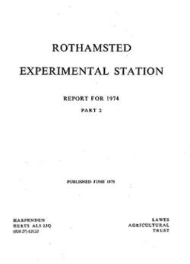
Rothamsted Experimental Station Report for 1974 Part 2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PART 2

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C. A. Edwards and J. R. Lofty

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The Invertebrate Fauna of the Park Grass Plots

I. Soil Fauna

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Introduction

The Park Grass experiment, begun in 1856, was designed to investigate how various manurial treatments affected the productivity of old pasture. Prior to the experiment, the land has been in grass for several centuries and seemed to have a uniform vegetation. Originally, there were 20 plots ranging in area from one-half to one-eighth of an acre but these have since been subdivided. The unreplicated treatments (Fig. 1) compared the yields of hay from plots that received no manure with those from others that received organic manure (farmyard and fishmeal); a range of only mineral fertilisers; a range of only nitrogenous fertilisers and a range of mixed mineral and nitrogenous fertilisers involving different levels of nitrogen. The nitrogen was in two main forms, nitrate of soda or sulphate of ammonia. In the original experiment, two plots received organic manure and two no manure, but, seven years after the beginning of the experiment (1863) no more manure was given to one of the organic manure plots (Plot 2). As a result of the treatments some plots became acid and the sward deteriorated, so from 1903, lime was applied regularly to the southern half of most plots (Fig. 1). In 1965, each half plot was subdivided again into two, giving four plots treated in the following ways:

(a) Lime added to maintain the pH as in 1965.
(b) Lime added to give a pH as close to 6·0 as possible.
(c) Lime added to the more acid plots to give a pH as close to 5·0 as possible.
(d) No lime added.

Nevertheless, the pH of the various plots is still very variable, ranging in (a) plots from 4·6 to 7·5, (b) plots from 4·9 to 7·3, (c) plots from 4·4 to 6·0 and (d) plots from 3·8 to 6·0. The treatments have greatly influenced the very varied flora of the plots, which includes grasses, clovers and weeds. The botanical composition of the sub-plots has been studied annually since 1900 at regular intervals through the year; it changes seasonally and there is also a gradual change (Brenchley, 1935, 1969; Williams, 1974). The numbers of plant species range from only two species (11/1d) to up to 30 species (12a), the greatest diversity still being in the unmanured plots although these yield poorly.

Other studies that have been made on Park Grass include the distribution of nodule bacteria, Protura (Raw, 1956), earthworm casts (Richardson, 1938) and earthworms (Satchell, 1953). Madge (private communication) sampled the limed and unlimed halves of plots 3, 11/2 and 13 for soil invertebrates on several occasions in 1962 but the results have not been published. The nematode fauna of the limed and unlimed halves of plots 1, 3, 4/2, 7, 9, 12 and 19 was assessed in 1960–61 but no details of the results were published (Winslow, 1961). The present investigation involved a thorough investigation of the soil and surface invertebrate fauna of a selected series of plots between April 1972 and June 1974. The soil fauna will be discussed in the present paper; in a later paper data on the occurrence of arthropods associated with the crop will be discussed.

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TABLE 1

Comparative numbers of soil invertebrates extracted from soil samples (numbers in eight soil cores)

					Acarina					Collembola									
Treatment	Plot no.	Nematoda	Enchytraeidae	Myriapoda	Prostigmata	Mesostigmata	Astigmata	Cryptostigmata	Total Acarina	Protura	Onychiuridae	Poduridae	Isotomidae	Entomobryidae	Sminthuridae	Total Collembola	Insecta	Total soil invertebrates	Total soil invertebrates (1000/m³)
N_1	1b	13	27	2	72	381	58	384	895	6	69	39	256	8	47	419	14	1382	173
	c	3	42	3	34	145	16	320	515	0	52	20	205	9	33	319	11	894	118
	d	1	35	5	44	246	17	147	454	4	45	11	287	50	15	408	25	932	116
None	2a	15	39	12	52	172	18	627	869	19	81	25	166	7	52	331	13	1298	162
	d	3	29	3	71	432	24	274	801	2	106	55	201	8	89	459	24	1322	165
PKNaMg	7b	7	31	17	86	403	19	134	642	56	172	15	107	8	75	377	16	1148	143
	c	6	14	34	154	245	807	435	1641	6	134	27	428	6	45	640	36	2377	297
PNaMg	8b	28	65	11	65	280	18	450	813	24	98	5	144	5	57	309	21	1272	159
	c	5	9	26	153	305	34	474	966	12	126	31	121	10	52	340	17	1376	172
PKN_2 NaMg	9a	6	10	11	86	148	10	180	424	1	79	12	138	8	41	278	51	781	98
	b	16	30	6	127	177	12	135	451	5	219	10	114	2	28	373	30	911	113
	c	6	5	0	1016	111	15	629	1771	0	44	66	59	6	36	211	8	2003	250
	d	1	0	0	93	135	22	788	1038	1	22	0	42	0	12	76	10	1126	140
PN_2NaMg	10a	2	8	10	78	277	8	534	897	1	68	21	108	4	57	258	11	1187	148
	b	12	6	8	73	331	23	694	1121	0	69	9	119	5	72	274	29	1451	181
	c	1	17	1	232	203	51	506	992	0	41	111	378	20	56	606	12	1630	203
	d	1	0	0	42	115	71	800	1028	0	29	2	63	1	12	107	10	1146	143
PKN_3Na Mg	11/1a	4	5	0	25	95	2	67	189	0	52	9	98	1	46	206	20	424	53
	b	11	10	5	44	177	8	126	355	4	104	9	304	3	73	493	16	894	111
	c	10	9	0	74	169	8	668	919	0	110	89	199	2	80	480	17	1435	179
	d	0	5	0	39	107	24	411	581	0	14	3	42	1	23	83	10	681	85
FYM and fishmeal	13b	11	25	11	56	196	54	293	599	3	118	0	166	5	90	379	22	1050	131
	c	8	20	14	46	209	42	533	830	1	81	42	102	1	59	285	29	1188	148
	d	4	10	9	52	146	39	318	555	2	70	36	68	0	69	243	23	846	105
PKN_3*Na Mg	14b	7	26	5	19	250	5	76	350	0	46	11	144	16	37	254	27	669	84
	c	5	8	4	68	268	1	70	407	3	152	49	188	9	107	505	130	1062	133
N_1*	17b	20	41	5	44	365	12	942	1363	31	63	3	219	14	47	346	28	1834	229
	c	7	37	12	54	314	28	428	824	2	220	32	421	6	26	705	40	1629	203

Methods

In April 1972, eight soil cores (5 cm diameter by 15 cm deep) were taken from plots 1b, c, d; 2a, d; 7b, c; 8b, c; 9a, b, c, d; 10a, b, c, d; 11/1a, b, c, d; 13b, c, d; 14b, c; 17b, c. The animals were extracted from these samples in modified Macfadyen-type high gradient, air-conditioned Tullgren funnels (Macfadyen, 1957; Edwards & Fletcher, 1970) and sorted into convenient taxonomic categories. Only Collembola and Coleoptera were identified to species.

Earthworm populations were sampled in March 1972 using a modification of the electrical method used by Satchell (1953). The plots sampled were the same, with the addition of 13a. For each sample two electrodes, each consisting of three steel rods 18 in. (45 cm) long and 18 in. (45 cm) apart were inserted into the soil to a depth of nearly 18 in. (45 cm) and 3 ft (0·91 m) apart. Current from a portable 220-V, 50-cycle generator was supplied to the electrodes and this brought worms to the surface. Only earthworms emerging between the electrodes (9 ft²; 0·83 m²) were collected, and stored in 5% formalin until they could be identified. However, the efficiency of extraction of worms seemed to be directly related to pH of the soil, so the method was not used for subsequent sampling.

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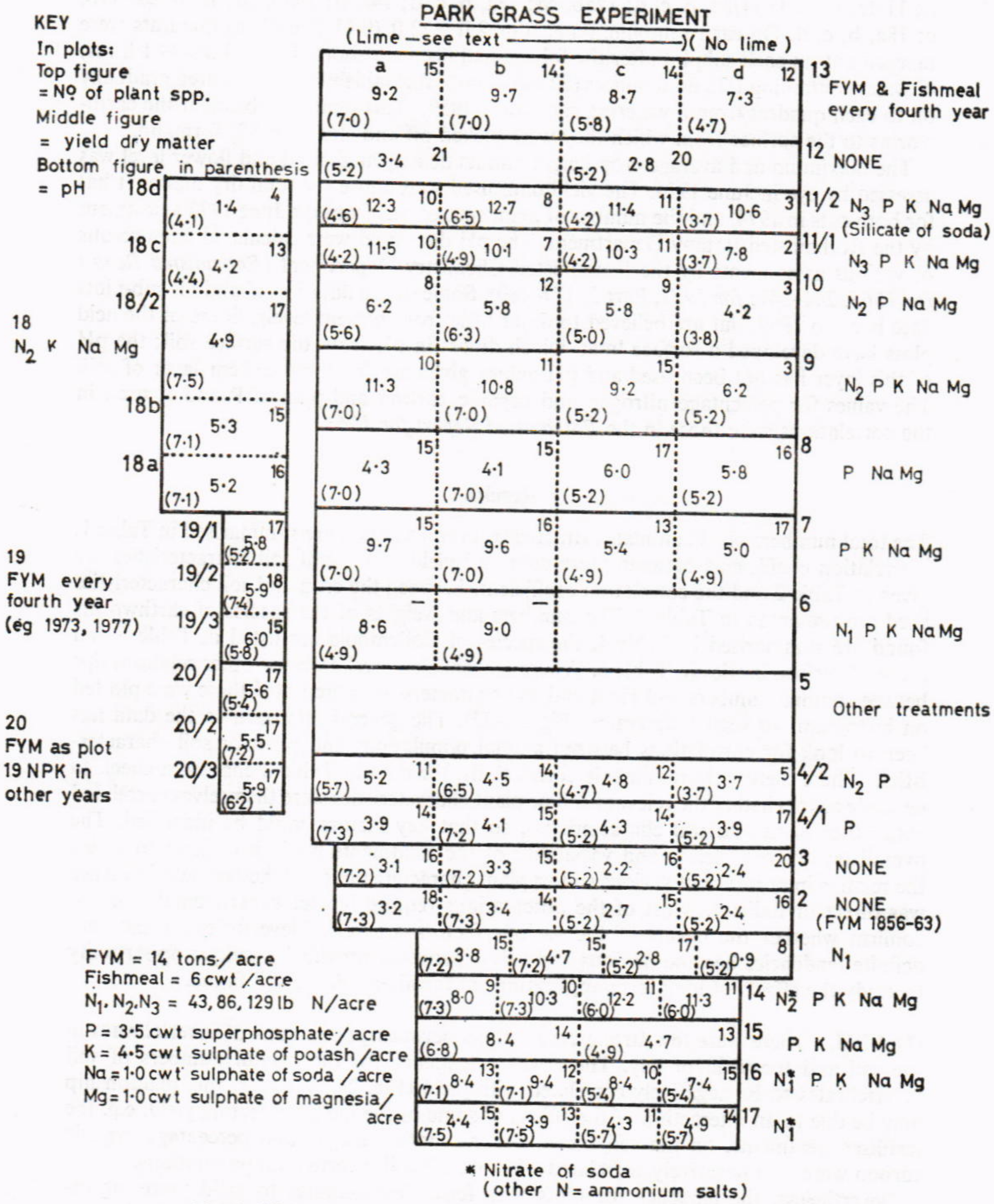

FIG. 1. Yields (1974), pH and numbers of plant species on Park Grass.

Earthworm populations were sampled again in April 1973 and May 1974, this time in plots 1a, b, c, d; 2ab, cd; 3ab, cd; 4/1ab, cd; 4ab, cd; 7c, d; 8c, d; 9a, b, c, d; 10a, b, c, d; 11/1a, b, c, d; 11/2a, b, c, d; 12ab, cd; 13a, b, c, d; 14a, d; 15ab, cd; 16ab, cd; 17b, c; 18a, b, c, d. On each sampling date, four 2 ft × 2 ft (0·61 × 0·61 m) quadrats were marked out on each subplot after the foliage had been cut short. Two gallons (9·1 litres) of water containing 1·76 fluid ounces (50 ml) of 40% formaldehyde were poured gradually on to each quadrat from a watering can (Raw, 1959). This treatment brought the earthworms to the surface from which they were picked off and stored in 5% formalin.

The maximum and average crop height and its density at ground and flower level was assessed by eye in June 1974. The yield data used were those for total dry matter (t/ha) for both cuts in 1974, and the number of plant species was from the June 1973 assessment by the Rothamsted Botany Department. The pH data used were calculated from results of various assessments by the Rothamsted Chemistry Department (*Rothamsted Report for 1963*, 244–247; *for 1971*, Part 2, 177–180). Some of the data for 'a' and 'd' sub-plots date back to 1959, but are believed to differ little from present levels. Some of the acid plots have developed a surface 'mat' which differs in pH from the surface soil; the pH of this layer has not been used and pH values given are for the 0–7·5 cm layer of soil. The values for percentage nitrogen and organic carbon and ppm of P and K used in the correlations were those in the *Rothamsted Report for 1963*.

Results

The total numbers of soil animals extracted from soil samples are summarised in Table 1. Correlation coefficients between these data and yield, plant and soil characteristics are given in Table 2 and the correlation coefficients between the crop and soil characteristics used are presented in Table 3. The numbers and weights of the species of earthworms found are summarised in Table 4, the species of Collembola are listed in Table 5 and those of surface beetles in Table 6. Where reasonable correlations or other relationships between animal numbers and plant and soil characteristics were noted these were plotted on histograms or scatter diagrams (Figs. 2–32). The general approach to the data has been to look for correlations between animal populations and plant or soil characteristics. Where there were reasonable correlations, the data in Table 3 enabled a check to be made as to whether the relevant soil or plant characteristics were themselves correlated with other plant and soil characteristics, so that key factors could be identified. The overall layout, complexity and variability of the treatments made it difficult to assess the relative importance of various soil or plant characteristics and whether their influence was direct or indirect. Most of the observations require further experimental work to confirm whether the effects of the various factors are real. Nevertheless, some very definite tendencies became obvious and this experiment provided a unique opportunity to study the effects of long-term applications of fertilisers on the soil fauna.

(1) Yield. There were few strong correlations between populations of invertebrates in the soil and the yield of hay. There was a tendency for the overall numbers of soil invertebrates to be negatively correlated with yield (Fig. 2). However, this relationship may be due to an interaction of the effects of some of the factors affecting yield, e.g. the fertiliser treatments, on the soil fauna, because both nitrogen and percentage organic carbon were also negatively correlated with overall soil invertebrate populations.

Nevertheless, the tendency for plots with fewer invertebrates to yield more, agrees well with findings that suppression of soil invertebrate populations by pesticides can increase yields of hay on both leys and old grassland by as much as 30% (Henderson, 1974), and would support the conclusion that soil invertebrates lower the yield of

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TABLE 2

Correlation coefficients between crop and Soil characteristics and soil animal populations

		June	September		June 1974								
		Yield 1st cut (t/ha)	Yield 2nd cut (t/ha)	Yield both cuts (t/ha)	Maximum crop height (cm)	Average crop height (cm)	Crop density (%)	No. of plant species	pH	Soil N (%)	Soil P (ppm)	Soil K (ppm)	Soil carbon (%)
Acarina	Trombidiformes	0·2285	−0·1037	0·1307	−0·0858	0·0355	−0·1882	0·1772	−0·1845	0·0307	0·2954	0·0603	0·1648
	Gamasina	−0·1642	−0·4324	−0·2699	−0·2142	−0·1799	−0·2237	−0·2674	−0·2325	−0·0517	0·1785	−0·2374	−0·0055
	Rhodacaridae	−0·3066	0·1013	−0·1885	−0·0203	−0·3110	0·4107	0·5119	0·6394	−0·2651	−0·5174	0·0831	−0·4734
	Uropodina	−0·3547	−0·2647	−0·3507	−0·2398	−0·3361	−0·0410	0·2504	0·1962	−0·1899	−0·2534	−0·0696	−0·2510
	Tyroglyphidae	−0·1716	−0·0228	−0·1331	−0·0762	−0·1672	0·0277	0·0662	−0·1002	−0·3050	0·1075	0·4583	−0·3154
	Oribatidae	−0·3353	−0·5180	−0·4245	−0·5440	−0·4156	−0·0740	−0·0820	−0·0751	0·2703	0·2645	−0·4631	0·2114
	Total Acarina	−0·2781	−0·4169	−0·3476	−0·4566	−0·4243	−0·0456	0·1736	−0·0299	−0·0086	0·2339	−0·0922	−0·0365
Collembola	Onychiuridae	0·1244	0·4096	0·2330	0·3702	0·1197	−0·0247	0·3731	0·3827	−0·3018	−0·2827	0·3649	−0·3668
	Poduridae	0·1573	−0·1947	0·0472	−0·0800	−0·0756	0·0919	0·2318	−0·1671	0·0158	0·2004	−0·0864	0·0486
	Isotomidae	−0·2937	−0·2684	−0·3075	−0·0396	−0·2235	0·0450	0·1418	0·0968	−0·2806	−0·2506	0·0429	−0·3503
	Entomobryidae	−0·3642	−0·3980	−0·4039	−0·2721	−0·2962	−0·1384	−0·0237	0·0071	−0·2524	−0·2998	−0·1078	−0·2929
	Sminthuridae	0·2828	0·3743	0·3363	0·3260	0·2471	0·1633	0·4321	0·3533	−0·1437	−0·1997	0·1235	−0·1527
	Total Collembola	−0·1108	−0·0446	−0·0963	0·1205	−0·1061	0·0559	0·3367	0·2254	−0·3335	−0·2855	0·1529	−0·4023
Myriapoda	Symphyla	−0·2019	0·0648	−0·1248	0·0018	−0·1564	−0·0714	0·2618	0·0605	−0·4030	−0·0752	−0·1597	−0·4808
	Pauropoda	−0·3399	0·1031	−0·2122	−0·0072	−0·2337	−0·1823	0·4920	0·5500	0·0441	−0·2415	0·1140	−0·1516
	Chilopoda	−0·1216	0·2387	−0·0058	0·1213	−0·0150	−0·0078	0·2993	0·1575	−0·3879	−0·0919	0·5779	−0·4697
	Total Myriapoda	−0·2189	0·2512	−0·0725	0·1172	−0·0895	−0·0676	0·4287	0·2668	−0·4302	−0·1573	0·3428	−0·5649
	Enchytraeidae	−0·5412	−0·1731	−0·4549	−0·1183	−0·3629	−0·0259	0·5357	0·5960	−0·0264	−0·5980	−0·1853	−0·2800
	Nematoda	−0·1059	0·1846	−0·0132	0·1363	−0·0252	−0·1049	0·4425	0·7103	0·3137	−0·2608	−0·0705	0·0587
	Protura	−0·2041	0·1750	−0·0881	0·0454	−0·1292	−0·1331	0·4052	0·5302	0·0704	−0·1764	0·2402	−0·1291
Insecta	Thysanoptera	−0·2194	−0·0186	−0·1665	−0·0615	−0·0791	0·2457	0·2142	0·0645	−0·0991	−0·3853	−0·1440	−0·1963
	Hemiptera	0·3838	0·2568	0·3692	0·2829	0·1096	0·0438	−0·0360	0·1027	−0·4361	−0·1519	0·3511	−0·2706
	Hymenoptera	0·0661	0·1857	0·1127	0·1398	0·1269	−0·1654	0·1398	0·1046	0·0958	−0·0246	0·0025	−0·0127
	Coleoptera larvae (except wireworms)	−0·0012	0·2027	0·0695	0·2337	0·0923	−0·0090	0·0984	0·0186	−0·4386	−0·0728	0·4589	−0·4704
	Wireworms	−0·4820	−0·1791	−0·4138	−0·0669	−0·3065	−0·0291	0·1965	0·1253	−0·2790	−0·2165	−0·2439	−0·4435
	Total Coleoptera larvae	−0·2304	0·0855	−0·1384	0·1651	−0·0681	−0·0214	0·1764	0·0753	−0·5023	−0·1644	0·2705	−0·6074
	Diptera	−0·1832	0·0945	−0·1008	0·1697	−0·0038	−0·1671	0·1519	0·2263	−0·1337	−0·3535	−0·0713	−0·2749
	Earthworms	—	—	−0·1609	—	—	—	0·6416	0·2722	−0·2084	−0·4251	−0·2458	−0·3680
	Total fauna	−0·3034	−0·3621	−0·3471	−0·3391	−0·4253	−0·0312	0·3273	0·1200	−0·1614	0·0529	0·0013	−0·2265

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TABLE 3

Correlation coefficients between plant and soil characteristics

	June	September		June 1974								
	Yield 1st cut (t/ha)	Yield 2nd cut (t/ha)	Yield both cuts (t/ha)	Maximum crop height (cm)	Average crop height (cm)	Crop density (%)	No. of plant species	pH	Soil N (%)	Soil P (ppm)	Soil K (ppm)	Soil carbon (%)
Yield 1st cut (t/ha)	0·0000											
Yield 2nd cut (t/ha)	0·6855	1·0000										
Yield both cuts (t/ha)	0·9675	0·8473	1·0000									
Maximum crop height (cm)	0·7276	0·8784	0·8358	1·0000								
Average crop height (cm)	0·8270	0·7764	0·8729	0·8563	1·0000							
% crop density	−0·1186	−0·1875	−0·1516	−0·2408	−0·3191	1·0000						
No. of plant species	−0·2904	−0·0321	−0·2230	−0·1289	−0·2943	0·2920	1·0000					
pH	−0·1041	0·3118	0·0323	0·2271	−0·0781	0·0985	0·4606	1·0000				
Soil N%	0·1679	0·0720	0·1475	−0·0352	0·1803	−0·2578	−0·1796	0·0957	1·0000			
Soil P (ppm)	0·4188	0·0595	0·3262	−0·0252	0·1969	−0·2132	−0·4342	−0·5346	0·4507	1·0000		
Soil K (ppm)	0·5297	0·5857	0·5898	0·5032	0·3939	−0·0546	−0·0720	0·0826	−0·1454	0·1808	1·0000	
Soil carbon %	0·3671	0·0784	0·2951	−0·0283	0·2989	−0·2182	−0·3579	−0·1956	0·8964	0·6262	−0·0637	1·0000

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TABLE 4

Comparative numbers and weights of earthworms sampled 1973–74

Treatment	Plot No.	Numbers: *Allolobophora nocturna* Evans	Numbers: *Allolobophora caliginosa* (Savigny)	Numbers: *Allolobophora rosea* (Savigny)	Numbers: *Octolasium cyaneum* (Savigny)	Numbers: Total (species other than *L. terrestris*)	Numbers: *Lumbricus terrestris* Linnaeus	Number of species	Weights: *L. terrestris*	Weights: Other species	Totals (all samples): Number	Totals (all samples): Weight	Totals/m²: Number	Totals/m²: Weight
N_1	1a	0	14	12	2	23	44	4	82·4	10·8	67	93·2	23	31·4
	b	1	0	2	0	3	58	3	91·8	0·3	61	92·1	21	31·0
	c	0	11	3	0	18	40	6	50·2	6·0	58	56·2	20	18·9
	d	0	0	0	0	0	0	0	0·0	0·0	0	0·0	0	0·0
None	2ab	0	1	7	2	12	99	5	106·2	3·8	111	110·0	37	37·0
	cd	2	9	42	27	81	52	6	95·9	29·6	133	125·5	45	42·2
None	3ab	0	2	5	1	11	81	5	141·8	1·2	92	143·0	31	48·1
	cd	3	1	26	8	42	74	6	122·1	19·0	116	141·2	39	47·5
P	4/1ab	2	6	14	10	35	65	6	147·8	9·5	100	157·3	34	53·0
	cd	1	22	8	23	55	54	6	97·7	28·2	109	125·9	37	42·3
N_2P	4/2a	10	7	0	10	27	30	4	31·1	17·8	57	48·9	19	16·5
		3	12	0	6	25	22	5	59·1	15·1	47	74·2	16	25·0
		3	29	9	1	65	40	7	48·6	19·1	105	67·7	35	22·8
		0	0	0	0	0	0	0	0·0	0·0	0	0·0	0	0·0
PK	7c	2	1	15	0	25	53	5	83·1	15·1	78	98·2	26	33·1
	d	3	6	3	6	20	45	7	72·8	13·1	65	85·9	22	28·9
PNaMg	8c	3	5	4	28	40	62	5	130·4	33·9	102	164·3	34	55·3
	d	11	3	1	36	52	100	6	172·2	45·9	152	218·1	51	73·4
N_2PKNaMg	9a	1	1	0	1	3	27	4	50·2	3·3	30	53·5	7	18·0
	b	0	1	3	0	4	21	3	62·5	0·4	25	62·9	8	21·2
	c	1	15	0	7	36	52	5	70·2	18·6	88	88·8	30	29·9
	d	0	0	0	0	0	0	0	0·0	0·0	0	0·0	0	0·0
N_2PNaMg	10a	9	4	2	5	21	32	5	53·9	16·1	53	70·0	18	23·6
	b	8	4	3	5	21	48	7	97·9	12·2	69	101·1	23	37·1
	c	4	6	1	5	26	48	6	84·7	21·6	74	106·3	25	35·7
	d	0	0	0	0	0	0	0	0·0	0·0	0	0·0	0	0·0
N_3PKNaMg	11/1a	3	2	2	4	11	40	5	61·3	13·1	51	74·4	17	25·1
	b	2	0	3	5	11	46	4	61·9	12·5	57	74·4	19	25·1
	c	0	2	1	5	11	33	5	69·0	8·5	44	77·5	15	26·1
	d	0	0	0	0	0	0	0	0·0	0·0	0	0·0	0	0·0
N_3PKNaMg (silicate of soda)	11/2a	8	0	0	2	10	35	2	44·1	12·1	45	56·2	15	18·9
	b	7	3	4	5	21	76	6	112·9	13·4	97	126·3	33	42·5
	c	0	2	0	3	9	41	3	45·7	3·9	50	49·6	16	16·7
	d	0	0	0	0	0	0	0	0·0	0·0	0	0·0	0	0·0
None	12a	22	10	7	28	67	14	7	24·3	41·2	81	65·5	27	22·1
	b	37	23	17	49	124	50	6	77·0	93·1	174	170·1	59	57·2
	c	38	26	17	110	81	36	6	64·7	121·3	117	186·0	39	62·6
	d	27	14	2	16	59	18	7	39·3	44·5	77	83·8	26	28·2
FYM and fishmeal	13a	33	9	5	0	51	80	5	144·5	52·1	131	196·6	44	66·1
	b	32	13	17	3	68	60	7	85·5	46·4	128	131·9	43	44·4
	c	48	37	8	16	113	79	7	134·3	92·9	192	227·2	65	76·5
	d	63	8	7	51	129	74	5	114·2	125·3	203	239·5	68	80·6
N_2*PKNaMg	14a	4	8	1	1	15	51	5	75·4	21·5	66	96·9	22	32·6
	d	0	11	1	1	13	29	4	41·2	4·5	42	45·7	14	15·4
PKNaMg	15ab	1	14	3	0	18	71	4	104·5	3·8	89	108·3	30	36·5
	cd	0	2	3	13	17	40	4	72·1	6·8	57	78·9	19	26·6
N_1*PKNaMg	16ab	0	2	3	1	5	37	4	59·3	0·9	42	60·2	14	20·3
	cd	0	11	2	14	29	28	5	44·3	11·2	57	55·5	19	18·7
N_1*	17b	0	5	8	1	15	52	5	95·0	3·8	67	98·8	23	33·3
	c	3	14	27	11	57	83	7	125·4	16·7	140	142·1	47	47·8
N_2KNaMg	18a	0	3	3	0	6	67	3	144·6	1·9	73	146·5	25	49·3
	b	0	2	1	10	13	71	4	144·8	1·4	84	146·2	28	49·2
	c	3	28	2	6	52	63	7	82·9	22·9	115	105·8	39	16·6
	d	0	0	0	0	0	0	0	0·0	0·0	0	0·0	0	0·0

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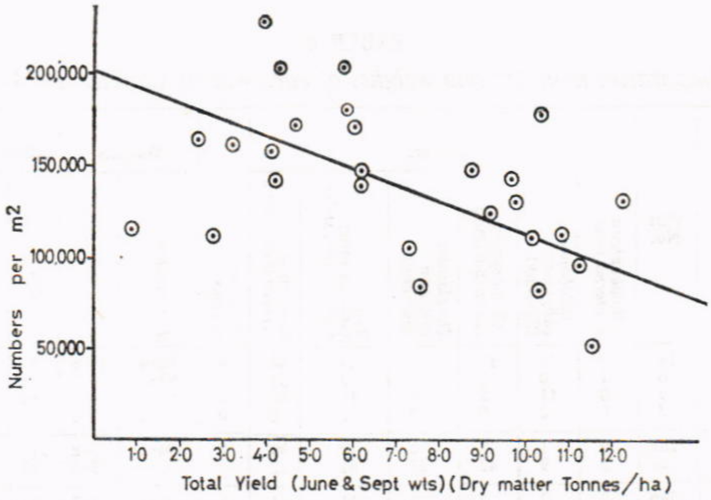

FIG. 2. Relationship between total numbers of invertebrates and yield.

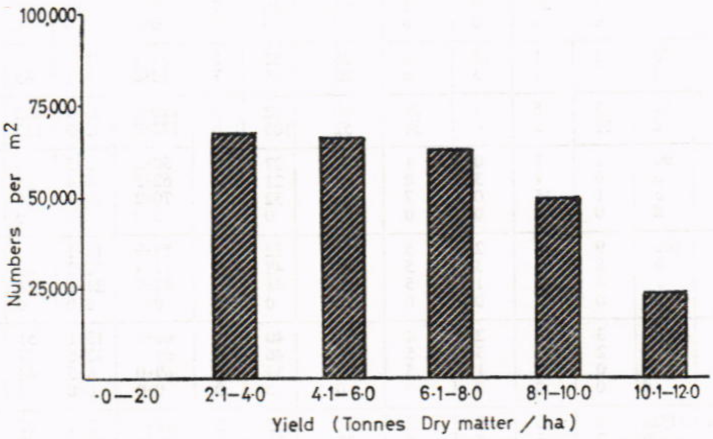

FIG. 3. Relationship between numbers of oribatid mites and yield.

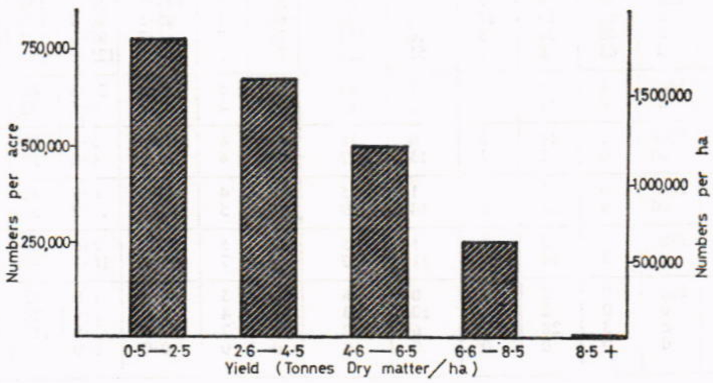

FIG. 4. Relationship between numbers of wireworms and yield.

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grassland. The only individual groups of soil invertebrates that showed any correlation with yield were the oribatid mites (Fig. 3), enchytraeid worms, and wireworms (Fig. 4) and populations of these animals were all negatively correlated with yield. It is difficult to postulate any reason why oribatid mite or enchytraeid worm populations should be related to yield, because these animals feed mainly on decaying organic matter and it might be expected that those plots that yielded most would have the most soil organic matter. The most obvious implication of wireworm populations negatively correlated with yield is that wireworms were causing loss of yield, because they are quite important pests of grassland. However, the maximum populations recorded in Park Grass of just over three-quarters of a million wireworms/acre (approx. 1¾ million/ha) are rather less than average for old grassland and although they would decrease yield it is certain that they could not cause such a marked fall in yield and there must be other contributory factors.

(2) Nitrogen level. One of the main features of the Park Grass experiment was the use of three levels of nitrogen on certain plots. Of the plots sampled, 8, 7 and 2 received no nitrogen, 1 and 17 received 43 lb/acre (48·0 kg/ha) (N_1), 9, 10 and 14 86 lb (96·0 kg/ha) (N_2) and 11/1 129 lb (144·0 kg/ha) (N_3) of nitrogen. The influence of these different nitrogen levels on soil invertebrate populations was assessed by calculating average numbers from all subplots and all treatments for each nitrogen level and comparing these for the various groups of invertebrates (Figs. 5–15). It should be noted that it is the level of nitrogen applied annually that is important, not the residual amounts in the plots which assess the level at only a single point in time. Of the factors studied, the effect of nitrogen was most likely to be a direct influence of the fertiliser because the amount of nitrogen applied was not itself strongly correlated with any of the other plant or soil characteristics (Table 2).

First, there was an overall deleterious effect of the nitrogen level on the total invertebrate populations (Fig. 5), the triple dose (N_3) having the greatest effect. This relationship was unexpected although there is some evidence that nitrogenous fertilisers have adverse effects on soil invertebrates.

The influence of nitrogen level on enchytraeid worms (Fig. 6) and lumbricid worms (Fig. 7) was very dramatic. The lowest dose of nitrogen had little effect on enchytraeid worms but the two higher doses greatly depressed their numbers. Populations of all species of earthworms were decreased by nitrogen, but the effects on *Lumbricus terrestris* were much less than on the other species. It has been suggested that ammonium sulphate as a fertiliser is particularly harmful to earthworms (Escritt & Arthur, 1948; Rodale, 1948; Jefferson, 1955) so the data was calculated in another way, so as to distinguish earthworm populations in plots treated with ammonium sulphate from those in plots to which sodium nitrate was applied (Fig. 8). It can be seen that the nitrate nitrogen applications were nearly as deleterious to earthworm populations as was ammonium nitrogen. By contrast, the organic fertiliser increased the numbers of earthworms.

Myriapod populations were also influenced by the level of nitrogen applied to the grass (Fig. 9). Chilopoda (centipedes) were the most sensitive, being almost completely eliminated from plots regularly treated with a triple dose of nitrogen (N_3); Symphyla and Pauropoda were also considerably decreased in numbers, with the Diplopoda (millipedes) being least affected. The effect of nitrogen level on soil mites (Fig. 10) was much less marked than on oligochaetes, numbers of prostigmatic mites being decreased much less than those of mesostigmatid, cryptostigmatid or astigmatid mites. There was an apparent increase in total numbers of mites and numbers of prostigmatic mites in plots receiving a double dose (N_2) of nitrogen but this was largely due to large increases in numbers of prostigmatid mites in a single subplot (9c) (Table 1).

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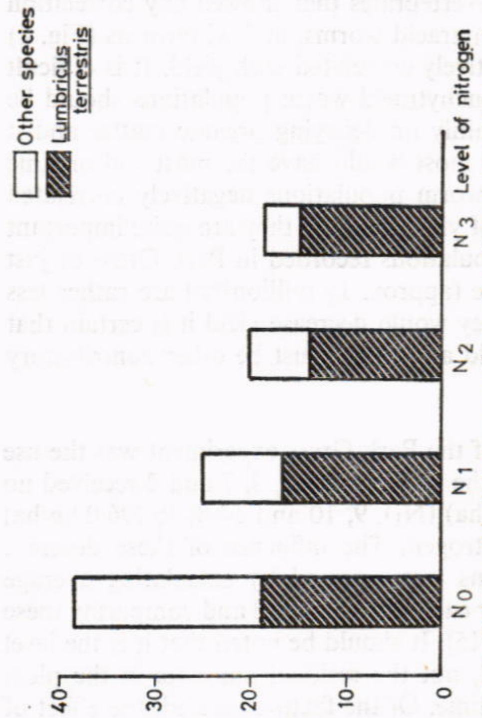

FIG. 7. Relationship between numbers of earthworms and level of nitrogen.

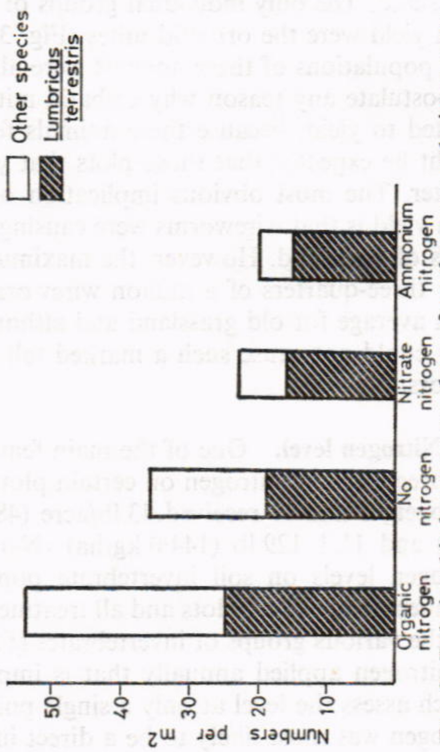

FIG. 8. Relationship between numbers of earthworms and nitrogenous fertilisers.

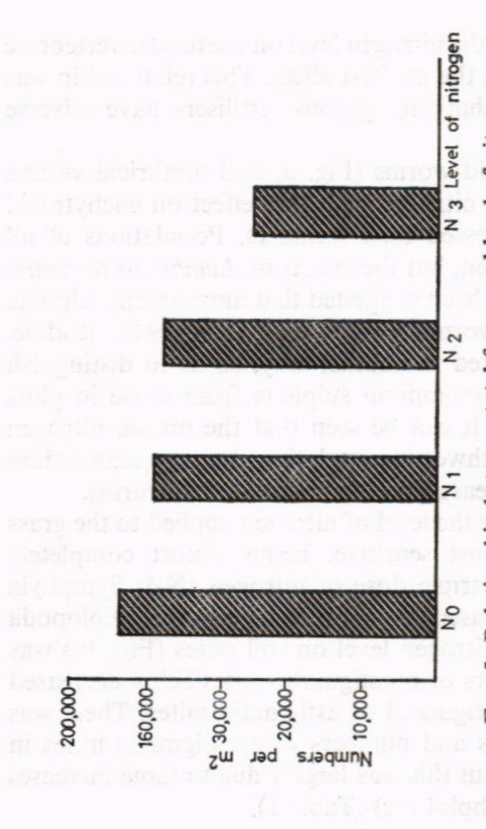

FIG. 5. Relationship between total fauna and level of nitrogen.

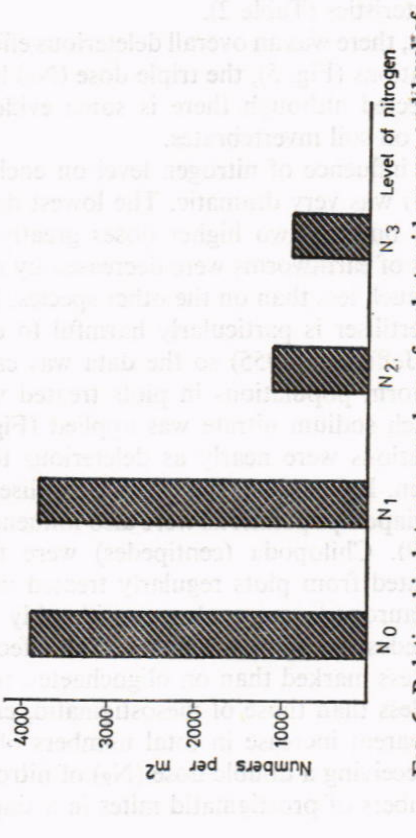

FIG. 6. Relationship between numbers of enchytraeid worms and level of nitrogen.

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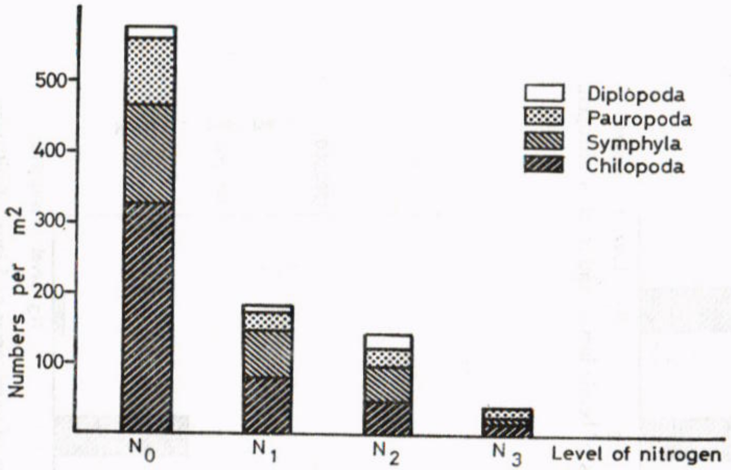

FIG. 9. Relationship between numbers of myriopods and level of nitrogen.

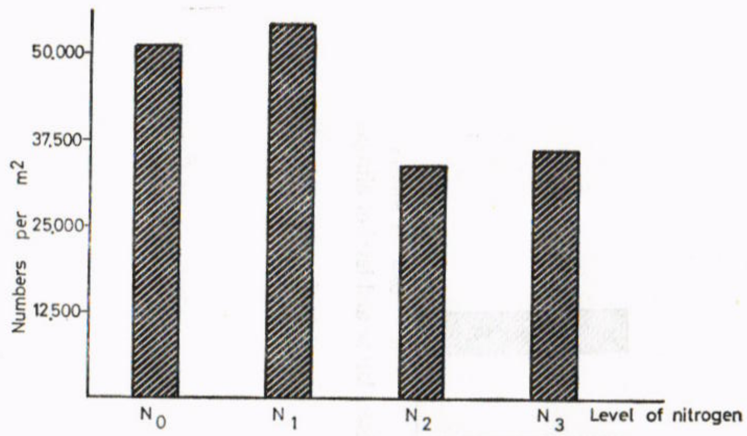

FIG. 11. Relationship between numbers of Collembola and level of nitrogen.

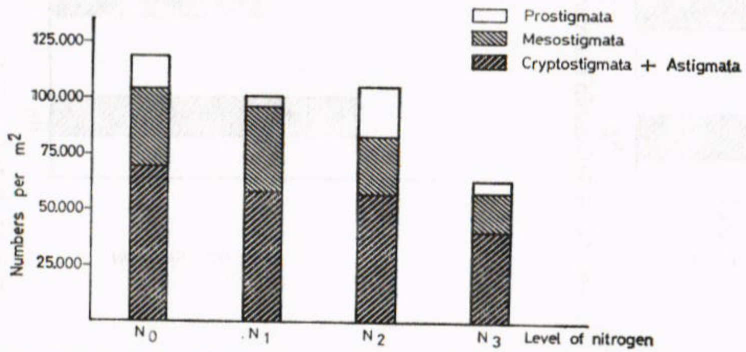

FIG. 10. Relationship between numbers of mites and level of nitrogen.

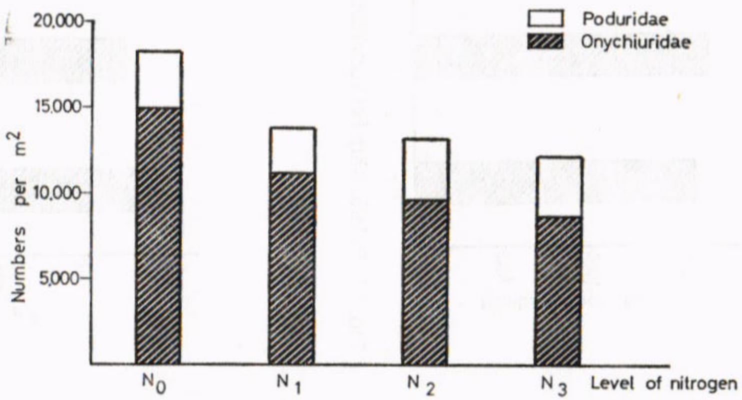

FIG. 12. Relationship between numbers of soil-living Collembola and level of nitrogen.

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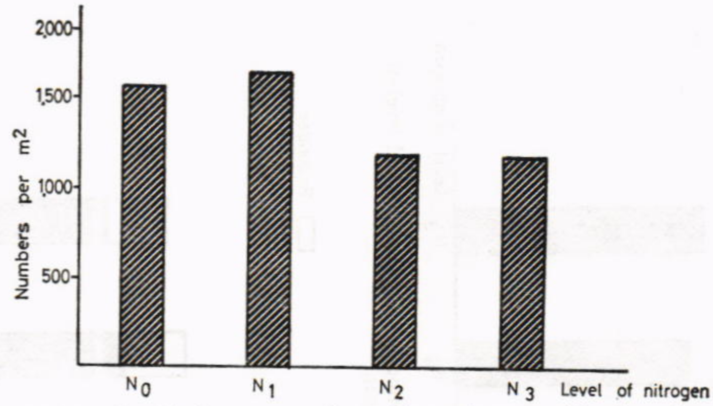

FIG. 13. Relationship between numbers of insect larvae and level of nitrogen.

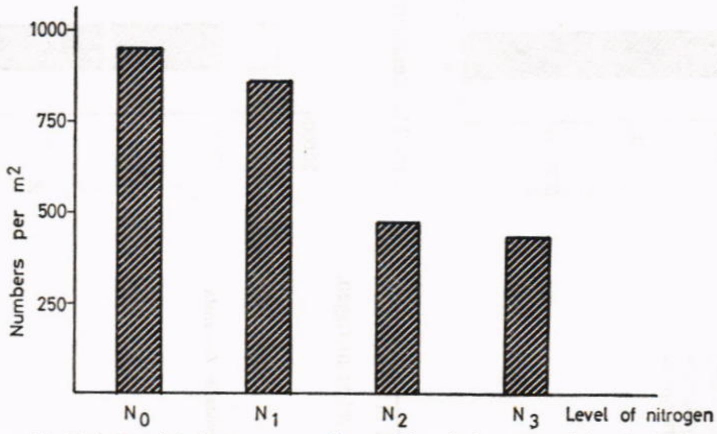

FIG. 14. Relationship between numbers of beetle larvae and level of nitrogen.

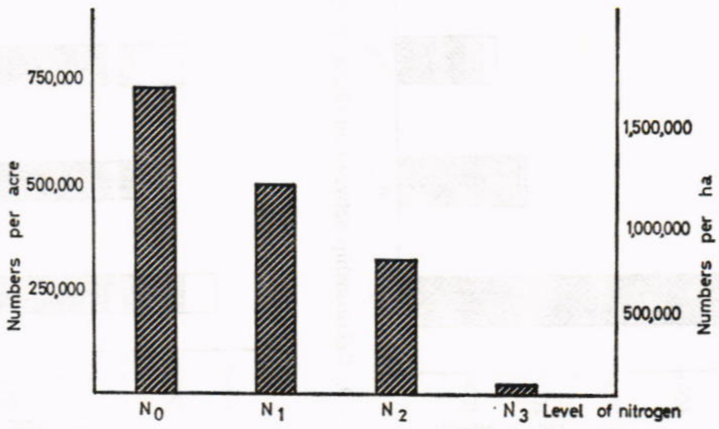

FIG. 15. Relationship between numbers of wireworms and level of nitrogen.

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Total Collembola (springtail) populations were not greatly affected by the level of nitrogen (Fig. 11), in fact, there was a slight increase in response to a single dose (N_1) of nitrogen. However, numbers of soil-living springtails (Onychiuridae and Poduridae) (Fig. 12) were decreased much more than those that live near the soil surface (Isotomidae, Entomobryidae and Sminthuridae).

Soil-inhabiting insect larvae taken together were not greatly decreased in numbers by the level of nitrogen applied (Fig. 13); in fact, more were recorded in plots that received a single dose than in those that were not treated. However, the total beetle larvae populations were very considerably depressed by nitrogen applications (Fig. 14) particularly by the two higher levels. In particular, the numbers of wireworms (Fig. 15) were extremely sensitive to the amount of nitrogen applied with very low numbers of wireworms occurring in plots that received the largest amount of nitrogen.

The observation that nitrogenous fertilisers can be harmful to populations of soil-inhabiting invertebrates is a most interesting and important one. The only reports of the effects of nitrogen on populations of these animals are by Huhta *et al.* (1967, 1969), Abrahamsen (1970) and Axelsson *et al.* (1973) and these workers all investigated the effects of one to three applications of fertiliser on the soil fauna of pine forests. Huhta *et al.* reported that 90 kg NPK fertiliser/ha (undefined) decreased numbers of soil animals for one year; thereafter there was a considerable increase, especially in enchytraeid and springtail populations. Abrahamsen studied the effects of 100, 400 and 1600 kg of nitrogen/ha (urea) and also reported an initial decrease, but his results were somewhat conflicting. Axelsson *et al.* in a much more thorough investigation, demonstrated clearly that when pine woodland was treated either with 60, 60 or 40 kg/ha ammonium nitrate (N_1) in three consecutive years and 180, 180 or 120 kg/ha ammonium nitrate (N_3) in the same years, there were decreases in populations of some soil animals, especially mites, springtails and enchytraeid worms, compared with those in untreated plots and corresponding with the level of nitrogen applied. Numbers of most of the microarthropods studied were affected by the largest doses of nitrogen. These data support the conclusions we reached from the sampling of Park Grass that nitrogenous fertilisers can be harmful to soil-inhabiting invertebrates. It seems probable that an extremely long period of exposure to repeated but small doses may depress populations as much as one or two much higher doses.

(3) pH. Since 1903, half of most of the plots have received regular treatments of lime and since 1965 these have been further subdivided and given different lime treatments. The resultant changes in pH have had considerable influence on populations of soil-inhabiting invertebrates. It seems probable that the effects are direct ones, because pH is not strongly correlated with any of the other soil or plant characteristics we studied, with the possible exception of floral diversity (Table 3).

The overall influence of pH on the total fauna is not great (Fig. 16) although there is a tendency for plots with a higher pH to support more soil animals.

The methods that were used for extracting invertebrates from soil were unsuitable for nematodes or enchytraeid worms. Nevertheless, sufficient numbers of these animals occurred in the extracts to indicate tentatively how pH affects them. Enchytraeid worms were strongly influenced by pH, with a linear increase in numbers up to a pH of 7·5 (Fig. 17). Numbers of nematodes were too small for the effects to be statistically significant but there were very few in plots with a pH below 4·0 and an almost linear increase with increasing pH.

The data on earthworms were based on two sets of samples in 1973 and 1974 and hence demonstrate more marked effects. Moreover, the effect of pH on earthworms has been studied more than its effect on other invertebrates. Not all species of earthworms

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reacted to pH in the same way but none of the species found in Park Grass could tolerate a pH below 4·0 (Figs. 18 and 19). *Lumbricus terrestris* became gradually more numerous as the pH increased from 4·0–7·5 but the other species (Table 4) tended to have an optimum pH range at 5·0–6·0, markedly decreasing in numbers at pH's on either side of this optimum. Richardson (1938) counted the numbers of wormcasts on the Park Grass plots, but this is evidence of the presence of only one species, *Allolobophora nocturna*, and is an inaccurate measure of populations since it depends on activity as well as numbers. In general, he found fewer casts on the unlimed halves of the plots than the limed halves, and plots 9 and 14 had fewer casts than did 3, 7, 12 and 13. In particular, the unlimed half of plot 9 had no casts. This agrees with the very few (2) individuals of *A. nocturna* that we found in plot 9 and there was good agreement when we plotted the number of casts reported by Richardson against the numbers of worms we found in the same plots that he sampled. The very good correlation showed that relative numbers have not changed greatly in the last 36 years. Satchell (1953) studied earthworms in Park Grass using an electrical extraction method. Whereas he found the lower pH tolerance limit for *A. caliginosa*, *A. nocturna*, *A. rosea* to be 4·6 and for *L. terrestris* and *Octolasium cyaneum* to be 4·1, we found that the lower limit for all these species was 4·2. At a pH of 4·1 there were no *L. terrestris*. Satchell (1955) considered *O. cyaneum* to be relatively acid-tolerant but we found this species to be absent from very acid plots. However, some of the discrepancies may be explained by the relative inefficiency of his electrical method for sampling earthworms. We found that soil resistance varied with pH and this greatly influenced the efficiency of extraction.

There was no direct correlation between myriapod populations and pH (Fig. 20), the relationship being modal. Numbers of Chilopoda (centipedes) and Symphyla were much larger between 5·0 and 6·0 than at higher or lower pH's and none of these animals occurred at a pH below 4·0. Pauropoda tended to be tolerant of pH over the range 4·0–7·0, no consistent trend being obvious.

The overall influence of pH on mite populations was slight (Fig. 21). They could tolerate the soil conditions even in the most acid plots. In particular, numbers of prostigmatid mites (Fig. 22) tended to increase at pH's between 4·0 and 5·0. Mesostigmatid mites were progressively more numerous as the pH increased (Fig. 23), but nevertheless could tolerate acid conditions. Cryptostigmatid and astigmatid mites were most numerous in the acid plots (Fig. 24) but this is not surprising, because these mites are common in acid woodland mor soils.

Collembola (springtails) as a whole, were influenced by soil pH more than mites (Fig. 25) and, in particular, those species living below the soil surface (Poduridae and Onychiuridae) (Fig. 26) were much more numerous in soils with a nearly neutral pH whereas populations of those species that live on or near the soil surface (Entomobryidae, Sminthuridae and Isotomidae) (Fig. 27) differed little in plots with pHs ranging from 4·0–8·0.

Protura seemed to be much more limited by soil pH than most other invertebrates, very few occurring in plots with a pH less than 7·0 (Fig. 28). These results do not differ greatly from those reported by Raw (1959), although he recorded more of these animals in plots with pH lower than 7·0 than we did.

Insects (Fig. 29) and wireworms (Fig. 30) seemed to be more numerous in plots with a pH between 4·0 and 7·0, i.e. very acid or alkaline soils did not support large numbers of these arthropods.

(4) Flora and other factors. The flora of the Park Grass Plots differs greatly with the treatments. Hence, there is a possibility that some invertebrates in soil might tend to be correlated with some species, families, or associations of plants. Unfortunately the only

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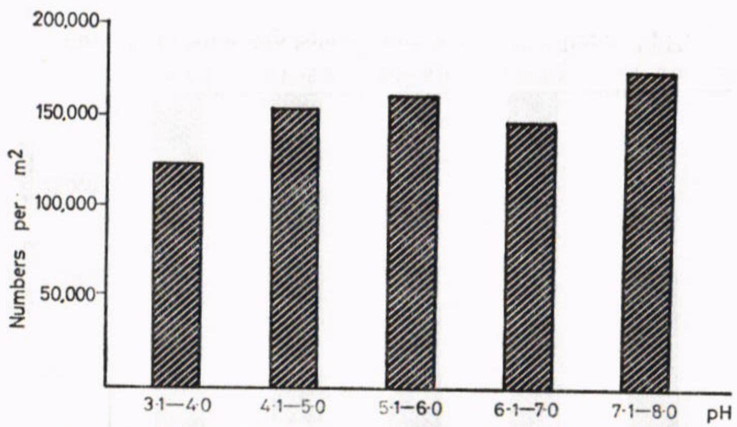

FIG. 16. Relationship between numbers of total fauna and pH.

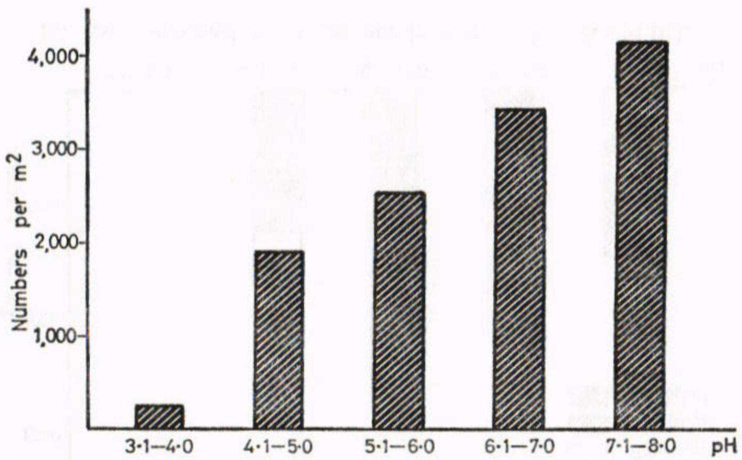

FIG. 17. Relationship between numbers of enchytraeid worms and pH.

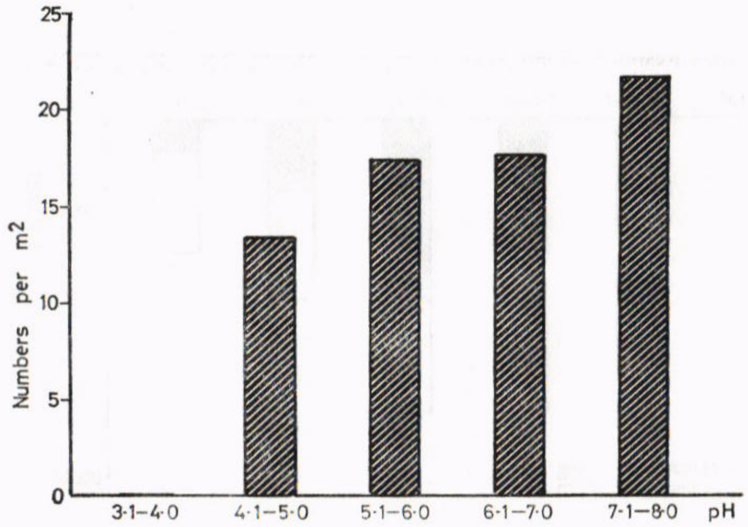

FIG. 18. Relationship between numbers of *L. terrestris* and pH.

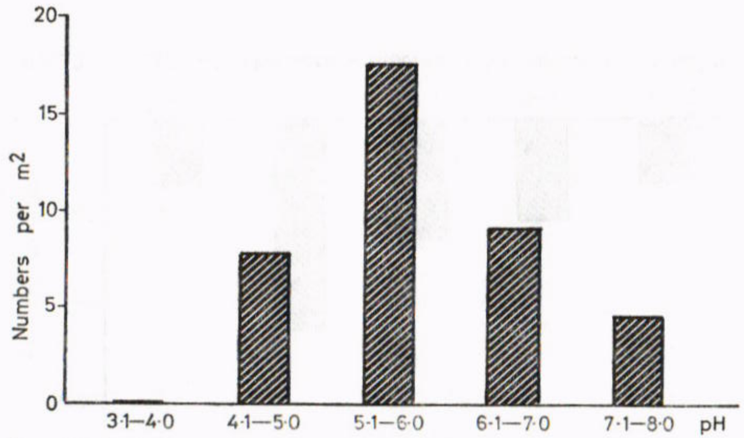

FIG. 19. Relationship between numbers of earthworms (other than *L. terrestris*) and pH.

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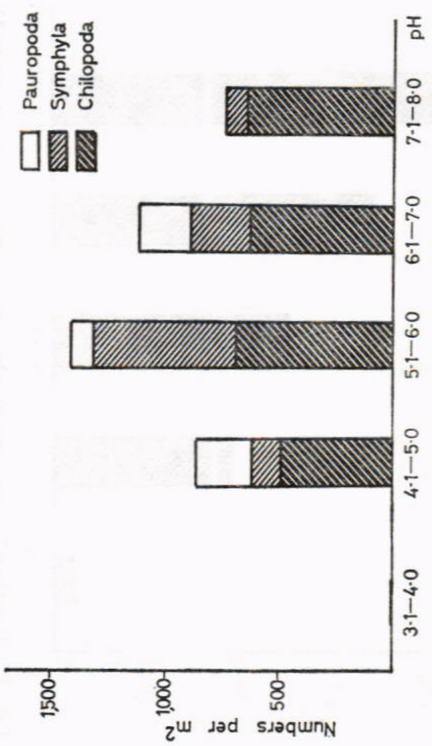

FIG. 20. Relationship between numbers of myriapods and pH.

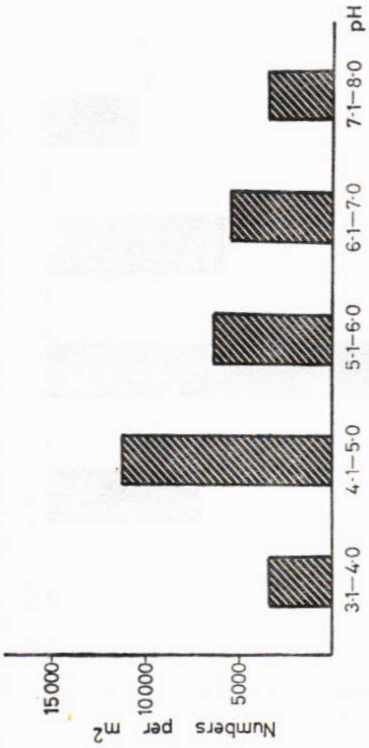

FIG. 22. Relationship between numbers of prostigmatid mites and pH.

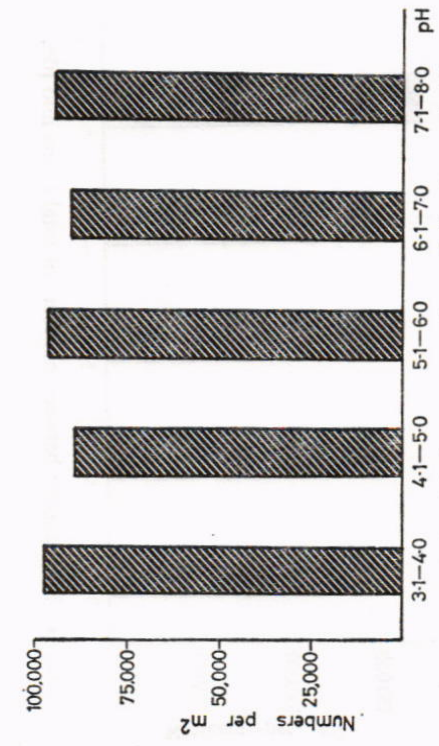

FIG. 21. Relationship between numbers of all mites and pH.

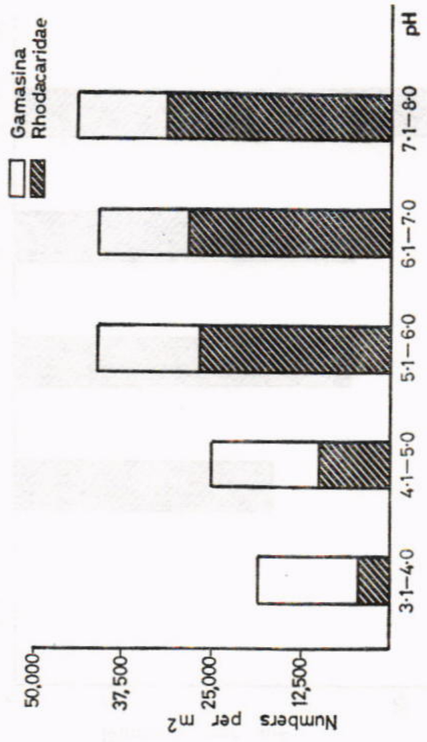

FIG. 23. Relationship between numbers of mesostigmatid mites and pH.

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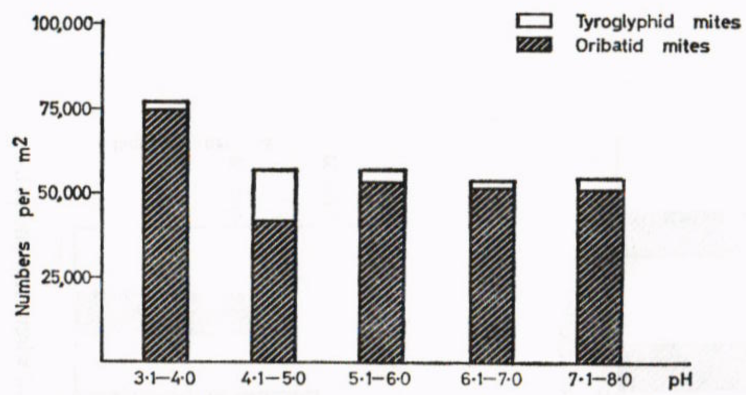

FIG. 24. Relationship between numbers of cryptostigmatid and astigmatid mites and pH.

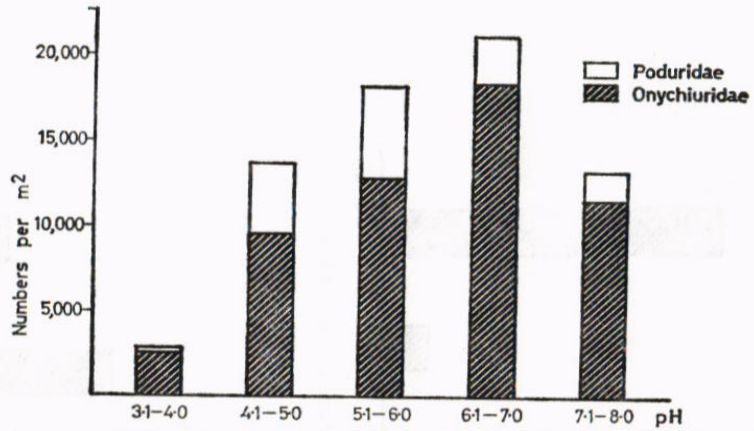

FIG. 26. Relationship between numbers of Collembola (Onychiuridae and Poduridae) and pH.

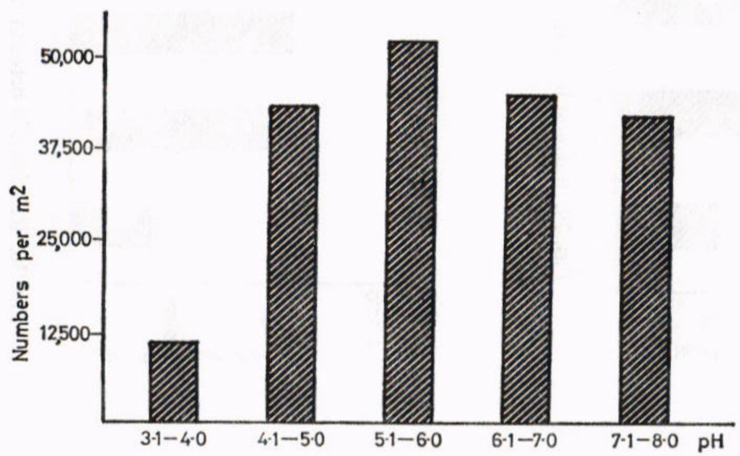

FIG. 25. Relationship between numbers of all Collembola and pH.

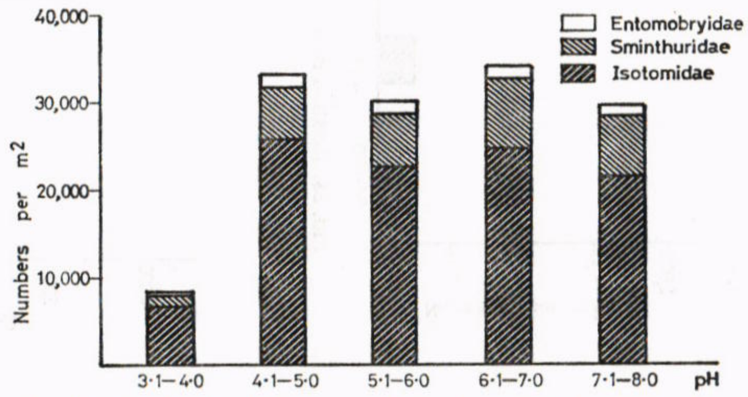

FIG. 27. Relationship between numbers of surface-living Collembola (Isotomidae, Entomobryidae and Sminthuridae) and pH.

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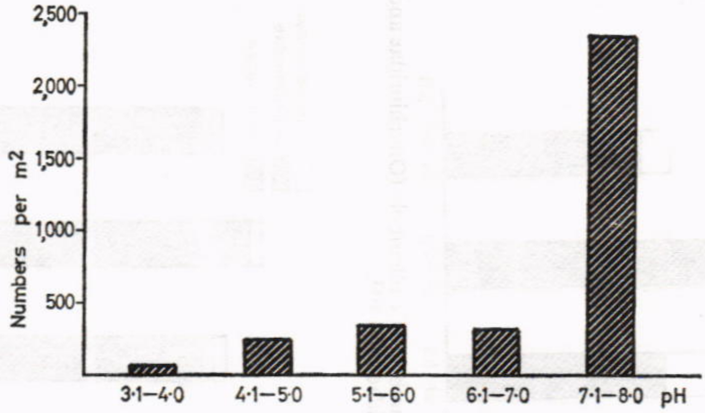

FIG. 28. Relation between numbers of Protura and pH.

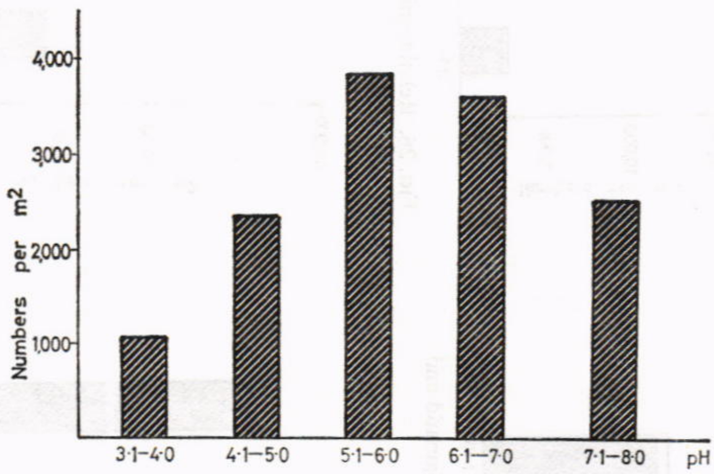

FIG. 29. Relation between numbers of insects and pH.

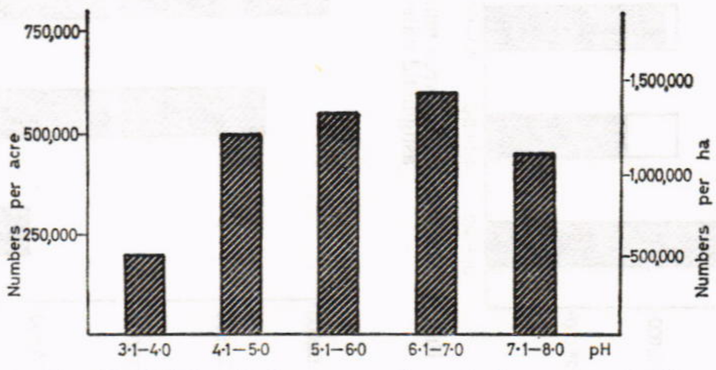

FIG. 30. Relationship between numbers of wireworms and pH.

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invertebrates that we identified to species were earthworms, Collembola and surface-living beetles. We studied the species diversity of these groups in relation to that of the flora and found no correlation between numbers of species of carabid beetles and numbers of plant species. However, there were good correlations between numbers of earthworm (Fig. 31) or Collembola species (Table 2) and numbers of plant species. This correlation is easier to understand for Collembola, many species of which live above ground, than for earthworms. However, earthworms have an extremely well-developed sense of taste and show very strong preference for one sort of decaying plant material over another and this could possibly explain our results. The species diversity of Collembola in the different plots is summarised in Table 5. Few tendencies are obvious, although there are usually fewer species in the unlimed subplots than in the limed ones.

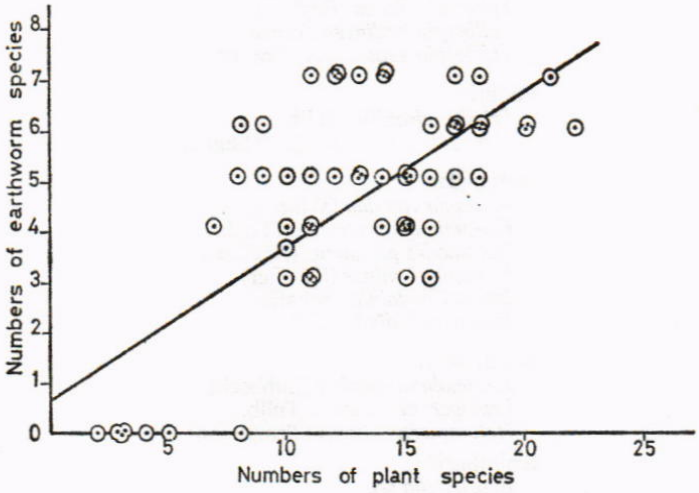

FIG. 31. Relationship between numbers of species of plants and numbers of species of earthworms.

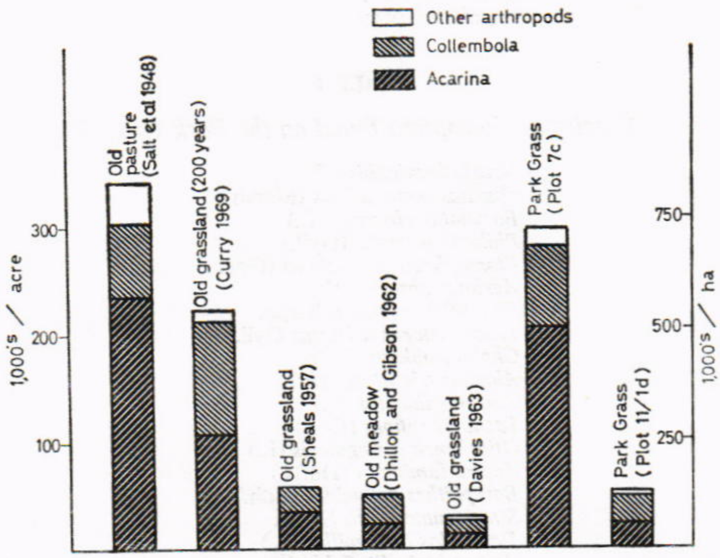

FIG. 32. Comparison between arthropod populations in Park Grass and those in other old grassland

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There were few correlations between invertebrate populations in soil, and soil or plant characteristics other than nitrogen or pH (Table 2). There was a negative correlation between the level of phosphorus in soil and the number of rhodacarid mites ($r = -0{\cdot}5174$) and there were also negative correlations between numbers of enchytraeid worms ($r = -0{\cdot}5980$) and earthworms ($r = -0{\cdot}4251$) and the amount of phosphorus in soil, but it is difficult to see how phosphorus would affect these animals. The amount

TABLE 5

Species of Collembola found on the Park Grass plots

Onychiuridae
- *Onychiurus ambulans* (L.) Stach.
- *Onychiurus armatus* (Tullb.) Gisin.
- *Onychiurus edinensis* Bagnall
- *Tullbergia denisi* (Bagnall)
- *Tullbergia callipygos* Borner
- *Tullbergia krausbaueri* Borner

Poduridae
- *Friesia mirabilis* (Tullb.)
- *Hypogastrura denticulata* (Bagnall)

Isotomidae
- *Folsomia candida* (Willem)
- *Folsomia quadrioculata* (Tullb.)
- *Isotomodes productus* (Axelson)
- *Isotomiella minor* (Schaffer)
- *Isotoma notabilis* (Schaffer)
- *Isotoma viridis* Bourlet

Entomobryidae
- *Entomobrya nicoleti* (Lubbeck)
- *Lepidocrytus cyaneus* Tullb.
- *Heteromurus nitidus* (Templeton)

Sminthuridae
- *Bourletiella* sp.
- *Dicyrtomina minuta* (Fabricius)
- *Sminthurus viridis* (L.)
- *Sminthurides pumilis* (Krausbauer)
- *Sminthurinus aureus* (Lubbeck)
- *Sminthurinus* sp.
- *Megalothorax* sp.

TABLE 6

Species of Coleoptera found on the Park Grass Plots

- *Nebria brevicollis* (F)
- *Quedius mesomelinus* (Marsh.)
- *Barynotus obscurus* (E.)
- *Philonthus varius* (Gyll.)
- *Ptomaphagus subvillosus* (Goeze)
- *Agriotes obscurus* (L.)
- *Philonthus cognatus* Steph.
- *Trachyphloeus aristatus* Gyll.
- *Choleva oblonga* Latr.
- *Alophus triguttatus* (F.)
- *Agriotes lineatus* (L.)
- *Tachinus rufipes* (Deg.)
- *Otiorhynchus singularis* (L.)
- *Amara familiaris* (Dufts.)
- *Barypeithes pellucidus* (Boh.)
- *Sitona puncticollis* Steph.
- *Demetrias atricapillus* (L.)
- *Amara lunicollis* Schiodte.

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of potassium in soil tended to be positively correlated with the numbers of centipedes ($r = 0{\cdot}5779$) and coleopterous larvae except wireworms ($r = 0{\cdot}4589$). The numbers of most groups of soil animals tended to be negatively correlated with the percentage of carbon in the soil, but an explanation of this observation is difficult.

In conclusion, the two main factors that influenced populations of invertebrates in the soil of the Park Grass plots seem to be either the level of nitrogen applied annually or the pH, with other factors relatively unimportant. In economic terms, the relationships between the numbers of invertebrates and yield, pH and the amount of nitrogen applied are probably the most important.

The populations of invertebrates in Park Grass seem to be fairly typical of those in other old grassland in Great Britain (Fig. 32). The numbers of invertebrates in the plot with the smallest populations (Plot 11/1) compare well with those reported in several of the earlier surveys and those in the plot with the largest population almost equal the largest recorded. In most of the fields Acarina (mites) were the dominant animal group but Collembola (springtails), almost equalled them in numbers. In terms of numbers, other arthropods were relatively unimportant, but in terms of weight would exert a considerable influence.

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References

ABRAHAMSEN, G. (1970) Forest fertilisation and the soil fauna. [Finnish.]. *Tidsskrift for Skogbruk* **78**, 296–303.

AXELSSON, B., LOHM, U., LUNDKVIST, H., PERSSON, T., SKOGLUND, J. & WIREN, A. (1973) Effects of nitrogen fertilisation on the abundance of soil fauna populations in a Scots pine stand. *Research Notes Institute Växtekologi Marklära* **14**, 18 pp.

BRENCHLEY, W. E. (1935) Park Grass Plots. *Rothamsted Experimental Station. Report for 1934*, 138–159.

BRENCHLEY, W. E. (1969) *The Park Grass Plots at Rothamsted, 1856–1949*. Harpenden: Rothamsted Experimental Station, 144 pp.

EDWARDS, C. A. & FLETCHER, K. E. (1970) Assessment of terrestrial invertebrate populations. *Methods of Study in Soil Ecology. Proceedings of the Paris Symposium UNESCO 1967*. Ed. J. Phillipson, pp. 57–66.

ESCRITT, J. R. & ARTHUR, J. H. (1948) Earthworm control—a résumé of methods available. *Journal of the Board of Greenkeeping Research* **7**, 49.

HENDERSON, I. F. (1974) Invertebrates and pasture productivity. *Rothamsted Experimental Station. Report for 1973*, Part 1, 201–202.

HUHTA, V., KARPPINEN, E., NURMINEN, M. & VALPAS, A. (1967) Effect of silvicultural practices upon arthropod, annelid and nematode populations in coniferous soil. *Annales Zoologici Fennici* **4**, 87–143.

HUHTA, V., MATLI, N. & VALPAS, A. (1969) Further notes on the effect of silvicultural practices upon the fauna of coniferous forest soil. *Annales Zoologici Fennici* **6**, 327–334.

JEFFERSON, P. (1955) Studies on the earthworms of turf. A. The earthworms of experimental turf plots. *Journal of the Sports Turf Research Institute* **9**, 6–27.

MACFADYEN, A. (1957) *Animal ecology; aims and methods*. London: Isaac Pitman. 344 pp.

RAW, F. (1956) The abundance and distribution of Protura in grassland. *Journal of Animal Ecology* **25**, 15–21.

RAW, F. (1959) Earthworm population studies: a comparison of sampling methods. *Nature, London* **187**, 257.

RICHARDSON, H. L. (1938) The nitrogen cycle in grassland soils: with especial reference to the Rothamsted Park Grass experiment. *Journal of Agricultural Science* **28**, 73–121.

RODALE, R. (1948) Do chemical fertilisers kill earthworms? *Organic Gardening* **12**, 12–17.

SATCHELL, J. E. (1955) Some aspects of earthworm ecology. In: *Soil Zoology*. Ed. D. K. McE. Kevan. London: Butterworths, pp. 180–201.

https://doi.org/10.23637/ERADOC-1-9

SATCHELL, J. E. (1953) *Studies in earthworms and their relation to soil fertility*. Ph.D. Thesis. Univ. London. 82 pp.
WILLIAMS, E. D. (1974) Changes in yield and botanical composition caused by the new liming scheme on Park Grass. *Rothamsted Experimental Station. Report for 1973*, Part 2, 67–73.
WINSLOW, R. D. (1961) Ecology of soil nematodes. *Rothamsted Experimental Station. Report for 1960*, 135–136.

https://doi.org/10.23637/ERADOC-1-9