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EFFECTS OF CONTINUOUS CULTIVATIONS AND OTHER AGRONOMIC PRACTICES ON SOIL MICROARTHROPODS : A UNIFYING CONCEPT OF AGRICULTURE AND ECOLOGY FOR TROPICAL AGROECOSYSTEM

S. K. MITRA

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सत्यमेव जयते

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PREFACE

This contribution is an outcome of a project, initiated with a research grant from the Department of Science and Technology, New Delhi (No. HCS/DST/430/77). This was continued till 1987 with periodic soil sampling from the experimental fields of Jute Agricultural Research Institute, Barrackpur, West Bengal with a view to monitoring regularly the changes in soil faunal composition as a result of crop rotations, application of chemical fertilizers, pesticides, herbicidal chemicals and other agronomic practices. Changes in soil fauna arising out of continuous cultivations was monitored every year to Indian Council of Agricultural Research (Jute Agricultural Research Institute, Barrackpur, West Bengal). The computation and analysis of data was carried out with the help of Indian Statistical Institute, Calcutta.

I am grateful to the Department of Science and Technology, New Delhi for providing me the grant, the Director, Zoological Survey of India (Ministry of Environment and Forests) for facilities, the Director, Jute Agricultural Research Institute, Barrackpur, West Bengal for their benevolent assistance and the Director, Indian Statistical Institute, Calcutta for assistance in statistical analysis.

I am also thankful to the staff members of the Apterygota Section (H. Q.) for their technical assistance and the regional stations of the Survey (Desert Regional Station, Jodhpur, Western Regional Station, Pune, Eastern Regional Station, Shillong) for sending me the collections of Collembola dealt with in section-B of this contribution.

SECTION—A

EFFECTS OF CONTINUOUS CULTIVATIONS ON SOIL MICROARPOTHODS WITH SPECIAL REFERENCE TO COLLEMBOLA (INSECTA)

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INTRODUCTION

Agroecosystems are man-made (hence, sometimes called "domesticated ecosystems"), originated mostly through deforestation and conversion of grasslands and wetlands. It is intermediate between natural ecosystems, such as grasslands and forests and man-made ecosystems, such as cities, industrial complexes and so on, requiring constant care for their maintenance. The so-called world food problem can not be mitigated by efforts of any one discipline, such as agronomy, working alone. Nor does ecology as a discipline offer any immediate or direct solutions, but the holistic and system-level approaches that underlie ecological theory can make a contribution to the integration of disciplines (Odum, 1984).

The agroecosystem, being a derived ecosystem, by nature itself is extremely fragile. Over and above, continuous rigour of agronomic practices like tillage, weeding, application of fertilizers, pesticides, chemical weedicides and crop rotation by using high yielding varieties, started in this country with the onset of Green Revolution for boosting crop production, have posed a serious question as to the ultimate effects of all such practices on soil structure and its self-replenishing property in tropical agroecosystem where soil fauna play key-role in the mineralisation process. Of late, the United Nations' Desertification Department struck a note of caution over such exploitation of arable ecosystem and according to them the world's deserts are advancing relentlessly and by 2000 A. D. one-third of arable farm land in hundred countries would turn into dust-bowls more suitable for camel racing than farming. This study also shows that 35% of the world's land surface is currently at risk and livelihood of 350 million people who live there is directly threatened unless nations set up remedial measures.

In tropical countries, where soil undergoes quick dessication, thus sapping out the most vital factor, the moisture from soil limiting the biological interactions and thereby the mineralisation process. In India, no intensive investigations have been carried out on the effects of long term application of fertilizers and crop rotations on Collembola and Acarina, chief constituents of soil microarthropods, as a part of long term experiments being carried out in different parts of the world to find out the effects of various agricultural practices on fauna, so useful for mineralisation and nutrient cycling in soil ecosystem. In some long term experiments at Rothamsted Experimental Station, England, the same fertilizers have been applied annually to plots of grass, root crops or wheat since the 1840's, in what are termed the "Classical Experiment". Reports on the effects of rotation of crops and fertilizers on Collembola in agroecosystem from India first came from Mitra *et al* (1983, 1986), based on observations of samples drawn from the experimental fields of All India Coor dinated Project on Long Term Fertilizer Experiment, initated at Jute Agricultural Research Institute, Barrackpur, West Bengal since 1977.

In this investigation, Acarina as a group has been taken into consideration bec iuse of their biotic relationship with Collembola in soil ecosystem.

Unlike Indian sub-continent, a wealth of information is available on the effects of various agronomic practices on soil microarthopods, specially Collembola and Acarina, in rable soil, a summary of which is incorporated.

Effects of tillage or no-tillage practices on soil Microarthropods :

Though tillage incorporates crop residues into the mineral soil, speeding their decomposition rates, its deterimental effects are lopsided. Wallwork (1976) summarized detrimental and beneficial effects of tillage practices. Many workers significantly contributed on this aspect, notable amongst them are Raw (1967), Edwards and Lofty (1969), Allison (1973), Edwards (1975), Andren and Langerlof (1980), Stinner and Crossley (1980) who concluded that no-tillage practice leads to nutrient and energy conservation, biotic and abiotic components of soil, left undisturbed, are organised into well defined soil structure and as such normal nutrient cycling is maintained with the minimum loss of nutrient from the system. Conversely, tilling or ploughing breaks the soil structure exposing the topsoil to leaching and erosion, biotic community is greatly disturbed causing the reduction in population and diversity of species. Raw (1967) recorded population density of soil arthropod as 1,80,000 per square yard in a permanent grassland while, 18,000 per square yard from a permanent arable land resulting predominantly from strong reduction in numbers of Collembola and Acarina in arable soil. Bormann *et al.* (1974) and Waide and Swank (1976) demonstrated that ploughing once or twice yearly is a major perturbation even in forest floor with well defined soil structure over years destroying the soil system's structure and function and recycling of nutrients becomes minimal. Thus no-tillage or zero cultivation has gained considerable momentum in the West including the United States of America for conservation of soil structure and nutrient cycling in agroecosystem.

Effects of crop rotation on soil microarthropods :

Influence of croptype is markedly noticeable for oligophagous or specialised species. It has been suggested by Edwards and Lofty (1969) that crop rotation decreases species diversity even to a greater extent than monocultures eliminating those species which are associated with other plants. Species diversity during crop rotation depends also on the differences of C/N ratios of the types of crops used for rotation.

Aleinikova and Utrobina (1969, 1975) through experiment on crop rotations demonstrated that the plant cover affects greatly the structure and animal population within one region and one soil type. They also concluded that the dominance of the individual collembolan species changes depending on the plant cover. Effect of fertilizers on microarthropods also depend on the nature of crop (Artemjeva and Gatilova, 1975). Faizy *et al.* (1980) observed that soil insects were not only related to a species of crop but also a function of the cultivar in relation to two cultivars of paddy used for cultivation.

Effects of mineral fertilizers and manure on soil microarthropods :

Application of organic manure and chemical fertilizers enhances the abundance of soil animal with the increase of activities of microbes. Raw (1967), Edwards and Lofty (1969), Artemjeva and Gatilova (1975), Faizy *et al* (1980), Andren and Langerlof (1980), Mitra *et al* (1983) studied the effects of mineral fertilizers and organic manures on soil fauna, specially Collembola and Acarina, in experimental agricultural fields. It was observed by them that inorganic fertilizers and manures enhance the population of Collembola and Acarina to a great extent. Raw (1967) reported density of arthropods as 18,000 per sq. yard in inorganic fertilizer treated plots (NPK and Mg) than untreated control plots (16,000 per sq. yard). Mitra *et al* (1980) reported nearly four times increase in collembolan population in the plots treated with NPK and farmyard manure than control plots in a crop rotation of jute, wheat and paddy. Edwards and Lofty (1969) concluded that organic manure directly influence collembolan population serving as food while inorganic fertilizers have indirect effect by enhancing growth of plants and microorganisms. Artemjeva and Gatilova (1975) stated that the effect of fertilizer is determined by the nature of plant cover and the specific reaction of the individual microarthropod groups and species. They observed a mixture of manure and mineral fertilzers have favourable effect in boosting Collembola and Acarina population and effect of manure was evident after 10-12 months. Marshall (1977) reviewed the effects of manures and fertilizers on soil fauna and concluded that the addition of farmyard manure is also important for the higher abundance of soil fauna and consequent enhancement of soil fertility.

Effects of pesticides on soil Microarthropods :

Pesticides, being non-selective, have significant effects on soil microarthropods when these are applied on soil or comedown through percolating rainwater when applied on upper part of foliage.

Effects of pesticides on soil microarthropods, specially Collembola and Acarina, and their persistence in soil ecosystem were studied by various workers like Sheals (1955, 1956), Hartenstein (1960), Kevan (1962), Smith *et al* (1980), Edwards (1965a, 1965b), Edwards *et al* (1960, 1967), Edwards and Lofty (1969), Voronova (1968), Heungens (1968), Dempster (1968), Dindal (1975) and others. Chandra (1967) observed that the persistence of pesticides in soil is dependent on soil type and temperature. At higher temperature (26°C) detoxification occurred for heavy clay and mountain loam soils but it persisted at lower temperatures as observed from non-nitrification of soil. While Edwards (1965a) observed that Sevin, a carbamate compound, when applied to soil, retains its toxicity for 6 months, Voronova (1968) found the retention of toxicity upto one year period though initially there was an increase of Cryptostigmatid mites. The reports on the effect of malathion (an organophosphate compound) on soil microarthropods, specially Collembola and Acarina, are contradictory. While Voronova (1968) observed its no effect on Collembola and Acarina, Edwards and Lofty (1969) observed diminution of Collembola and nonpredatory mites during the first two months after application followed by several times increase during subsequent months. The most persistent of all pesticides are organochlorines like DDT, BHC, heptachlor, aldrin and dieldrin which are retained in the soil and continue to affect soil microarthropods for longer period and cause population imbalance. Sheals (1965) found that while DDT application increases the population of Collembola several times than control, BHC reduces it. The same author also observed that both pesticides affect adversely the population of Mesostigmatid and Cryptostigmatid mites. The observation was later on confirmed by Edwards and his coworkers (*l. cit.*) and other workers like Dempster (1968) and Klee (1973) who observed that *Folsomia candida* remains unaffected by DDT levels upto the order of 1,00,000 ppm in its food. Hartenstein (1960) observed a temporary effect of DDT on Collembola through a surface application. Heugens (1968) observed that Nemagon-20 adversely affects the populalation of mites while population of Collembola increased by 84% than control plots. Dindal *et al* (1975) observed initial suppression of microbial respiration in an old field community for a period of one month following an application of granular technical DDT at the rate of 1.12 kg./ha followed by a stimulation for 17 months. They came to the conclusion that mortality of phytophagous insects increased litter deposition and consequently, increased microbial substrate.

Effects of Herbicidal Chemicals on Soil Microarthropods :

Weeds developing in the cultivated land, compete with food crops for nutrients, can be removed mechanically or chemically. Conventional mechanical weeding needs regular repetition and is too expensive. With the advancement of Industrial Revolution, many chemicals have been developed which selectively kill undesirable herbs and shrubs in cultivated fields. Considerable amount of these chemicals, applied on the weeds, reach the soil of cultivated land/forest floor. Eijsackers (1975) estimated under field conditions three or ten litres of 2, 4, 5-T per hectare can drip from the leaves on to the forest floor after spraying this chemical with a mixture of water. This contamination of soil by chemical herbicides, has caused alarming concern on their possible effects on soil fauna, playing key role in mineralisation process.

Of all the chemical herbicides, 2, 4-D, which is being widely used in different parts of the world, has received considerable attention of soil biologists. Rappoport and Cangioli (1963), Fox (1964) and Edwards (1965) after application of single dose of 2, 4-D while, Davies (1965) and Bieringer (1969) after repeated applications of this herbicide for 10 and 11 years respectively found little or no significant effect on collembolan and mite populations in the soil. Prasse (1975) observed an increase in population of these soil microarthropods which he ascribed to the increased microbiological activity and particularly bacteriological activity in the soil as a direct response to this herbicide. It was concluded that prolonged application of this herbicide, suppresses the growth of weeds and deprives the soil of organic material and thereby decreasing the population of Collembola and mites.

Simazin, when applied to sandy soil, increased population of Collembola significantly while that of Acarina slightly 6-7 weeks after its application in a dose of 2 Kg./ha (Steinbrenner *et al*, 1960). Edwards (1965) observed that this herbicide reduced populations of soil animals to the third or even half of those in untreated soil. He further observed that hemiedaphic Collembola particularly the Isotomidae were worst affected by Simazine and other forms of Collembola including mites, earthworms, enchytraeids, dipterous and coleopterous larvae decreased significantly and the effect of the application continued for 3-4 months. Prasse (1975) noted that the effect of Simazine of soil microarthropods continued for more than one year which he attributed to worsening living conditions of most of the soil inhabiting species for weed control through this chemical herbicide. Eijsackers (1975, 1978a, b, c, d, 1980) studied the effects of 2, 4, 5 tricholoro phenoxy acetic acid (2, 4, 5-T) on some species of Collemboles, isopods, millipedes and carabids in laboratory cultures simultating natural condions by using the herbicide in different concentrations. He observed that the direct spraying of herbicide at different concentrations has varying effects ranging from immobilisation of animals to their death. He further observed that the herbicide has lethal effect also through food chain on those organisms.

Edwards (1970) studied the effects of Shell WL 19805 and observed that the effect of this chemical herbicide is less lethal to soil microarthropods when mixed thoroughly with soil than spraying as thin film on the surface.

Bhattacharyya and Joy (1977, 1980a, b) studied the effects of Banvel-D, Baldex-G (Amine 2, 4-D), Nitrofen (Tok, E-25) and Propanil (Stam, F-34) in tropical agricultural fields with lateritic soil as well as in laboratory conditions. They observed that Nitrofen has more adverse effects on cryptostigmatid mites than Propanil.

Edwards and Lofty (1975) studied the effects of the application of Paraquat in uncultivated field *vs.* ploughed field without Paraquat and observed that while the hemiedaphic species of Collembola increased in Paraquat treated uncultivated field, the euedaphic species of Collembola decreased in number. They also observed higher population of Acarina, Symphyla, Diplopoda and other insects in Paraquat treated uncultivated field than ploughed field without treatment of this herbicide. It appears, therefore, that the effect of this chemical herbicide on nontarget organisms is not so severe barring the euedaphic Collembola.

MATERIAL AND METHODS

The present investigation was undertaken in the experimental plots of All India Coordinated Project on Long Term Fertilizer Experiments, located at Jute Agricultural Research Institute, Nilgunj, Barrackpur, West Bengal. This project was initiated towards the end of 1970 during the Fourth Five Year Plan and subsequently was taken up at different centres of Indian Council of Agricultural Research.

Location :

The experimental area about one hectare (86m × 138m approx.) is situated in the Main Farm A_7 of the Jute Agricultural Research Institute, Barrackpur at a latitude of 22.45N and longitude of 88.22E and is about 10.00 metres above the mean sea level.

Description of the Area and Soil :

The soil is well drained light alluvium. It is non-calcareous, loamy in texture with medium cation exchange capacity and is neutral in reaction ; the pH in water suspension usually ranges from 7.0 to 7.3 in the surface layers. According to the existing limits of soil test values, it was categorised as medium to high in organic carbon, available phosphorus and potassium and was found free from salinity. The entire area has been under general cropping (jute, paddy, potato) or multiplication trials without maintaining any differential manuring for the preceding three years. The initial characteristics of the soil of the experimental field is given in Table—1.

TABLE 1. Initial characteristics of the Soil of the Experimental Area.

Constituents ;	
pH	7.1
Electrical conductivity	0.2314 milliohms/cm at 25°C
Organic carbon	0.714%
Total Nitrogen	0.086%
Available Nitrogen	212.50 Kg/ha
Available P	40.90 Kg/ha
Available K	137.10 Kg/ha
Cation Exchange Capacity	19.0 m. e./100 g of soil

TABLE 1. (*Continued*)

Constituents :	
Exchangeable Ca	15.0 m. e./100 g of soil
Exchangeable Mg	2.4 -do-
Exchangeable K	0.7 -do-
Free $CaCO_3$	0.4 -do-
Available sulphur	3.26 ppm
Heat soluble sulphur	7.49 ppm
Organic sulphur	13.04 ppm
Total (Fusion Extract) Analysis :	
Hcl—insoluble matter (Silaca)	85.60%
Sesquioxide	8.25%
Total iron (Fe_2O_3)	4.30%
Total Calcium (Ca)	0.40%
Total P	0.105%
Total K	0.225%
Total Sulphur	26.08 ppm
Available Micronutrient Analysis (DTPA Extractable) :	
Zn	2.46 ppm
Mn	16.02 ppm
Fe	30.28 ppm
Cu	2.46 ppm
Physical Characteristics :	
Majar soil group	Recent alluvium
Texture	Sandy loam
Mechanical composition	Sand : 53.8% Silt : 28.5% Clay : 17.5%
Water holding capacity	44.3%
Sticky point	25.1%
Particle density	2.65 gm/cc
Bulk density	1.33 gm/cc
Pore space	49.4%

Layout of the Experiment :

As per approved technical programme of the experiment, a randomised block design was adopted with ten treatments and four replications for each treatment. The layout plan of the experiment along with the randomisation of the treatment is given in Figure 1. Other relevant details are given below :

Net unit plot size	=10 m×20 m (2sq. metres)
Width of the border between blocks	=3.0 metres.
Width of the border between plots	=1.5 metres.

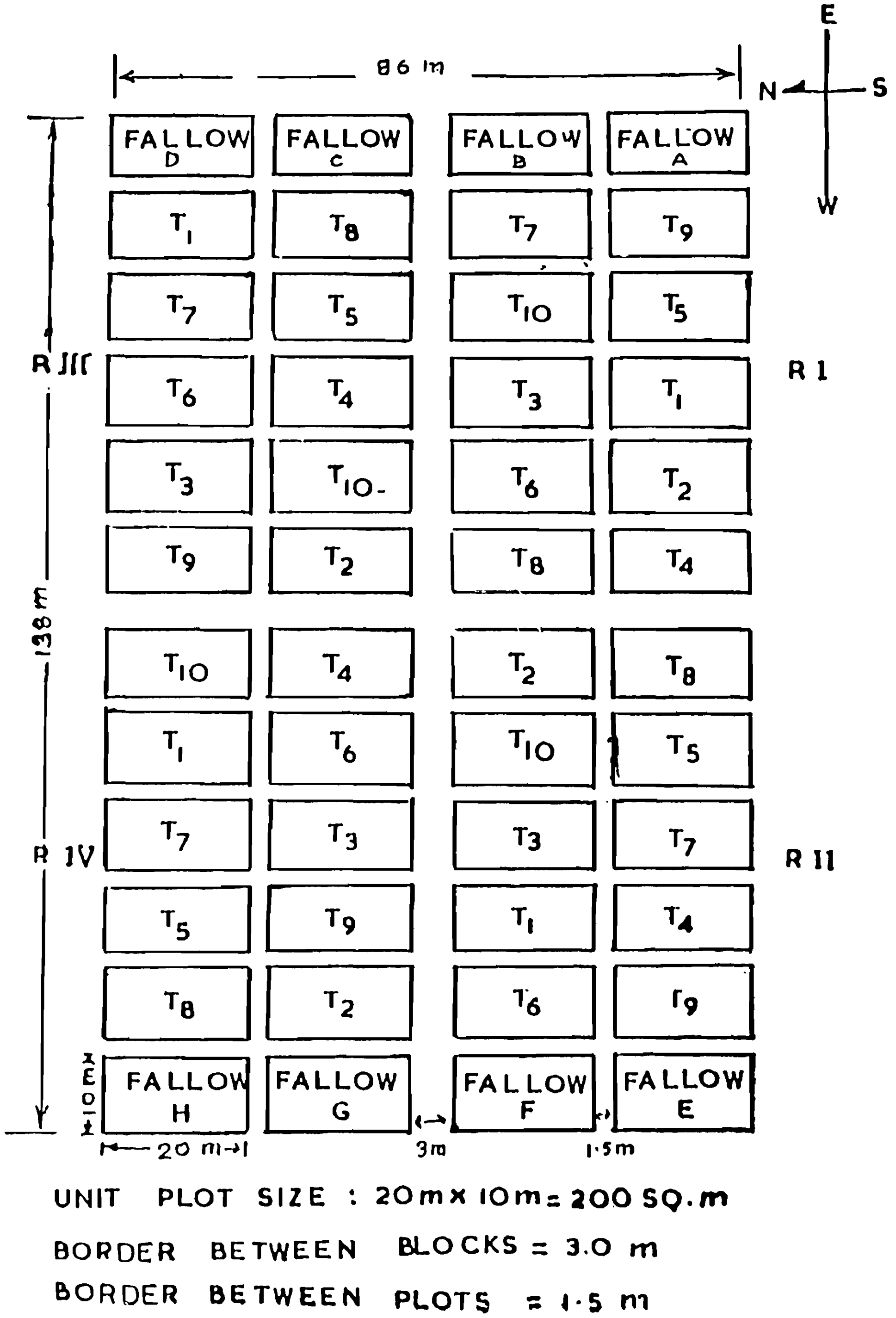
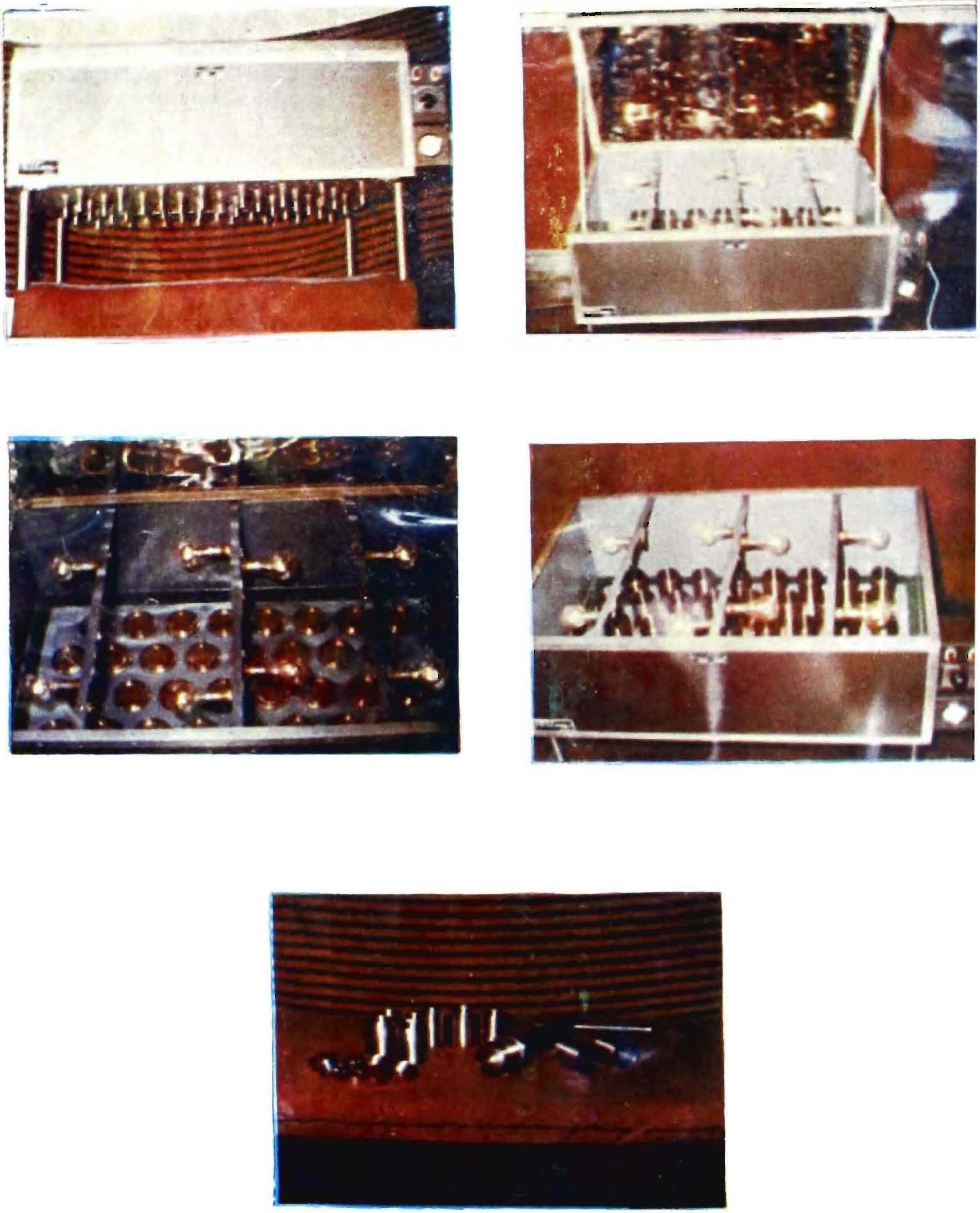


Fig. 1. Layout plan of the long term field experiment. Main Farm A_7, J. A. R. I., Nilgunj, Barrackpore. Rotation ; Jute-Paddy-Wheat.

MITRA Plate 1

Jute, Wheat and Rice Cultivations at the Experimental fields at Jari, Barrackpur, West Bengal,

Plate 2



Extraction apparatus and soil samplers used in the investigation (Devised by the Author)

The experimental area is kept isolated by the similar plot size of fallow strips (naturally grown vegetation) on east west sides only. The photographs of standing crops of jute, wheat and paddy are given in Plate 1.

Cropping pattern :

An intensive cropping pattern in the rotation of three crops in a year involving high yielding and improved varieties has been adopted. The concerned crops grown in the sequence are jute (*Corchorus olitorius* Linn.), Paddy (*Oryza sativa* Linn.) and Wheat (*Triticum aestivum* Linn. emend. Thell.). Jute-Paddy-Wheat is a typical rotation which is widely followed in eastern part of West Bengal and neighbouring regions. The crop varieties used are JRO 7835 (Jute), Jaya (Paddy) and Sonalika (Wheat). Jute was the first crop which was sown during summer (April-July) followed by Paddy (August-November) and Wheat (December-March).

Treatments :

The ten treatments constitute of selected combination and levels of N, P and K and also of farmyard manure (alongwith NPK). The details of the treatment are given in Table-2. The controls were maintained with usual cultivation but without any application of fertilizers while fallows were left uncultivated. The NPK doses were graded to 50,100 and 150 percent of the optimum level to examine the effect of sub and above optimal scales of fertilizer application to each crop. The chemical method of weed control is followed in treatment No. 9 and for comparison, hand weeding was carried out in one case (Treatment No. 4) to see their relative effect on crop and faunal composition. In case of jute cropping except T_9 all the treatments were hand weeded as the jute crop essentially requires hand weeding for its initial growth. Weedicides Basalin, 2, 4-D and a mixture of Stam F-34 and 2, 4-D were used for jute, wheat and paddy respectively. As regards the use of pesticides, this has been practised uniformly for all the treatments as and when needed involving mostly Thiodan EC-35 and Furadan 3G.

Climate and weather conditions :

The experimental site is situated within the Equatorial zone. The presence of the Bay of Bengal and network of the river systems, canals, tanks, etc. of southern lower portion of West Bengal does not allow extreme climatic conditions to prevail upon during summer and winter seasons. The mean annual precipitation is about 1600 mm most of which is confined to the monsoon period between May to September. Pre-monsoon rains also start by the second week of April and amount to about 225 mm. The winter rainfall is normally low and uncertain and when it occurs generally towards the early spring.

TABLE 2. Details of treatments of field experiment with jute-rice-wheat sequence.

Treatments	Nutrient doses kg/ha					
	Jute			Rice and Wheat		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
T_1 50% of optimum* NPK	30	15	30	60	30	30
T_2 100% of optimum NPK	60	30	60	120	60	60
T_3 150% of optimum NPK	90	45	90	180	90	90
T_4** 100% of optimum NPK +hand weeding	60	30	60	120	60	60
T_5 100% of optimum NPK +ZnSO @ 10 Kg/ha to wheat only	60	30	60	120	60	60
T_6 100% of optimum NP	60	30	0	120	60	0
T_7 100% of optimum N only	60	0	0	120	0	0
T_8 100% of optimum NPK +farmyard manure @ 10 t/ha (added before jute sowing)	60	30	60	120	60	60
T_9 100% of optimum NPK+ Chemical weeding	60	30	60	120	60	60
T_{10} Control (no fertilizer)	0	0	0	0	0	0

* Optimum doses of N, P and K on the basis of initial soil test values.

** In case of jute there is no difference between the treatments T_2 and T_4 but for rice and wheat, hand weeding is given only in T_4 treatment. The sources of N, P and K were ammonium sulphate, single superphosphate and muriate of potash respectively, except in treatments T_5 and T_9 for which urea was the source of N and diammonium phosphate for P.

Methods of sampling and extraction :

Samples were drawn monthly for three crop seasons @ three samples from each treatment including fallow (F) from adequately replicated plots, barring T_2, T_5 by using cylindrical samplers, made up of stainless steel, each having a length of 9 cm. with a cross sectional area of 28.29 cm^2 with a sharp cutting edge. Before sampling, the sampler was fitted within the sampler holder for forcing the sampler within soil for sample collection (Plate-2). Sampler, charged with soil sample, was placed in the extraction apparatus with the cutting edge above to facilitate the emergence of hyperedaphic and hemiedaphic species at first out of the samples. The extraction apparatus used is a modified Tullgren one, developed by Mitra (Plate-2). Within the extractor, temperature was maintained through a thermostat control unit. 45°C-50°C was found to be effective for extraction of soil samples drawn during monsoon while 40°C-45°C for samples drawn during other seasons. Ethyl alcohol (90%) was ussd in the collecting vials and PL_3 medium (Salmon, 1951) was used for mounting specimens of Collembola.

Measurement of environmental parameters :

Physical parameters, considered in this investigation, are relative humidity and temperature, measured in the field, by using a hair hygrometer and soil thermometer respectively. Moisture was measured in the laboratory by using infrared moisture balance.

Statistical analysis :

Statistical analysis and tests of data were carried out at the Indian Statistical Institute, Baranagore, Calcutta by using computers and programmes, available there.

MICROARTHROPOD COMPONENTS OF AGROECOSYSTEM

Collembolans are the commonest soil insects and from the point of their abundance they only rival rcari in this respect. Being extremely soft bodied and sensitive to various measures, adopted in agroecosystem, their population and diversities are depleted. Particularly mechanical abrasive action involved in ploughing, application of chemical fertilizers, pesticides, herbicidal chemicals, etc. impair their growth and development. The species of Collembola, particularly the hyperedaphic and hemiedaphic ones, that occur in agroecosystem indicate their tolerance to such rigors of cultivation. In the present investigation, eleven species of Collembola of which three belonging to suborder Symphypleona and eight to Arthropleona were found to occur predominantly in the studied agroecosystem (Fig. 2).

The most abundant and ubiquitous were *Isotomurus balteatus* (Reuter), *Cryptopygus thermophilus* (Axelson), *Lepidocyrtus* (*Lepidocyrtus*) sp., *Cyphoderus javanus* Börner and *Brachystomella* sp. occurring during cultivation of all the three crops while the rest were found to remain restricted to a specific type of crop.

Besides Collembola, Acarina was the most abundant component and was represented mostly by Mesostigmatid, Oribatid, Scheloribetes, Cryptostigmatids, Trombidiformes groups of mites. The nymphal forms constituted the bulk of the acarine population. Sporadically, Diplurans, represented by Projapygids and Japygids, were found in the soil samples extracted. Very infrequently, some Symphyla, Coleopterous larvae and psocids came into the extracts of soil samples.

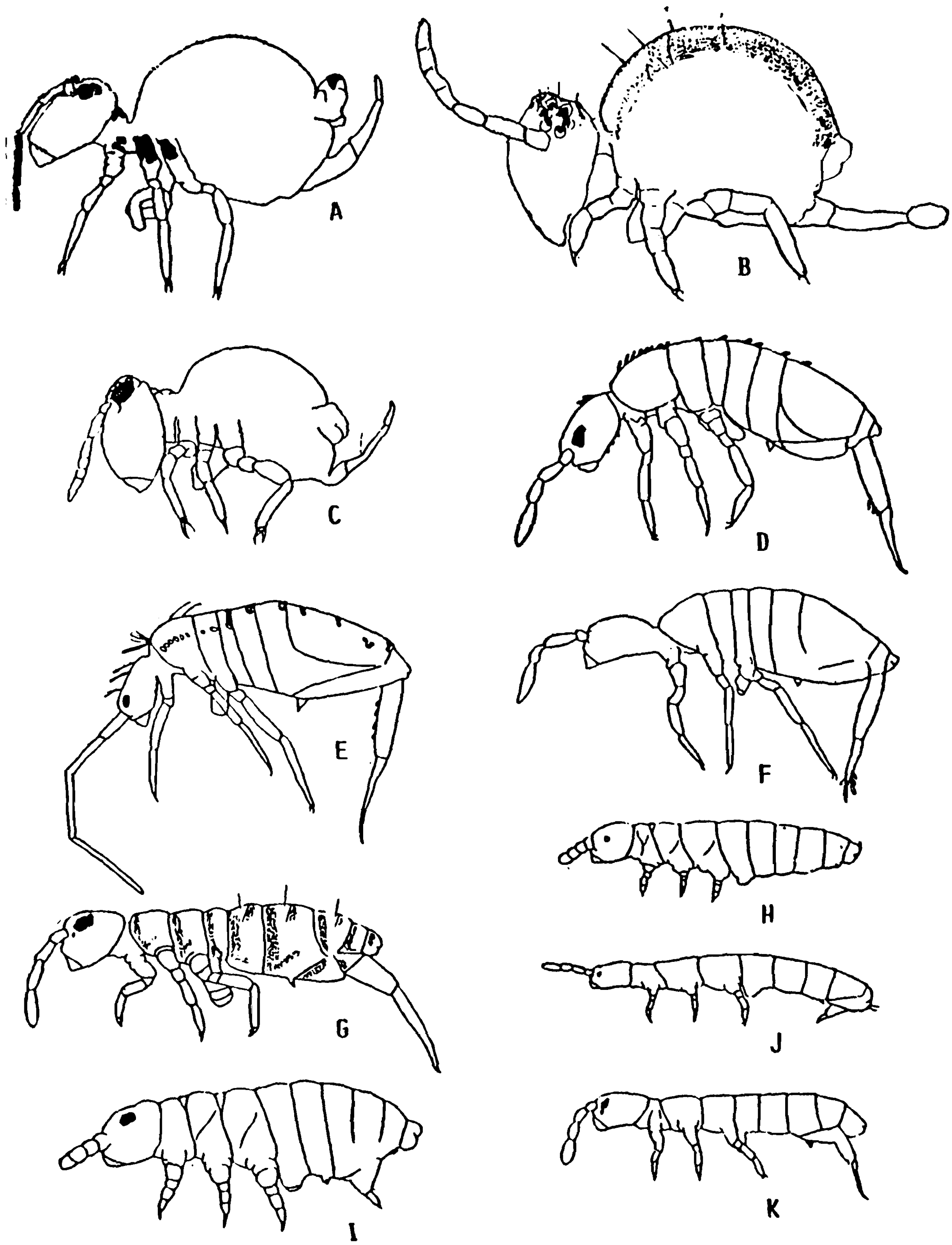


Fig. 2. Collembolan components of Agroecosystem. **Symphypleona** : A, *Sminthurus* sp. ; B, *Sminthurides appendiculatus* Imms ; C, *Sphaeridia cornuta* Murphy. **Arthropleona** : D, *Lepidocyrtus* (*Lepidocyrtus*) sp. ; E, *Seira indica* (Ritter) ; F, *Cyphoderus javanus* Borner ; G, *Isotomurus balteatus* (Reuter) ; H, *Acherontiella* sp. ; I, *Brachystomella* sp. ; J, *Isotomodes* sp. ; K, *Cryptopygus thermophilus* (Axelson).

RESULTS

Quantitative analysis : Effects of months and crop rotations on Collembola and Acarina :

In general, Acarina dominated over Collembola during the period under investigation. Population build up of both Collembola and Acarina was, however, nearly

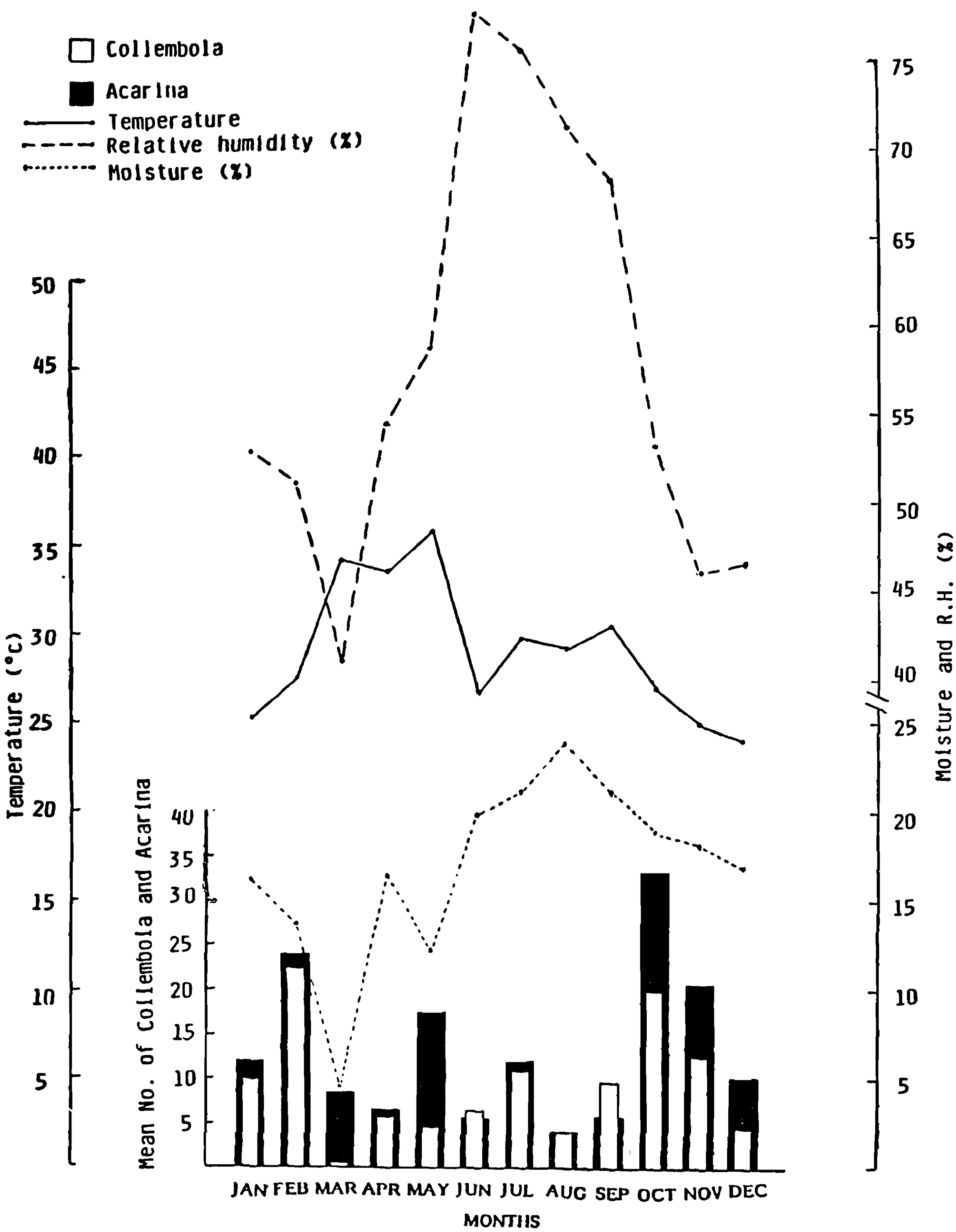


Fig. 3. Mean number of Collembola and Acarina in relation to months.

identical during jute and paddy cultivations, while, during wheat cultivation Acarina greatly dominated over Collembola. During Jute cultivation, generally, population-maxima of Acarina occurred during May and July while that of Collembola during

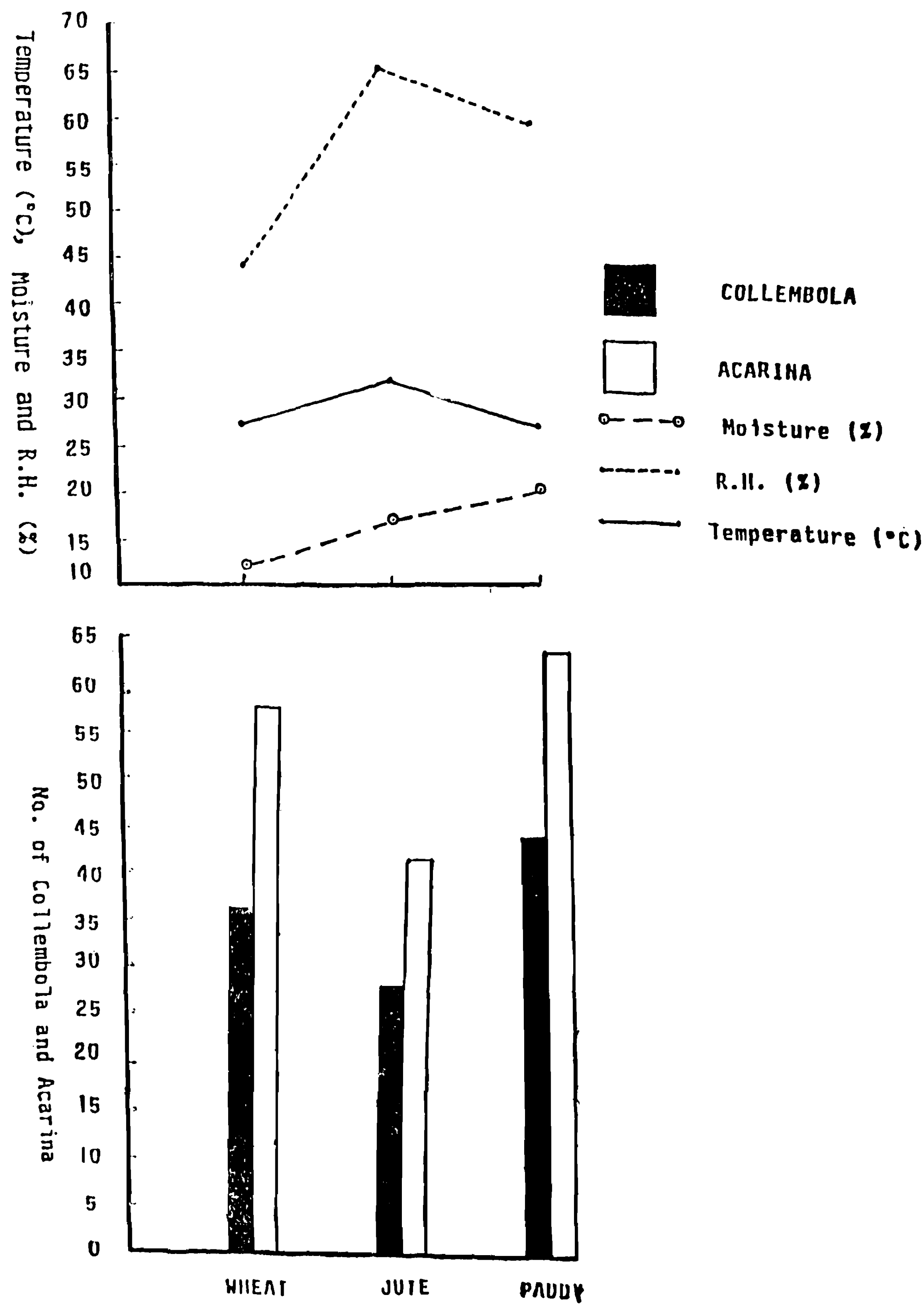


Fig. 4. Cropwise mean of Collembola and Acarina.

June ; during paddy cultivation, peak of population of Acarina occurred in the months of August, October and November while that of Collembola during September ; during wheat cultivation, Acarina reached maxima population build up in March while Collembola during February.

Mean population of Collembola was dominated by Acarina during all months except during June (Jute) and September (Paddy) though population build up of both was low. Maximum population of Collembola occurred during February (Wheat) while that of Acarina during October (Paddy). Higher moisture, R/H and moderate temperature encouraged the growth of Collembola while higher temperature, less moisture and R/H boosted the population of Acarina (Fig. 3).

A comparison of the population of Collembola and Acarina reveals that Acarina dominated over Collembola during the cultivation of all three crops. Highest population of both the groups occurred during Paddy cultivation and lowest during Jute (Fig. 4).

Qualitative Analysis of Collembola with reference to Crops :

Qualitative analysis of total Collembola, obtained from the experimental plots during cultivation of all the three crops, reveals the presence of eleven species of which

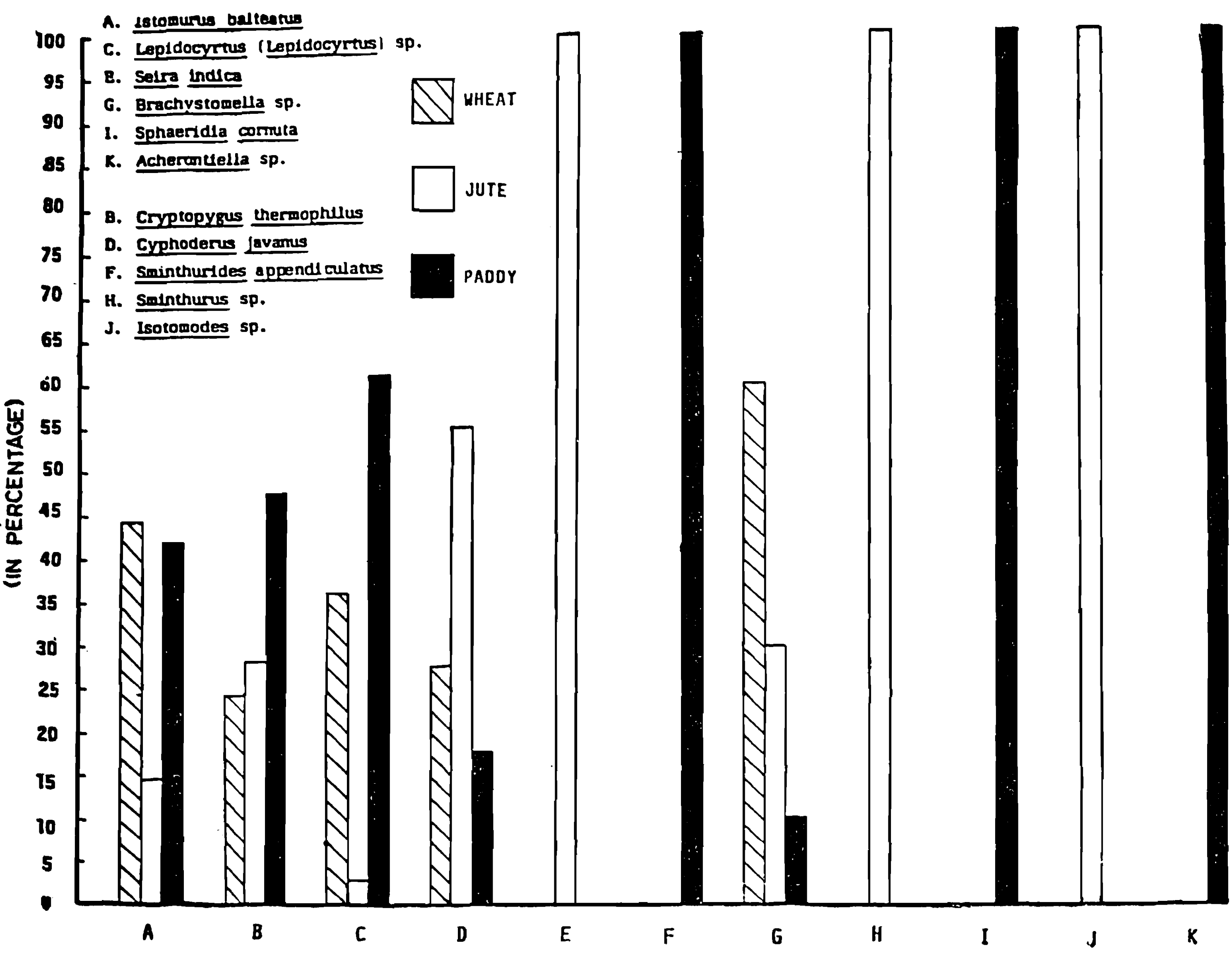


Fig. 5. Cropwise abundance of collembolan species.

six species were crop-specific while others were present during cultivation of all the three crops. Three species, *viz.*, *Seira indica*, *Sminthurus* sp. and *Isotomodes* sp. occurred during cultivation of jute while *Sminthurides appendiculatus*, *sphaeridia cornuta* and *Acherontiella* sp. were found to remain associated with paddy only.

An analysis of species, remaining associated with all the three crops, reveals that *Isotomurus balteatus* reached its population-maxima during wheat cultivation and its lowest population occurred during jute cultivation. *Cryptopygus thermophilus* and *Lepidocyrtus* (*Lepidocyrtus*) sp. exhibited their peaks during paddy cultivation and minimum for the former was during wheat cultivation while for the later during jute cultivation. *Cyphoderus javanus* reached its peak of population during jute cultivation and its minimum population occurred during jute cultivation. *Brachystomella* sp. reached its peak of population during wheat cultivation and its minimum population was during paddy cultivation (Fig. 5).

Qualitative composition of Collembola, obtained during cultivation of each crop, reveals that eight species of Collembola remain associated with both jute and paddy while five species with wheat. *I. balteatus*, *C. thermophilus*, *Lepidocyrtus* (*Lepidocyrtus*) sp., *C. javanus* and *Brachystomella* sp. occurred during wheat cultivation of which the bulk of the population was of *I. balteatus* and the least was that of *Brachystomella* sp.

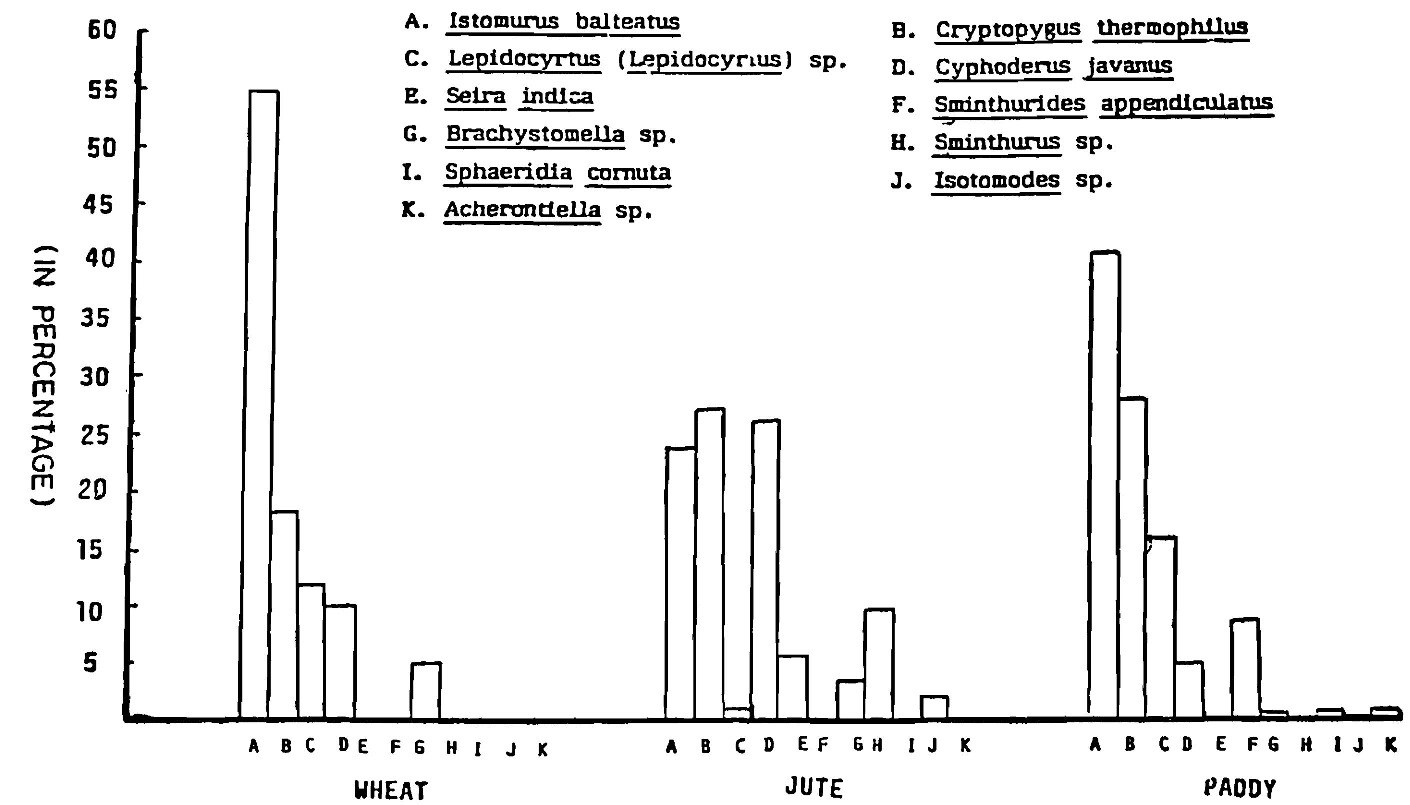


Fig. 6. Abundance of each collembolan species in relation to each crop type.

During jute cultivation, *C, thermophilus* was most dominant followed by *C. javanus*, *I. balteatus*, *Sminthurus* sp., *S. indica*, *Brachystomella* sp., *Isotomodes* sp. and *Lepidocyrtus* (*Lepidocyrtus*) sp.

During paddy cultivation, *I. balteatus* was most predominant followed by *C. thermophilus*, *Lepidocyrtus (Lepidocyrtus)* sp., *S. appendiculatus*, *C. javanus*, *S. cornuta*, *Acherontiella* sp. and *Brachystomella* sp. (Fig. 6).

Occurrence of collembolan species according to vegetation type

Species	Vegetation		
	Wheat	Jute	Paddy
Isotomurus balteatus	++++	++	+++
Cryptopygus thermophilus	++	++	++
Lepidocyrtus (*Lepidocyrtus*) sp.	+	+	++
Cyphaderus javanus	+	++	+
Seira indica	–	+	–
Sminthurides appendiculatus	–	–	+
Brachystomella sp.	+	+	+
Sminthurus sp.	–	+	–
Sphaeridia cornuta	–	–	+
Isotomodes sp.	–	+	–
Acherontiella sp.	–	–	+

++++	within 60%	++	within 30%	–	Absent
+++	within 45%	+	within 15%		

Qualitative analysis of Collembola with reference to Months :

Four species of Collembola *viz.*, *I. balteatus*, *C. thermophilus*, *C. javanus* and *Brachystomella* sp. occurred during January with the highest population of *I. balteatus* followed by others as arranged above in graded sequence. During February, *I. balteatus* continued to dominate the population with four other species, *viz.*, *C. thermoplitus*, *Lopidocyrtus* sp., *C. javanus*, *Brachystomella* sp. *I. balteatus* was absent during March and the entire population obtained during this month was represented by *C. thermophilus* only. During April, *I. balteatus* continued to remain absent and *C. thermophilus* constituted half of the population followed by *C. javanus* (5.56%), *Sminthurus* sp. (38.89%) and *Isotomodes* sp. (5.56%). *I. balteatus* was also absent during May with *C. thermophilus* representing the highest population (64.29%) followed by *C. javanus* (14.29%), *S. indica* (7.14%), *S. appendiculatus* (7.14%) and *Isotomodes* sp. (7.14%). *I. balteatus* reappeared during June with 15.79% of the population for this month. The population for this month was, however, dominated by *C. javanus* (42.11%) followed by *S. indica* (21.05%), *C. thermophilus* (15.79%) and *Sminthurus* sp. (5.26%). During July, *I. balteatus* dominated the population with 51.52% followed by *C. javanus* (36.36%),

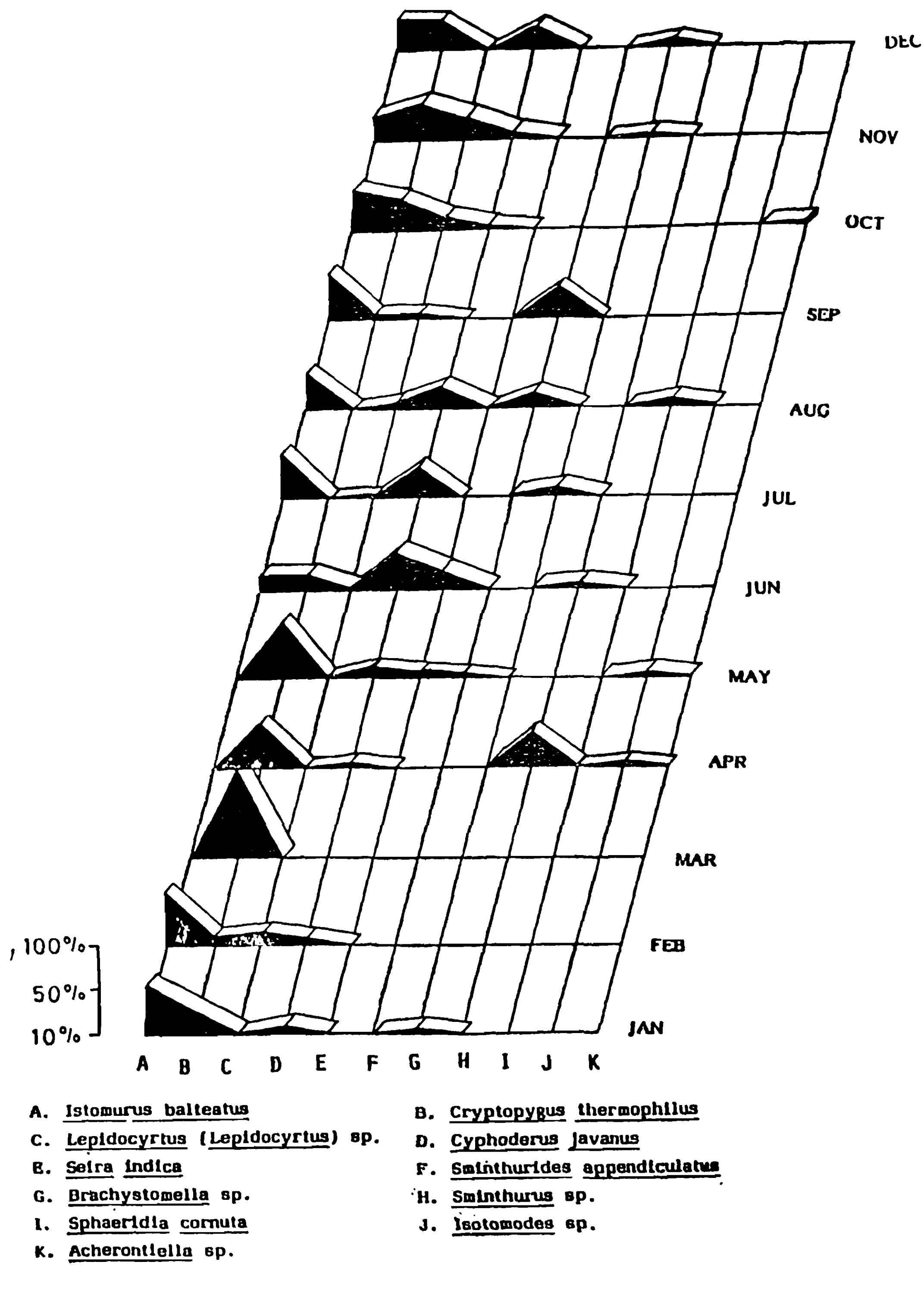


Fig. 7. Monthwise occurrence of collembolan species.

Brachystomella sp. (9.09%) and *Lepidocyrtus* sp. (3.03%). *C. thermophilus* was noticeably absent during this month. During August, *I. balteatus* continued to dominate the population with 41.67% followed by *C. javanus* (25%), *S. appendiculatus* (16.67%), *Lepidocyrtus* sp. and *S. cornuta* each with 8.33%. *C. thermophilus* remained unrepresented during this month. During September, *I. balteatus* dominated the population with 51.72% followed by *S. appendiculatus* (34.48%) and *Lepidocyrtus* sp. (6.9%). *C. thermophilus* reappeared in this month constituting 6.9% of the population. During October, *I. balteatus* continued to dominate the population with 44.26% of the population followed by *C. thermophilus* (36.07%), *Lepidocyrtus* sp. (14.75%), *C. javanus* (3.28%) and *Acherontiella* sp. (1.64%). During November, *C. thermophilus* dominated the population with 39.47% followed by *I. balteatus* (26.32%), *Lepidocyrtus* sp. (26.32%), *C. javanus* (5.26%) and *Brachystomella* sp. (2.63%). During December, both *I. balteatus* and *C. thermophilus* was represented by the same population (33.33% each) followed by *C. javanus* (25%) and *Brachystomella* sp. (8.33%) (Fig. 7).

Monthly Dynamics of each collemboian species :

I. balteatus maintained its population buildup throughout the year except being absent in the samples during March-May. It reached its peak of population during February and its minimum population was observed during June.

C. thermophilus occurred during all months except during July and August. It reached its peak during October and the minimum population was during March.

Lepidocyrtus sp. was unrepresented in samples of six months. Its highest population occurred during February with minimum population observed during July and August.

C. javanus was absent during months of March and September. Its peak of population occurred during July with minimum population during April.

S. indica had a shorter span appearing during May and reachtng its peak in June and disappearing subsequently.

S. appendiculatus was found in the samples of May, August and September with the peak of population during the later month.

Brachystomella sp. occurred during January, February, July, November and December. Its peak of population was during July and the minimum population occurred during November and December.

Sminthurus sp. was found only during two months (April and June) with the highest population during April. *S. cornuta* occurred only during August.

Isotomodes sp. occurred in equal proportions during April and May only and *Acherontiella* sp. during the month of October (Fig. 8).

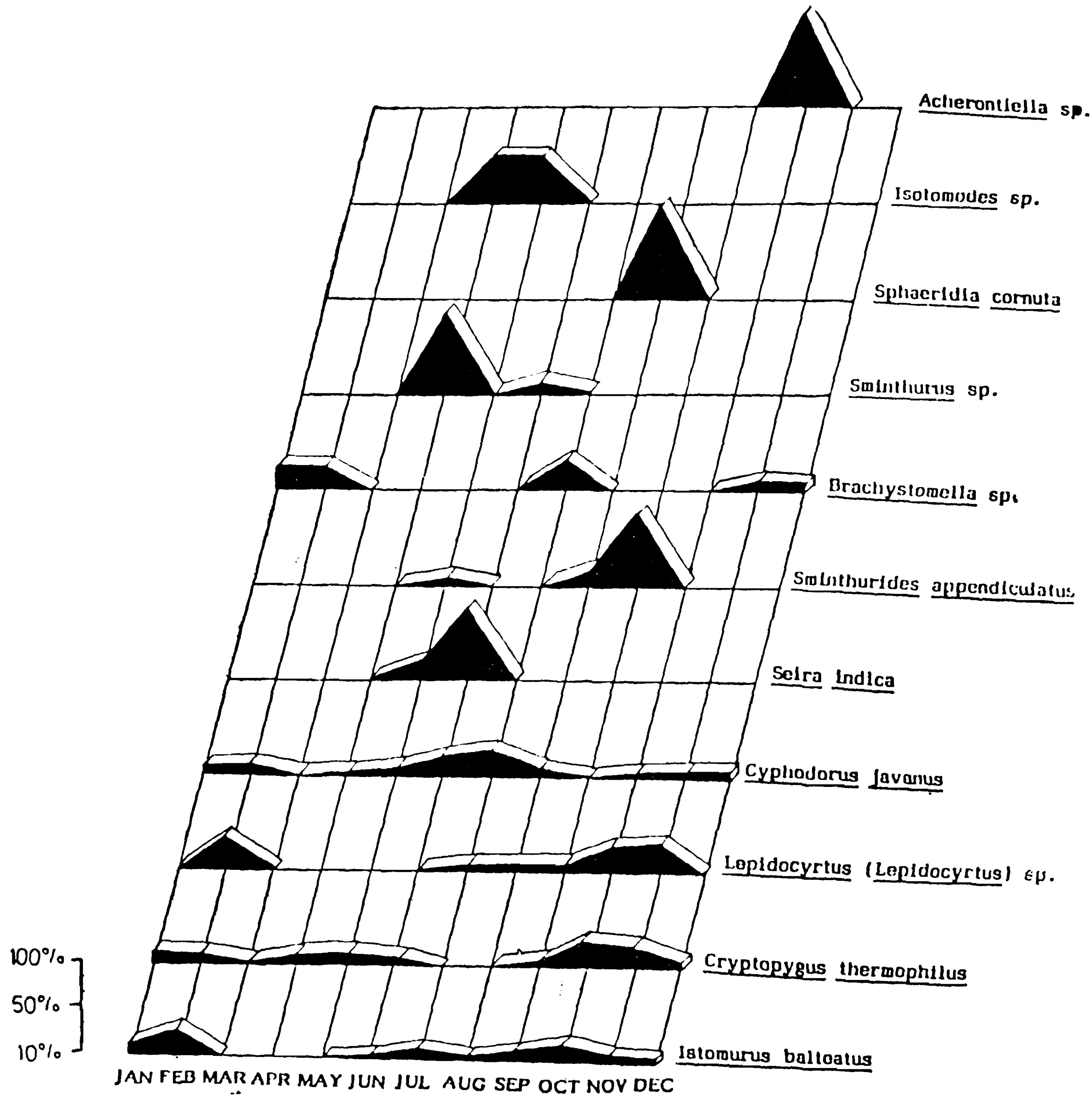


Fig. 8. Monthly dynamics of collembolan species.

Plotwise analysis of Collembola and Acarina according to various agricul·ural practictices :

A comparison of T_1 and T_{10} shows that cultivation without fertilizers gives rise to better build-up both Acarina and Collembola populations than plots treated with lower dose of NPK (50% of optimum NPK). Application of higher dose of NPK (150% of optimum NPK as in T_3) results nearly same population of Collembola and Acarina as that of Control (T_{10}). Application of optimum dose of fertilizers (N_{60} P_{80} K_{60} as in T_4) also does not invigorate the collembolan and acarine populations as compared to control (T_{10}). Absence of potassium with optimum dose of NP (as in T_6) though slightly increases the population of Collembola in comparison to T_4, nevertheless, the population of both the groups with this dose of fertilizer in T_6 was

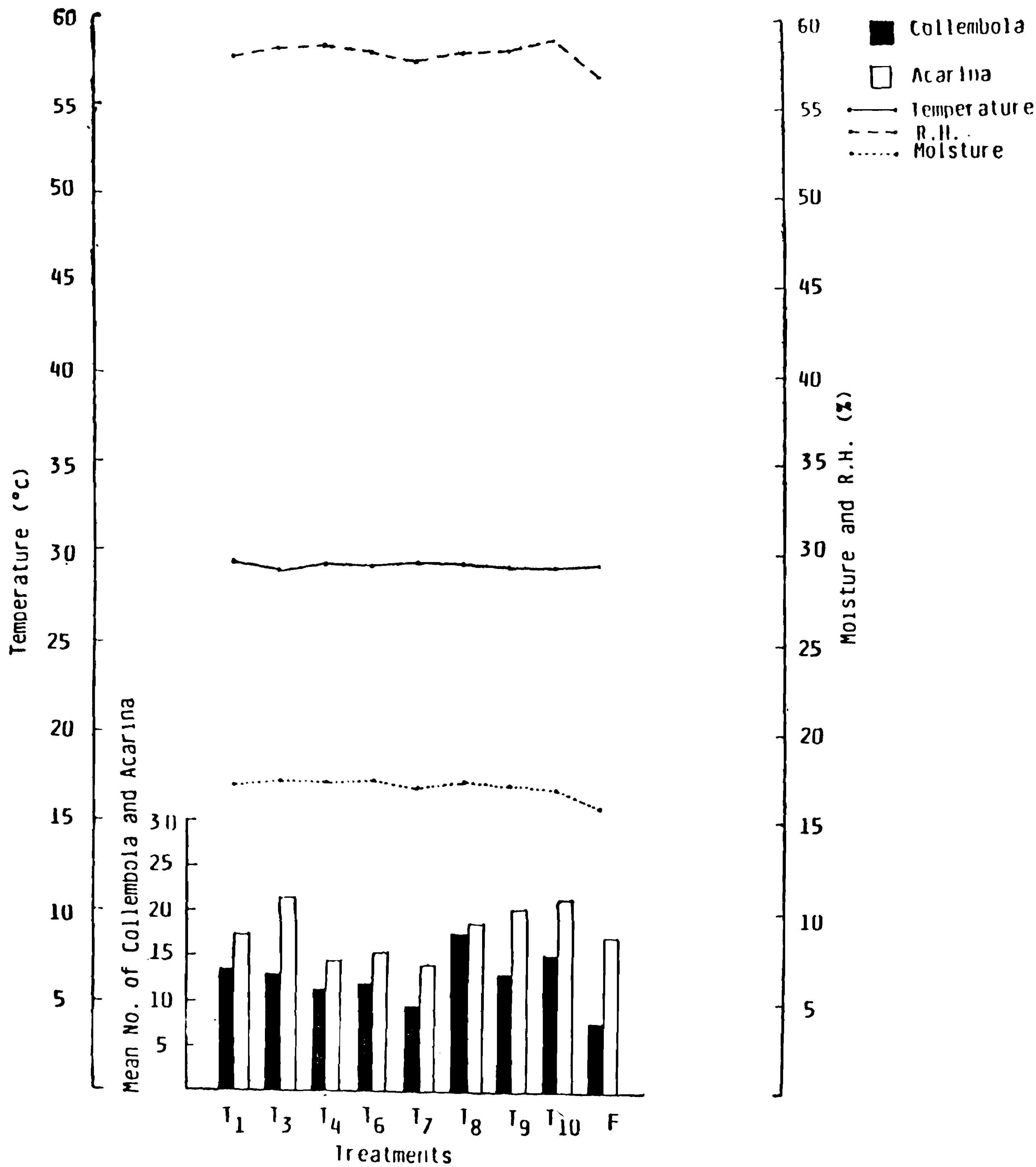


Fig. 9. Plotwise analysis of Collembola and Acarina obtained during cultivation of all the three crops.

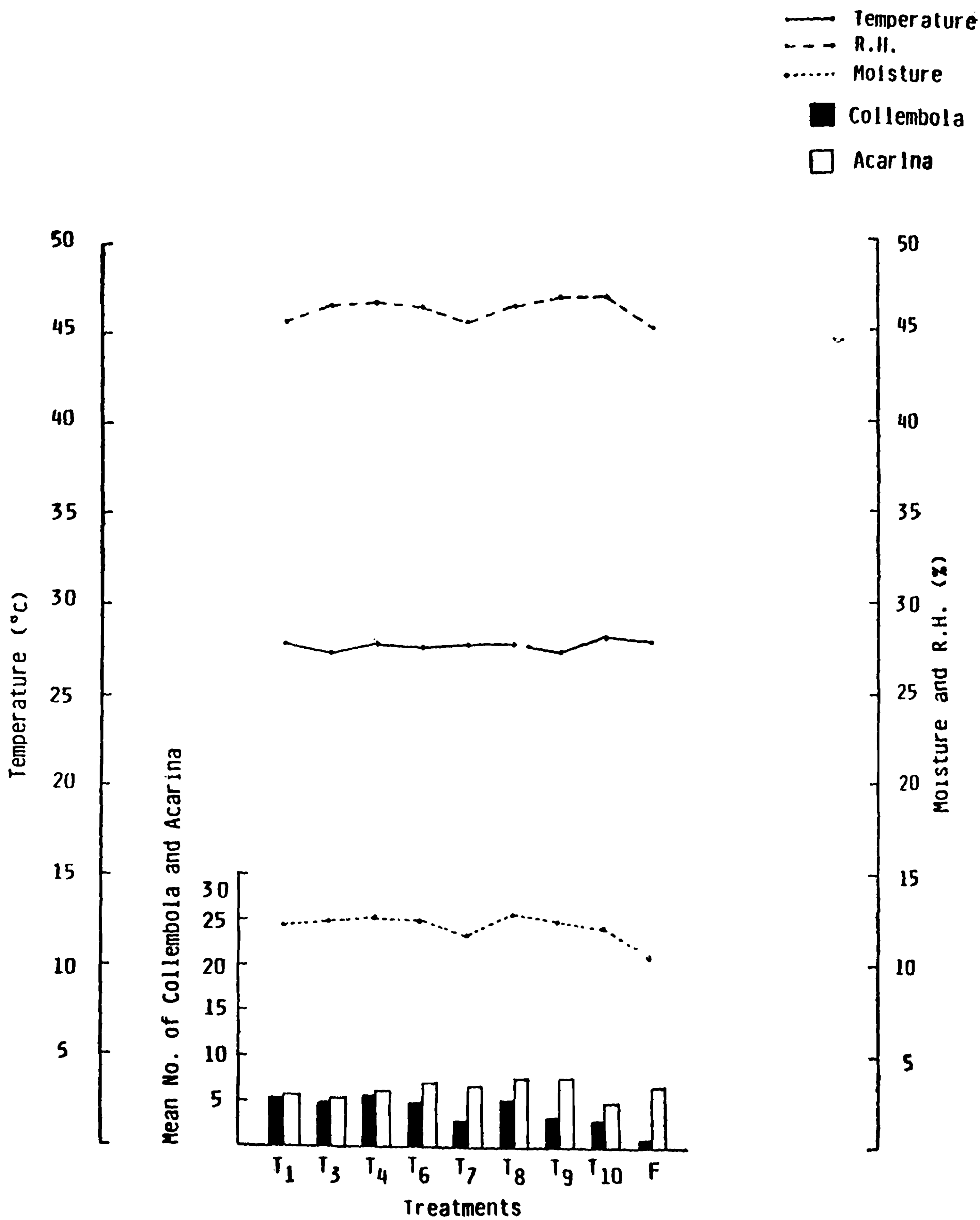


Fig. 10. Effect of graded level of NPK on Collembola and Acarina during Wheat cultivation.

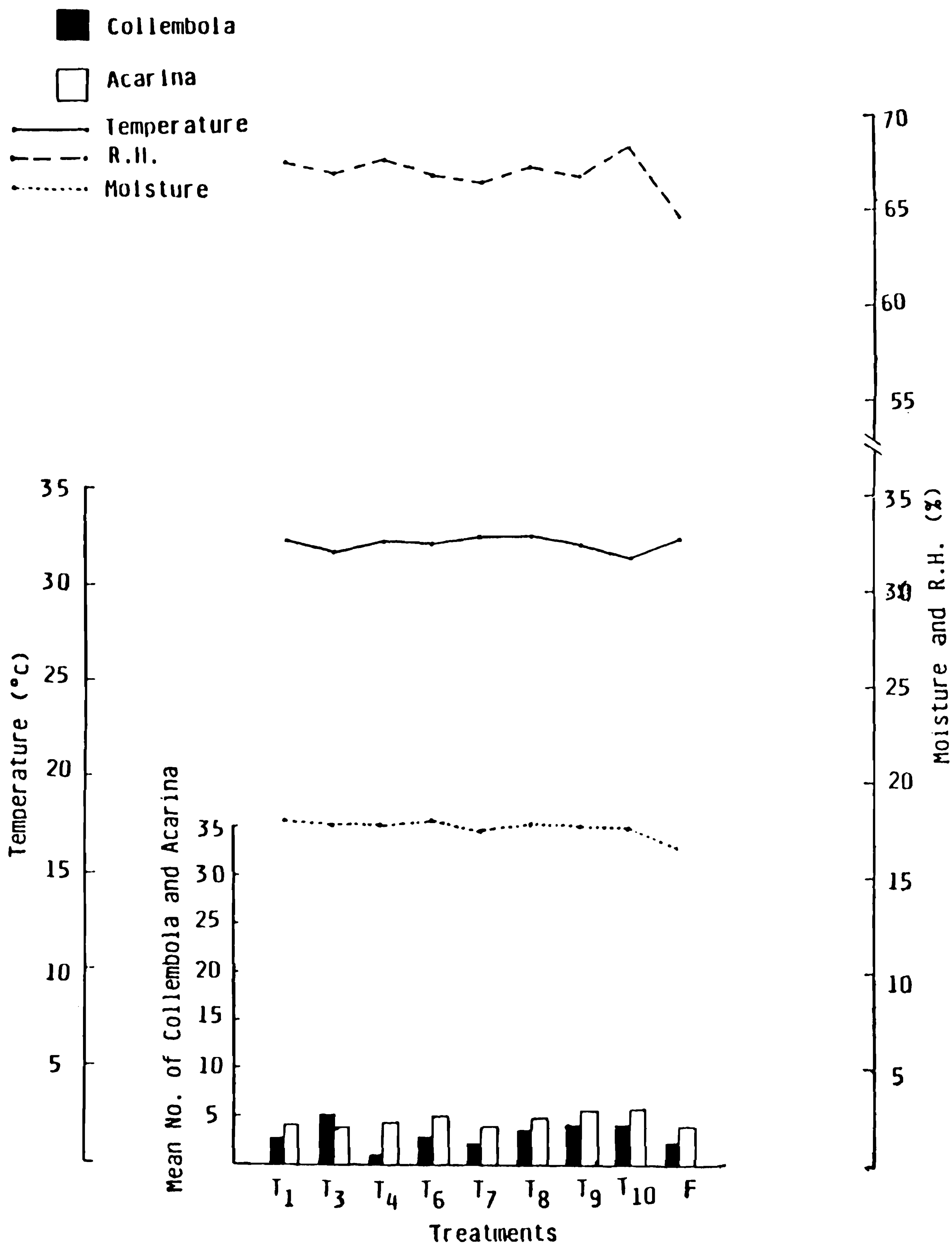


Fig. 11. Effect of graded level of NPK on Collembola and Acarina during Jute cultivation.

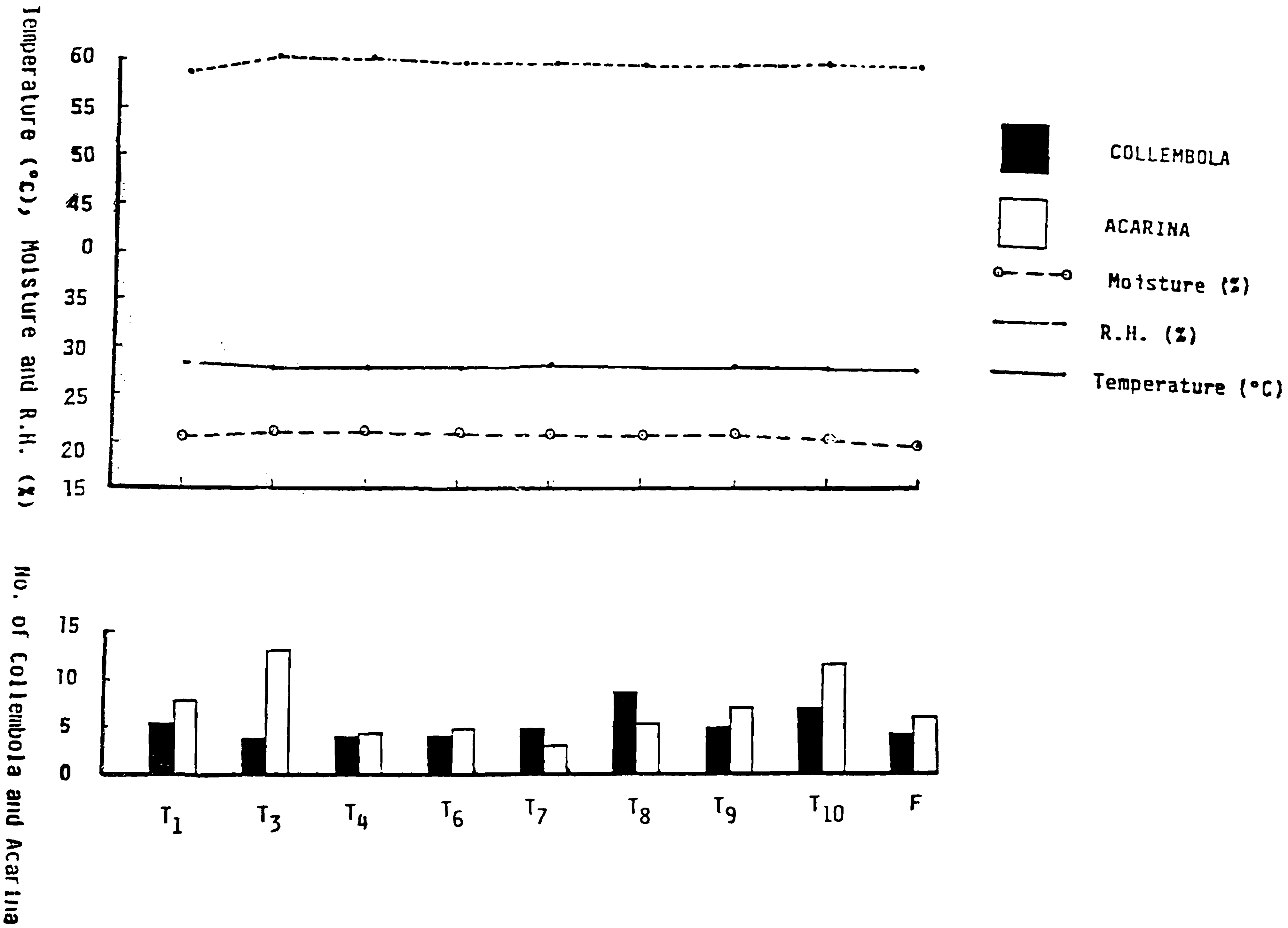


Fig. 12. Effect of graded level of NPK on Collembola and Acarina during Paddy cultivation.

significantly lower than T_{10}. Effect of optimum dose of N (N_{60}) without P and K (P_0 and K_0), as applied in T_7, retards the population build-up of Collembola and Acarina (cf. T_4) though its effect is least significant as compared to control (T_{10}). Nevertheless, this goes to prove that phosphorus plays a positive role in population build-up of these microarthropods. Effect of optimum dose of NPK with farmyard manure (@ 10 tons/hectare), applied in T_8, has significant effect in enhancing the population of Collembola and silightly that of Acarina (cf. T_8 Vs. T_8, T_4, T_6, T_7). T_{10}, where crop rotation was practised without fertilizers, showed better development of the population of Collembola and Acarina than fallow without cultivation.

A comparison of T_4 with T_9 shows that chemical weeding in general encourages the population growth of Collembola and Acarina, specially that of Acarina, than hand weeding. Application of farmyard manure alongwith optimum dose of NPK enhances population of Acarina significantly and also of Collembola which is revealed through coparison of T_4 with T_8. Acarina shows greater increase with application of farmyard manure. Slight increase in the population of Collembola and Acarina is perceptible in the absence of muriate of potash, used as source for K fertilizer in T_4 (T_4 *Vs.* T_6). It was further noted that absence of both P and K fertilizers has significant effect on the population build-up of both Collembola and Acarina (T_4 *Vs.* T_7) [Fig. 9] and the positive role P fertilizer plays in population build-up of soil microarthropods, (cf. T_4, T_6, T_7).

Effect of graded levels of NPK Application During cultivation of each type of crop :

Application of 50% NPK (T_1) effected significant increase of Collembola and slightly of Acarina during wheat cultivation over control (T_{10}). This effect was just reverse during jute and paddy cultivations (Figs. 10, 11, 12).

Under an application of 100% of the optimum NPK (T_4), the effect was though significant in boosting Collembola and Acarina population during wheat cultivation, it was insignificant during jute and paddy.

Application of 150% of NPK (T_3) had a significant effect in increasing Collembola population during wheat and jute cultivations but the effect was insignificant during paddy cultivation when compared to control. This effect of higher dose of fertilizers was just reverse for Acarina during jute and paddy cultivations.

Application of 100°/₀ of NPK (T_4) exhibited similar effects as that of 150°/₀ NPK (T_3) resulting in increased population of Collembola and Acarina during cultivation of wheat only as compared to control (T_{10}).

Optimum dose of N & P only (i. e., absence of potassium) in T_6, as is evident, boosted the population of Collembola during wheat cultivation as compared to T_{10}

(control) and T_4 but the effect of the treatment had little impact during jute and paddy cultivations on Collembola and Acarina population.

Application of 100% of Nitrogen only (as in T_7) significantly reduced the population of both Collembola and Acarina during wheat and jute cultivations (cf. T_6) but there was slight increase in collembolan population during paddy cultivation. During wheat cultivation, population of Collembola at T_7 was not different from T_{10} (control) though the Acarina population was higher than the later. During jute and paddy cultivations, population of both Collembola and Acarina were significantly low in T_7 than control.

Application of 100% of optimum NPK along with farmyard manure (in T_8) remarkably increased population of both Collembola and Acarina as compared to control (T_{10}) and T_3 (receiving 150% of NPK) during cultivation of wheat and paddy with the exception of Acarina in T_8 and T_{10}. The effect was, however, found not so significant during cultivation of jute, when FYM is actually applied just before the sowing of this crop.

Chemical weeding (as applied in T_9) encourages the growth of both collembolan and acarine populations during jute and paddy cultivations (cf. T_9 *vs.* T_4). During cultivation of wheat, however, collembolan population was higher in T_4 than T_9.

The effect of FYM had a positive effect in boosting population of Collembola and Acarina during jute, paddy and wheat cultivations with the exception of collembolan population which was greater during wheat cultivation in T_4 than in T_8. Potassium was found to have little significance during cultivation of all the three crops (cf. T_4 *vs.* T_6). The role of phosphorus and potassium did not appear significant for the population of both Collembola and Acarina when the effects were analysed individually for each type of crop (cf. T_4 *vs.* T_6 *vs.* T_7).

Cultivation of each type of crop without fertilizers (T_{10}) supported greater population of Collembola and Acarina than fallow (F) without cultivation.

Treatmentwise abundance of collembolan species during Wheat cultivation :

Five species, *viz.*, *I. balteatus*, *C. thermophilus*, *Lepidocyrtus* sp., *C. javanus* and *Brachystomella* sp. occurred during wheat cultivation.

I. balteatus :

It was most predominant in the plots treated with 100% of optimum NPK with farmyard manure (T_8) followed by 150% of optimum NPK (T_3), 100% of optimum NPK (T_4), 100% of optimum NP (T_6), control (T_{10}), 100% of optimum N only (T_7). The species was least in abundance in T_9, treated with 100% NPK and chemical weedicides and in fallow.

C. thermophilus ;

Most predominant in plots treated with 100% of optimum N only (T_7) followed by T_1 (50% of optimum NPK), T_4 (100% of optimum NPK and Handweeding), T_{10} (control), T_3 (150% of optimum NPK). T_6 (100% of optimum NP), T_8 (100% of

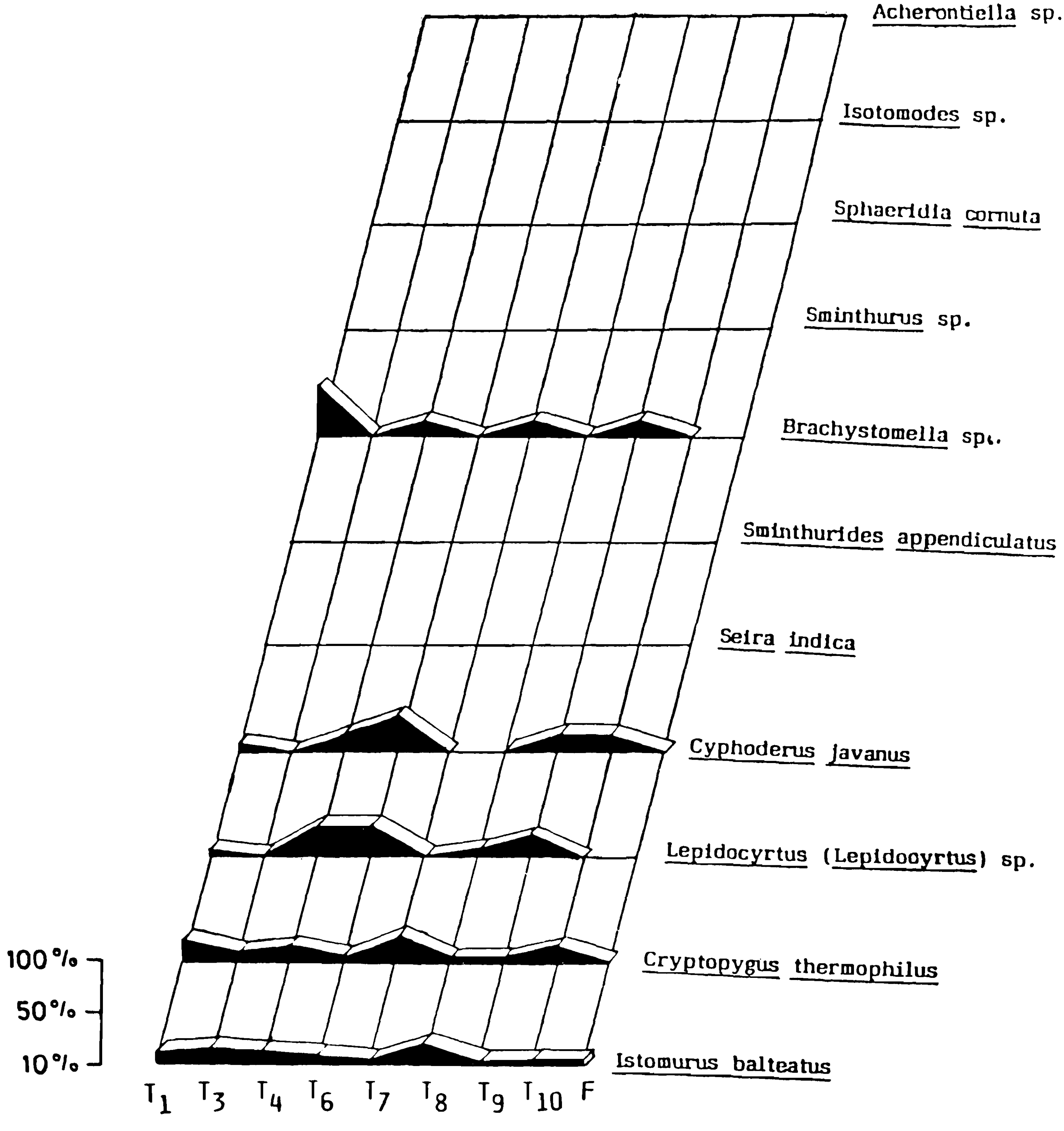


Fig. 13. Treatmentwise abundance of collembolan species during Wheat cultivation.

optimum NPK and farmyard manure) and T_9 (100% of optimum NPK+chemical weeding) supported the same population of the species.

Lepidocyrtus sp. :

Most predominant in plots treated with 100% of optimum NPK (T_4) and 100% NP (T_6) followed by plots treated with chemical weedicides and 100% of optimum NPK (T_9) ; T_1 (50% of optimum NPK) and T_8 (50% of optimum NPK and farmyard manure) supported the same population of this species ; the species did not occur in the plots treated with 150% of optimum NPK (T_3), 100% of only N(T_7), T_{10} (control) and fallow.

C. javanus :

Highest population in T_6 (100% of optimum NP) followed by identical population in T_4 (100% of optimum NPK), T_9 (100% of optimum NPK plus chemical weeding) and control (T_{10}). The species did not occur in T_3, T_7, T_8 and fallow.

Brachystomella sp. :

Highest population occurred in T_1 (50% of optimum NPK) followed by identical populatiun in T_4, T_7, T_9. The species did not occur in other fertilizer treated plots.

During cultivation of wheat *I. balteatus* favoured plots treated with 100% of optimum NPK and farmyard manure (T_8), *C. thermophilus* showed preference for T_7 (treated with 100% of optimum N only), *Lepidocyrtus* (*Lepidocyrtus*) sp. favoured both T_4 (with 100% of optimum NPK) and T_6 (with 100% of optimum NP), *C. javanus* T_6 (100% of optimum NP) and *Brachystomella* sp. the lowest dose of fertilizer at T_1 (50% of optimum NPK) (Fig. 13).

Treatmentwise Abundance of collembolan species during Jute cultivation :

Eight species of Collembola occur during jute cultivation in the experimental plots. These are *Istomodes* sp., *Sminthurus* sp., *Brachystomella* sp., *S. indica*, *C. javanus*, *Lepidocyrtus* (*Lepidocyrtus*) sp., *C. thermophilus* and *I. balteatus*.

I. balteatus :

The species favoured most T_3, receiving 150% of optimum NPK, showed identical preference to T_1 (50% of optimum NPK) and T_6 (100% of optimum NPK). In T_4 (with 100% of optimum NPK), it did not occur at all and in other plots it showed a moderate build up of population between 5-10%.

C. thermophilus :

As above, this species was most predominant in T_3 (plot receiving highest dose of NPK fertilizers) followed by identical population at T_6 (100% of optimum NP), T_9

(100% of optimum NPK and Chemical Weeding) and T_{10} (control). In other plots, it was represented moderately at below 10% level and was absent in T_8.

Lipidocyrtus (*Lepidocyrtus*) sp. :

Occurred only in T_3, receiving highest fertilizer dose of 150% of optimum NPK.

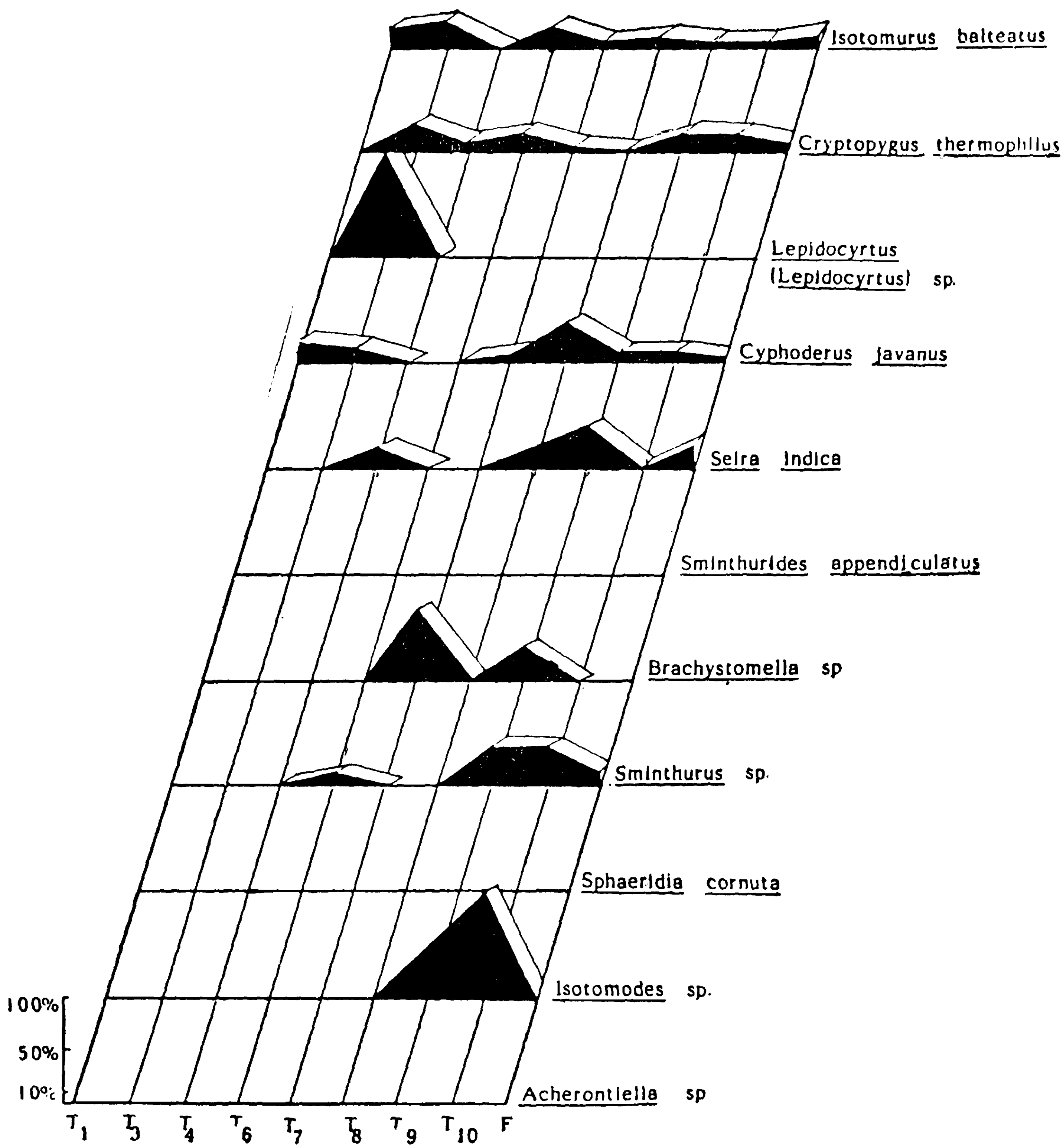


Fig. 14. Treatmentwise abundance of collembolan species during Jute cultivation.

C. javanus :

Highest population build up of the species was observed in T_8 (100% of optimum NPK+FYM) followed by T_1, T_8. It was completely absent in T_4 and T_6 and was moderately represented in other plots within the range of 5·9%.

S. indica :

The species showed most affinity to T_9, receiving 100% of optimum NPK and undergoing chemical weeding followed by identical population in T_4 (100% of optimum NPK), T_8 (100% of optimum NPK+FYM) and fallow. It was unrepresented in other plots, receiving graded levels of NPK and in control.

Brachystomella sp. :

The species occurred only in two plots with the highest population in T_7 (optimum dose of N only) and in T_9 (optimum dose of NPK and chemical weeding).

Sminthurus sp. :

Highest identical population occurred in T_9 and T_{10} (control) and lowest identical population in T_6 and fallow. It remained unrepresented in other plots.

Isotomodes sp. :

The species was absent in all fertilizer treated plots and occurred in T_{10} (control) only (Fig 14).

Treatmentwise abundance of collembolan species during Paddy cultivation :

Altogether eight species occurred in the experimental plots during paddy cultivation. These are *I. balteatus*, *C. thermophilus*, *Lepidocyrtus* (*Lepidocyrtus*) sp., *C. javanus*, *S. appendiculatus*, *Brachystomella* sp., *S. cornuta* and *Acherontiella* sp..

I. balteatus :

The species occurred in all fertilizer treated plots with highest population at T_1 and also almost identical population at T_8. In other plots, it occurred almost uniformly. In fallow, however, it was most abundant.

C. thermophilus :

Highest population was recorded from three plots, *viz*., T_8, T_9, T_{10} and occurred in all plots including fallow.

Lepidocyrtus (*Lepidocyrtus*) sp. :

The species occurred in all plots except T_3, receiving 150% of optimum NPK. Its highest population was recorded from T_8 and T_{10} followed by T_1 and with identical population at T_7 and T_9, T_4 and T_6, T_8 and T_{10}.

C. javanus :

The species did not occur in T_3 (150% of optimum NP), T_6 (100% of optimum NP), T_7 (100% of optimum N) and T_9 (100% of NPK with chemical weeding). Its highest

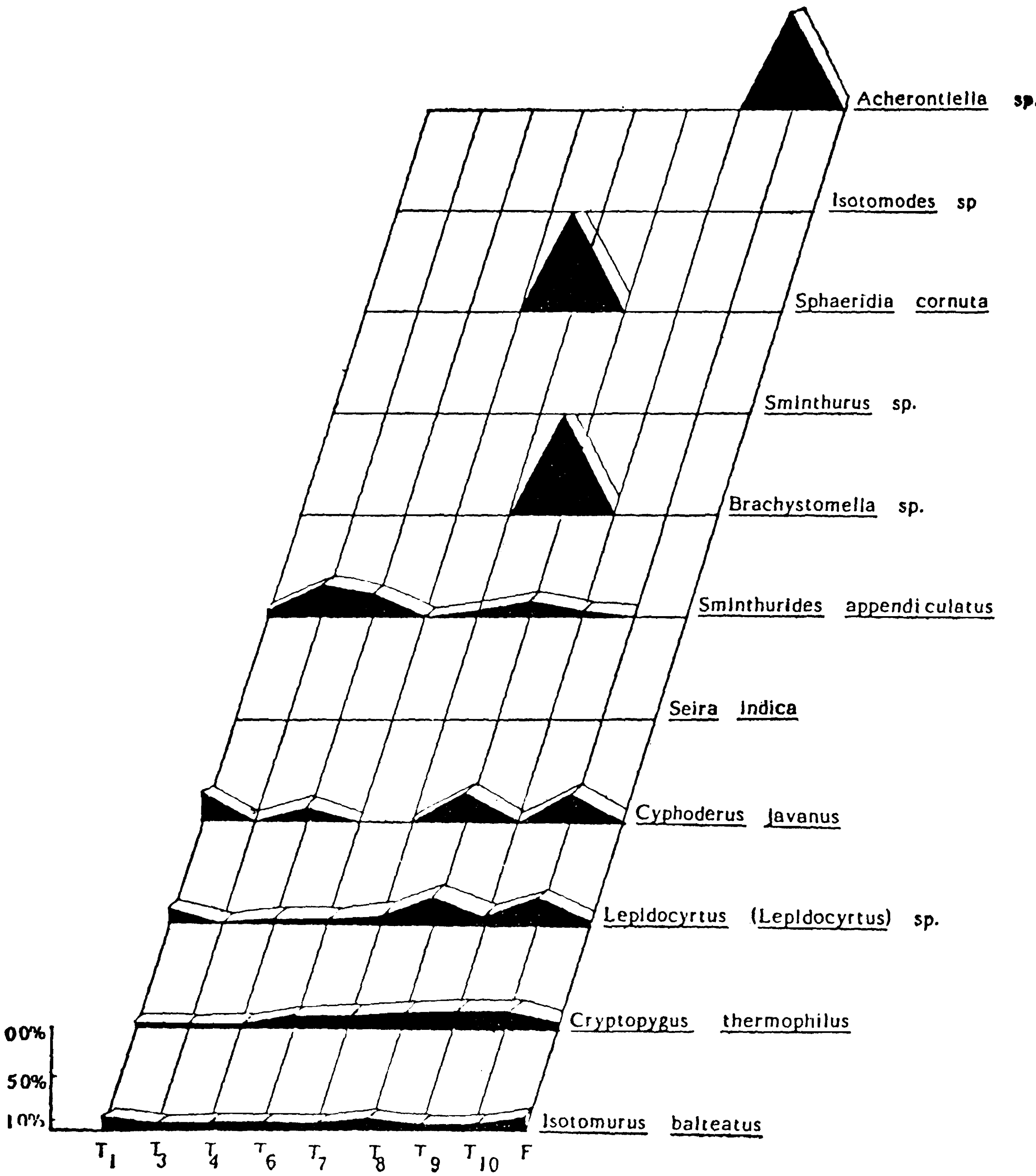


Fig. 15. Treatmentwise abundance of collembolan species during Paddy cultivation.

population occurred identically at T_1 (50% of optimum NPK), T_8 (100% of optimum NPK with FYM) and T_{10} (control). The species was absent in fallow.

S. appendiculatus :

Highest population occurred at T_3 (receiving highest dose of NPK), followed by T_4 (with 100% of optimum NPK), T_8 (with 100% of optimum NPK and FYM). T_1, T_7, T_9 exhibited lowest identical population. The species was absent in T_6, T_{10} and fallow.

Brachystomella sp. : Occurred only in T_8 (with 100% optimum NPK+FYM).

S. cornuta : Occurred only in T_7 (with 100% optimum N only).

Acherontiella sp. : Occurred only in T_{10} (control).

During cultivation of paddy, the highest population build up of *I. balteatus* was in T_1 and T_8 and *C. thermophilus* in T_8, T_9 and T_{10}. Highest population of *C. javanus* was recorded from T_1, T_3 and also from control (T_{10}). S. *appendiculatus* occurred predominantly in T_3 while *Brachystomella* sp. remained restricted in T_8, *S. cornuta* in T_7 and *Acherontiella* sp. in T_{10} (Fig. 15).

Overall abundance of collembolan species according to treatments of NPK :

Species of Collembola, encountered in the experimental plots, mostly were ubiquitous with the exception of a few, showing restricted appearance, specific to a particular treatment.

I. balteatus occurred in all treatments with the peak of its population in T_8. Similarly, *C. thermophilus* was also present in all the treatments with highest population buildup at T_{10}. *Lepidocyrtus* sp. and *C. javanus* also evenly occurred in all treatments with highest population at T_8. *S. indica* exhibited its highest population at T_9 with identical population at T_4 and T_8. The species was found to be absent in other fertilizer treated plots but occurred in fallow. Barring control (T_{10}) and fallow (F), *S. appendiculatus* occurred in all treatments with its highest population build-up at T_3. *Brachystomella* sp. was absent in T_3, T_6, T_{10} (control) and fallow with its highest population abundance at T_7 followed by identical population at T_1, T_9 and then at T_4, T_8. Out of nine treatments, *Sminthurus* sp. occurred in four with the highest population at T_9, T_{10} followed by identical population at T_6 and fallow. *S. cornuta* occurred only in T_7, *Isotomodes* sp. and *Acherontiella* sp. in T_{10} only (Fig. 16).

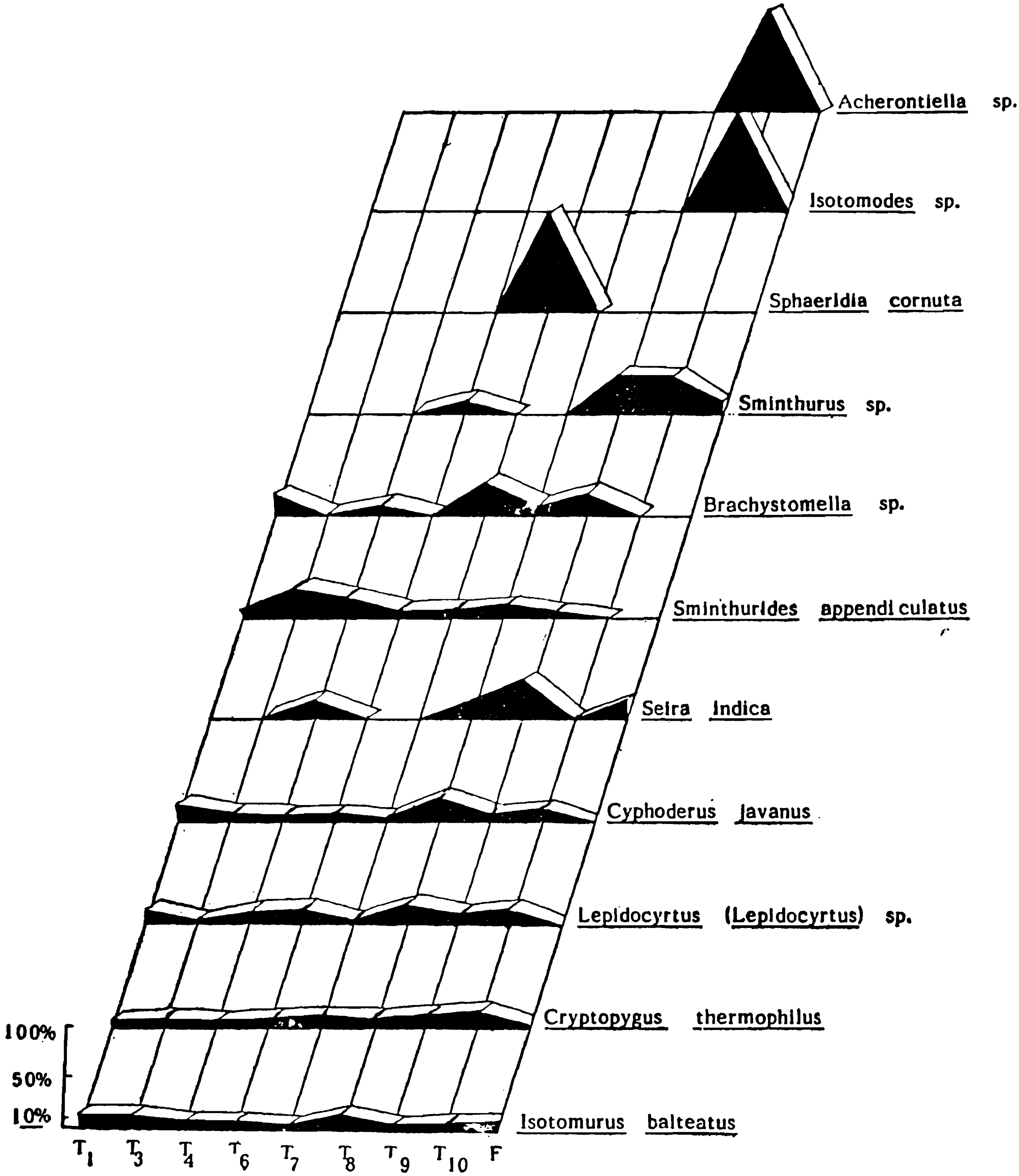


Fig. 16. Treatmentwise overall abundance of collembolan species.

Abundance of collembolan species in relation to total Collembola obtained from each treatment during wheat cultivation :

T_1 *(50% of optimum NPK)*: Out of the total Collembola obtained from this treatment, *I. balteatus* formed the main bulk being 43.75%, followed by *C. thermophilus* (25%), *Brachystomella* sp. (18.75%), *Lepidocyrtus* sp. and *C. javanus* each of 6.25%.

T_3 (150% of optimum NPK) : Out of the total Collembola, obtainted from this plot, *I. balteatus* quantitatively was more predominant representing 84.62% and the rest was *C. thermophilus.*

T_4 (100% of optimum NPK and Handweeding) : *I. balteatus* was represented by 47.37%, followed by *Lepidocyrtus* (*Lepidocyrtus*) sp. (21.05%), *C. thermophilus* (15.79%), *C. javanus* (10.53%) and *Brachystomella* sp. (5.26%).

T_6 (100% of optimum NP) : Out of the total Collembola, 40% was represented by *I. balteatus*, 26.67% by each of *C. javanus* and *Lepidocyrtus* (*Lepidocyrtus*) sp. and 6.67% by *C. thermophilus.*

T_7 (100% of optimum N) : *C. thermophilus* constituted the main component being 55.66% followed by *I. balteatus* (33.3%) and *Brachystomella* sp. (11.11%).

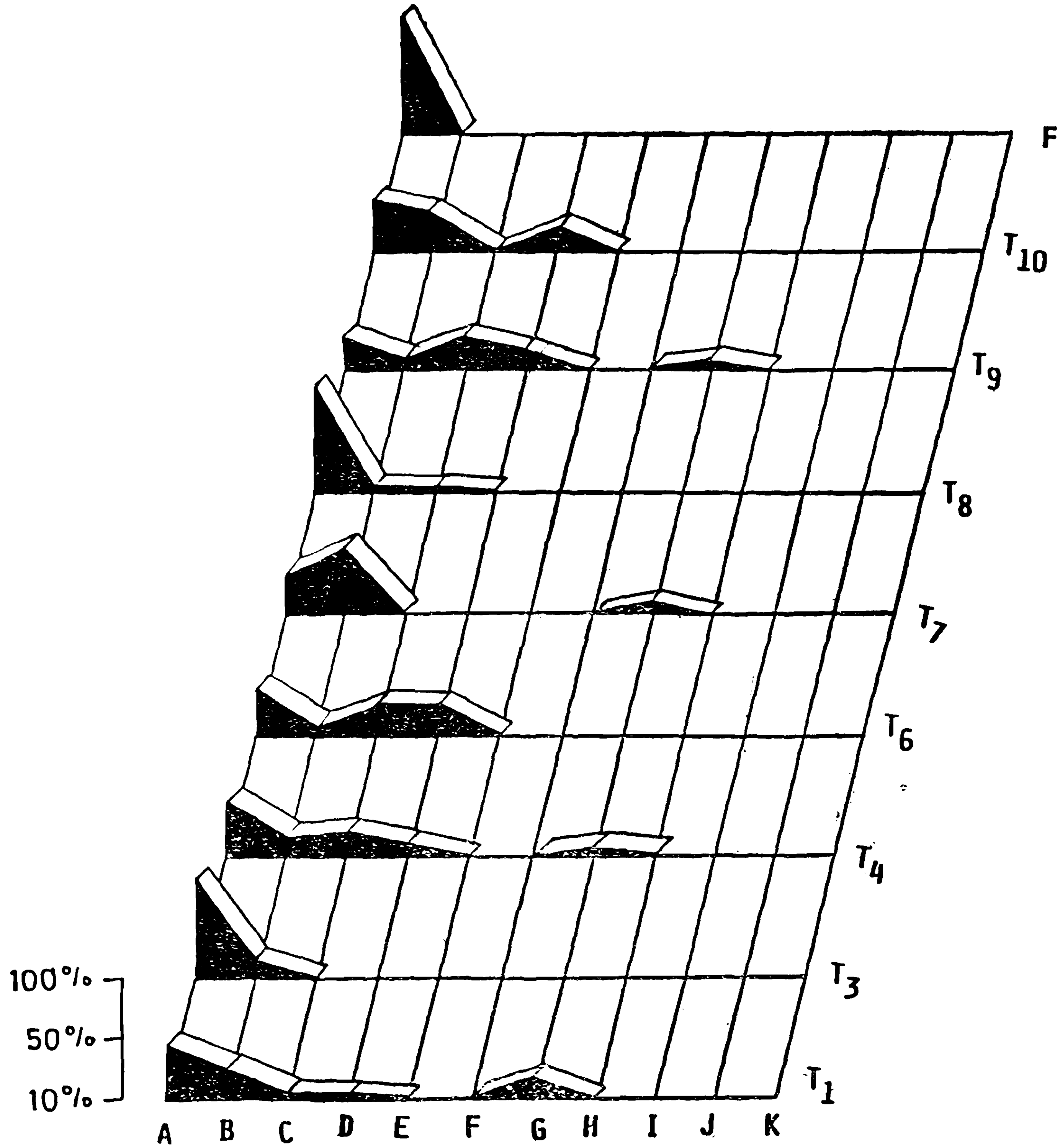
T_8 (100°/₀ of optimum NPK and FYM) : *I. balteatus* formed the main constituent being 87.50°/₀ followed by *C. thermophilus* and *Lepidocyrtus* (*Lepidocyrtus*) sp. each forming 6.25°/₀ of the total Collembola obtained from this treatment.

T_9 (100°/₀ of optimum NPK and chemical weeding) : The predominant constituents were two species, viz., *I. balteatus* and *Lepidocyrtus* (*Lepidocyrtus*) sp. each forming 30°/₀ followed by *C. javanus* (20°/₀) ; *C. thermophilus* and *Brachystomella* sp. each contituted 10°/₀ of the total Collembola obtained from this treatment.

T_{10} (Control) : Major constituent of total Collembola obtained from this plot was *I. balteatus* (44.44°/₀) followed by *C. thermophilus* (33.33°/₀) and *C. javanus* (22.22°/₀).

F (Fallow) : During wheat cultivation, fallow plot was represented only by *I. balteatus.*

In all the treatments barring T_7, *I. balteatus* was found to be the main component of total Collembola obtained from each plot. *C. thermophilus* formed the major constituent in T_7 and *Lepidocyrtus* (*Lepidocyrtus*) sp. exhibited identical abundance as that of *I. balteatus* in T_9 (Fig. 17).



A. Istomurus balteatus
B. Cryptopygus thermophilus
C. Lepidocyrtus (Lepidocyrtus) sp.
D. Cyphoderus javanus
E. Seira indica
F. Sminthurides appendiculatus
G. Brachystomella sp.
H. Sminthurus sp.
I. Sphaeridia cornuta
J. Isotomodes sp.
K. Acherontiella sp.

Fig. 17. Abundance of collembolan species in each treatment during Wheat cultivation.

Abundance of collembolan species in relation to total Collembola obtained from each treatment during jute cultivation :

T_1 (50°/ₒ of optimum NPK) : The total Collembola obtained from this plot was represented by *I. balteatus* and *C. javanus*, each constituting 50°/ₒ of total Collembola.

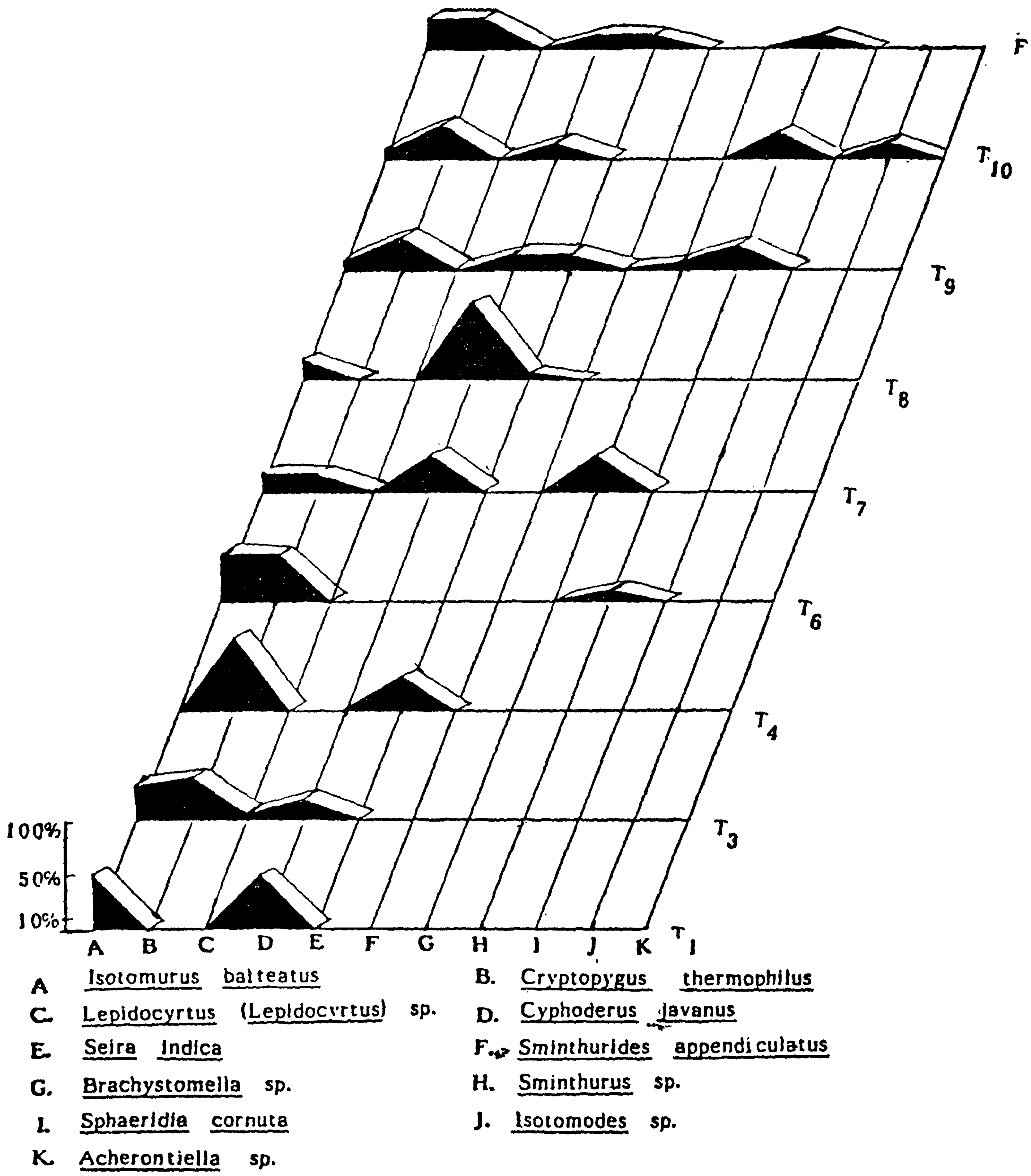


Fig. 18. Abundance of collembolan species in each treatment during Jute cultivation.

T_3 (150°/₀ of optimum NPK) : *C. thermophilus* constituted the highest proportion of total Collembola obtained from this plot followed by *I. balteatus*, *C. javanus* and *Lepidocyrtus* (*Lepidocyrtus*) sp.

T_4 (100°/₀ of optimum NPK) : 66.67°/₀ of total Collembola of this plot was represented by *C. thermophilus* and *S. indica* (33.33°/₀).

T_6 (100°/₀ of optimum NP) : *I. balteatus* and *C. thermophilus* occurred in the same proportions (44.44°/₀ each) and *Sminthurus* sp. (11.11°/₀).

T_7 (100°/₀ of optimum N) : *C. javanus* and *Brachystomella* sp. each exhibited equal abundance (33.33°/₀) followed by *I. balteatus* and *C. thermopilus*, each occurring in equal proportions (16.66°/₀).

T_8 (100°/₀ of optimum NPK and FYM) : This treatment was represented by 72.73°/₀ *C. javanus* followed by 18.18°/₀ *I. balteatus* and 9.09°/₀ *S. indica.*

T_9 (100°/₀ of optimum NPK and chemical weeding) : *C. thermophilus* dominated the population (30.77°/₀) followed by *Sminthurus* sp. (23.08°/₀), *C. javanus* (15.38°/₀) and 7.69°/₀ each of *I. balteatus* and *Brachystomella* sp..

T_{10} (control) : *C. thermophilus* represented the bulk of total Collembola (33.33°/₀) followed by *Sminthurus* sp. (25°/₀), *C. javanus* (16.67°/₀) and *Isotomodes* sp. (16.66°/₀).

F (Fallow) : Total Collembola was composed of *I. balteatus* and *C. thermophilus* each representing by 28.57°/₀ followed by 14.29°/₀ each of *C. javanus*, *S. indica* and *Sminthurus* sp..

During jute cultivation, six plots were predominantly represented by *C. thermophilus* followed by *I. balteatus* and *C. javanus* each of which dominated in three plots and *Brachystomella* sp. in one plot (Fig. 18).

Abundance of collembolan species in relation to total Collembola obtained from each treatment during Paddy cultivation :

T_1 (50°/₀ of optimum NPK) : *I. balteatus* constituted the major component of total Collembola representing 50°/₀ followed by *Lepidocyrtus Lepidocyrtus*) sp. (18.75°/₀), *C. thermophilus* and *C. javanus* each by equal proportions (12.5°/₀) and *S. appendiculatus* by 6.25°/₀.

T_3 (150°/₀ of optimum dose of NPK) : *I. balteatus* forming the major component being 45.45°/₀ of total Collembola followed by *S. appendiculatus* (36.36°/₀) and *C. thermophilus* (18.18°/₀).

T_4 (100°/₀ of optimum NPK and handweeding) : *I. balteatus*, constituted the major proportion being 50°/₀ followed by *S. appendiculatus* (25°/₀), *C. thermophilus*, *Lepidocyrtus* sp. and *C. javanus* each 8.33°/₀.

T_6 (100°/₀ of optimum NP) : *I. balteatus* represented 50°/₀ of the total Collembola followed by 41.67°/₀ *C. thermophilus* and 8.33°/₀ *Lepidocyrtus* sp.

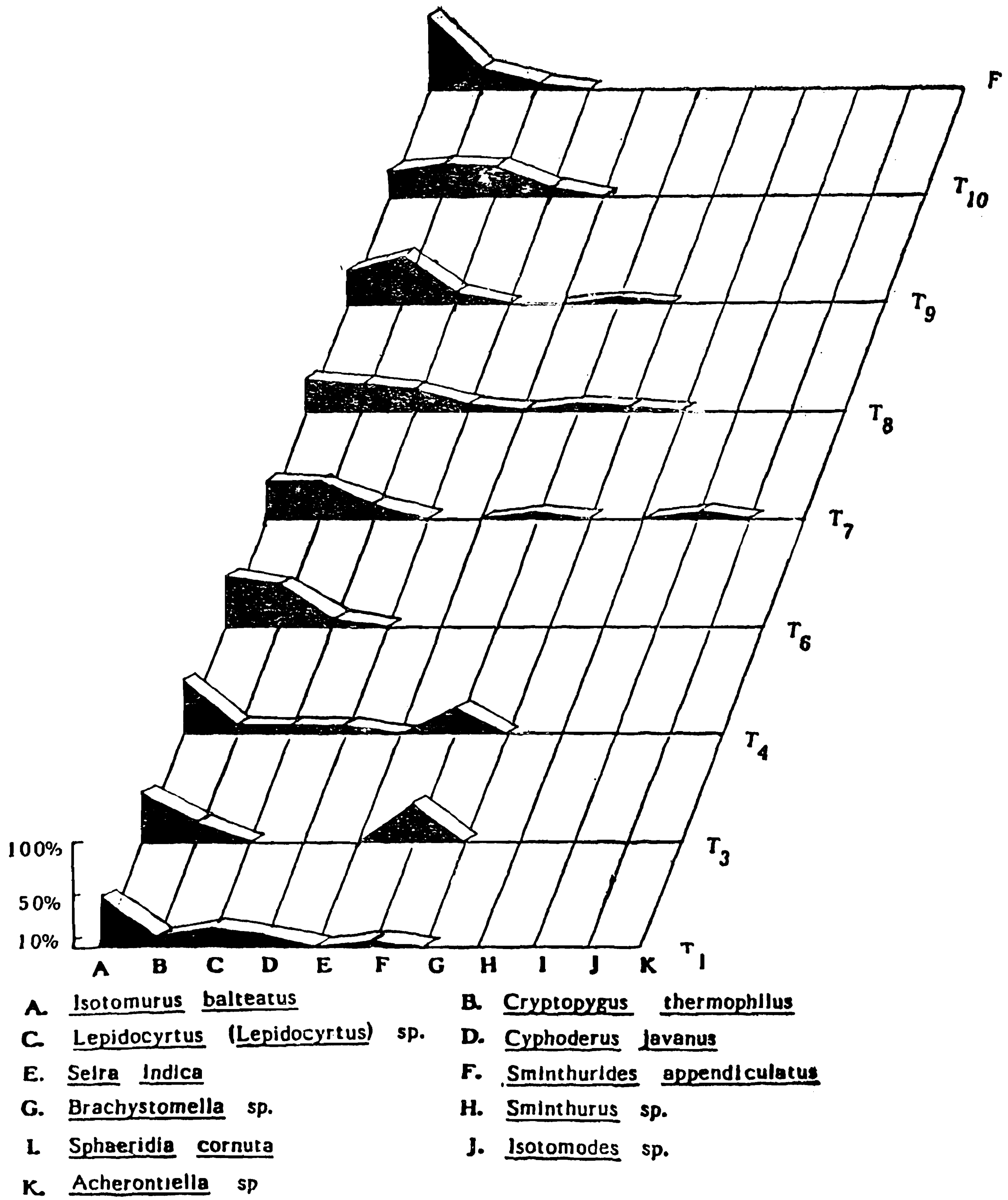


Fig. 19. Abundance of collembolan species in each treatment during Paddy cultivation.

T_7 (100°/₀ of optimum N) : *I. balteatus* and *C. thermophilus* occurred in identical proportions (33.71°/₀) followed by *Lepidocyrtus* sp. (14.29°/₀ and *S. appendiculatus* and *S. cornuta* in equal proportions (7.14°/₀).

T_8 (100°/₀ optimum NPK and FYM) : *I. bulteatus* dominated this treatment being 30.77°/₀ followed by *C. thermophilus* 26.93°/°, *Lepidocyrtus* (*Lepidocyrtus*) sp. (23.08°/₀), *C. javanus* and *S. appendiculatus* each with 7.69°/₀.

T_9 (100°/₀ of optimum NPK and Chemical Weeding) : *C. thermophilus* formed the major component being 46.67°/₀ of the total Collembola followed by *I. balteatus* (33.33°/₀), *Lepidocyrtus* sp. (13.33°/₀) and *S. appendiculatus* (6.67°/₀).

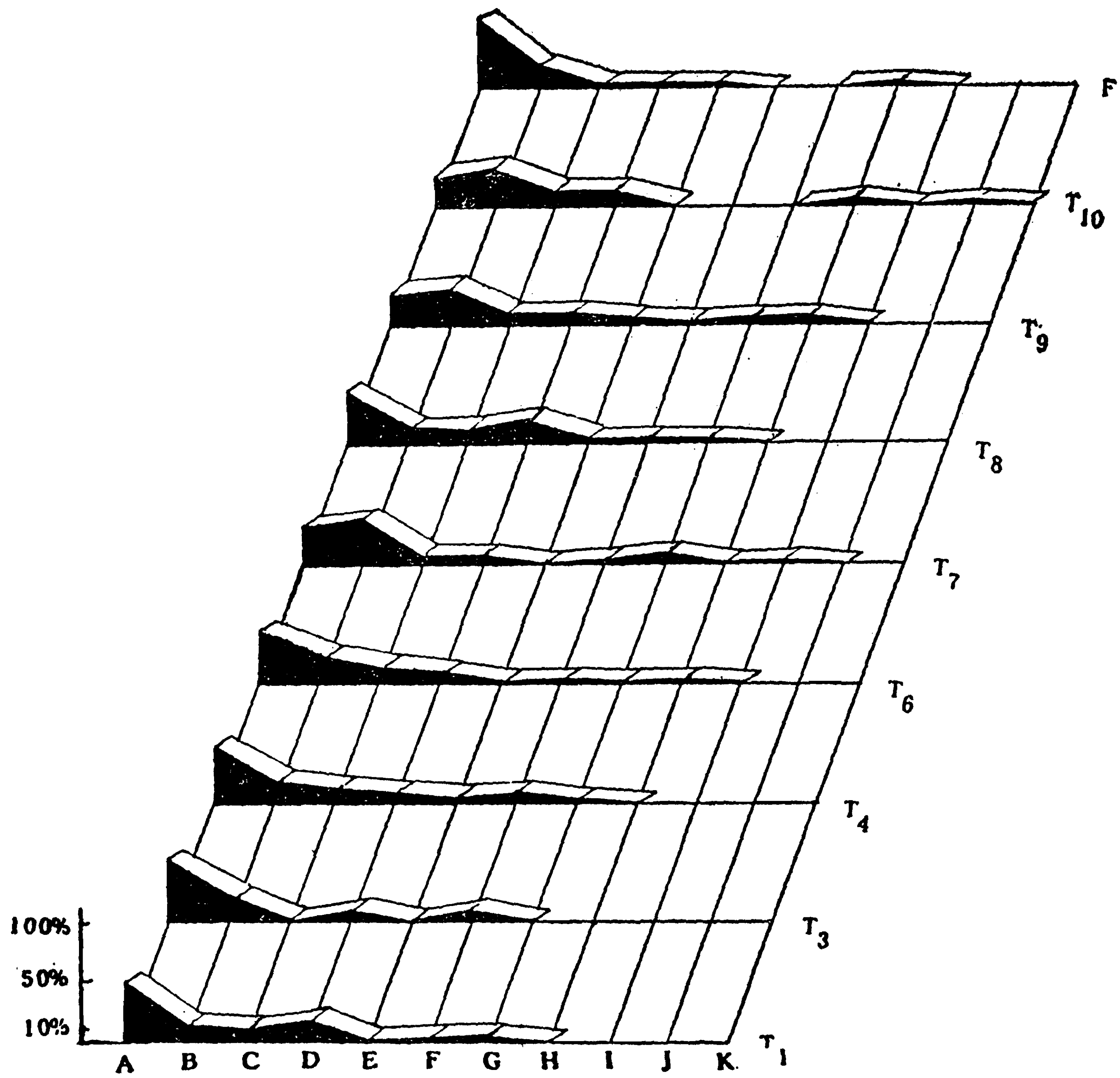
T_{10} (Control) : *C. thermophilus* was the major constituent being 33.33°/₀ of the total Collembola followed by *Lepidocyrtus* sp. (28.57°/₀), *I. bulteatus* (23.81°/₀), *C. javanus* (9.52°/₀) and *Acherontiella* sp. (4.76°/₀).

F (Fallow) : *I. balteatus* formed the major constituent being represented by by 69.23°/₀ followed by *C. thermophilus* (23.08) and *Lepidocyrtus* sp. (7.69°/₀).

Out of 9 plots, *I. balteatus* dominated seven plots during paddy cultivation. *C. thermophilus* besides dominating in two treatments (T_9, T_{10}) was quantitively similar to *I. balteatus* in 7_7 (Fig. 19).

Overall abundance of collembolam species in relation to total number of Collembola from all the plots :

I. balteatus formed the major constituent in the experimental plots barring only three treatments 7_7, T_9 and T_{10} where *C. thermophilus* dominated. The second dominant species was *C. thermophilus* followed by *C. javanus*, *Lepidocyrtus* (*Lepidocyrtus*) sp., *S. appendiculatus*, *Brachystomella* sp., *S. indica*, *Isotomodes* sp., *S. cornuta* and *Acherontiella* sp. (Fig. 20).



A. Isotomurus balteatus

B. Cryptopygus thermophilus

C. Lepidocyrtus (Lepidocyrtus) sp.

D. Cyphoderus javanus

E. Seira indica

F. Sminthurides appendiculatus

G. Brachystomella sp.

H. Sminthurus sp.

I. Sphaeridia cornuta

J. Isotomodes sp.

K. Acherontiella sp.

Fig. 20. Overall abundance of collembolan species in different treatments in relation to total number of Collembola obtained from all the plots.

STATISTICAL TREATMENT OE DATA

The data based on 1720 soil samples, drawn from 9 treatments [T_1, T_3, T_4, T_6, T_7, T_8, T_9, T_{10} (control), T_{11} (fallow)] @ 3 samples from each treatment (i. e., 27 samples per month), representing five crop-seasons for each crop-type, were subjected to statistical analysis at the Indian Statistical Institute, Baranagar, Calcutta. Analysis of covariance (ANACOVA) and multiple regression, comparisons of treatments (t-values of significance) besides correlations between variables were undertaken to find out the effects of various doses fertilisers (NPK), three crop rotations (jute, wheat, paddy), pesticides, chemical weedicides, farmyard manure (FYM) and three abiotic factors, *viz.*, temperature, moisture, R. H. on collembolan and acarine populations.

Analysis of Covariance (ANACOVA) :

For studying the effects of various doses of N. P. K. (treatments) on Collembola and Acarina, the effects of three physical factors were to be eliminated at the first instance. Accordingly, for each crop, separate analysis of covariance is considered the most appropriate by using the following model. It is found that each time a separate root transformation is appropriate both for the numbers of Collembola and Acarina.

$$Y_{ijk}^{(1)}=\mu+\alpha_i+\beta_j+\gamma_{ij}+\theta_1 t_{ijk}+\theta_2 m_{ijk}+\theta_3 r_{ijk}+\theta_4 y_{ijk}^{(2)}+\varepsilon_{ijk}$$

Where, $Y_{ijk}^{(1)}$=the squareroot of the numbers of Collembola or Acarina when ith treatment is applied corresponding to jth month and kth year

μ=general effect

α_i=main effect of ith treatment

β_j=main efiect of jth month

γ_{ij}=interaction between ith treatment x jth month

t_{ijk}=the corresponding temperature

m_{ijk}=the corresponding moisture

r_{ijk}=the corresponding relative humidity

$y_{ijk}^{(2)}$=the corresponding suareroot of the numbers of Collembola or Acarina

θ_1, θ_2, θ_3, θ_4 are regression parameters and E_{ijk} are the unobservable errors.

It is assumed to be a fixed effect model and $E(\varepsilon)=0$ and $D(\underset{\sim}{\varepsilon})=\delta^2 I$, where, ε is the vector of ε_{ijk}'s.

The results of analysis, carried out following the above model, is presented in ANACOVA Tables 3-8. From the Table 3, pertaining to collembolan population, it would be evident that month, treatments, acarina, R. H. and all covariates are significant for collembolan population during wheat cultivation. While, treatments, moisture, R. H. and all covariates together are significant during jute cultivation (Table 4). Table 5 shows that during paddy cultivation treatments are not significant for collembolan population while, month, temperature, moisture and R. H. are significant.

TABLE 3. Analysis of Covariance for Collembola population with respect to Wheat.

Source	Sum of Squares	Degrees of freedom	Mean Square	F	*Tail Probability	Beta Estimates
Mean	0.70009	1	0.70009	1.49	0.2239	
MN	9.23386	3	3.07795	6.56	0.0003	
TR	9.79972	8	1.22496	2.61	0.0108	
MT	10.04635	24	0.41860	0.89	0.6118	
1st Covar. (Acarina)	6.98649	1	6.98649	14.89	0.0002	0.17892
2nd Covar. (Temp.)	0.10482	1	0.10482	0.22	0.6371	-0.00437
3rd Covar. (Moist.)	0.04372	1	0.04372	0.09	0.7606	0.00117
4th Covar. (R. H.)	4.14141	1	4.14141	8.83	0.0035	-0.01938
All Covariates	12.65042	4	3.16260	6.74	0.0001	
Error	65.67022	140	0.46907			

*(<0.05—Significant)

TABLE 4. Analysis of Covariance for Collembola population with respect to Jute.

Source	Sum of Squares	Degrees of freedom	Mean Squares	F	*Tail Probability	Beta Estimates
Mean	0.05885	1	0.05885	0.37	0.5451	
MN	0.65256	3	0.21752	1.36	0.2575	
TR	2.58446	8	0.32306	2.02	0.0482	
MT	5.01720	24	0.20905	1.31	0.1699	
1st Covar. (Acarina)	0.12296	1	0.12296	0.77	0.3820	0.05218
2nd Covar. (Temp.)	0.13557	1	0.13557	0.85	0.3588	-0.00616
3rd Covar. (Moist.)	1.83621	1	1.83621	11.48	0.0009	0.00754
4th Covar. (R. H.)	2.29937	1	2.29937	14.38	0.0002	-0.02234
All Covariates	4.34207	4	1.08552	6.79	0.0001	
Error	22.38808	140	0.15991			

*(<0.05—Significant)

TABLE 5. Analysis of Covariance for Collembola population with respect to Paddy.

Source	Sum of Squares	Degree of freedom	Mean Square	F	*Tail Probability	Beta Estimates
Mean	1.53562	1	1.53562	3.01	0.0850	
MN	7.77748	3	2.59249	5.08	0.0023	
TR	4.01422	8	0.50178	0.98	0.4516	
MT	7.47292	24	0.31137	0.61	0.9208	
1st Covar. (Acarina)	0.56142	1	0.56142	1.10	0.2960	0.09546
2nd Cova. (Temp.)	6.02279	1	6.02279	11.80	0.0008	0.04627
3rd Covar. (Moist.)	3.33446	1	3.33446	6.53	0.0116	0.00859
4th Covar. (R. H.)	8.27786	1	8.27786	16.22	0.0001	-0.04019
All Covariates	20.92789	4	5.23197	10.25	0.0000	
Error	71.43874	140	0.51028			

*(<0.05—significant)

TABLE 6. Analysis of Covariance for Acarina population with respect to Wheat.

Source	Sum of Squares	Degree of freedom	Mean Squares	F	*Tail Probability	Beta Estimates
Mean	5.06405	1	5.06405	3.59	0.0600	
MN	6.65793	3	2.21931	1.58	0.1981	
TR	30.40408	8	3.80051	2.70	0.0086	
MT	21.02187	24	0.87591	0.62	0.9127	
1st Covar. (Collembola)	20.98531	1	20.98531	14.89	0.0002	0.53743
2nd Covar. (Temp.)	2.84488	1	2.84488	2.02	0.1576	0.02262
3rd Covar. (Moist.)	30.61032	1	30.61032	21.73	0.0000	-0.02873
4th Covar. (R. H.)	0.91119	1	0.91119	0.65	0.4227	0.00935
All Covariates	62.74346	4	15.68586	11.13	0.0000	
Error	197.25348	140	1.40895			

*(<0.05—Significant)

TABLE 7. Analysis of Covariance for Acarina population with respect to Jute

Source	Sum of Squares	Degree of freedom	Mean Squares	F	*Tail Probability	Beta Estimates
Mean	0.00095	1	0.00095	0 00	0.9566	
MN	1.07080	3	0.35693	1.11	0.3462	
TR	7.05462	8	0.88183	2.75	0.0075	
MT	8.70094	24	0.36254	I.13	0.3194	
1st Covar. (Collembola)	0.24667	1	0.24667	0.77	0.3820	0.80468
2nd Covar. (Temp.)	0.24080	1	0.24080	0.75	0,3878	0.00822
3rd. Covar. (Moist.)	2.17460	1	2.17460	6.78	0.0102	0.00833
4th Covar. (R. H.)	3.81539	1	3.81539	11.89	0.0007	-0.02901
All Covariates	11.39028	4	2.84757	8.88	0.0000	
Error	44.91144	140	0.32080			

*(<0.05—Significant)

TABLE 8. Analysis of Covariance for Acarina population with repect to Paddy

Source	Sum of Squares	Degree of freedom	Mean Squares	F	*Tial Probability	Beta Estimates
Mean	8.28098	1	8.28098	18.96	0.0000	
MN	25.83601	3	8.61200	19.72	0.0000	
TR	10.37161	8	1.29645	2.97	0.0042	
MT	5.71173	24	0.23799	0.55	0.9578	
1st Covar. (Collembola)	0.48041	1	0.48041	1.10	0.2960	0.08168
2nd Covar. (Temp.)	17.65176	1	17.65176	40.43	0.0000	0.07267
3rd Covar. (Moist.)	0.03369	1	0.03369	0.08	0.7816	-0.00088
4th Covar. (R. H.)	0.17704	1	0.17704	0.41	0.5253	0.00620
All Covariates	24.74627	4	6.18657	14.17	0.0000	
Error	61.13081	140	0.43665			

*(< 0.05—Significant)

The treatments are significant for acarine population during cultivation of all the three crops (Tables 6-8) while, moisture and R. H. are significant only during jute cultivation.

It is of interest to note that treatments are significant for collembolan and acarine populations barring the paddy season when it is not significant for collembolan population presumably due to the water-logged conditions.

Comparison of Treatments (t-values and significance) :

Since there is no interaction between months and treatments, all pairs of differences for collembolan and acarine populations for different treatments are also tested and the results are given in Tables 9 and 10. In the Tables, against "Fallow (T_{11})", "W" (for wheat), "P" (for paddy) and "J" (for jute) have been used for denoting "fallow during wheat cultivation", "fallow during paddy cultivation" and "fallow during jute cultivation."

Out of 36 t-values for each crop, significant values run parallel for both Collembola and Acarina. Thus for wheat, significant values are 27 for Collembola and 25 for Acarina ; for paddy, these are 18 for Collembola and 20 for Acarina and for jute, 15 for Collembola and 16 for Acarina. It is evident, therefore, that effects of treatments of various doses of fertilizers are most pronounced during wheat cultivation, followed by paddy and jute.

The above differences in t-values for each crop can be plausibly explained following the course of application of pesticides in these fields. Since no pesticides are applied during cultivation of wheat, fertilizer treatments have significant influence both on collembolan and acarine populations. On the other hand, during paddy cultivation, there had been occasional application of pesticides (not even in every year) which too had little effect on Collembola and Acarina because of the supersaturated condition of soil which diluted the effects of the pesticides. Contrary to this, every year during jute cultivation, two pesticides, *viz.*, Thiodan EC_{35} and Furadan 3G [former a chlorinated hydrocarbon, having residual effect on Collembola (Mitra *et al.*, 1983)], are used to repel pest attack (red mite, semilooper, stem borer, gall midges, mealy bug, gandhi bug) neutralising considerably the treatment effects on collembolan and acarine populations.

Comparison of Treatments for Collembolan Population :

Comparison of T_1 *vs* T_{3-11} reveals that higher dose of fertilizers have significant effect on collembolan population during paddy cultivation while sporadic significant effects during wheat cultivation. Insignificant effects inspite of increase in fertilizer dose is maximum during jute cultivation followed by wheat and paddy. Control (T_{10}) and fallow have better influence on collembolan population during wheat and paddy cultivations than the treated plot (T_1).

T_8 *vs* T_{4-11} shows that T_8 (higher dose) has greater significance than other fertilizer doses where t-values are significant. Significant but lesser effect of this dose is only visible during wheat cultivation. Nonsignificant effects of T_8 remain evenly distributed for all the crops.

t-values are nonsignificant for all the three crops in case of T_4 *vs* T_6 presumably due to the application the same dose of fertilizers in both plots. T_4 *vs* T_7 shows that T_4 has greater significant effect than the latter. It is of intererest to note that though both plots receive the same dose of N, K and P are not applied in T_7. It is most probably due to the intrinsic effect of one or both, T_4 has greater significance on collembolan population than T_7. T_4 *vs* T_8 reveals that T_8 has greater significance on collembolan population during wheat and paddy cultivations. It may be mentioned that T_8 in addition to the same dose of NPK, as applied in T_4, is treated with FYM, which might be the cause for greater significance of T_8 on collembolan population than T_4. During jute cultivation, however, the effect of FYM becomes insignificant owing to the application of pesticides during cultivation of this crop.

T_4 and T_9 receive the above dose of NPK with the difference that hand weeding/hoeing is practised in the former and chemical weeding in the later. It is seen that during wheat cultivation T_9 has greater significance on collembolan population than T_4 presumably due to incorporation of organic material, arising out of dead weeds and absence of pesticides during this cultivation. During paddy and jute cultivations, however, the weedical effect is neutralised presumably due to application of pesticides resulting in insignificant effects when compared to T_4. T_4 *vs* T_{10} reveals that the later (control) has greater significance on collembolan population during wheat cultivation ; the trend is just reverse during jute cultivation while, it is nonsignificant during paddy cultivation. During wheat cultivation, since no pesticide is applied, the available organic matter is able to play more significant role on collembolan population than T_4 contrary to jute cultivation when there is no boosting of the loss of population due to pesticidal action (at T_4) through fertilizer application, absent in T_{10}. T_4 *vs* T_{11} exhibit the same significance as that of T_4 *vs* T_{10} and the reasons, given above, are also applicable for this treatment difference.

T_6 has greater significance on collembolan population than T_7 during wheat and paddy cultivations presumably because of the presence of P which is absent in T_7. T_8 has greater significant t-values during wheat and paddy cultivations than T_6 because of the application of FYM along with NPK. The value, however, is insignificant during jute cultivation probably for the application of pesticides during this crop.

T_6 *vs* T_9, T_{10}, T^{11} : T_9 undergoing chemical weeding and receiving P_{60} (absent in T_6), have greater t-values during cultivation of wheat but the values are nonsignificant during cultivations of jute and paddy for pesticidal effects.

T_7 *vs* T_8 : T_8 has greater significant t-values for collembolan population obviously for the application of FYM and presence of P & K, absent in T_7. For jute, however, the value is not significant. T_7 *vs* T_9 : t-values for T_9 are of greater significance for collembolan population during wheat and paddy cultivations while, it is not significant during Jute cultivation. It may be mentioned that cumulative effect of P & K (absent in T_7) and chemical weeding of this plot, helping in the incorporation of organic material through dead weeds (*vs* hand weeding/hoeing in T_7), play key role for greater significant t-values in T_9. T_7 *vs* T_{10} : During wheat cultivation when pesticides are not applied, T_{10} has greater significant t-value ; however, the value is smaller than T_7 during jute cultivation ; for paddy, the value is not significant. It seems, therefore, that the fertilizer has the role for significant higher t-value in case there is application of pesticides. This runs parallel when T_7 is compared with T_{11} (fallow).

When T_8 is compared to T_9, it is seen that the former has greater significant t-value probably because of the application of both NPK and FYM. The amount of organic material generated out of dead weeds through the application of chemical weedicides in T_9 may not be equivalent to the amount of FYM, applied in T_8. t-values for paddy and jute, obtained through comparison of these two treatments, are not significant.

When T_9 is compared to T_{10}, it is not significant for wheat but has greater t-values for collembolan population during paddy and jute cultivations. t-values, however, are insignificant when it is compared to T_{11} during cultivation of all the three crops. t-values for T_{10} *vs* T_{11} are not significant for all the three crops.

Comparison of treatments for acarine population :

Like Collembola, T_1 *vs* T_{3-11}, reveals that higher dose of fertilizers have significant effect during paddy cultivation, while little significance during wheat cultivation. Control (T_{10}) and fallow (T_{11}) have grearer significant t-values during wheat and paddy cultivations.

T_3, as in Collembola, has greater significant t-values than other treatments where these are significant. The treatment has greater significant t-values during paddy and jute cultivations while smaller values during wheat cultivation.

T_4, in general, has smaller t-values, where these are significant, in comparison to other treatments. The values are mostly significant during wheat cultivation.

For T_6, majority values are not significant except some occasional ones during wheat and jute cultivations.

TABLE 9. Results of test for comparision of treatments for Collembola population (t values and significance)

T_1	T_2			T_4			T_6			T_7			T_8			T_9			T_{10}			T_{11} (Fallow)		
	W	P	J	W	P	J	W	P	J	W	P	J	W	P	J	W	P	J	W	P	J	W	P	J
T_1	1.94 n.s.	4.01 <	0.71 n.s.	1.78 n.s.	2.19 <	0.70 n.s.	2.21 >	2.37 <	2.01 >	5.83 >	0.98 n.s.	0.67 n.s.	4.07 <	4.20 <	0.68 n.s.	1.93 n.s.	3.88 <	1.84 n.s.	1.97 <	1.98 <	2.74 >	1.98 <	2.19 <	2.06 >
T_2				0.60 n.s.	1.94 n.s.	1.63 n.s.	1.01 n.s.	1.01 n.s.	2.10 >	3.98 >	3.19 >	0.07 n.s.	4.99 <	0.41 n.s.	1.58 n.s.	3.10 <	0.20 n.s.	1.98 >	2.81 <	2.03 >	2.94 >	2.91 <	1.97 >	2.41 >
T_4							1.89 n.s.	0.03 u.s.	1.97 n.s.	4.01 >	0.98 n.s.	1.74 n.s.	4.50 <	2.21 <	0.00 n.s.	2.51 <	0.83 n.s.	0.50 n.s.	2.47 <	0.07 n.s.	2.10 >	2.68 <	0.03 n.s.	1.98 >
T_6										2.13 >	1.99 >	2.00 <	8.17 <	2.07 <	1.78 n.s.	4.71 <	1.03 n.s.	1.10 n.s.	4.83 <	1.01 n.s.	1.23 n.s.	4.91 <	0.21 n.s.	0.10 n.s.
T^7													12.87 <	4.87 <	1.61 n.s.	7.41 <	2.34 <	1.93 n.s.	7.91 <	0.31 n.s.	2.81 >	7.98 <	1.27 n.s.	2.14 >
T_8																2.13 >	0.98 n.s.	9.80 n.s.	2.03 >	3.57 >	2.20 >	1.99 >	3.01 >	1.97 >
T_9																			0.78 n.s.	2.07 >	1.98 >	0.79 n.s.	1.21 n.s.	1.40 n.s.
T_{10}																						0.04 n.s.	0.87 n.s.	0.94 n.s.
T_{11} (Fallow)																								

W = Wheat ; P = Paddy ; J = Jute ; n.s. = Not significant

TABLE 10. Results of test for comparison of treatments for Acarina population (t values and signicance)

T_1	T_3			T_4			T_6			T_7			T_8			T_9			T_{10}			T_{11} (Fallow)		
	W	P	J	W	P	J	W	P	J	W	P	J	W	P	J	W	P	J	W	P	J	W	P	J
T_1	0.9187	3.8413	1.23	0.7836	1.8921	1.25	2.1583	2.0123	1.26	1.5012	1.9682	1.24	3.8762	1.8216	1.23	0.9621	3.6874	1.71	3.2187	2.1018	1.26	6.2821	5.8387	1.98
	n.s.	<	n.s.	n.s.	n.s.	n.s.	<	<	n.s.	n.s.	>	n.s.	>	ns.	n.s.	n.s.	<	n.s.	<	<	n.s.	<	<	<
T_3				1.8717	2.0831	2.01	2.4813	1.7001	2.03	2.0001	1.9987	0	2.8132	2.2087	1.99	1.9472	0.1408	2.12	3.8186	1.9891	2.01	7.8287	2.6867	0.99
				n.s.	>	>	<	n.s.	>	<	>	n.s.	>	>	>	n.s.	n.s.	>	<	>	>	<	<	n.s.
T_4							2.2182	1.3108	0.12	0.8712	0.3210	1.98	4.2125	0.3181	0	0.1204	2.0178	0.46	2.810	0.7887	0.01	5.8910	4.8186	2.27
							<	n.s.	n.s.	n.s.	ns.	<	>	n.s.	n.s.	n.s.	<	n.s.	<	n.s.	n.s.	<	<	<
T_6										1.8680	0.6583	2.01	4.9192	0.9318	0.09	2.0101	1.4012	0.16	1.7084	0.7431	0.08	2.8502	3.9982	2.29
										n.s.	n.s.	<	>	n.s.	n.s.	>	n.s.	n.s.	n.s.	n.s.	n.s.	<	<	<
T_7													4.0136	0.4173	2.03	0.4084	2.2164	2.11	3.0018	0.4812	2.02	5.2139	4.6381	0.94
													>	n.s.	>	n.s.	<	>	<	n.s.	>	<	<	n.s.
T_8																4.0108	2.3081	0.44	7.2103	0.9378	0.03	12.8410	4.9179	2.26
																<	<	n.s.	<	n.s.	n.s.	<	<	<
T_9																			3.1241	1.8762	0.41	5.1018	2.7015	2.31
																			<	n.s.	n.s.	<	<	<
T_{10}																						2.61	4.1083	2.26
																						<	<	<
T_{11} (Fallow)																								

W = Wheat ; P = Paddy ; J = Jute ; n.s. = Not significant

The significant t-values for T_8 are smaller where these are significant, signifying least impact of FYM on Acarina.

T_9 undergoing chemical weeding have smaller significant t-values indicating organic material incorporated through dead weeds have little effect on acarine population.

T_{10} has smaller t-values in comparison to T_{11} (fallow) signifying the absence of cultivation has better impact on collembolan population than cultivated plot.

Treatmentwise analysis of collembolan and acarine populations :

T_1 : Nearly half of the t-values for this dose is insignificant for both collembolan and acarine populations. This treatment in general has smaller t-values than other treatments.

T_3 : Nearly half of the t-values for this treatment is not significant for both collembolan and acarine populations. t-values are greater for both Collembola and Acarina where these are significant.

T_4 : Half of the t-values for this treatment are neither significant for Collembola nor Acarina. Most of the t-values have lower significance for Collembola as well as Acarina.

T_6 : Half of the t-values for this are nonsignificant for both collembolan and acarine populations. During wheat cultivation this dose has greater significance on collembolan population.

T_7 : Significant but lower t-values in most of the cases for both Collembola and Acarina indicate the intrinsic effects of N or P or both on their populations. However, during paddy and jute cultivations, there are some greater t-values for this dose.

T_8 : Greater significant t-values in all cases for collembolan population indicate the profound effect of FYM on collembolan population during wheat cultivation which persists till paddy cultivation and nonsignificant during wheat cultivation. FYM has the same effect on Acarina, as that of Collembola, during wheat cultivation. It has, however, very little effect on Acarina during jute cultivation and least during paddy cultivation.

T_9 : In general has greater significant t-values for Collembola (except in comparison with T_8, treated with NPK+FYM) during wheat cultivation signifying the incorporation of organic material arising out of dead weeds in contrast to hand weeding/hoeing in other plots. For Acarina, the values are mostly nonsignificant, signifying least impact of weedicidal treatment on Acarina.

T_{10} (Control) : t-values are significant during wheat cultivation in comparison to fertilizer treated plots for collembolan population. During paddy and jute cultivations, however, it is reverse presumably because of application of pesticides and absence of chemical fertilizers to replenish the loss. For Acarina also this plot has greater significant t-values in comparison to treated plots. For paddy and jute cultivations, in most cases, t-values are not significant signifying the pesticidal effect and absence of fertilizers for replenishing the loss.

T_{11} (Fallow) : The fallow has greater significance on collembolan population during wheat cultivation. During paddy cultivation, values are not very significant for Collembola. During jute cultivation, it has lesser significance than all other treatments. Fallow has greater significance on acarine population during cultivation of all the three crops in comparison to all fertilizer treated plots.

Multiple Regression Analysis

The regression equations of Collembola/Acarina on temperature, moisture, relative humidity and Acarina/Collembola are obtained and presented in tables 11 and 12. Regression equation, $y=\hat{\alpha}+\hat{\beta}_1x_1+\hat{\beta}_2x_2+\hat{\beta}_3x_3+\hat{\beta}_4x_4$ can be used to estimate Collembola/Acarina population (y), given the observation en $x_1=\sqrt{\text{No. of Acarina}}$ or $\sqrt{\text{No. of Collembola}}$, x_2=temperature, x_3=moisture and x_4=R. H. Likewise, the multiple regression equation $y=\hat{\alpha}+\hat{\beta}_1x_1+\hat{\beta}_2x_2+\hat{\beta}_3x_3+\hat{\beta}_4x_4+\hat{\beta}_5x_5$ can be used to estimate yield (y), given the observations x_1=No. of Collembola, x_2=No. of Acarina, x_3=temperature, x_4=moisture, x_5=R. H. Table-13, dealing with partial regression coefficients, shows that partial regression coefficients corresponding to Acarina ($\hat{\beta}_2$) are found to be insignificant for yield for all the three crops. $\hat{\beta}_1$, representing partial regression coefficients of Collembola for yield are marginally significant for paddy and jute and for wheat it is insignifieant. Partial regression coefficients of moisture and R. H. ($\hat{\beta}_4$ and $\hat{\beta}_5$) are significant for paddy and jute while insignificant for wheat. It has been seen that factors (Collembola, Acarina, moisture, R. H., temperature) are not useful for predicting yield of wheat.

TABLE 11. Multiple Regression Equation of Collembolan population on X_1, X_2, X_3, X_4 for Jute, Wheat and Paddy.

Regression equation : $y=\hat{\alpha}+\hat{\beta}_1X_1+\hat{\beta}_2X_2+\hat{\beta}_3X_3+\hat{\beta}_4X_4$

	Paddy	Wheat	Jute
$\hat{\alpha}$	−0.4863	0.3887	0.1968
$\hat{\beta}_1$	0.1998	0.1325	0.0700
$\hat{\beta}_2$	0.0327	−0.0024	−0.0056
$\hat{\beta}_3$	0.0030	0.0012	0.0062
$\hat{\beta}_4$	−0.0220	−0.0169	−0.0198

$\hat{\alpha}$=Intercept ; $\hat{\beta}_1$, $\hat{\beta}_2$, $\hat{\beta}_3$, $\hat{\beta}_4$=Corresponding regression coefficients of Y on X_1, X_2, X_3, X_4 ; y=Square root of collembolan population ; $X_1=\sqrt{\text{No. of Acarina}}$; X_2=Temperature ; X_3=Moisture ; X_4=R.H.

TABLE 12. Multiple Regression Equation of Acarine population on X_1, X_2, X_3, X_4 for Jute, Wheat and Paddy.

Regression equation : $y=\hat{\alpha}+\hat{\beta}_1X_1+\hat{\beta}_2X_2+\hat{\beta}_3X_3+\hat{\beta}_4X_4$

	Paddy	Wheat	Jute
$\hat{\alpha}$	-1.1917	1.3418	0.2716
$\hat{\beta}_1$	0.2007	0.3265	0.1679
$\hat{\beta}_2$	0.0550	0.0201	0.0021
$\hat{\beta}_3$	-0.0004	-0.0289	0.0068
$\hat{\beta}_4$	-0.0043	0.0083	-0.0293

$\hat{\alpha}$=Intercept ; $\hat{\beta}_1$, $\hat{\beta}_2$, $\hat{\beta}_3$, $\hat{\beta}_4$=Corresponding regression coefficients of Y on X_1, X_2, X_3, X_4 ; y=Square roof of Acarine population ; $X_1=\sqrt{\text{No. of Collembola,}}$ X_2=Temperature ; X_3=Moisture ; X_4=R.H.

TABLE 13. Multiple Regression Equation of Yield on X_1, X_2, X_3, X_4, X_5 for Jute, Wheat and Paddy

Regression equation : $y=\hat{\alpha}+\hat{\beta}_1X_1+\hat{\beta}_2X_2+\hat{\beta}_3X_3+\hat{\beta}_4X_4+\hat{\beta}_5X_5$

	Paddy	Wheat	Jute
$\hat{\alpha}$	-109.083	29.715	29.729
$\hat{\beta}_1$	55.1856 s*	-0.7359 n.s.	-30.581 s*
$\hat{\beta}_2$	18.2299 n.s.	-0.1712 n.s.	-8.0396 n.s.
$\hat{\beta}_3$	-3.9062 n.s.	-1.0158 n.s.	-1.7744 s*
$\hat{\beta}_4$	33.3599 s*	-0.9497 n.s.	-3.074 s*
$\hat{\beta}_5$	-4.8818 s*	0.0643 n.s.	0.3239 s*

$\hat{\alpha}$=Intercept ; $\hat{\beta}_1$=Regression coefficient of Collembola ; $\hat{\beta}_2$=Regression coefficient of Acarina ; $\hat{\beta}_3$=Regression coefficient of Temperature ; $\hat{\beta}_4$=Regression coefficient of Moisture ; $\hat{\beta}_5$=Regression coefficient of R.H. ; y=Yield ; X_1=No. of Collembola ; X_2=No. of Acarina ; X_3=Temperature ; X_4=Moisture ; X_5=R.H. s*=Marginally significant.

Correlations Between Different Variables

Correlations between different variables for wheat are given in Table 14. It is seen that correlations of the population of Collembola and Acarina with other variables like temperature, moisture, R.H. and yield are negative.

From Table 15, it is seen that correlations between collembolan population with acarine population, temperature, yield are positive while it is negative with moisture and R.H. during jute cultivation. Acarine population has also positive correlation with R.H. during cultivation of this crop. During paddy cultivation (Table 16), it is that collembolan population is positively correlated with temperature and yield and negatively correlated to temperature and R.H., presumably due to supersaturated condition of soil during paddy cultivation. Acarine population is positively correlated with temperature, moisture and R.H. during cultivation of this crop.

TABLE 14. Correlations between different variables for Wheat

	Collembola	Acarina	Temperature	Moisture	R.H.	Yield
Collembola	1.000					
Acarina	−0.206	1.000				
Temperature	−0.121	−0.080	1.000			
Moisture	−0.032	−0.441	−0.551	1.000		
R.H.	−0.337	−0.541	−0.040	0.384	1.000	
Yield	−0.043	−0.122	−0.742	0.096	0.322	1.000

TABLE 15. Correlations between different variables for Jute

	Collembola	Acarina	Temperature	Moisture	R.H.	Yield
Collembola	1.000					
Acarina	0.584	1.000				
Temperature	0.231	−0.222	1.000			
Moisture	−0.738	−0.286	−0.803	1.000		
R.H.	−0.226	0.158	−0.985	0.813	1.000	
Yield	0.502	−0.029	0.724	−0.829	−0.732	1.000

TABLE 16. Correlations between different variables for Paddy.

	Collembola	Acarina	Temparature	Moisture	R.H.	Yield
Collembola	1.000					
Acarina	−0.098	1.000				
Temperature	0.474	0.148	1.000			
Moisture	−0.624	0.390	0.249	1.000		
R.H.	−0.525	0.542	0.208	0.959	1.000	
Yield	0.691	−0.530	0.231	−0.788	−0.880	1.000

DISCUSSION

Ghilarov (1975) compared permanent agricultural field continuously undergoing tillage for cultivation to a debris of a building permanently destroyed through powerful and deadly weapons, unsuitable for any habitation. Effects of tillage practices on soil fauna are though not clear (Loring *et al*, 1981 : Moore *et al*, 1984), Edwards and Lofty (1969, 1975) observed that tillage greatly reduces the diversity and density of euedaphic and hemiedaphic Collembola including prostigamatid, mesostigmatid and cryptostigamatid mites. On the other hand, in general, no tillage provides a more favourable environment for soil-litter biota ; crop residues are left on the soil surface, reducing the moisture loss and providing relatively continuous substrate for decomposers ; organic matter input is more gradual, as is nutrient release ; faunal interactions are probably more pronounced and more significant in regulating decomposition rates under no-tillage conditions. Root growth, in turn, can be enhanced by increased invertebrate animal activity (Edwards and Lofty, 1977). As observed by Bormann *et al* (1974) and Waide and Swank (1976), ploughing is a major perturbation even in forest floor with well defined soil structure. Andren *et al* (1980) observed greatest abundance of soil microarthropods in a five year old ley than that of barley undershown with ley mixture in crop rotations 1 and 2. Reason cited by them for greatest abundance in five year old ley is the absence of ploughing during all these years. Ryl (1977) also observed that ploughing severely depletes enchytraeid population in rye and potato fields.

Reduction of soil tillage increases the number of soil animals including earthworms, which contribute to the redistribution of decomposing crop residues and effects dynamics of soil structure with quantitative effects on nutrient turnover (Andersen, 1983 ; House and Parmelee, 1985 ; Syers and Springett, 1984). Hendrix *et al* (1986) hypothesised that minimal cultivation may change the detrital patpway from bacterially dominated to fungal dominated as a result of the changed distribution of decomposing matter in the topsoil incorporated from surface residues.

In tropical agroecosystem, moisture content of soil being very low due to high temperature, the abundance and diversity of soil fauna are greatly reduced. Even in fallow, uncultivated land density of population is too low as compared to temperate countries. Over and above, ploughing further reduces population of Collembola and Acarina drastically through abrassive action and breaking down of soil structure. In the agroecosystem under study, where crop rotation is practised round the year, mean population of Collembola has been estimated as 3,689m^{-2} and Acarina as 8,368m^{-2}. Such poverty in numbers of two major components of soil microarthropods clearly reveals the state of nutrient cycling and nutrient flux in this tropical agricultural field. During cultivations, when conditions are maintained through periodic irrigation, fertilizer application and other agronomic practices, population of Collembola remains too low as compared to temperate agroecosystem. Raw (1967) reported density of arthropods as 18,000 per sq. yard in inorganic fertilizer treated plots in temperate agroecosystem. Mitra *et al* (1983) reported fourteen species of Collembola on the basis of data from 1978-79 but after monthly sampling during subsequent three-year period only eleven species were found to occur in the same experimental fields. This clearly goes to prove that continuous cropping with ploughing has the most deliterious effect on the abundance and diversity of Collembola coupled with the moisture content of the soil which is greatly reduced by high temperature in tropical agroecosytem.

Species diversity of Collembola was, however, higher during jute and paddy cultivations each supporting eight species while during wheat cultivation only five species came into being. Edwards and Lofty (1969) suggested that crop rotation decreases species diversity even to a greater extent than monocultures eliminating those species which are associated with other plants. Besides, the specific plant cover not only affects the qualitative and quantitative composition of Collembola but also dominance of individual species changed with crop rotations (Aleinikova and Utrobina 1969, 1975). Predominance of *I. balteatus* during cultivation of two cereal crops while that of *C. thermophilus* during fibre crop, having entirely different nitrogen content (3.69%) than the two cereal crops (paddy with 1.81% and wheat with 2.13%) reveals the influence of specific crop-type on differentiation and dominance of a particular species of Collembola. It was further noted that certain species were specific for jute (*S. indica*, *Sminthurus* sp., *Istomodes* sp.) and for paddy (*S. appendiculatus*, *S. cornuta*, *Acherontiella* sp.) suggesting the specificity of occurrence of some collembolan species according to particular crop-type.

The chemical fertilizers boosted the population of Collembola though the increase was not always proportional to the fertilizer doses used in various plots. The application of fertilizers, however, had no significant effect on the population of Acarina. Similarly, application of organic manure (FYM) though has positive impact on population of Collembola, no effect was observed for Acarina (Table-20). Edwards and Lofty (1969) suggested that organic and inorganic fertilizers affect the numbers of Collembola favourably, former exerting direct influence by providing as food and latter indirectly through their effect on the growth of plants and microorganisms.

Of all the treatments, T_8 (Optimum NPK+FYM) was found to support highest population of Collembola followed by T_1, receiving the minimum dose of NPK. Edwards (1980) observed large doses of ammonium nitrogen decreased the population of earthworms significantly and probable cause was attributed to the increase in soil acidity due to use of ammonium nitrogen. In T_8, where 150% NPK was applied, collembolan population did not show significant increases in comparison to other lower doses.

Effect of FYM on Collembola was most pronounced during wheat cultivation followed by paddy. Its effect, however, was not perceptible during jute cultivation when FYM was applied (Tables 17, 18, 19). Artemjeva and Gatilova (1975) observed that the effect of organic manure was evident after 10-12 months of its application, obviously only after its microbial transformations.

Applications of different combinations of NPK (NPK, NP & N only) exerted different effects on collembolan population. It is seen from Table-20, that NPK combination had better influence than NP, while NP had marginally better impact than application of nitrogen only. This effect, however, varied when it was analysed crop-wise. Application of NPK and NP during wheat cultivation though gave rise to identical population of Collembola, applica tion of N only staggeringly lowered the population (Table-17). Conversely, during jute cultivation, application of NPK supported the highest population followed by N and NP (Table-18). Effects of application of NPK, NP and N, during paddy cultivation, though were similar to the other cereal crop (wheat), application of NP marginally reduced the population of Collembola (Table-19). It is clear, therefore, that the effects of a particular dose or combination of fertilizers is dependent on the nature of crop. Such crop-wise differential effects of fertilizers were also noted by Artemjeva and Gatilova (1975) who considered it to be a function of specific reaction of the individual microarthropod groups and species. It is, however, interesting to note that both the cereal crops exerted almost similar effects on collembolan population in response to various combinations of fertilizers.

Effects of chemical herbicides on collembolan and acarine population varied according to the croptype and the type of herbicide used. In case of wheat, 2, 4-D

TABLE 17 : Mean over 5 crop seasons for Wheat

Treatments	Yield Quintal/ Ha	Collembola/ Ha	Acarina/ Ha	Temperature (°C)	Moisture (%)	Relative-humidity (%)
T_1	16.58	33,58,077	71,87,463	28.95	13.54	46.77
T_3	26.87	16.69,220	23,56,545	27.92	14.00	48.07
T_4	22.88	14,13,927	33,58,077	27.60	13.57	53.03
T_6	19.76	14,13,927	90,72,699	28.66	13.95	48.35
T_7	18.61	58,914	88,37,045	28.91	13.61	46.72
T_8	22.63	60,09.191	26,51,114	28.92	13.78	47.23
T_9	23.32	24,15,459	65,39,413	28.51	13.02	47.11
T_{10}	7.95	16,29,944	1,43,55,288	28.67	12.89	48.18

TABLE 18 : Mean over 5 crop seasons for Jute

Treatments	Yield Quintal/ Ha	Collembola/ Ha	Acarina/ Ha	Temperature (°C)	Moisture (%)	Relative-humidity (°/。)
T_1	19.27	14,13,927	18,06,685	31.85	16.34	68.71
T_3	21.05	4,71,307	34,95,542	31.42	16.07	69.68
T_4	22.12	13,15,738	19,63,788	31.98	15.99	69.20
T_6	19.60	5,30,223	9,42,618	32.03	16.44	69.29
T_7	18.82	10,99,721	24,35,096	31.89	16.89	69.94
T_8	21.56	8,24,791	14,33,565	31.75	15.60	68.49
T_9	20.86	7,26,601	7,46,239	32.07	16.37	68.84
T_{10}	13.43	1,37,465	15,90,668	31.74	16.64	69.77

TABLE 19 : Mean over 5 crop seasons for Paddy

Treatments	Yield Quintal Ha	Collembola/ Ha	Acarina/ Ha	Temperature (°C)	Moisture (°/。)	Relative-humidity (°/。)
T_1	29.26	9,42,618	9,42,618	30.09	20.47	64.44
T_3	37.19	17,87,047	20,81,615	30.22	20.85	64.35
T_4	37.19	17,87,047	20,81,615	30.22	20.86	64.35
T_6	38.90	14,33,565	21,99,442	30.30	20.51	64.44
T_7	33.92	17,67,409	12,72,534	30.25	20.50	64.34
T_8	42.79	26,11,837	21,60,166	30.48	20.57	65.61
T_9	29.92	18,85,236	21,01,253	30.19	21.26	64.07
T_{10}	16.28	1,86,322	20,81,615	30.59	20.49	64.32

TABLE 20 : Treatmentwise Mean of Collembola and Acarina over 5 crop seasons

Treatments	Collembola/ Ha	Acarina/ Ha	Temperature (°C)	Moisture (°/。)	Relative-humidity (°/。)
T_1	57,14,622	99,36,766	30.29	16.78	59.97
T_3	39,27,574	79,33,702	29.85	16.97	60.70
T_4	45,16,712	74,03,520	29.93	16.88	62.11
T_6	33,77,715	1,22,14,759	30.83	16.96	60.69
T_7	29,26,044	1,12,72,141	30.35	17.00	60.33
T_8	94,45,819	62,44,845	30.38	16.65	60.44
T_9	50,27,296	93,86,905	30.25	16.88	60.00
T_{10}	19,53,731	1,80,27,571	30.33	16.67	60.75

(sprayed once @ 760 gm. in 800 litres of water/ha at six week croppage) showed an increase in the population of both Collembola and Acarina than hand weeding (T_9 *vs.* T_4) [Table-17]. While during jute, application of Basalin once @ 2 litres in 400 litres of water/ha followed by laddering reduced considerably the population of both Collembola and Acarina than the handweeded plot (T_9 *vs.* T_4) (Table-18]. Application of a mixture of 1 Kg. of 2, 4-D and 6 litres of Stam F-34 in 400 litres of water per hectare sprayed once at 40 days croppage during paddy cultivation increased population of both Collembola and Acarina marginally than the handweeded plot (T_9 *vs.* T_4) [Table-19]. An increase in population of Collembola and Acarina after application of 2, 4-D during wheat cultivation coincides with the observation of Prasse (1975) while, Bhattacharyya *et al* (1980) observed no effect of Stam F-34 on mites. Adverse effects of Basalin both on Collembola and Acarina during jute cultivation is difficult to suggest because of the laddering after the application of the weedicide. In general, Treatment T_9 supported higher population of Collembola ($502m^{-2}$) than handweed T_4 ($451\ m^{-2}$). It appears, therefore, that chemical herbicide has positive influence on collembolan and acarine population.

Effects of pesticides on Collembola and mites are revealed by following the course of application of pesticides in the studied agroecosystem. During all the years, pesticides (Thiodan EC 35 and Furadan 3G) were consistently applied during jute cultivation because of the repeated incidence of pest attack followed by paddy where Thiodan EC 35 was sporadically applied in case of infestation (not in every year). During wheat cultivation, no pesticides were applied because of no or least infestation. It is seen from the data of five crop seasons (1979-83) that highest density of Collembola and Acarina occurred during wheat cultivation (Collembola : $1797m^{-2}$ and Acarina : $5434m^{-2}$) followed by paddy (Collembola : $1240m^{-2}$ and Acarina : $1492m^{-2}$) and jute supported least density (Collembola : $652m^{-2}$ and Acarina : $1441m^{-2}$).

It was further noted that the incidence of pest attack was most critical in the plots receiving recommended doses of 50%, 100% and 150% NPK. The magnitude of the attack has been observed significantly lower in control treatments as per the results obtained during five crop seasons for jute cultivation. No significant difference has, however, been observed in the incidence of pest attack during paddy cultivation according to the doses of NPK.

Mitra *et al.* (1983) noted the greater susceptibility of Collembola to Thiodan EC 35, residual effect of which persisted for more than three months while that of Furadan 3G for less than two weeks as indicated by the appearance of Collembola in soil samples after application of each pesticide.

Density of Collembola might be taken as a biological test for soil productivity as observed by Buckle (1921) and Brauns (1955). Their observations were further corroborated by Faizy *et al.* (1980) who observed that the density of Collembola was not only positively correlated with grain yield for two cultivars of paddy but also to the dry weight of roots. In the present investigation, regression coefficients of Collembola were found marginally significant for the yield of paddy and jute (Table-13).

Nutrients, organic matter and soil structure determine the primary production in any region. Survey of literature clearly indicates the dearth of knowledge about the below ground ecosystem, where soil microorganisms and soil microarthropods together play key role in the mineralisation process. Curl (1982) suggested both positive and negative interactions between roots, microbes and soil fauna with the later acting as regulators than active decomposers. Dissemination of mycorrhizal spores by arthropods further suggest the role played by them in plant-fungal interactions. Further, there is some evidence that soil arthropods may play a significant role in dispersing mycorrhizal propagules (Rabatin and Rhodes, 1982).

Biological productivity of soil ecosystem is largely governed by the interactions of these microorganisms and soil fauna. Vannier (1980) observed that colonisation of microarthropods is influenced by microbial growth. Reid *et al.* (1969) suggested that nitrogen regimes are principally functions of immobilization and remineralisation rates, processes largely mediated by microbial activities. In this investigation, after five years cropping alongwith continuous use of fertilizers, a decreasing trend in microbial population was observed (JARI Report, 1979-80). Decrease in microbial population and soil fauna, specially microarthropods, was found to lower the nitrogen immobilisation and mineralisation process. Chemical fertilizers did not help to reverse the trend except in the plot (T_8) treated with NPK and FYM. Similarly, in T_9, due to availability of organic matter arising out of dead weeds after herbicidal application supported better population of Collembola along with consistent crop yield. Edwards (1980) observed that herbicides have considerable indirect effects by changing the surface vegetation which ultimately provides soil organic matter. Sankaram (1989) mentioned that in Punjab, application of double doses of fertilizer instead of improving, decreased the production of wheat and there was no significant difference in rice yield in IARI experiments at 60 Kg. and 90 Kg. of nitrogen use per hectare. In the experimental fields, under study, similar trends of decreased crop production has been observed over a ten-year period (Mandal, 1985).

It appears, therefore, that intensive cultivation through ploughing and continuous application of nitrogenous fertilizers in this agroecosystem have caused significant reduction in microbial and faunal population resulting in loss of nutrients from soil in the reduction of the processes of immobilisation of N and its mineralisation resulting its loss through leaching.

Steiner and Crossley (1980) observed that ploughing increases loss of nitrate througeh leaching as its concentration was found more in ground water of tilled plots than of no-till plots. This suggested that no-tillage practices retard nitrate loss via leaching. No-tillage practice of cultivation helps to conserve nutrients in soil and there seem to be long-term benefits in terms of mineral nitrogen availability (Coleman, Cole and Elliott, 1984). It may be mentioned that in tropics loss of nitrogen also occurs through gaseous fluxes in soil systems as such there is much need to stop its wastage through leaching in ground water. Minimal or zero cultivation of agricultural land through use of "no-till" planter and direct drilling (slit seeding) is being increasingly adopted in the West as standard practice (Edwards and Lofty, 1977) with exceptionally good results and without any noticeable negative effects on soil fauna. There is urgent need for replacement of the system of ploughing by minimal or zero cultivation in this country and it has been found that the root growth of plants and yield of crops are appreciably good without causing damage to soil structure and soil processes in agroecosystem (Edwards, 1977 ; Steiner, *et al.* 1980).

Application of abundant N fertilizers not only makes the plants susceptible to pest attack but also decreases the resistence of plants to soil borne diseases (Faizy, 1980) and contaminates ground water. Over and above, ammonium nitrogen increases soil acidity and thereby affects the soil fauna causing imbalance in mocrobial population. Edwards (1980) suggested use of calcium nitrate (nitro-chalk) as fertilizer source for N and the addition of lime to soil for better growth and development of earthworms. Use of Calcium nitrate prevents loss of nitrogen through volatilazation or gaseous flux incontrast to the use of ammonium nitrogen.

Baeumer and Bakermans (1973) observed that FYM treatment favours water infiltration rates, gas exchange and deep root penetration and helps to maintain soil productivity by maintaining balance of microbial and soil faunal composition. Of all the treatments in this investigation, T_8, receiving 100% optimum NPK+FYM, was found to support better population of Collembola and Acarina with sustained yields for all the three crops. At T_8, even after ten successive croppings through crop rotations and application of NPK, a favourable C/N ratio of soil was maintained consistently in contrast to other plots receiving NPK alone and undergoing periodic hand weeding (Mandal, 1985). Vishanath (1931) was of opinion that superiority of bulky organic manures could be evidenced after several years of cropping was confirmed subsequently by Artemjeva and Gatilova (1975) who attributed it to the time taken for its mineralisation through microbial and soil faunal interactions. The effect of FYM on soil productivity was confirmed in many long term experiments (Kalamakar and Sripal Singh, 1935 ; Wright *et al.* 1950 ; Millar, 1963 ; Rao and Krishnan, 1963 ; Tisdale and Nelson, 1965 ; Cooke, 1970 ; Maurya and Ghosh, 1972 ; Krishnamoorthy and Kumar, 1973).

Application of pesticides is less hazardous to tropical arable ecosystem than ploughing. Because of the high temperature of soil, the persistence does not appear to last longer. Chandra (1967) observed that two organochlorine pesticides, *viz.*, heptachlor and dieldrin lost their residual effects, as observed from nitrification of soil, at 26°C for heavy clay and mountain loam soils while inhibitory effects on nitrification persisted at lower temperatures for these soils. This observation was corroborated by Mitra *et al.* (1983) who found that residual effect of Thiodan EC 35 lasted for about three months and that of Furdan 3G for less than two weeks in field conditions.

The most persistent of soil pesticides is DDT, banned in many countries. Its persistence in tropical soil like India with high temperature, however, remains to be ascertained through field bioassay. Biological detoxification of DDT occurs rapidly in the presence of Collembola converting it into nontoxic DDE in the presence of an enzyme, DDT—Dehydrochlorinase, and as reported, population of Collembola shot up to 110% after application of DDT in the field than controls (Sheals, 1955). This observation was subsequently confirmed by many workers (Edwards, 1963, 1964, 1965b ; Edwards and Dennis, 1960 ; Edwards *et al.* 1967 ; Dempster, 1968 ; Klee *et al.* 1973). Edwards and Jeffs (1974) and Edwards (1980) reported such detoxification of DDT in earthworms. The fact that DDT can accumulate in the tissues of soil fauna, by a factor of 10, than that occurring in the sprayed soil, acting as biological concentrators, can deliver lethal dose to other organisms by entering into food chain. As such, there is need for use of more labile pesticides, other than organochlorines, with least persistence in agroecosystem of Indian subcontinent till bioassay of DDT is carried out in field conditions as to its persistence and residual effect.

Conclusion : Strategy for Nineties :

Deserts advancing relentlessly, monitored by the United Nations' Desertification Department (1984), coincides with the assessment of National Wasteland Development Board that of the 154 million hectares under cultivation in India 80 million hectares require rehabilitation (Swaminathan, 1989). There is crying need for adoption of strategies for an integrated arable farming to change the face of Indian agriculture, initiated in many countries for sustenance and conservation of agroecosystem. Notable amongst them are Swedish Arable Land Project (Roswall and Paustian, 1984), the North American Detrital Food Web Project (Hunt *et al*, 1984, 1987) and the Dutch Programme on soil Ecology of Arable Farming Systems (Brussaard *et al*, 1988). The integrated arable farming envisages to integrate various objectives in the field of economy, employment, nature, landscape, food quality and well-being (Vereijken, 1986). At the farm level, an important aspect of integrated arable farming is the acceptance of crop yield reduction, if offset by cost reduction, the latter being a strong incentive efficiency of crop production. Swaminathan (1989), the noted protagonist of Green Revolution in this country, has recognised the importance for sustainable management of the basic agricultural assets of land, water, flora, fauna and the atmosphere and proposed a new definition of productivity, as follows and urged for maintenance of biological potential of soil.

$$\text{Productivity} = \frac{\text{Output value}}{\text{Input value}} + \text{Changes in environmental capital stocks.}$$

Most significantly from an ecological standpoint, input efficiency can be increased by strengthening ecosystem characteristics that control fertility and productivity. In the humid tropics, the retention of basic structure and process that operate in mature soil ecosystem is perhaps the most realistic means of developing crop-ecosystems with sustainable productivity (Cooper, 1981). The capacity of tropical lowland soils to release nutrients by decomposition is low, their ability to retain nutrients in available forms weak, and the risk of nutrient loss by leaching great in contrast to temperate agroecosystem. Keeping this in view, input of nutrient in Indian agroecosystem should be tuned perfectly to the optimal requirement and uptake by crop and sealing all the pathways of its leaching to ground water by invigorating the process of immobilisation and release of nutrients by harmonising crop—microorganisms—faunal interactions.

The most urgent problems of today, arising out of conventional agricultural practices, are :

(i) Deterioration of soil structure due to use of ploughing and heavy machinery leading to erosion and leaching of precious topsoil.

(ii) Gradual loss of response of crops to mineral fertilizers and contamination of ground water and atmosphere due to intensive use of chemical fertilizers and manures.

(iii) Use of pesticides for crop protection, weed control and soil fumigation impling high costs and possible environmental hazards.

Management of agroecosystems to achieve more efficient production with cost reduction without jeopardising natural nutrient cycling with least environmental pollution requires a thorough understanding of fundamental mechanisms of the functioning of the soil crop ecosystem.

Advancement of scientific knowledge on soil biology, has opened the way to manipulate the structure and functioning of arable ecosystems for better nutrient use efficiency, sustained improvement of soil structure and effective pest, disease and weed control. Following changes in management practices are envisaged :

Restriction on conventional deep ploughing or use of heavy machinery used for large scale inversion of top soil. When ploughing is unavoidable, depth of tilth should be superficial. Tilling in rows and tillage of the entire surface of a field should be avoided. To adopt minimal or zero cultivation by direct drilling or slit seeding (being used in England and other European countries) or use of no-till planter (being used in U. S. A.). The former used in England cuts slits in rows and drops the seeds automatically without large scale disturbance on soil surface after application of paraquat, a harbicide, for killing and preventing growth of weeds. The no-till planter, used in U. S. A., cuts narrow seed furrows in rows leaving most of the top soil undisturbed. Conventional tillage usually entails six or more trips across the field (ploughing, disking, planting, cultivating at least once, herbiciding and harvesting). No-tillage or direct drilling (slit seeding) requires only one trip each for planting, herbiciding and harvesting and therefore, requires far less energy than conventional ploughing or tillage. Important benefits from no-tillage practices are conservation of soil and water resources, preventing nutrient losses and least perturbation of soil, helpful for maintaining soil structure and soil processes. It has been observed that in no-till cultivation weed problems can be controlled effectively by using herbicides or weed growth can be reduced by companion planting (Phillips and Young, 1973). Musick and Petty (1974) have reported increase in pest attack which can be controlled by reduced N input and by adoption of biological control. In extreme cases of pest attack, if unavoidable, using approprite labile pesticides other than organochlorines, as minimum as possible (HEIJBROEK, 1973). Inspite of two disadvantages, minimal or zero cultivation, as it is called, has gained considerable momentum in the West including England and U.SA. and has become increasingly popular to farmers.

Application of reduced nutrient inputs through the tuning of the nutrient supply to soil to the nutrient demand of the plants for reducing nutrient losses. Application of chemical fertilizers (NPK), with sufficient amount of organic manure (FYM) for maintaining favourable C/N ratio, soil structure, water holding capacity as well an microbial and faunal interactions for immobilisation and mineralisation of nutrients for proper uptake by plants. Nitrogen should be supplied as calcium nitrate instead of ammonium nitrogen to prevent loss by volatilization as well as to check soil acidity and pollution. Periodic lime application is envisaged for better growth of earthworms and other soil faunafavouring alkaline conditions.

Reduced use of biocides for fewer pest and disease problems at lower N inputs ; no soil fumigation and application of biological control methods, for enhancement of the contribution of soil organisms to soil structure formation and mineralisation of nutrients.

Integration and augmentation of researches to trace the mechanisms that regulate pools and flows of carbon and nitrogen in the soil-crop ecosystem and to gain as understanding of the interactions betweem soil organisms and soil structure to be undertaken by scientists from various scientific fields like climatology, soil chemistry, physics, geology, microbiology and ecology of plants and animals.

Various agronomic practices, beneficial or detrimental, influencing the biotic community directly or indirectly in a tropical agroecosystem leading it to a sustainable or degraded one, are given in Fig. 21.

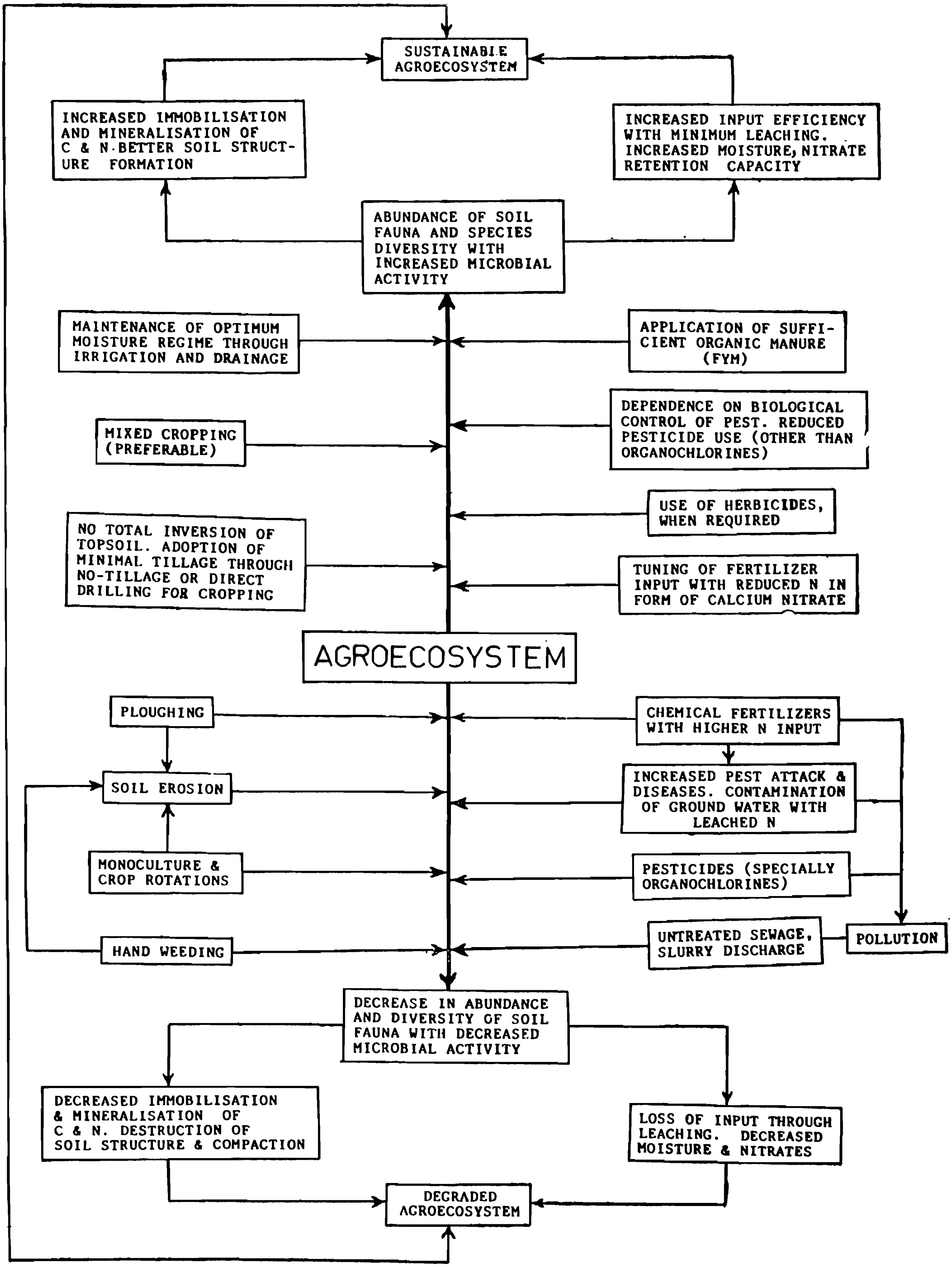


Fig 21. Ecological Relationships between Biotic Community and Agronomic Practices in a Tropical Agroecosystem.

SECTION—B

DISTRIBUTION OF COLLEMBOLA ACCORDING TO DIFFERENT SOIL AND CROP TYPES OF INDIA

I. Distribution of Collembola according to different soil types of India :

Fauna of alluvial soil, is represented by collembolan species like *Folsomides parvulus* Stach, *Cryptopygus thermophilus* (Axelson), *Sminthurides appendiculatus* Imms, *Seira lateralis* Yosii, *Isotomiella minor* (Schaeffer), *Lepidocyrtus* (*Ascocyrtus*) *scaber* (Ritter), *Heteromuricus cercifer*. Although majority of these species are extremely insignificant quantitatively in the samples examined so far, their presence on each occasion in these plots signifies the effect of long term use of fertilizers on soil microarthropods.

Collections from the desert soil at Jodhpur are represented by the collembolans like *Isotoma* sp., *Isotomurus balteatus* (Reuter), *Friesea* sp., *Acherontiella* sp., *Brachystomella* sp., respectively. Among these species, *Folsomides* and *Cryptopygus* occur in significant proportions in the desert soil of Rajasthan.

From the analysis of the species of Collembola made so far it is observed that the species of *Xenylla*, *Isotomurus*, *Acherontiella*, *Brachystomella* are predominant in desert soil ; *Sminthurides* cf. *parvulus*, *Seira lateralis*, *Heteromuricus cercifer* are found to occur only in soil associated with jute cultivation so far and *Cyphoderopsis* sp., *Mesaphorura* sp., *Dicranocentrus* sp., *Callyntrura* sp., *Lepidoseira* sp., *Sinella* sp., *Alloscopus tetracantha*, *Ceratophysella* cf. *planipila* etc. are restricted mostly to hill soil of Meghalaya (*vide*, Tables I-IV for details).

Black cotton soil was found to support 4 genera and species, *viz.*, *Cryptopygus thermophilus*, *Xenylla* sp., *Seira indica* and *Deuterosminthurus* sp. was found to be restricted to black cotton soil only.

Table 1. Differential Distribution of Collembolan Genera/Species in Four Soil Types.

Different Genera/ Species	Soil Types			
	Desert Soil	Alluvial Soil	Black Cotton Soil	Hill Soil
Folsomides sp.	+	+	—	+
Proisotoma sp.	+	—	—	+
Cryptopygus sp.	+	+	+	+
Cyphoderus sp.	+	+	—	+
Xenylla sp.	+	—	+	—
Isotoma sp.	+	—	—	+

Table 1. *(continued)*

Different Genera/ Species	Soil Types			
	Desert Soil	Alluvial Soil	Black Cotton Soil	Hill Soil
Isotomurus balteatus	+	—	—	—
Friesea sp.	+	—	—	+
Acherontiella sp.	+	—	—	—
Brachystomella sp.	+	—	—	—
Sminthurides cf. *parvulus*	—	+	—	—
Seira lateralis	—	+	—	—
Isotomiella sp.	—	+	—	+
Lepidocyrtus sp.	—	+	—	+
Heteromuricus cercifer	—	+	—	—
Cyphoderopsis sp.	—	—	—	+
Mesaphorura sp.	—	—	—	+
Dicranocentrus sp.	—	—	—	+
Callyntrura (*Callyntrura*) sp.	—	—	—	+
Lepidoseira sp.	—	—	—	+
Sinella sp.	—	—	—	+
Alloscopus tetracantha	—	—	—	+
Ceratophysella cf. planipila	—	—	—	+
Seira indica	—	+	+	—
Deuterosminthurus sp.	—	—	+	—

Table 2. Faunal Analysis (Collembola) of Various Vegetational Types Associated with Desert Soil

Crop Types	Different Genera/Species									
	Folaomides sp.	*Proisotoma* sp.	*Cryptopygus* sp.	*Cyphoderus* sp.	*Xenylla* sp.	*Isotoma* sp.	*Isotomurus balteatus*	*Friesea* sp.	*Acherontiella* sp.	*Brachystomella* sp.
Wheat	+	+	+	—	—	—	—	—	—	+
Bajra	+	+	+	+	—	—	—	—	—	—
Jowar	—	—	+	—	—	—	+	—	—	—
Cucurbita	+	+	—	—	—	—	—	—	—	—
Papita	—	—	—	—	—	—	—	+	+	—
Chillies	—	—	—	—	—	—	—	—	—	—
Til	—	—	—	—	—	—	—	—	—	—
Vegetables	+	—	+	—	+	—	—	—	—	—

Table 3. Genera/Species of Collembola Apparently Found Specific to Each of Three Soil Types in this Study.

Desert Soil	Alluvial Soil (with jute Cultivation)	Hill Soil	Black Cotton Soil
Xenylla sp.	*Sminthurides* cf. *parvulus*	*Cyphoderopsis* sp.	*Deuterosminthurus* sp.
Isotomurus sp.	*Seira lateralis*	*Mesaphorura* sp.	
Acherontiella sp.	*Heteromuricus cercifer*	*Dicranocentrus* sp.	
		Cyllyntrura (*Callyntrura*) sp.	
		Lepidoseira sp.	
		Sinella sp.	
		Alloscopus tetracantha	
		Ceratophysella cf. *planipila*	

Table 4. Faunal Analysis (Collembola) of Various Vegetational Types Associated with Hill Soil.

Crop Types	Different Genera/Species										
	Friesea sp.	*Cyphoderus* sp.	*Folsomides* sp.	*Cryptopygus* sp.	*Isotoma* (*Desoria*) *trispinata*	*Cyphoderopsis* sp.	*Mesaphorura* sp.	*Proisotoma* sp.	*Lepidocyrtus* (*Lepidocyrtus*) sp.	*Dicranocentrus* sp.	*Isotomiella* sp.
Tapioca	+	+	+	+	+	—	—	—	—	—	—
Lady's fingers	—	+	—	—	—	+	—	—	—	—	—
Soyabeen	—	—	—	—	—	—	—	—	—	—	—
Grass land	—	—	—	—	—	—	+	+	—	—	—
Paddy	—	—	—	—	—	+	—	—	—	—	—
Pine apple	—	—	—	+	+	—	—	—	+	—	—
Maize	—	+	+	—	—	—	—	—	—	—	—
French Bean	—	—	+	—	—	—	—	—	—	—	—
Brinjal	—	—	—	+	—	—	—	—	—	—	—
Sheima wallachei forest	—	—	+	+	+	—	—	—	—	+	+
Turmeric	—	—	—	+	—	—	—	—	—	—	—

SUMMARY

Effects of cultivation through crop rotation by the method of ploughing, continuous application of graded doses of NPK, Farmyard manure+NPK, chemical herbiciding *vs.* hand weeding and application of pesticides on soil fauna, chiefly Collembola and Acarina, were studied in the longterm experimental fields at Jute Agricultural Research Institute, Barrackpur, West Bengal. It was observed that crop rotations and other agronomic practices over years significantly reduced collembolan population and diversity of species with consequent reduction of C/N ratio of soil, microbial activities and crop yield. Acarina population also showed a declining trend.

T_8, receiving NPK and FYM, maintained sustained C/N ratio of soil and crop yield over years with higher density of Collembola. T_9, yeceiving herbicidal treatment, thus incorporating organic material into soil had positive effect on Collembola and

crop yield in comparison to T_4, receiving same dose of fertilizer and undergoing hand weeding. Crop-type together with different doses of NPK was found to govern population of Collembola both quantitatively and qualitatively. Higher doses of fertilizers had no significance on the crop yield at least for wheat and paddy and had a deliterious effect on collembolan and acarine population.

Coefficients of regression of Collembola were found marginally significant for yield of paddy and jute. ANACOVA and t-values for significance and multiple regression analysis were carried out to find out the significance of different treatments, months and other variables on yield, Collembola and Acarina during cultivation of each type of crop.

Distribution of various genera and species of Collembola according to four soil types and associated cultivated vegetation is also incorporated in this contribution.

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