

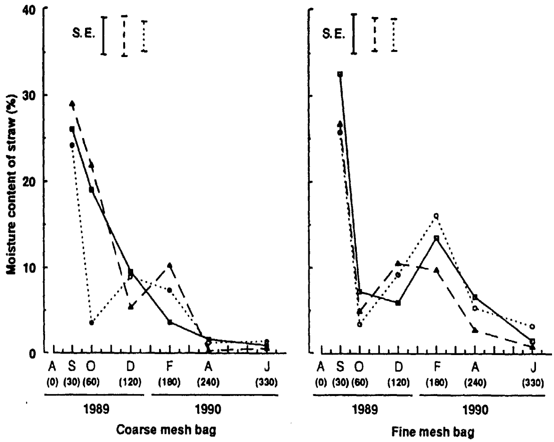
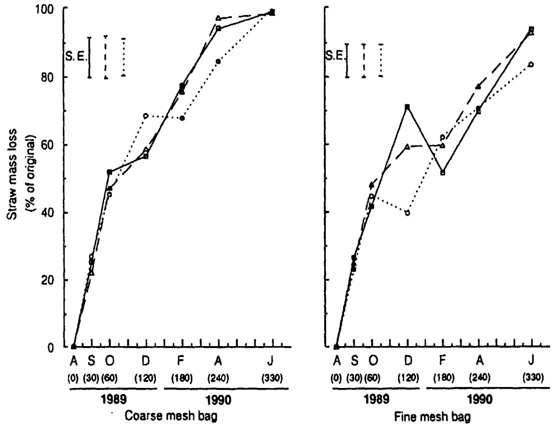


Fig. 3 Cumulative mass loss of straw in coarse- and fine-mesh bags across tillage treatments. For further explanations, see Fig. 1



more important than that of all other arthropods during the dry period. The continuous higher mass loss during the dry period was probably the result of termite activity.

The temporal variations seen in arthropod abundance was probably a result of the influence of dryness and the weathered condition of straw (Seastedt and Crossley 1980; Reddy and Venkataiah 1989). This was particularly the case for Collembola, which appeared only during the rainy season, their activity being highly dependent on soil and litter moisture. There was a distinct seasonal variation in the moisture content of the straw, which was higher during the rainy season, and gradually decreased as the

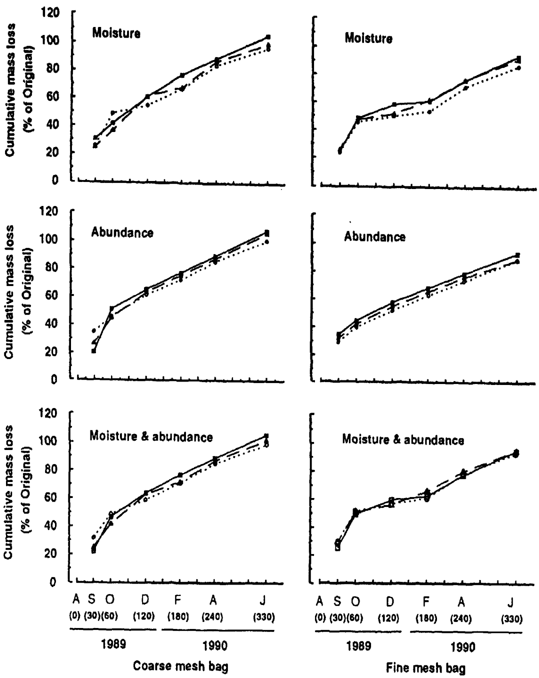


Fig. 4 Estimate of cumulative mass loss of straw in coarse- and fine-mesh bags as affected by moisture and arthropod abundance, and both, over the time period. For further explanations, see Fig. 1

dry season progressed (Fig. 2). Tillage affected the moisture content of the straw in coarse-mesh bags during the rainy season. The moisture content was higher in fine-mesh bags in the no-tillage and 20-cm tillage treatments compared to that of coarse-mesh bags, and ranged between 1.5 and 32.6% in the no-tillage and between 3.2 and 25.7% in 20-cm tillage treatment. The moisture content ranged from 0.3 to 28.9% in the 10-cm tillage, and was higher in coarse-mesh bags compared to fine-mesh bags.

On the 60th day after the straw-filled bags had been placed in the field, the mass loss was independent of mesh size and tillage treatment, and was about 46% of the initial mass (Fig. 3). On the 120th day, there was a significant ($P<0.02$) interaction between mesh size and tillage treatment. In the no-tillage treatment, after 120 days, the mass loss in the coarse-mesh bags was lower than that in the fine-mesh bags, but the opposite trend was recorded for the 20-cm tillage treatment, where the mass loss was 73 and 58% ($P<0.06$) on the 180th day, 92 and 73% ($P<0.06$) on the 240th day, and 99 and 91% ($P<0.02$) on the 330th day in coarse- and fine-mesh bags, respectively. For most of the study period there was no tillage effect, but by the 330th day the no-tillage and 10-cm tillage treatments were showing a significantly ($P<0.05$) greater mass loss than the 20-cm tillage treatment (97, 96, 92%, respectively; Fig. 3). The greater mass loss in the coarse-mesh bags can be attributed to the ease with which larger pieces of straw were able to extrude from these litterbags.

We found very little tillage effect on the rate of straw mass loss, although the mass loss was slightly higher in the no-tillage than in the 10-cm and 20-cm tillage treatments (Fig. 4). Friebe and Henke (1991) recorded a distinct increase in straw decomposition with a reduced tillage intensity. The mass loss of straw in the present study was much higher than that of blue grama grass litter, which was only 29.4% after 9 months in a temperate semi-arid region (Vossbrinck et al. 1979), and that of rice and sorghum straw (78.2 and 82.0%, respectively) after a period of 285 days in a dry tropical subhumid region (Lekha et al. 1989). Cogle et al. (1987) found losses of between 35 and 55% for wheat straw in a Vertisol in the subtropics after only 45 days. The mass loss results in the present study are similar to the mass loss results for the leaf and stem litter of a grass, *Imperata cylindrica* (94.02 and 97.04%, respectively), after 10 months in the humid tropics (Reddy and Toky 1990).

The straw mass loss in both the mesh bag sizes across the tillage treatments was significantly correlated with moisture content and the total arthropod abundance. Most of the variation in straw mass loss (Fig. 4) was explained by variations in moisture content ($R^2 = 0.95$ for coarse-mesh bags; $R^2 = 0.93$ for fine-mesh bags) and in arthropod abundance ($R^2 = 0.95$ for coarse-mesh bags; $R^2 = 0.89$ for fine-mesh bags). This indicates that the straw moisture content, which strongly influenced the abundance of the arthropods (particularly Acarina during the rainy season and termites during the dry season), probably affected the straw mass loss. When the moisture content was favourable, the straw was probably fragmented and ingested by the arthropods, passed through their guts, ejected as small pellets of excreta, and then mineralized on or in the soil. However, there is little information on the combined effects of abiotic and biotic factors on the mass loss of plant material during the process of decomposition, to compare with the present findings. More research on these aspects is needed in the tropics, particularly in semi-arid tropical regions.

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