REC. ZOOL. SURV. INDIA
66 (1-4) : 81-101, 1972

AN ECOLOGICAL STUDY ON COLLEMBOLA OF WEST BENGAL (INDIA)

By

D. K. CHOUDHURI AND S. ROY
Department of Zoology, University of Burdwan, Burdwan

(With 2 Text-figures and 5 Tables)

CONTENTS

I—INTRODUCTION

Ecological study of the subterranean Collembola is a comparatively young discipline. In view of the probable role of the subterranean micro-and mesofauna in the economy of soil, the possible long-term effects of agricultural practices, and the desirability of controlling soil pests, an ecological study of the soil fauna especially the Collembola, has become a matter of urgent practical importance. In the present era this particular discourse has evoked a considerable revival of interest among the pedobiologists. Symptomatic of this revival is the persistent pouring of literature, concerned with the autecological or the synecological studies of the soil Collembola, from the different parts of the world especially Europe, U.S.A. and Latin America. In India, however, this aspect of soil zoology has not received due attention despite the abundance of springtails in Indian soils, and so far there have come out only two noteworthy publications (Choudhuri and Roy, 1966 and 1967) that offer some useful information as to the ecological behaviour of Indian Collembola. It is this paucity of knowledge in regard to the bionomics of Indian Collembola and further because of the large confusion that still centres round the probable effects of the various edaphic factors in limiting the populations of Collembola the present authors undertook an extensive investigation by taking numerous samples from the different plots of the ten districts of West Bengal having equable and different soil conditions. The chief purpose of this investigation is to evaluate the quantitative and the qualitative composition of collembolan fauna, their seasonal variations and distributional patterns in relation to different soil factors namely moisture, organic carbon, nitrate, phosphate, calcium carbonate, hydrogen ion concentration (pH), particle size and soil cover (vegetation) and finally to compare the results of this study with those of the existing works in this line.

II—Sampling, Extraction and Analysis of Soil factors

Soil samples were collected by a modified soil auger (Dhillon, 1964) and were extracted by an apparatus originally devised by Macfadyen (1953) and subsequently modified by Dhillon (1964 a). Polyvinyl lactophenol was employed as a mounting-clearing medium in the preparation of slides. To determine the water content the soil was dried in an oven at 105°C. The loss in weight (expressed in percentage) represented the moisture derived from hygroscopic and some of the capillary water. The pH was determined from soil suspension by an electric pH meter and organic carbon by rapid titration method of Walkley and Black (1934). Particle size was measured by using an ocular micrometer taking 1000 particles at random from each sample. Calcium carbonate was determined by rapid titration method as described by Piper (1942); nitrate and phosphate contents were estimated colorimetrically by Phenol—disulphonic acid method and Molybdenum blue test as described by Dowdeswell (1959).

III—Habitats Studied

348 samples (108 from Nadia, 60 from 24-Parganas, 24 from Calcutta, 24 from Howrah, 24 from Midnapore, 24 from Hooghly, 24from Bankura, 24 from Burdwan, 24 from Jalpaiguri and 12 from Darjeeling) were collected generally from a depth ranging from 0—15 cm., from 30 plots of which 28 were sampled once in a month of a year while the remaining 2 plots at Darjeeling were sampled six times each over a period of two years. Most of the plots were uncultivated, well vegetated and in the Gangetic plain, being subjected to tropical climates with high humidity and fairly high temperature and containing mainly alluvium and in places laterite and red soils as in Bankura and Darjeeling districts. The mechanical characteristics of soil of different plots are given in table 1. The plots were found to be covered with grass and weeds belonging to the families of Amarantaceae, Compositae, Verbenaceae, Euphorbiaceae, Vitaceae, Polygonaceae and Commelinaceae in Nadia district ; Verbenaceae, Euphorbiaceae, Compositae, Polygonaceae, Convolvulaceae and Gramineae in 24 Parganas district ; Euphorbiaceae, Polygonaceae, Caesalpinnae and Compositae in Calcutta ; Amarantaceae, Vitaceae, Polygonaceae, Euphorbiaceae, Scitaminae and Malvaceae in Howrah district ; Amarantaceae, Rubiaceae, Nyctaginaceae, Euphorbiaceae, Vitaceae and Verbenaceae in Hooghly district ; Euphorbiaceae, Compositae and Gramineae in Burdwan district ; Convolvulaceae, Papaveraceae, Euphorbiaceae, Mimosae and Palmae in Bankura district ; Lythraceae, Convolvulaceae and Euphorbiaceae in Jalpaiguri district ; Compositae, Malvaceae and some gymnosperms in Darjeeling district.

TABLE 1.—Mechanical analysis of sampling plots

Plot	District	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)
Kalyani A		1.32	66.63	16.00	13.50
Kalyani B		2.60	64.07	21.20	11.50
Kalyani C		0.30	62.44	31.80	3.75
Majherchar		2.64	22.02	53.00	20.00
Chandmari	Nadia	1.10	35.83	38.50	21.80
Chasarhati		0.18	62.77	16.50	20.35
Haringhata		0.45	50.93	24.50	19.80
Mohanpur A		3.24	33.79	37.00	21.50
Mohanpur B		0.37	50.76	29.50	12.50
Kanchrapara A		1.75	34.25	29.18	33.22
Kanchrapara B		2.35	35.15	30.16	31.44
Halisahar	24-Parganas	2.68	57.36	24.24	11.82
Khardaha		0.78	46.32	19.89	30.61
Budge Budge		3.37	66.73	14.00	12.50
Beliaghata A	Calcutta	0.48	35.62	38.79	22.81
Beliaghata B		3.24	34.89	37.21	21.46
Bantul A	Howrah	1.28	46.92	29.74	24.86
Bantul B		0.98	43.12	28.16	27.24
Arambag A	Hooghly	5.38	38.36	32.24	20.22
Arambag B		4.36	32.44	28.67	32.73
Pahalanpur A	Burdwan	1.45	52.90	23.25	17.70
Pahalanpur B		1.60	51.20	23.45	19.15
Bankura A	Bankura	0.90	59.31	19.63	10.27
Bankura B		7.25	61.21	16.47	11.64
Garhbeta A	Midnapore	3.39	32.68	30.12	28.51
Garhbeta B		3.87	36.83	30.40	24.30
Carron A	Jalpaiguri	16.40	46.31	10.22	26.13
Carron B		17.21	43.90	12.64	24.36
Darjeeling A	Darjeeling	6.54	50.92	20.18	19.26
Darjeeling B		5.98	52.66	21.32	18.14

IV—COMPOSITION OF COLLEMBOLAN FAUNA

The spectrum of Collembola as found in this study is not very large. The total collembolan fauna obtained belonged to 25 genera (Table 2) of the families Entomobryidae, Onychiuridae, Hypogastruridae, Neanuridae, Poduridae, Isotomidae and Sminthuridae, the specific identity of which are given in table 3. The number of genera also varied being maximum in Nadia (14) and minimum in Burdwan (4). Moreover some forms differed in abundance in the plots of the same district or of the different districts. The most widely distributed genera were *Lepidocyrtus*, *Proisotoma*, *Cyphoderus*, *Lobella* and *Isotomurus* being found respectively in 7, 9, 7, 6 and 4 districts. None of the 25 genera was universal in occurrence. The

TABLE 2.—Collembola encountered in different months in West Bengal

Collembolan form	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jly.	Aug.	Sept.	Oct.	Nov.	Dec.	% of total Collembola
Lepidocyrtus sp.	265	328	339	314	359	585	985	908	622	349	283	367	26.13
Cyphoderus sp.	239	263	199	246	263	387	599	650	420	222	266	175	18.14
Proisotoma sp.	303	205	282	267	227	315	578	448	376	490	375	352	19.83
Xenylla sp.	4	18	6	16	4	18	9	14	16	7	16	8	0.61
Lobella sp.	45	47	51	52	58	53	61	65	72	59	46	52	3.09
Seira sp.	53	66	28	42	39	40	49	32	36	28	41	35	2.26
Friesea sp.	8	4	5	12	16	20	24	40	8	8	8	—	0.70
Pseudosinella sp.	179	48	67	35	73	119	127	73	98	49	79	84	4.99
Sinella sp.	14	40	9	49	59	—	34	32	4	27	9	12	1.33
Entomobrya sp.	2	11	2	8	2	10	12	3	2	13	2	—	0.25
Hypogastrura sp.	64	76	56	80	104	144	132	80	96	116	84	52	8.00
Isotomiella sp.	—	—	—	12	32	8	8	—	—	16	—	20	0.42
Isotoma sp.	—	8	—	8	8	—	—	—	20	20	16	—	0.36
Sminthurinus sp.	57	92	21	64	34	16	67	66	22	31	38	36	2.51
Sphaeridia sp.	44	45	38	23	27	21	67	56	50	37	8	19	2.00
Arrhopalites sp.	—	11	—	17	22	—	15	24	—	9	—	—	0.45
Onychiurus sp.	—	6	—	19	24	8	25	8	—	8	8	8	0.52
Alloscopus sp.	8	12	8	8	20	4	4	4	8	4	4	—	0.38
Dicranocentrus sp.	48	67	51	82	96	80	42	56	48	48	69	56	3.42
Isotomurus sp.	90	134	36	80	86	62	82	122	47	72	32	31	4.03
Callyntrura sp.	27	47	4	27	22	16	46	33	16	32	7	14	1.32
Pseudachorutes sp.	—	—	—	12	—	—	—	—	20	—	—	—	0.14
Salina sp.	18	17	21	20	23	12	32	17	40	14	22	19	1.17
Protanura sp.	20	7	9	5	8	7	10	15	11	7	23	26	0.68
Neanura sp.	—	10	—	16	10	—	5	14	—	—	—	—	0.24

plots of Jalpaiguri and Darjeeling supported the fauna distinct from that of the other plots. The species *Alloscopus tetracantha* found in Jalpaiguri and *Arrhopalites caecus*, *Onychiurus himalayensis* and *Neanura intermedia* found in Darjeeling were not recorded elsewhere. The important genera like *Lepidocyrtus*, *Proisotoma*, *Cyphoderus*, *Seira*, *Callyntrura*, *Onychiurus*, *Sminthurinus*, etc. were represented by more than one species. The order of dominance of the widely distributed genera could be expressed as *Lepidocyrtus*>*Proisotoma*>*Cyphoderus*>*Isotomurus*>*Lobella* (Table 2). The mean number of Collembola per plot is figured in the text—figure 1.

TABLE 3.—Species of Collembola encountered in West Bengal

Suborder : ARTHROPLEONA

Family : ENTOMOBRYIDAE

Lepidocyrtus suborientalis
L. heterolepis
L. cyaneus
Lepidocyrtus sp.
Cyphoderus javanus
C. assimilis
Cyphoderus sp.
Sinella montana
Sinella sp.
Seira boneti
S. indica
Salina indica
Entomobrya sp.
Callyntrura sp.
C. cingulata
Dicranocentrus indicus
Alloscopus tetracantha

Family : ISOTOMIDAE

Proisotoma thermophila
P. minuta
Proisotoma sp.
Isotomurus ciliatus
Isotomiella minor
Isotoma sp.

Suborder : SYMPHYPLEONA

Family : SMINTHURIDAE

Sminthurinus bimaculatus
S. alpinus
Sminthurinus sp.
Arrhopalities caecus
Sphaeridia brevipila

Family : OONYCHIURIDAE

Onychiurus indicus
O. himalayensis

Family : NEANURIDAE

Neanura intermedia
Protanura carpentari

Family : HYPOGASTRURIDAE

Xenylla sp.
Pseudachorutes sp.
Lobella sp.
Hypogastrura sp.

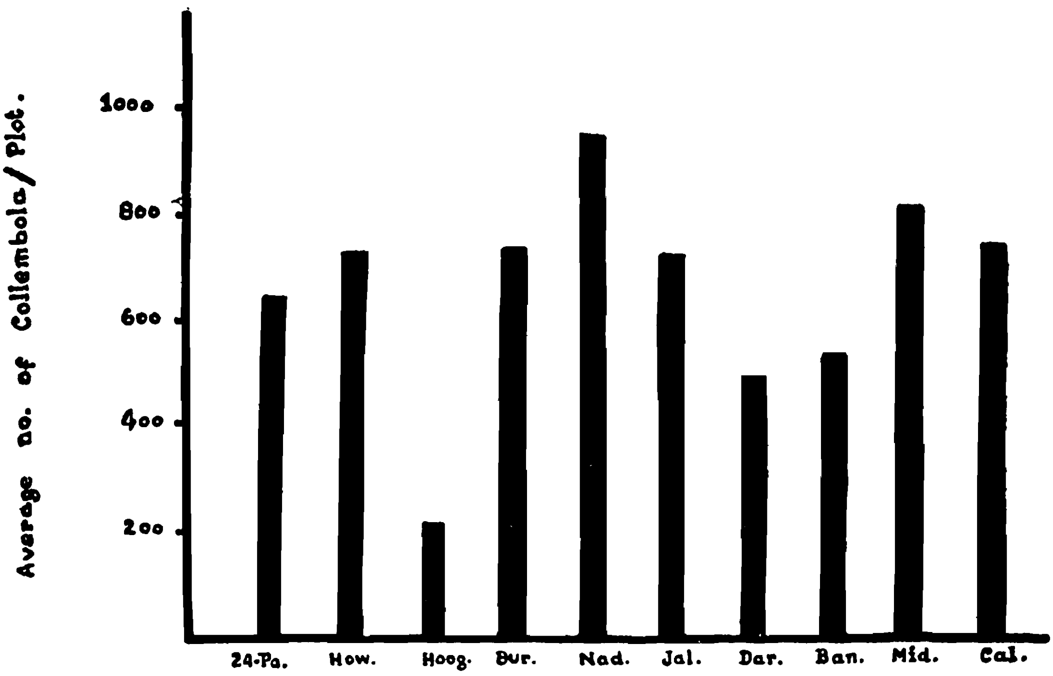
Family : PODURIDAE

Friesea sp.

V—SEASONAL VARIATION OF COLLEMBOLAN FAUNA

The seasonal variation patterns were different in different forms. The general form of the population curve was determined by *Lepidocyrtus*, *Proisotoma* and *Cyphoderus* which were the overwhelmingly dominant genera and members of which attained their peak in July-August (Table 2). The populations of *Hypogastrura*, *Lobella*, *Sphae-*

ridia and *Salina* also attained similar maxima. But the individuals of *Pseudosinella, Isotomurus, Sminthurinus* and *Callyntrura* exhibited two peaks, one being in the winter months and the other in monsoon months. *Sinella* and *Dicranocentrus* showed an annual cycle of another sort having the peak population in May. The population of Collembola, when considered district-wise showed their maxima in

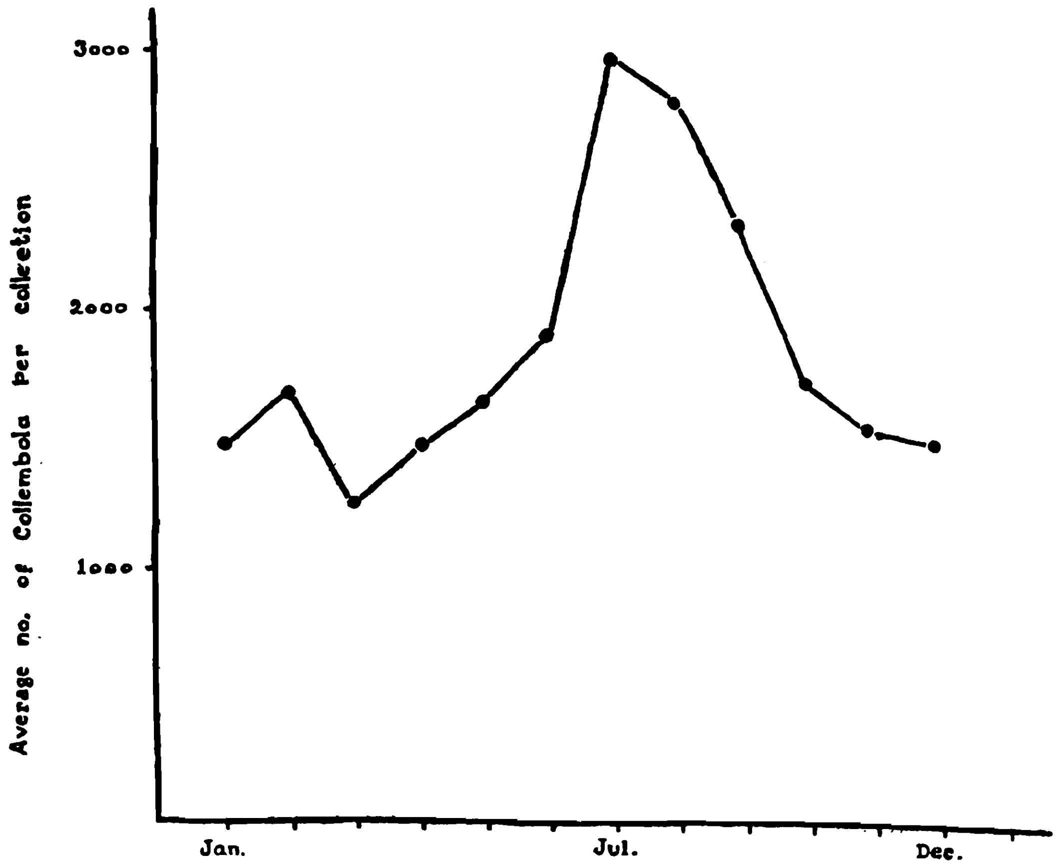


TEXT-FIG. 1.—Mean number of Collembola per plot in different districts of West Bengal.

July-September (in Nadia, 24-Parganas and Howrah), in June-August (in Calcutta, Bankura and Midnapore), in November-January (in Burdwan), in January-February (in Jalpaiguri) and in April-May (in Darjeeling) ; and minima in February-April (in Nadia and Hooghly), in May (in 24 Parganas), in March (in Calcutta) in February and April (in Burdwan), in March-April (in Bankura), in April-May and December (in Midnapore and Jalpaiguri), and in October (in Darjeeling). The total Collembola of Hooghly district was more or less at the same level throughout the year with, of course, a slight increase during the period June to August. The occurrence of two minimal periods in the same year as found in Burdwan, Midnapore and Jalpaiguri was perhaps due to the exhibition of two peak periods by some forms. The total number of Collembola of West Bengal was at the lowest level in March and in the monsoon months, July-August, it attained the peak (Text-fig. 2).

VI—CORRELATION OF SOIL FACTORS AND COLLEMBOLAN POPULATION

Calculation of the mean values of soil factors and mean number of Collembola in different months (not recorded here) clearly revealed that in most of the cases the population rose to peak when the important soil factors like moisture, organic carbon or organic matter, nitrate and phosphate became concentrated. The values of pH of most of the samples were between 6 and 7. The moisture content showed wide range of variation from 2.9% (Bankura district) to 14.7% (Nadia District). The organic carbon content varied from 0.11% (24 Parganas district) to 3.24% (Darjeeling district). The calcium carbonate content ranged between 1.3% (Darjeeling district) to 8% (Bankura district) and the nitrate content varied from 0.32 ppm (Hooghly district) to 4.4 ppm (24 Parganas district). The phosphate content of all the samples were less than 1 ppm ranging from 0.08 ppm (24-Parganas district) to 0.98 ppm (Calcutta). The mean particle size also showed variations along with the mechanical composition and in many cases the variation in the same plot was noted. It varied from 0.022 mm (24 Parganas district) to 0.127 mm (Midnapore district).



TEXT-FIG. 2.—Fluctuation of total collembolan population in the sampling plots of West Bengal.

In order to find out as to whether there was a significant correlation between the soil factors and the monthly collembolan population, correlation coefficient values (r) were worked out (table 4.) The water content, organic carbon and particle size, in most of the cases, and the nitrate as well as the phosphate in a few cases were significantly correlated. The calcium carbonate also in a few cases showed correlation with the collembolan population but that was weakly positive or weakly negative.

TABLE 4.—Correlation coefficient (r) for soil factors and Collembolan population

Factors correlated	Nadia	24-Parganas	Calcutta	Howrah	Hooghly	Burdwan	Bankura	Midnapore	Jalpaiguri	Darjeeling
Collembola : Water content	+0.663	+0.877	+0.563	+0.865	+0.549	—0.157	—0.891	+0.485	+0.064	—0.018
Collembola : Organic carbon	+0.975	—0.839	+0.816	+0.806	+0.375	+0.078	+0.291	+0.945	+0.798	+0.440
Collembola : Nitrate	+0.613	+0.180	+0.416	+0.100	+0.720	—0.198	+0.441	+0.845	+0.500	+0.052
Collembola : Phosphate	+0.438	—0.602	+0.332	+0.185	+0.699	—0.248	—0.472	+0.838	+0.881	+0.061
Collembola : Calcium carbonate	+0.539	+0.317	+0.347	+0.323	—0.147	+0.258	—0.189	—0.348	—0.325	—0.209
Collembola : Particle size	+0.811	+0.213	+0.239	—0.113	+0.359	+0.114	+0.419	+0.312	+0.862	+0.146
Water content : Organic carbon	+0.790	+0.753	+0.572	+0.902	+0.360	+0.584	—0.011	+0.292	+0.193	+0.478
Water content : Nitrate	+0.528	—0.512	+0.552	+0.197	+0.620	—0.412	—0.223	+0.710	—0.267	+0.498
Water content : Phosphate	+0.572	+0.713	+0.102	—0.016	+0.686	+0.414	—0.263	+0.580	+0.460	—0.592
Organic carbon : Nitrate	+0.312	—0.509	+0.796	+0.151	+0.342	—0.171	+0.152	+0.081	+0.011	—0.009
Organic carbon : Phosphate	+0.112	+0.158	+0.041	—0.015	+0.568	—0.075	+0.431	+0.238	+0.038	+0.093
Nitrate : Phosphate	+0.013	—0.317	+0.293	—0.085	+0.830	—0.428	—0.301	+0.622	+0.686	—0.174
Organic carbon : Particle size	+0.512	+0.139	+0.232	+0.019	—0.096	+0.131	—0.145	+0.689	+0.487	—0.231
Calcium carbonate : Particle size	+0.492	—0.224	—0.119	+0.432	+0.412	+0.096	+0.141	+0.449	+0.662	+0.124

VII—VERTICAL DISTRIBUTION

It is well known that in the undisturbed plots of temperate regions the majority of the individuals are generally concentrated in the upper layers of the soil as reported by Murphy (1953), Poole (1957), Dhillon and Gibson (1962) and Davis (1963). The similar pattern of distribution of tropical Collembola has also been on record (Choudhuri and Roy 1967). The vertical distribution was studied by dividing the samples in 3 subsamples in 3 depth ranges *viz.*, upper (0–5 cm.), middle (5–10 cm.) and lower (10–15 cm.). In table 5 are listed the total number of different forms extracted in 3 subsamples from all the sampling plots. The fauna, as a whole, and most of the species in all areas were found to be greater in concentration in the upper or middle subsample than the lower one.

VIII—DISCUSSION

Since the composition of the collembolan fauna was found to vary from one plot to another it would be worthwhile to see which of these plots or habitats were the most distinct and the degree of similarity among them. The distinctiveness in the faunal make up in Jalpaiguri and Darjeeling could be attributed to the existence of an ecological set up different from that of the plain region of West Bengal. High altitude, low temperature, different types of vegetation, high amount of rainfall, low pH, etc. were the characteristic features in the ecology of both districts of Jalpaiguri and Darjeeling. The maximum number of genera (14) of Collembola were recorded from the district of Nadia and in this respect next in position was Calcutta which supported 10 different genera. These two areas had the following advantages from the point of view of the soil fauna : (i) plots remained uncultivated and undisturbed for a long period permitting the development and prevalence of a more or less stable climatic conditions and a mature community of animals as well as plants, (ii) relatively greater abundance of plant remains and high organic content and thus affording possibly stable food supply. These conditions, being favourable, led to the establishment of a greater average number of Collembola in the plots of those districts (Text-fig. 1).

It has already been mentioned that the plots under review were mostly well vegetated and macroflora of an area obviously has some effects on the nature of the soil and humus. The thickness of humus layer or the total content of organic carbon depend greatly on the intensity of vegetation and the macroflora are supposed to exert some indirect influence on the populations of soil Collembola through its effect on soil cavity size, humus formation and soil moisture (Strickland, 1947, Bellinger, 1954, Knight, 1961, Davis, 1963). But how far the species composition of a population is dependant upon the plant community is difficult to ascertain. However, like the previous workers it can well be assumed that the vegetation is just one of the components of the ecological complex that limit the populations of Collembola.

The collembolan populations vary both in quantity and in quality from plot to plot. These variations might be due to the local differences in the composition of the substrate, but there also seems to be a tendency towards hyperdisposition or clumping of organisms in the homogeneous environment. The differences exhibited by the fauna in all the cases may not be real ; but some, at least, seem so clear-cut that they must represent real differences in the fauna. Some of the cases may be considered in greater detail as examples.

The genus *Lepidocyrtus* was represented mainly by four species *viz. L. medius, L. suborientalis, L. heterolepis* and *L. cyaneus* being concentrated in most cases in the upper (0–5 cm.) or middle subsamples. Their wide distribution and numerical dominance suggest that they are capable of existing in varying ecological niches. Their total absence from the himalayan and sub-himalayan West Bengal is interesting and is perhaps an indication of their lack of adaptability to high altitude climate. Again the reports of *L. cyaneus* by Bellinger (1954), Sheals (1957), Dhillon and Gibson (1962) and Davis (1963) from the different parts of the world suggest the cosmopolitan nature of the genus.

The genus *Proisotoma* was represented by mainly two forms *P. thermophila* and *P. minuta.* Its distribution in the Gangetic plain as well as in the sub-himalayan West Bengal signifies its widespread nature and also its capability to withstand diverse ecological conditions.

Cyphoderus, the third important genus of this investigation, was represented mainly by two species, *C. javanus* and *C. assimilis,* being steadily adapted to the gangetic alluvium as well as to the red and lateritic soil. Their maximum occurrence in the upper substratum makes one to consider them as humus or litter forms and their absence from the plots of Darjeeling and Jalpaiguri districts signifies their nature of distribution being restricted to the plain region. Moreover, the presence of *C. assimilis* and *C. javanus* in both Nadia and Midnapore having different soil conditions further justifies their not too narrow range of distribution in the plains at least.

Among other forms the numerically important genera were *Pseudosinella, Hypogastrura, Isotomurus* and *Lobella.* Both *Pseudosinella* and *Hypogastrura* were significantly present in Nadia being numerically higher than in the other districts suggesting their non-randomised distribution. *Isotomurus ciliatus* was not quantitatively so significant in any particular district. The species of *Lobella* were numerically lesser than the previous forms but being present in 6 districts in the Gangetic plain exhibited their wide range of distribution in West Bengal. This particular finding is consistent with the works of Yosii (1959 and 1966) who has reported many of these forms from the different localities of Eastern Asia.

The Collembola extracted only from himalayan and sub-himalayan part of West Bengal were *Alloscopus tetracantha, Arrhopalites caecus, Neanura intermedia* and *Onychiurus himalayensis.* The last two species have already been reported as high altitude forms by Imms

(1912) and by Choudhuri (1958). The species *Arrhopalites caecus* was also extracted from agricultural soils of England by Dhillon and Gibson (1962). In view of this the absence of *Alloscopus tetracantha* and *Arrhopalites caecus* in the plains of West Bengal is really difficult to explain. The members of Symphypleona like *Sphaeridia brevipila* and *Sminthurinus bimaculatus* were present in greater numbers in the plots of Jalpaiguri district. Similarly *Sinella montana* was numerically dominant in Darjeeling district. Among other strictly localised forms were *Protanura carpentari* and *Sminthurinus alpinus* extracted only from the plots of Howrah district, *Isotoma* sp., *Onychiurus indicus* from 24 Parganas, *Seira indica* from Midnapore, *Pseudachorutes* sp. and *Isotomiella minor* from Nadia. The last named species, though insignificant here, was reported from different ecological niches by Haarlov (1960), Poole (1961) and Milne (1962). The other important forms were *Seira boneti* present in 3 districts nnd *Diacranocentrus indicus*, *Xenylla* sp., *Friesea* sp. and *Entomobrya* sp. all of which were present only in two districts.

The existing literature on the seasonal fluctuation of population indicate maximum populations between late autumn and early spring and fall to a minimum during summer months (Ford, 1935, 1937, 1938, Glassgow, 1939, Weis-Fogh, 1948, Macfadyen, 1952, Sheals, 1957, Haarlov, 1960, Milne, 1962, Davis, 1963, Rapoport & Najt, 1966 and Rapoport & de Izarra, 1966). But the results obtained in the present investigation, especially with regard to dominant species are different from those of the previous workers. The dominant species begin to increase in number from April-May reaching their respective maxima in July-August after which they again decline (Table 2). The occurrence of single population peak may be due to the existence of a single generation per year while the record of two peaks may be attributed to the existence of more than one generation.

The causes of monsoon maxima in the dominant forms may further be attributed to the direct influence of soil moisture due to increased rainfall. In warmer months on the other hand, low rainfall combined with a high evaporation rate may result in desiccation which if sufficient to bring about a decrease in humidity, is bound to reduce the numbers because of the high mortality of the delicate and susceptible forms. Fluctuation in number may depend on factors like availability of food, presence or absence of predators, and inter-and intra-specific relations. The plots in different districts under this investigation were ecologically different and consequently the pattern of fluctuation in regard to the total population and also the specific population was found to be different.

The fluctuation pattern as exhibited here, though unusual, is not a unique one. Absence of winter maxima was reported by several workers (Vander Drift, 1951, Bellinger, 1954, Stöckli, 1957, Poole, 1961, Dhillon and Gibson, 1962). The observations so far made in this line undoubtedly suggest that in Collembola regular seasonal occurrence is rare and especially so in soil forms. Whatever are the existing tendencies towards regularity these are readily masked by environment. Consequently the pattern of population fluctuation varies not only from species to species but from year to year and geographically.

In the present study the vertical distribution was variable in the plots sampled. During the summer months there was a tendency of migration of the surface forms into deeper layers to avoid drought or desiccation as already reported by Strickland (1947). According to Glasgow (1939) different genera and even different species of the same genus inhabiting the same soil may show marked difference in distribution. This was also observed in the present investigation. The greater was the concentration ln *Lepidocyrtus*, *Cyphoderus*, *Proisotoma*, *Lobella*, *Dicranocentrus*, *Isotomurus* and *Callyntrura* in the topmost subsample ; in *Salina*, *Hypogastrura*, *Pseudachorutes*, *Pseudosinella* in the middle and in *Onychiurus* and *Xenylla* in the lower subsample (Table 5). This distribution was more or less similar to that described by Volz (quoted by Bellinger,1954) who studied the vertical distribution of collembola in forest soils of Europe.

TABLE 5.—Vertical distribution of Collembola

Collembolan forms	Total number in upper layer (0-5 cm.)	Total number in middle layer (5-10 cm.)	Total number in lower layer (10-15 cm.)
Lepidocyrtus sp.	3319	1658	348
Cyphoderus sp.	2278	1339	437
Proisotoma sp.	1998	1287	405
Xenylla sp.	32	45	55
Lobella sp.	231	203	199
Seira sp.	145	159	177
Friesea sp.	90	53	84
Pseudosinella sp.	202	416	82
Sinella sp.	201	155	44
Onychiurus sp.	17	21	47
Alloscopus sp.	24	56	8
Dicranocentrus sp.	395	169	55
Isotomurus sp.	451	301	195
Callyntrura sp.	153	54	14
Pseudachorutes sp.	0	31	6
Salina sp.	73	201	89
Protanura sp.	88	49	16
Neanura sp.	42	11	7
Entomobrya sp.	15	32	15
Hypogastrura sp.	320	462	23
Isotomiella sp.	129	21	7
Isotoma sp.	12	24	0
Sminthurinus sp.	227	234	107
Sphaeridia sp.	154	136	127
Arrhopalites sp.	62	31	14

The probable reasons for concentration of collembolan forms in the upper layers of the soil have already been discussed by the present authors (1967). It is also worth mentioning that, with the reduction in the percentage porosity, the gaseous exchange is hindered and organisms living in the deeper layers must be able to tolerate higher tension of carbon dioxide and lower tensions of oxygen than individuals living near the surface (Dhillon and Gibson, 1962). The degree of parallelism between the porosity and the vertical distribution of fauna (Dhillon and Gibson, 1962) further supports the importance of porosity as a limiting factor in the colonisation of soil Collembola. Not only does the total porosity decrease with depth, but so also does the average diameter of the pore spaces and, as Weis-Fogh (1948), Haarlov (1955) and Stöckli (1957) have pointed out, this diminution must, for purely mechanical reasons, limit the larger species to the upper layers. Although the fundamental vertical zoning of species in the soil can be tentatively accounted for in terms of size, nutritional preferences and carbon dioxide tolerance, it is really difficult to explain the temporary changes in distribution which are superimposed upon the basic pattern. Movements of the fauna into the deeper layers may be ascribed to such causes as (1) drying or flooding of the upper layers of the soil, (2) prevalence of unfavourably high or low surface temperatures and (3) responses to alterations in the carbon dioxide content of the interstitial air (Kühnelt, 1950). Baver (1956) has stated that the carbon dioxide content of the soil air is subject to significant variations, even at considerable depths. Moreover it undergoes seasonal changes in relation to temperature and moisture content of the soil. More recently Rapoport and de Lzarra (1966) suggest that the availability of larger number of collemboles in deeper layer might be due to their occurrence in rhizosphere along the thinnest rootlets or in the hollows of root channels formed by decayed roots.

A critical study of the soil factors revealed that in most of the sampling areas the population was maximum in July when the moisture, and organic carbon content were fairly high, the carbonate, nitrate and phosphate contents were moderate and soil reactions were nearly neutral. But the samples of Jalpaiguri, Darjeeling and Burdwan, where the maximum population was obtained in February, April and May, respectively, had lower concentration of moisture than those with the minimum population at these places.

The values of pH of most of the samples under this study were between 6 and 7. According to Buckman and Brady (1960) this intermediate pH range perhaps presents the most satisfactory biological regime. Here nutrient conditions are favourable without being extreme and availability of certain salts are maximum. Besides, the values of pH were well within the tolerance range of most or rather all of the species. This is indicated by the steady occurrence of the forms like *Seira boneti* and *Isotomurus ciliatius* in Jalpaiguri and Darjeeling (having pH value 5.9) and also in Calcutta and Bankura (having higher pH value). Moreover, workers like Agrell (1941), Bellinger (1954), Dhillon and Gibson (1962), Davis (1963) did not observe any correlation of pH with collembolan populations. As the values of pH in most cases were near the neutral point and also because these values were well within the tolerance range of most of the forms, the correlation coefficient values (r) of pH and collembolan population need not be calculated. Well representation of the same species in two different soil pH (5.9 at Darjeeling and 7.3 at Calcutta) is really interesting and contradicts the views of Gisin (1943, 1955). It is quite clear from the present study that pH has very little or no direct effect on collembolan population, but it may do so by indirectly influencing soil reaction. Nitrification and nitrogen fixation by the micro-organism take place vigorously in soils only at pH values well above 5.5. Moreover, mobility of calcium and magnesium and satisfactory availability of phosphorus is restricted to a pH range of approximately 6 to 7. Vegetation is also sometimes related to the pH value of soil.

In most of the samples of the present study moisture content showed significant positive correlation with the collembolan population since the monsoon months mostly witnessed maximum population and upward fluctuation. But the occurrence of same species in different moisture levels of the different areas may indicate that the role of moisture is more pronounced in seasonal fluctuation than in species composition as emphasized by Davis (1963). Actually the position as to the role of moisture on collembolan fauna is still confusing. Some investigators like Hammer (1953), Stebayev (1962), Dhillon and Gibson (1962) have found that certain forms arene gatively correlated to soil moisture. Again workers like Agrell (1941), Knight (1961), Poole (1961) and Christriansen *et al.* (1961) have found a positive correlation, while Macfadyen (1952) and Marcuzzi (1962) found no correlation at all. The increased populations with increased moisture content may be due to the existence of forms having "preferences" to moisture condition. Besides this, the capacity of collembolans to withstand the condition of drought or desiccation as some time prevails in nature varies from species to species (Choudhuri, 1963) and therefore may be considered to be one of the reasons for population fluctuation. Moisture content also exerts large influence on soil fauna through diverse effects on plants and soil conditions (1) by acting as the solvent which together with the dissolved nutrients makes up the soil solution, (2) by maintaining hydrogen ion concentration of the soil and (3) also by taking part in the process of nitrification. In view of this it may be assumed that the moisture, the availability of which depends on rainfall, temperature, percolation, evaporation etc., exerts profound influence, direct or indirect on soil microfauna.

The data presented here clearly indicate that high organic carbon content has a significant bearing on the probability of a larger population of Collembola. It is well established that carbon forms the most important constituent part of the total organic matter which generally contains 55-50% carbon. Therefore increased percentage of organic carbon in any soil obviously leads to the greater organic matter content. Increased population of Collembola with increased organic matter content has also been reported by workers like Haarlov (1960), Christiansen *et al.* (1961), Holler-land (1962) Chernova (1963), Davis (1963), Choudhuri and Roy (1966). The soil organic matter may exert direct or indirect influence on the collembolan population through its effect on vegetation and soil conditions by (1) modifying the physical and chemical properties of soil ; (2) determining the nature of microbial population and its activities through supplies of organic and inorganic nutrients essential for (3) buffering soil reaction ; (4) influencing moisture holding capacity, soil temperature, oxidation-reduction potential of soil, (5) absorbing certain toxic materials injurious to plant growth and (6) in supplying certain catalytic agents and various trace elements essential for plant growth (Russell 1954 and 1957). Above all, the occurrence of larger number of collembolans in the litter and humus layers also substantiate the affinity of the collemboles to organic matter content.

Availability of organic carbon again depends on many factors. In general under comparable conditions, the nitrogen and organic carbon increase as the effective moisture becomes greater. For this reason a tendency of increase in the percentage of organic carbon was observed in many plots with the onset of monsoon months. Significant correlation existing between soil moisture and organic carbon content, as has been observed, also supports this view. Texture of the soil also seems to influence the percentage of organic carbon present. A sandy soil, for example, usually carries less organic matter and nitrogen than that of a finer texture. This is probably due to the lower moisture content and to the ready oxidation that occurs in the lighter soil. Carbonate content of soil and its vegatative covers, are other factors that may affect the accumulation of soil organic carbon.

It is well known that most of the collembolans are either saprophagous or phytophagous. They generally feed on algae, fungi, lichens, decayed and undecayed leaves, bacteria and fungal spore, the abundance of which is related to the quantity of organic matter. Therefore it appears very probable that the total concentration of potential food, as measured by the percentage of organic matter, is of profound importance in the distribution of soil Collembola (Haarlov, 1960 ; Christiansen *et al*, 1961).

On analysis it has been observed that calcium carbonate has significant correlation with collembolan population only in few cases and that too is either weakly positive or negative. This possibly indicates that direct relationship between carbonate content and population distribution is insignificant or absent. Moreover the occurrence of same species (*Sinella montana*) in the district of Darjeeling and Nadia having widely different carbonate level further supports the above contention. The concentration of calcium carbonate in most of the cases did undergo little change with the change of season and thus appeared to make little contribution towards the seasonal variation of collembolan population except that it might exert its influence indirectly through vegetation and physico-chemical characteristics of soil (Russel, 1954, 1957).

The concentration of nitrate was found to increase in most cases with the onset of monsoon months when the collembolan population also became comparatively numerous suggesting thereby that nitrate is one of the factors that contributes to the seasonal fluctuation, but how far this contention is true is still to be established. On analysing the correlation coefficient values of nitrate and collembolan population it was observed that in few cases nitrate has significant correlation with the population density. On the other hand collembolan forms were not found to be specific to any concentration of nitrate since *Lepidocyrtus* sp., *Proisotoma* sp. etc. were abundant in the sampling plots of Nadia and Hooghly districts with different concentration of nitrates. The nitrate content of samples taken from Hooghly district was considerably low and there the population of Collembola was also significantly low. Nitrate is one of the most essential macronutrients used by plants to keep their successful existence and it is usually formed from the organic nitrogenous compounds by decomposition—ammonification and nitrification brought about through the activities of some bacteria. The latter are extremely sensitive to their environment conditioned by aeration, temperature, moisture, pH, calcium carbonate, carbon-nitrogen ratio, etc. The optimum moisture-suitable for nitrification is generally attained in the monsoon months in the tropics for which nitrate content of the soil samples under this study increased to some extent at that period.

Nitrate in the soil with its variations in concentration sometimes brings about changes in the microclimate which may be favourable or unfavourable to the microfauna. It also influences greatly the macroenvironment by helping exuberant growth of vegetation. Therefore the nitrate content of the soil is capable of establishing a balanced soil climate, which, in its turn, is expected to support a larger fauna.

In some plots phosphate content showed significant correlation with the collembolan population which was compatible with findings of Wakerley (1963). In many cases of this investigation phosphate content was also weakly or negatively correlated which signifies that the relation of soil phosphate and collembolan population was not regular. The occurrence of same species *Proistoma thermophila* in the plots of Halisahar and Beliaghata, having different phosphate levels, makes the role of the phosphate content in species composition of a plot dubious. Both organic and inorganic forms of phosphates are present in the soil. Organic compounds of phosphorus form a constituent part of humus complex of the soil. Rock and other insoluble phosphates are the inorganic forms present in the native rocks from which the soil is derived. With possible exception of nitrate, no other compound has been as critical in the growth of plants in the fields as phosphate. A lack of this element is really serious since it may preclude the access of other nutrients to the plants. Introduction of a number of phosphate fertilizers in agricultural farming further speaks for its tremendous importance as a plant growth prompter. In view of this the influence of phosphate, direct or indirect, may not be overruled despite the lack of strong positive correlation between it and the collembolan population as found here.

In many plots the average particle size showed some positive correlation with the collembolan population being consistent with the findings of Christriansen *et al.* (1961) who obtained maximum population in the particle size ranging from 0.09 to 0.119 mm., while in many other cases the relation was weak or negative. Actually the role of size of particles in limiting the collembolan population is not well studied as in most cases the authors like Kühnelt (1950), Bellinger (1954), Haarlov (1960), Davis (1963) have studied the pore volume and pore space. But it is also well recognised that the amount of this space is determined largely by the arrangements of the particles. If they tend to lie close together, as in sands or compact subsoils, the total porosity is low. If they are arranged in porous aggregates, as is often seen in the case of medium textured soils rich in organic matter, the pore space per unit volume will be high (Buckman and Brady, 1960).

Pore volume and pore space which are secondarily related to particle size are again influenced by the concentration of the cementing agent *viz.* calcium carbonate and organic carbon. In this investigation two plots (one at Howrah and the other at Midnapore district) with varying average particle size supported the species *Cyphoderus javanus* in good number thus indicating that the distribution of the species is not restricted to any particular range of particle size.

There is a general agreement that available pore space decreases with depth which might be due to some compact sub-soil particles or due to decrease in organic matter content and a subsequent lowering of granulation. Decrease of pore space with depth thus leads to a decrease in population density (Haarlov, 1955). So from the relation of particle size and pore space and also from the data of the previous workers it can be assumed that soil particles provided with good amount of organic carbon will lead to the establishment of greater pore space and ultimately support a denser population by making more living space available.

Choudhuri (1961) reports that apart from the size restrictions there are also very important adsorptive and abrasive factors to be considered in relation to the mean diameter and particle size of the soil. These factors are only valid if the humidity of the soil falls below saturation level and the soil becomes deficient in organic food matter.

Several factors like rigidity, plasticity, moisture holding capacity, drainage etc., are also related to the size of the particles and thus may exert some influence on soil microfauna.

In view of the findings of the present investigations and also taking into consideration the comprehensive review work of Christiansen (1964) it can be assumed that the changes exhibited by the collembolan fauna might be more due to cumulative influence of small variations in a number of factors constituting a 'factorial complex' than the overriding effect of large changes in a component of that complex. Moreover the interrelationships among the factors analysed in this study are intricate, complex and inextricably intertwined. So the complexity of the soil as an environment makes it virtually impossible in field studies to take into consideration. Other important variables which might conceivably influence the nature, size or distribution of the subterranean forms. Further progress in unravelling these relationships is unlikely to be made until the behaviour of individual species in relation to single environmental factor is fully studied under controlled conditions in the laboratory.

IX—SUMMARY

Recorded in this paper are the results of an evaluation as to the quantitative as well as the qualitative composition of the collembolan fauna of West Bengal, India, their seasonal variations and distributional patterns, both horizontal and vertical, in relation to various soil factors namely moisture, organic carbon, nitrate, phosphate, calcium carbonate, hydrogen ion concentration, particle size and soil cover (vegetation). The results are based on 348 soil samples collected from 30 different uncultivated plots of West Bengal. The spectrum of Collembola as found in this study is not very large and the collembolan fauna extracted belong to 25 genera of the families Entomobryidae, Onychiuridae, Hypogastruridae, Neanuridae, Poduridae, Isotomidae and Sminthuridae ; of which the dominant genera are *Lepidocyrtus*, *Proisotoma*, *Cyphoderus*, *Lobella* and *Isotomurus*. The general form of the population curve seems to be determined by the aforesaid first three genera, members of which attained their peak in July-August. The occurrence of winter maxima is also obtained in some cases. The calculation of the mean values of soil factors and mean number of Collembola reveals that in most of the cases the population rises to peak when the important soil factors like moisture, organic carbon, nitrate and phosphate become relatively more concentrated. The particle size is also found to be significantly correlated with the population at least in some cases. The reasons for fluctuation of population are also discussed in terms of edaphic factors. The majority of the individuals has been found to be aggregated in the upper layers of soil and this is consistent with the findings of the other workers in this field. From the experimental results obtained in this study, it can be assumed that the changes exhibited by the collembolan fauna might be more due to cumulative influences of small variations in a number of factors constituting a factorial complex than the overriding effect of large changes in a component of that complex.

X—REFERENCES

AGRELL, I. 1941. Zur Ökologie der Collembolan. Untersuchun gen in Schwedischen Lappland. *Opusc. ent.*, Suppl., **3** : 1-236.

BAVER, L. D. 1956. *Soil Physics*, New York.

BAWEJA, K. D. 1939. Studies of the soil fauna with special reference to the recolonisation of sterilised soil. *J. Anim. Ecol.*, **8** : 120-161.

BELLINGER, P. F. 1954. Studies of soil fauna with special reference to Collembola. *Conn. Agric. Expt. Sta. Bull.*, **583** : 67.

BUCKMAN, O. H. and BRADY, C. N. 1960. *The nature and properties of soil.* The Macmillan Company.

CHERNOVA, N. V. 1963. Population dynamics of Collembola (Insecta) in compost made from fallen leaves. *Zool. Zh.*, **42**(a) : 1370-1382.

CHOUDHURI, D. K. 1958. Some new species of *Onychiurus* Gervais (Collembola : Onychiuridae) from Nepal and Uganda. *Proc. ent. Soc. Lond.*, (B) **27** : 147-154.

CHOUDHURI, D. K. 1961. Effect of soil structure on Collembola. *Sci. & Cult.*, **27** : 494-495.

CHOUDHURI, D. K. and Roy, S. 1966. Role of edaphic factors on the distribution of subterranean collembolan fauna of West Bengal. Part I. Monograpias, Progresos En Biologia del suelo Actas Del Primer Coloquio Latin Americano de Biologia del Suelo : 391-403.

CHOUDHURI, D. K. and ROY, S. 1967. Qualitative composition of the collembolan fauna of some uncultivated fields in Nadia district (West Bengal) with a correlation between monthly population and individual soil factor. *Rev. d' ecol. et. biol. du sol.*, **4**(3) : 507-515.

CHRISTIANSEN, K. 1964. Bionomics of Collembola. *Ann. Rev. Entomol.*, **9** : 147-178.

CHRISTINSEN, K., WILLSON, M. and TECKLIN, J. 1961. The Collembola of Hunter Cave, with a preliminary study of micro arthropod ecology of Hunter Cave. *Bull. Natl. Speleological Soc.*, **23** : 59-69.

DAVIS, B. N. K. 1963. A study of microarthropod communities in mineral soils near Corby, Northants. *J. Anim. Ecol.*, **32** : 49-71.

DHILLON, B. S. 1964 Estimations of soil arthropod population I. Development of sampling tool. Proceedings of All India Entomological Research Workers' Conférence and Plant Protection Seminar. I.C.A.R., New Delhi.

DHILLON, B. S. 1964. Estimations of soil arthropod population II. Extraction apparatus. Proceedings of All India Entomological Research Workers' Conference and Plant Protection Seminar, I.C.A.R., New Delhi.

DHILLON, B. S. and GIBSON, N.H.E., 1962. A study of the Acarina and Collembola of agricultural soils. *Pedobiologia.*, **1** : 189-209.

DOWDESWELL, W H. 1959. *Practical Animal Ecology.* Methuen & Co., London.

FORD, J. 1935 The animal population of meadow near Oxford. *J. Anim. Ecol.*, **4** : 195-207.

GISIN, H. 1943. Öklogie and Lebensgemeinschaften der Collembolen in Schewizerischen Exkursionsgebiet Basels. *Rev. suisse Zool.*, **50** : 131-224.

GISIN, H. 1955. Recherches sur la relation entre la faune endogee de Collemboles et les qualities agrologiques de sols Viticoles. *Rev. suisse Zool.*, **62** : 601-648.

HAARLOV, N. 1955. Vertical distribution of mites and Collembola in relation to soil structure : in *Soil Zoology*. Ed. Kevan, D. K. McE. Butterworth, London.

HAARLOV. N. 1960. Microarthropods from Danish soils,e cology and phenology. *Oikos*, Suppl., **3** : 1-176.

HAMMER, M. 1953. Investigations of the microfauna of Northern Canada. II Collembola. *Acta Artica*, **6** : 1-108.

HOLLER-LAND, G. 1962. The dependance of soil inhabiting Collembola on fertilisation and other local factors under conditions prevailing at Dikopthof. *Mongr. Angew.*, **18** : 80-120.

IMMS, A. D. 1912. On some Collembola from India, Burma and Ceylon. *Proc. zool. Soc. London* : 80-124.

KNIGHT, C. 1961. The Tomocerinae in old field stands of North Carolina. *Ecology*, **42** : 140-149.

KÜHNELT, W. 1950. *Bodenbiologie mit besonderer Berucksichtigung der Ticrwelt.*. Vienna. Harold.

MACFADYEN, A. 1952. The small arthropods of a Molinia fen at Cothill. *J. Anim. Ecol.*, **21** : 87-117.

MACFADYEN, A. 1953. Notes on methods for the extraction of small soil arthropods. *J. Anim. Ecol.*, **22** : 65-77.

MARCUZZI, G. 1962. Contributes to the knowledge of soil fauna of South-Eastern Alps. *Intern. Congr. entomol.*, Wien, 1960-Verhandl, **3** : 154-158.

MILNE, S. 1962. Phenology of a natural population of soil Collembola. *Pedobiologia*, **2** : 41-52.

MURPHY, P. W 1953. The biology of the forest soils with special reference to mesofauna or meiofauna. *J. Soil Sci.*, **4** : 155-193.

PIPER, C. S. 1942. Soil and plant analysis. *Mongr. Waite Agric. Res. Inst., Univ. Adelaide*, South Australia.

POOLE, T. B. 1961. An ecological study of the Collembola in a coniferous forest soil. *Pedobiologia*, **1** : 113-137.

RAPOPORT, E. H. and Najt, J. 1966. Ecologia de los microarthropods en suelos Gley and Solonchak de Bahia Blanca, A rgentina. Monografias, Progreses En Biologia del Suelo, Actas Del Primer Coloquio Latin Americano de Biologia del Suelo : 521-546.

RAPOPORT, E. H. and de IZARRA, D. C. 1966. On the rhizosphere of some Argentine plants and its relation to soil microfauna. Monografias, Progressos En Biologia del Suelo, Actas Del Primer Coloquio Latin Americano de Biologia del Suelo : 609-614.

RUSSELL, E. J. 1954. *Soil conditions and plant growth.* Longmans.

RUSSELL, E. J. 1957. *The world of soils.* Collins.

SHEALS, J. G. 1957. The Collembola and Acarina of uncultivated soil. *J. Anim. Ecol.*, **26** : 125-134.

STÖCKLI, A. 1957. Die Metazoenfauna vol Wiesen und Ackerboden aus der Umgebung von Zurich. *Landw. Jb. Schweiz.*, **6** : 571-595.

STRICKLAND, A. H. 1947. The soil fauna of two contrasted plots of lands in Trinidad, British West Indies. *J. Anim. Ecol.*, **16** : 1-10.

VAN DER DRIFT, J. 1951. Analysis of the animal community of beech forest floor. *Tijdschr. Ent.*, **94** : 1-168.

WAKERLEY, S. B. 1963. Effect of lime and phosphate on soil Collembola. *Ann. appl. Biol.*, 5(1) : 171-172.

WALKLEY, A. and Black, I. A. 1934. An examination of the Degtjareff method for determining soil organic matter, and a broposed modification of the chromic acid titration method. *Soil Sci.*, **37** : 29-38.

WEIS-FOGH, T. 1948. Ecological investigation of mites and collemboles in the soil. *Nat. Jutland.*, **1** : 135-270.

YOSII, R. 1959. Studies on the collembolan fauna of Malaya and Singapore. Contributions from the Biological Laboratory Kyoto University. No. **10** : 1-65.

YOSII, R. 1966. On some Collembola of Afganisthan, India and Ceylon, collected by Kuphe Expedition 1960. Kyoto University Scientific expedition to the Karakoram and Hindukush 1955. **8** : 333-405.