THE INSECT AND OTHER INVERTEBRATE FAUNA OF ARABLE LAND AT ROTHAMSTED[1]

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(With 7 Text-figures.)

CONTENTS.

This investigation was carried out from February 1920, to January 1921, with the object of obtaining information as to the species of insects and other invertebrates present in the soil of an arable field. The various species and their relative numbers, the depth at which these organisms occur, and the effect upon them of the application of farmyard manure to the land were the principal points considered.

I am very much indebted to Dr A. D. Imms for suggestions and advice throughout this investigation. I am also indebted to Miss K. Warington for information regarding the weeds; to Mr G. C. Sawyer for estimating the nitrogen content of several groups; to Mr H. J. Page for the mechanical and chemical analyses; and for help in the identification of species of *Insecta*, *Myriapoda* and *Arachnida* to Messrs S. G. Brade-Birks, J. M. Brown, E. A. Butler, H. St J. K. Donisthorpe, F. W. Edwards, H. F. Fryer, J. E. Hull, R. C. L. Perkins.

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1. Description of the Area examined.

The area dealt with in this investigation was the Broadbalk field belonging to the Rothamsted Experimental Station, Harpenden. The soil of the Rothamsted fields is "clay with flints," which overlies chalk.

Broadbalk field is roughly rectangular in shape, the long sides running W.N.W. to E.S.E., and it lies on a gentle slope, the south-east side being the lowest, this side being slightly over 400 feet above sea level.

The field is divided into a number of plots, of which numbers 2 and 3 were dealt with in this investigation. Plot 2 has received annually a dressing of farmyard manure at the rate of fourteen tons to the acre since 1843. Plot 3, which is a control, has received no farmyard or artificial manure of any kind since the commencement of the experiments in 1843 and actually since 1839.

These plots are about half an acre in area, and lie side by side along the northern side of the field, being separated by a path two yards wide.

The effect of the different treatment of the plots is very noticeable in their yield of grain and straw, and in the general growth of the wheat and weeds. This treatment having been the same in either case for so many years makes them particularly well fitted for an investigation of the soil fauna which they support.

The plots were ploughed on October 13th, the manure having been applied to plot 2 just previously.

2. Method of Investigation.

The samples of soil which were examined in the course of this investigation were taken from the western end of the plots, and were taken from the edges of the plots so as to disturb the soil of the plots as little as possible. Successive samples from the same plot were not taken next to each other, nor were any two samples taken nearer together than about a yard.

The method of taking the sample was as follows. Four iron plates were used, two of them twelve inches long by ten inches wide, one twelve inches long by nine inches wide, and one four inches long by nine inches wide. Each plate had an iron bar fastened to it at the top, and each of the three larger plates had two projecting teeth at the bottom. These

teeth and the lower edges of the plates were kept sharpened in order that they might enter the ground more easily (Fig. 1).

The plates were driven into the ground to form a box nine inches square, the smallest plate being on the side towards the outside of the plot (Fig. 2). A hole was then dug in the path, extending about two feet

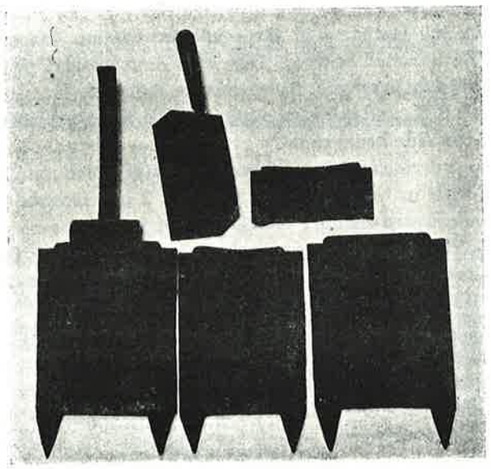


Fig. 1. Iron plates and trowel used in taking soil samples.

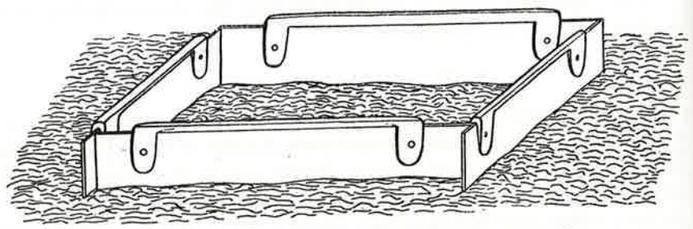


Fig. 2. Plates in position, before any soil has been removed.

from the smallest plate, and about a foot in width, in order to give room to remove the soil from the box. This hole was first made to a depth of about two inches, the front plate was then removed, and by means of the special trowel it was possible to remove the top layer of soil enclosed by the "box." This soil was then extracted to a depth of one inch;

owing to the unevenness of the soil the latter level was measured from the lowest point of the surface. On removal the soil was placed in a linen bag.

The small plate was then replaced and driven down another two inches; and the hole in the path was deepened by about another two inches (Fig. 3). The soil in the box was then removed in the same way as before. The second and succeeding samples were taken at depths of two inches at a time, each being placed in a separate bag.

The soil was removed in this way to a depth of nine inches, giving five samples, which consisted of—I, the soil between the surface and a depth of one inch below the lowest point of the surface; II, the soil

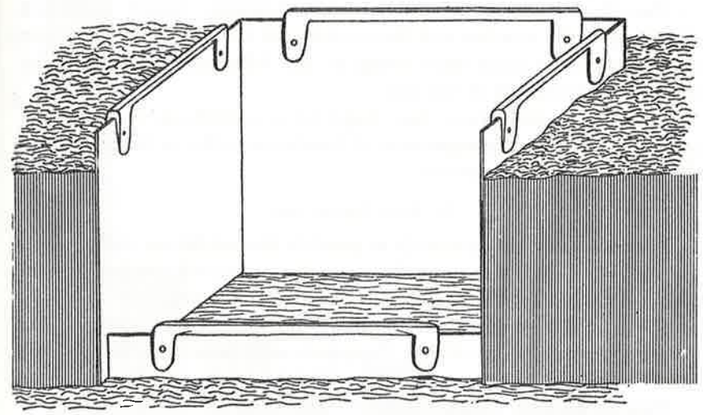


Fig. 3. Plates in position after three samples of soil have been removed.

between a depth of one inch below the lowest point of the surface and a depth of three inches; III, the soil between three inches and five inches; IV, the soil between five inches and seven inches; V, the soil between seven inches and nine inches.

The samples obtained in this way were taken to the laboratory for examination. When the soil was wet it was necessary to spread it out to dry for some time, before it was possible to examine it thoroughly. The examination had to be carried out by crumbling the soil on to sheets of brown paper, and watching for the appearance of insects, etc., as the soil was broken up. The soil was examined over brown paper instead of white, which at first might seem more suitable, because the most

abundant small insects, and the majority of the larvae, were white or light-coloured. Other methods of obtaining the insects, etc., from the soil were considered, but were not found to be feasible. By taking a small quantity of soil at a time, and examining it in this way, it is possible to obtain, probably, practically all the insects, etc., from the soil, although it is likely that a few of the smaller forms would be overlooked.

Twenty-three cubes of soil, each 9″ × 9″ × 9″, were examined in this way, from each plot. They were taken alternately from the plots about every six days, so that a cube was taken from each plot about every 12 days.

The time between successive cubes, however, varied somewhat according to the weather and the condition of the soil. Cubes were not usually taken on rainy days owing to the difficulties entailed in the thorough examination of wet soil.

Since this investigation was completed a method has been devised by means of which the separation of insects and other arthropods from the soil is much facilitated (11).

3. Soil Analyses.

In order to define as exactly as possible the conditions under which the soil fauna was existing on the two plots examined, mechanical and chemical analyses of the soil of both plots were obtained.

Plot 2. Percentages. Moisture (in air-dry soil) 2·22; Nitrogen 0·258; Potash (soluble in HCl) 0·333; Phosphoric acid (soluble in HCl) 0·203; Lime (as $CaCO_3$) 3·43.

Fine gravel 1·63; Coarse sand 2·57; Fine sand 21·96; Silt 17·30; Fine silt I 11·66; Fine silt II 5·06; Clay 13·87; Loss on solution 7·38; Loss on ignition 11·95.

Plot 3. Percentages. Moisture (in air-dry soil) 1·7; Nitrogen 0·114; Potash (soluble in HCl) 0·284; Phosphoric acid (soluble in HCl) 0·099; Lime (as $CaCO_3$) 4·01.

Fine gravel 1·01; Coarse sand 3·17; Fine sand 23·31; Silt 20·36; Fine silt I 6·22; Fine silt II 3·81; Clay 16·56; Loss on solution 6·88; Loss on ignition 8·54.

The figure for loss on ignition includes combined moisture as well as organic matter.

4. Meteorological Conditions.

As the meteorological conditions probably exercise an influence on the soil fauna, especially the rainfall and soil temperature, records of these were obtained. The soil temperatures were registered by a recording thermometer at a depth of six inches.

These records have been preserved but are not considered in the present instance.

The total rainfall during the period February 1st, 1920, to January 29th, 1921, was 26·459 inches.

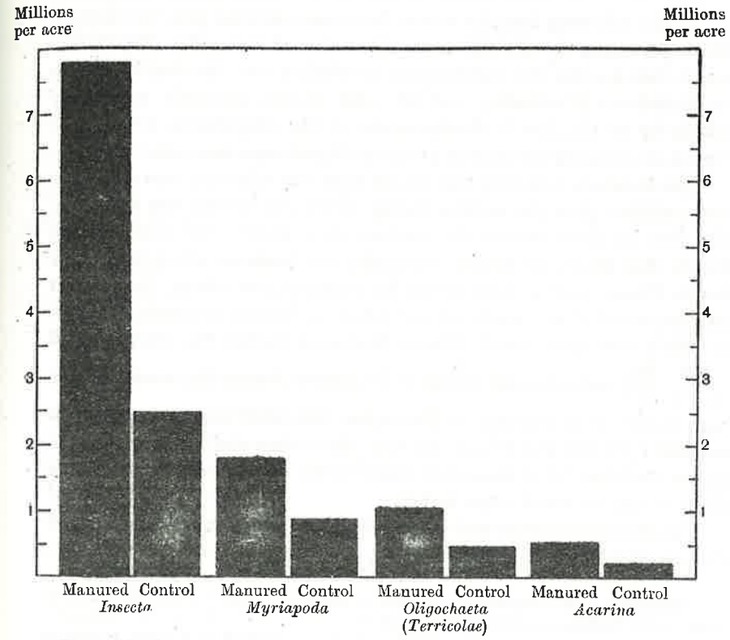


Fig. 4. Number of individuals in the more important groups in the manured and control plots.

5. Occurrence of Weeds.

Plot 2. In the spring the most abundant weeds are *Veronica hederaefolia*, *Scandix pecten* and *Galium aparine*, and in addition to these *Alopecurus agrestis* and *Carduus arvensis* are plentiful.

In the summer *Scandix pecten* and *Galium aparine* are still abundant, and in addition to those occurring earlier, *Caucalis arvensis*, *Equisetum arvense* and *Tussilago farfara* are plentiful, and later still *Convolvulus arvensis* is also prevalent.

Plot 3. In the spring the most plentiful weeds are *Veronica hederaefolia* and *Galium aparine*. In the summer *Tussilago farfara*, *Sonchus arvensis*, *Vicia sativa* and *Lathyrus pratensis* are plentiful and *Alopecurus agrestis*, *Equisetum arvense*, *Carduus arvensis* and *Scabiosa arvensis* are generally distributed, and later still *Convolvulus arvensis* is also plentiful.

6. Soil Fauna of the Manured Plot.

In the following lists the worms have been divided into two groups, those belonging to the sub-order *Terricolae* of the order *Oligochaeta*, which includes the true earthworms, *Lumbricus*, etc., forming one group as *Oligochaeta* (*Terricolae*), and all other worms, probably principally belonging to the family *Enchytraeidae* of the *Oligochaeta*, and to the *Nematoda*, forming the second group as *Oligochaeta* (*Limicolae*), etc.

The numbers following the names have the following meaning—the first numbers give the months during which the species was met with. The first numbers within the brackets give, above, the total number found, and below, in Roman numerals, the levels in which they were found. The second numbers within the brackets give, above, the greatest number found at any one level, and below, in Roman numerals, the level at which they were found. Thus—*Trichocera fuscata* Mg. (larvae) 1–12 $\left(\frac{108}{\text{I–IV}}; \frac{54}{\text{II}}\right)$ indicates that larvae of *Trichocera fuscata* Mg. were found in each month from January to December; 108 were found altogether in samples I, II, III and IV, *i.e.* between the surface and a depth of seven inches, and that 54 of these were found in the second sample, between a depth of one inch and three inches.

The species of insects and other invertebrates present in the manured plot are as follows:

INSECTA.

Collembola. Onychiuridae. *Onychiurus fimetarius* (Linn.) 1–12; *O. ambulans* (Linn.) 1–12; *Tullbergia quadrispina* (Börn.) 2, 9.

Isotomidae. *Isotoma viridis* Bourl. 2–3, 8–10; *I. minor* Schäff. 1, 4, 5, 10; *I. olivacea* (Tullb.) 2; *Folsomia quadrioculata* (Tullb.) 4; *Isotomurus palustris* (Müll.) 10.

Entomobryidae. *Entomobrya multifasciata* (Tullb.) 8; *Lepidocyrtus cyaneus* (Tullb.) 1, 5, 8; *L. albus* Pack. 4; *Orchesella villosa* (Geoff.) 8, 10; *Heteromurus nitidus* Templ. 2, 4, 8, 10, 12.

Smynthuridae. *Smynthurus viridis* (Linn.) 8.

Collembola. All species 1–12 $\left(\frac{710}{\text{I–V}}; \frac{264}{\text{II}}\right)$.

Thysanura. Campodeidae. *Campodea staphylinus* Westw.; *C. gardneri* Bagn.; *C. fragilis* Meinert. Spp. 2–11 $\left(\frac{33}{\text{I–IV}}; \frac{14}{\text{II}}\right)$.

Orthoptera. Forficulidae. *Forficula auricularia* L. 2, 6, 8, 10 $\left(\frac{4}{\text{I–II}}\right)$.

Thysanoptera. Spp. 5–8 $\left(\frac{7}{\text{I}}\right)$

Hemiptera. Capsidae. *Lygus pastinacae* Fall. 4 $\left(\frac{1}{\text{I}}\right)$.

Aphididae. *Aphis* sp. 9 $\left(\frac{1}{\text{I}}\right)$.

Lepidoptera. Hepialidae. Unidentified larvae 1–5, 8–12 $\left(\frac{7}{\text{I–V}}; \frac{3}{\text{II}}\right)$

Unidentified larvae 3, 8 $\left(\frac{2}{\text{I}}\right)$.

Coleoptera. Carabidae. *Notiophilus aquaticus* L. 4 $\left(\frac{1}{\text{I}}\right)$; *Badister bipustulatus* F. 3 $\left(\frac{1}{\text{I}}\right)$; *Bradycellus verbasci* Duft. 8 $\left(\frac{2}{\text{I}}\right)$; *Harpalus ruficornis* F. 5 $\left(\frac{1}{\text{I}}\right)$; *H. aenus* F. 2 $\left(\frac{1}{\text{I}}\right)$; *Pterostichus madidus* F. 4–6 $\left(\frac{5}{\text{I–III}}; \frac{3}{\text{II}}\right)$; *Bembidium guttula* F. 2 $\left(\frac{1}{\text{I}}\right)$.

Hydrophylidae. *Helophorus nubilus* F. 5, 6, 8, 9 $\left(\frac{5}{\text{I}}\right)$.

Staphylinidae. *Homalota* spp. 2, 3, 5, 9, 11 $\left(\frac{7}{\text{I–V}}\right)$; *Tachyporus hypnorum* F. 5, 8 $\left(\frac{4}{\text{I}}\right)$; *Quedius cinctus* Payk. 4, 5 $\left(\frac{2}{\text{I, II}}\right)$; *Oeypus morio* Grav. 9 $\left(\frac{1}{\text{II}}\right)$; *Philonthus trossulus* Nord. 9 $\left(\frac{1}{\text{I}}\right)$; *Lathrobium fulvipenne* Grav. 2 $\left(\frac{1}{\text{IV}}\right)$; *L. longulum* Grav. 10 $\left(\frac{1}{\text{V}}\right)$; *Scopaeus* sp. 8 $\left(\frac{1}{\text{II}}\right)$; *Medon propinquus* Bris. 5 $\left(\frac{1}{\text{I}}\right)$; *Stenus subaeneus* Er. 10 $\left(\frac{1}{\text{I}}\right)$; *Oxytellus laqueatus* Marsh. 6, 11 $\left(\frac{6}{\text{I–IV}}; \frac{2}{\text{I, IV}}\right)$; *O. inustus* Grav. 9 $\left(\frac{1}{\text{I}}\right)$; *O. sculpturatus* Grav. 4, 6, 9 $\left(\frac{5}{\text{I–IV}}; \frac{2}{\text{III}}\right)$; *O. nitidulus* Grav. 10 $\left(\frac{1}{\text{III}}\right)$; *O. tetracarinatus* Block. 3 $\left(\frac{1}{\text{III}}\right)$.

Pselaphidae. *Bryaxis fossulata* Reich. 3 $\left(\frac{1}{\text{I}}\right)$.

Lathridiidae. *Enicmus minutus* L. 10 $\left(\frac{1}{\text{III}}\right)$; *Melanophthalma fuscula* Humm. 6 $\left(\frac{1}{\text{I}}\right)$.

Cucujidae. *Silvanus surinamensis* L. 6 $\left(\frac{1}{\text{I}}\right)$.

Elateridae. *Agriotes sputator* L. 3, 5 $\left(\frac{2}{\text{I}}\right)$.

Chrysomelidae. *Phyllotreta undulata* Kuts. 8 $\left(\frac{1}{\text{I}}\right)$; *Plectroscelis concinna* Marsh. 6 $\left(\frac{1}{\text{I}}\right)$.

Curculionidae. *Sitones humeralis* Steph. 8 $\left(\frac{1}{\text{I}}\right)$.

Larvae and Pupae—Carabidae 1, 4, 5, 9–12 $\left(\frac{14}{\text{I–V}}; \frac{9}{\text{II}}\right)$; Staphylinidae 1–6, 10–12 $\left(\frac{103}{\text{I–V}}; \frac{36}{\text{I}}\right)$; Elateridae 1–12 $\left(\frac{59}{\text{I–V}}; \frac{19}{\text{IV}}\right)$; Telephoridae 1, 3, 8, 10 $\left(\frac{4}{\text{I, V}}\right)$; Curculionidae 10, 11 $\left(\frac{2}{\text{III, IV}}\right)$; unidentified 4, 12 $\left(\frac{4}{\text{I, II}}\right)$.

Diptera. Mycetophilidae. *Sciara* sp. 12 $\left(\frac{1}{\text{III}}\right)$.

Chironomidae. *Camptocladius aterrimus* Mg. (Reared from larvae.)

Tipulidae. *Pachyrrhina maculosa* Mg. (larva) 4 $\left(\frac{1}{\text{I}}\right)$; *P. histrio* F. (larva) 5 $\left(\frac{1}{\text{I}}\right)$; *Trichocera fuscata* Mg. (larvae) 1–12 $\left(\frac{108}{\text{I–IV}}; \frac{54}{\text{II}}\right)$.

Scatopsidae. *Scatopse halterata* Mg. (larvae) 1 $\left(\frac{2}{\text{III, IV}}\right)$.

Empidae. Sp. reared from larvae.

Unidentified larvae of the following families also occurred:

Cecidomyidae 1–12 $\left(\frac{58}{\text{I–IV}}; \frac{39}{\text{I}}\right)$; Mycetophilidae 1–12 $\left(\frac{35}{\text{I–IV}}; \frac{12}{\text{III}}\right)$; Chironomidae 1–6, 9–12 $\left(\frac{153}{\text{I–III}}; \frac{92}{\text{II}}\right)$; Tipulidae 4, 5, 10, 11 $\left(\frac{5}{\text{I–III}}; \frac{4}{\text{I}}\right)$; Empidae 1–12 $\left(\frac{48}{\text{I–IV}}; \frac{25}{\text{II}}\right)$; Syrphidae 1, 4, 9 $\left(\frac{3}{\text{I}}\right)$; Anthomyidae 3, 9–12 $\left(\frac{9}{\text{I–III}}; \frac{4}{\text{II, III}}\right)$

Hymenoptera. Chalcididae. One species, unidentified 6 $\left(\frac{1}{\text{III}}\right)$.

FORMICIDAE. *Myrmecina graminicola* Fabr. 2, 8 $\left(\frac{32}{\text{I–V}}; \frac{17}{\text{IV}}\right)$; *Myrmica laevinodis* Nyl. 4–6, 9–10 $\left(\frac{835}{\text{I–V}}; \frac{759}{\text{I}}\right)$; *Acanthomyops (Donisthorpea) nigra* L. 8 $\left(\frac{8}{\text{I–II}}\right)$.

ANDRENIDAE. *Andrena chrysosceles* Kirby 3 $\left(\frac{1}{\text{III}}\right)$.

"MYRIAPODA[1]."

DIPLOPODA. *Brachydesmus superus mosellanus* Verhoeff 1–12 $\left(\frac{96}{\text{I–V}}; \frac{30}{\text{III}}\right)$; *Cylindroiulus londinensis* var. *caeruleocinctus* (Wood) (=*C. londinensis* var. *teutonicus* (Pocock) of some records) 1–12 $\left(\frac{129}{\text{I–V}}; \frac{41}{\text{II}}\right)$; *Blaniulus guttulatus* (Bosc.) 1–12 $\left(\frac{138}{\text{I–V}}; \frac{34}{\text{V}}\right)$; *Archiboreoiulus pallidus* Brade-Birks 2, 3, 6–12 $\left(\frac{40}{\text{I–V}}; \frac{15}{\text{II}}\right)$.

CHILOPODA. *Lithobius* sp. 8 $\left(\frac{1}{\text{I}}\right)$; *Geophilus longicornis* Leach 1–12 $\left(\frac{57}{\text{I–V}}; \frac{23}{\text{II}}\right)$.

SYMPHYLA. Spp. 1–12 $\left(\frac{64}{\text{I–V}}; \frac{32}{\text{V}}\right)$.

ARACHNIDA.

Araeinida. *Porrhomma pygmaeum* Pd. 4 $\left(\frac{1}{\text{I}}\right)$; *P. microphthalmum* Cb. 10 $\left(\frac{1}{\text{IV}}\right)$; *Robertus lividus* Bl. 6 $\left(\frac{1}{\text{III}}\right)$; *Linyphia* spp. 6, 8 $\left(\frac{2}{\text{I, III}}\right)$; *Oedothorax agrestris* Bl. 3 $\left(\frac{1}{\text{I}}\right)$.

Acarina. ANYSTIDAE. *Anystis baccarum* L. 5, 6 $\left(\frac{3}{\text{I}}\right)$.

GAMASIDAE. *Gamasus magnus* Kr. 4–6, 9–12 $\left(\frac{10}{\text{I–III}}; \frac{6}{\text{I}}\right)$; *Gamasus* sp. (immature) 2–5, 8–9 $\left(\frac{13}{\text{I–III}}; \frac{7}{\text{I}}\right)$; *Pergamasus crassipes* L. 4–12 $\left(\frac{11}{\text{I–IV}}; \frac{7}{\text{I}}\right)$; *P. meridionalis* Berl. 10 $\left(\frac{1}{\text{I}}\right)$; *P. hamatus* Koch 3–5, 8–11 $\left(\frac{14}{\text{I–V}}; \frac{5}{\text{II}}\right)$; *P. septrionalis* Oud. 1, 5–12 $\left(\frac{33}{\text{I–III}}; \frac{19}{\text{I}}\right)$; *P. rumiger* Berl. 5, 8, 9 $\left(\frac{5}{\text{I–II}}; \frac{4}{\text{I}}\right)$; *P. alpestris* Berl. 10 $\left(\frac{1}{\text{I}}\right)$; *Pergamasus* spp. (immature) 1–5, 8–10 $\left(\frac{40}{\text{I–IV}}; \frac{17}{\text{I}}\right)$; *Pachylaelaps pectinifer* Berl. 4 $\left(\frac{1}{\text{II}}\right)$.

TARSONEMIDAE. *Pigmephorus morrisii* Hull. 2, 8 $\left(\frac{4}{\text{II, III}}; \frac{3}{\text{III}}\right)$.

TYROGLYPHIDAE. *Rhizoglyphus echinopus* Rob. 3 $\left(\frac{5}{\text{II}}\right)$; *Histiostoma julorum* Koch (hypopus) 3 $\left(\frac{1}{\text{II}}\right)$.

OLIGOCHAETA (*Terricolae*) 1–12 $\left(\frac{300}{\text{I–V}}; \frac{111}{\text{II}}\right)$.

OLIGOCHAETA (*Limicolae*), **NEMATODA**, etc. 1–12 $\left(\frac{1072}{\text{I–V}}; \frac{403}{\text{II}}\right)$.

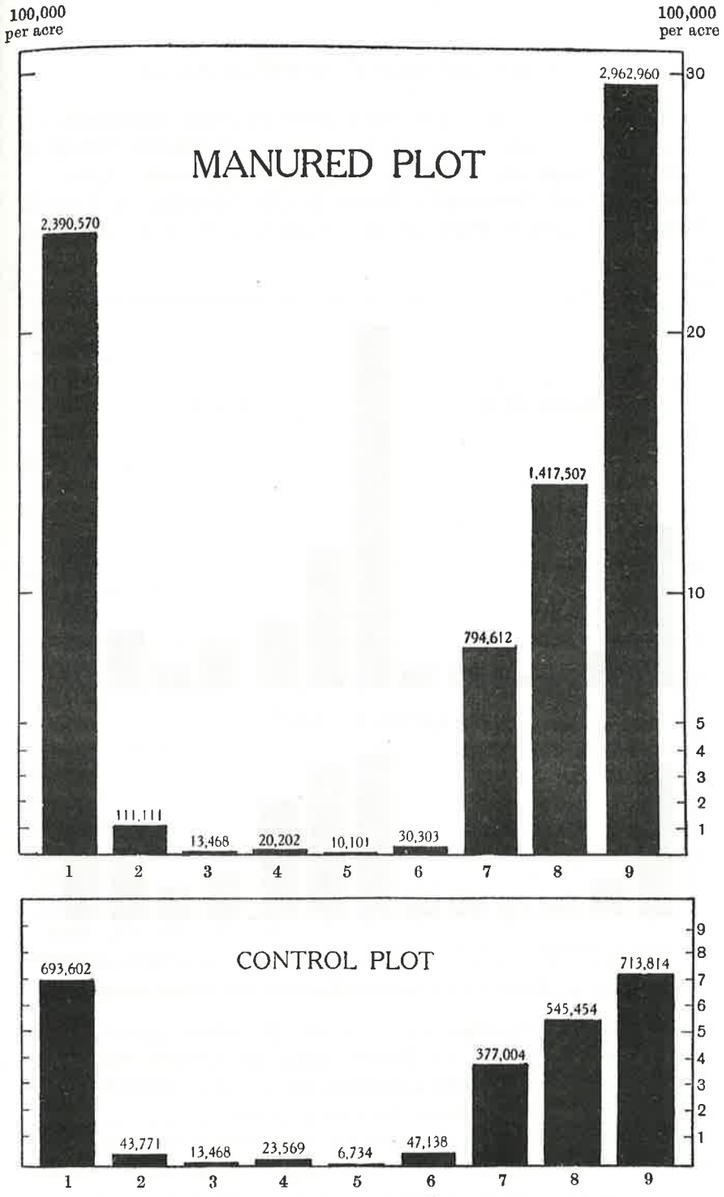
ISOPODA 4, 5, 8–11 $\left(\frac{24}{\text{I–V}}; \frac{7}{\text{II}}\right)$.

GASTROPODA 2, 4 $\left(\frac{10}{\text{I, III}}; \frac{6}{\text{II}}\right)$.

7. CENSUS OF MANURED PLOT.

The total number of invertebrates found in plot 2, in twenty-three samples, was 4485, or 15,100,955 per acre. Of these 2295 were insects, or 7,727,265 per acre.

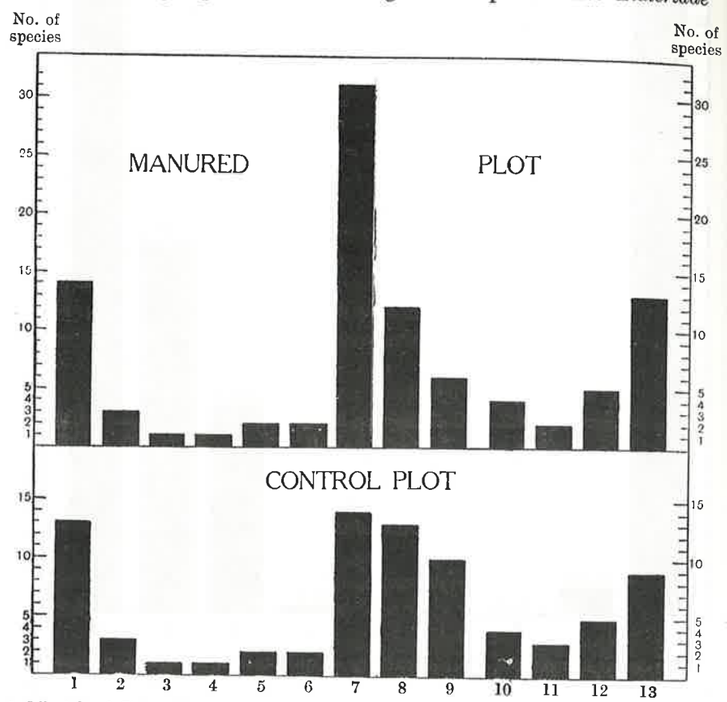
[1] The old term "Myriapoda" is used for convenience to include the classes *Diplopoda*, *Chilopoda* and *Symphyla*.



1, *Collembola*; 2, *Thysanura*; 3, *Orthoptera*; 4, *Thysanoptera*; 5, *Hemiptera*; 6, *Lepidoptera*; 7, *Coleoptera*; 8, *Diptera*; 9, *Hymenoptera*.

Fig. 5. Number of individuals in the different orders of insects in the manured and control plots.

The numbers per acre of the more abundant groups were as follows: *Oligochaeta* (*Limicolae*), etc., 3,609,424; *Formicidae* 2,946,125; *Collembola* 2,390,570; *Diplopoda* 1,367,002; *Oligochaeta* (*Terricolae*) 1,010,101; *Acarina* 531,986; *Chironomidae* (larvae) 515,151. The numbers of insects belonging to groups which are recognised as pests were: *Elateridae*



1, *Collembola*; 2, *Thysanura*; 3, *Orthoptera*; 4, *Thysanoptera*; 5, *Hemiptera*; 6, *Lepidoptera*; 7, *Coleoptera*; 8, *Diptera*; 9, *Hymenoptera*; 10, *Diplopoda*; 11, *Chilopoda*; 12, *Areinida*; 13, *Acarina*.

Fig. 6. Number of species in the different orders in the manured and control plots.

(larvae) 198,653; *Tipulidae* (larvae) 16,835; *Hepialidae* (larvae) 23,569. The numbers per acre in the different orders are shown in Fig. 5. The "probable error" in the total population per acre is ± 1,700,000, and in the number of *Elateridae* larvae per acre ± 22,000.

The number of species of insects which occurred in the samples was about 72 but the number may have been slightly higher, as all the larvae

found could not be exactly determined. The average number of insects per sample was 99·78.

The following orders occurred in the percentages given: *Collembola* 30·84; *Thysanura* 1·43; *Orthoptera* 0·17; *Thysanoptera* 0·26; *Hemiptera* 0·13; *Lepidoptera* 0·39; *Coleoptera* 10·25; *Diptera* 18·29; *Hymenoptera* 38·22.

The dominant order in respect of number of species present was the *Coleoptera*, with 31 species. The numbers of species in the different orders are shown in Fig. 6.

The most abundant species were *Myrmica laevinodis*, which made up 36·3 per cent. of the total insects; *Onychiurus ambulans*, 13·9 per cent. of the total; and *Onychiurus fimetarius*, 13·2 per cent. of the total.

Six species of *Myriapoda* (excluding *Symphyla*) occurred in this plot, and seventeen species of *Arachnida*.

8. Soil Fauna of the Control Plot.

The species of insects and other invertebrates present in the control plot are as follows:

INSECTA.

Collembola. Onychiuridae. *Onychiurus fimetarius* (Linn.) 1–10; *O. ambulans* (Linn.) 1–11; *Tullbergia quadrispina* (Börn.) 3, 4, 6, 10, 11.

Isotomidae. *Isotoma viridis* Bourl. 6, 9, 10; *I. minor* Schäff. 3, 4; *Folsomia quadrioculata* (Tullb.) 4; *Isotomurus palustris* (Müll.) 4, 10; *I. palustris* var. *aquatilis* 9.

Entomobryidae. *Entomobrya multifasciata* (Tullb.) 9; *Lepidocyrtus cyaneus* (Tullb.) 1, 10, 11; *L. albus* Paok. 3, 4, 9; *Orchesella villosa* (Geoff.) 1, 6, 9, 10, 12; *Heteromurus nitidus* Templ. 3, 4, 9, 10.

Collembola. All species 1–12 $\left(\frac{206}{\text{I–V}}; \frac{92}{\text{II}}\right)$.

Thysanura. Campodeidae. *Campodea staphylinus* Westw.; *C. gardneri* Bagn.; *C. fragilis* Meinert. Spp. 3–11 $\left(\frac{13}{\text{I–IV}}; \frac{6}{\text{II}}\right)$.

Orthoptera. Forficulidae. *Forficula auricularia* L. 2, 6 $\left(\frac{4}{\text{I–IV}}; \frac{2}{\text{II}}\right)$.

Thysanoptera. Spp. 6, 11 $\left(\frac{6}{\text{I}}\right)$.

Hemiptera. Jassidae. *Cicadula sexnotata* Fall. 9 $\left(\frac{1}{\text{I}}\right)$.

Cimicidae. *Lyctocoris campestris* Fall. 6 $\left(\frac{1}{\text{I}}\right)$.

Lepidoptera. Hepialidae. Unidentified larvae 2–4, 9 $\left(\frac{7}{\text{I–V}}; \frac{2}{\text{II, III, V}}\right)$.

Tineidae. Unidentified larva 8 $\left(\frac{1}{\text{II}}\right)$.

Unidentified larvae 3, 4, 9 $\left(\frac{6}{\text{I, II}}; \frac{5}{\text{I}}\right)$.

Coleoptera. Carabidae. *Clivina fossor* L. 4 $\left(\frac{1}{\text{II}}\right)$; *Bembidium guttula* F. 9 $\left(\frac{1}{\text{I}}\right)$.

Hydrophylidae. *Helophorus nubilus* F. 5 $\left(\frac{1}{\text{I}}\right)$.

Staphylinidae. *Homalota* spp. 2, 3, 6, 9, 10 $\left(\frac{6}{\text{I–IV}}; \frac{2}{\text{I, II}}\right)$; *Tachyporus hypnorum* F. 8

$\left(\frac{1}{II}\right)$; *Philonthus agilis* Grav. 9 $\left(\frac{1}{I}\right)$; *P. trossulus* Nord. 10 $\left(\frac{1}{I}\right)$; *Lathrobium longulum* Grav. 6, 9, 10 $\left(\frac{5}{II–V}; \frac{3}{III}\right)$; *Medon propinquus* Bris. 4 $\left(\frac{1}{I}\right)$; *Stenus subaeneus* Er. 5, 9 $\left(\frac{3}{I}\right)$; *Oxytellus insecatus* Grav. 2, 3 $\left(\frac{2}{I–III}\right)$.

CUCUJIDAE. *Silvanus surinamensis* L. 10 $\left(\frac{1}{I}\right)$.

ELATERIDAE. *Agriotes sputator* L. 3, 8 $\left(\frac{3}{I–III}\right)$.

CURCULIONIDAE. *Sitones humeralis* Steph. 2, 3, 8–10 $\left(\frac{10}{I}\right)$.

LARVAE AND PUPAE—CARABIDAE 4 $\left(\frac{1}{II}\right)$; STAPHYLINIDAE 2–4, 9–11 $\left(\frac{16}{I–IV}; \frac{8}{I}\right)$; SCARABAEIDAE 10 $\left(\frac{1}{I}\right)$; ELATERIDAE 1–12 $\left(\frac{49}{I–V}; \frac{16}{IV}\right)$; TELEPHORIDAE 10 $\left(\frac{1}{III}\right)$; CURCULIONIDAE, *Sitones humeralis* Steph. 9 $\left(\frac{1}{I}\right)$; Unidentified 4 $\left(\frac{1}{II}\right)$.

Diptera. CECIDOMYIDAE. *Campylomyza* sp. (larva) 2 $\left(\frac{1}{I}\right)$.

MYCETOPHILIDAE. *Sciara* sp. 9 $\left(\frac{1}{I}\right)$.

CHIRONOMIDAE. *Camptocladius aterrimus* Mg. Reared from larvae.

TIPULIDAE. *Trichocera fuscata* Mg. (larvae) 6–9 $\left(\frac{6}{I–III}; \frac{4}{I}\right)$.

BIBIONIDAE. *Dilophus febrilis* L. 9 $\left(\frac{1}{I}\right)$.

CHLOROPIDAE. Sp. 9 $\left(\frac{1}{I}\right)$.

Unidentified larvae of the following families also occurred:

CECIDOMYIDAE 1–6, 9–10 $\left(\frac{63}{I–V}; \frac{28}{I}\right)$; MYCETOPHILIDAE 2, 3, 9–11 $\left(\frac{23}{I–V}; \frac{10}{V}\right)$; CHIRONOMIDAE 3–5, 9, 10 $\left(\frac{8}{I–IV}; \frac{5}{II}\right)$; TIPULIDAE 1, 10, 12 $\left(\frac{5}{I, II}; \frac{4}{II}\right)$; SCATOPSIDAE 3 $\left(\frac{7}{II, IV}; \frac{6}{IV}\right)$; EMPIDAE 1–4, 9, 11 $\left(\frac{15}{I–IV}; \frac{8}{II}\right)$; SYRPHIDAE 3, 10 $\left(\frac{4}{I, II}; \frac{3}{I}\right)$; ANTHOMYIDAE 2, 10 $\left(\frac{7}{I}\right)$.

Hymenoptera. TENTHREDINIDAE. Unidentified larvae of two species 1, 6, 9 $\left(\frac{3}{I–V}; \frac{2}{I}\right)$.

CHALCIDIDAE. Three species, unidentified, 6, 10 $\left(\frac{3}{I–III}; \frac{2}{I}\right)$.

ICHNEUMONIDAE. *Pezomachus costatus* Bridge 9 $\left(\frac{1}{I}\right)$.

FORMICIDAE. *Myrmecina graminicola* Fabr. 10 $\left(\frac{1}{I}\right)$; *Myrmica laevinodis* Nyl. 3, 4, 6, 9 $\left(\frac{205}{I–V}; \frac{159}{III}\right)$; *Acanthomyops* (*Donisthorpea*) *nigra* L. 6 $\left(\frac{1}{I}\right)$.

ANDRENIDAE. *Andrena chrysosceles* Kirby 11 $\left(\frac{3}{III, IV}; \frac{2}{III}\right)$.

"MYRIAPODA."

DIPLOPODA. *Brachydesmus superus mosellanus* Verhoeff 1–5, 8–11 $\left(\frac{65}{I–IV}; \frac{26}{I}\right)$; *Cylindroiulus londinensis* var. *caeruleocinctus* (Wood) (= *C. londinensis* var. *teutonicus* (Pocock) of some records) 2–6, 9, 10 $\left(\frac{53}{I–V}; \frac{20}{I}\right)$; *Blaniulus guttulatus* (Bosc.) 1, 4–11 $\left(\frac{34}{I–V}; \frac{13}{V}\right)$; *Archiboreoiulus pallidus* Brade-Birks 1–12 $\left(\frac{25}{I–V}; \frac{7}{V}\right)$.

CHILOPODA. *Lithobius* sp. 6 $\left(\frac{1}{I}\right)$; *Geophilus longicornis* Leach 1–12 $\left(\frac{67}{I–V}; \frac{21}{IV}\right)$; *Geophilomorph* 2 $\left(\frac{1}{III}\right)$.

SYMPHYLA. Spp. 2–4, 9–11 $\left(\frac{19}{II–V}; \frac{6}{IV, V}\right)$.

ARACHNIDA.

Areinida. *Porrhomma pygmaeum* Pd. 3 $\left(\frac{1}{III}\right)$; *Centromerus bicolor* Bl. 3 $\left(\frac{1}{II}\right)$; *Trochosa terricola* Thor. 8, 9 $\left(\frac{2}{I}\right)$; *Stemonyphantes lineatus* L. 10 $\left(\frac{1}{III}\right)$; *Linyphia* spp. 9 $\left(\frac{1}{I}\right)$.

Acarina. ANYSTIDAE. *Anystis baccarum* L. 6 $\left(\frac{1}{I}\right)$.

GAMASIDAE. *Gamasus magnus* Kr. 1, 3–6, 9–12 $\left(\frac{14}{I–III}; \frac{9}{I}\right)$; *Gamasus* sp. (immature) 3, 4 $\left(\frac{2}{I}\right)$; *Pergamasus crassipes* L. 6, 10 $\left(\frac{7}{I–III}; \frac{6}{I}\right)$; *P. crassipes* var. *longicornis* 2, 10 $\left(\frac{4}{I, II}; \frac{3}{I}\right)$; *P. meridionalis* Berl. 11 $\left(\frac{1}{II}\right)$; *P. hamatus* Koch 6 $\left(\frac{1}{III}\right)$; *P. septrionalis* Oud. 6, 9, 12 $\left(\frac{6}{I}\right)$; *P. rumiger* Berl. 5, 10 $\left(\frac{2}{I}\right)$; *Pergamasus* spp. (immature) 3–11 $\left(\frac{13}{I–IV}; \frac{4}{I, II}\right)$.

OLIGOCHAETA (*Terricolae*) 1–12 $\left(\frac{136}{I–V}; \frac{56}{II}\right)$.

OLIGOCHAETA (*Limicolae*), **NEMATODA**, etc. 1–12 $\left(\frac{236}{I–V}; \frac{75}{III}\right)$.

ISOPODA 1, 3, 9–11 $\left(\frac{10}{I–V}; \frac{3}{V}\right)$.

GASTROPODA 1, 4, 10, 11 $\left(\frac{4}{I–III}; \frac{3}{I}\right)$.

Silvanus surinamensis L., which is recorded in the foregoing lists as having occurred once in the soil from each plot, is an introduced species which is usually recorded as having been found in stored foodstuffs, although Fowler(4) states that it has been taken under the bark of trees in Yorkshire, Epping Forest and Scotland. It seems doubtful if the specimens met with in the present instance could have been living in the soil; they may possibly have entered the soil in the laboratory before it was examined.

9. CENSUS OF CONTROL PLOT.

The total number of invertebrates found in plot 3, in twenty-three samples, was 1471 or 4,952,857 per acre. Of these 735, or 2,474,745 per acre, were insects.

The numbers per acre of the more abundant groups were as follows: *Oligochaeta* (*Limicolae*), etc., 794,612; *Collembola* 693,602; *Formicidae* 690,235; *Diplopoda* 595,959; *Oligochaeta* (*Terricolae*) 457,912; *Acarina* 215,488; *Chilopoda* 215,488. The numbers of insects belonging to groups recognised as pests were: *Elateridae* (larvae) 164,983; *Hepialidae* (larvae) 23,569; and *Tipulidae* (larvae) 16,835. The numbers per acre in the different orders are shown in Fig. 5.

The "probable error" in the total population per acre is ± 520,000, and in the number of *Elateridae* larvae per acre ± 44,000.

The number of species of insects which occurred in the samples was about 60 but, as in the other plot, this number might have been higher if all the larvae could have been exactly determined.

The average number of insects per sample was 31·95.

The following orders were represented in the percentages given: *Collembola* 28·14; *Thysanura* 1·78; *Orthoptera* 0·55; *Thysanoptera* 0·96; *Hemiptera* 0·27; *Lepidoptera* 1·91; *Coleoptera* 15·30; *Diptera* 22·13; *Hymenoptera* 28·96.

The dominant order in number of species present was the *Coleoptera*, with 14 species. The number of species in the different orders is shown in Fig. 6.

The most abundant species of insects were *Myrmica laevinodis*, which made up 27·9 per cent. of the total insects, *Onychiurus ambulans* 6·8 per cent., and *Onychiurus fimetarius* 6·5 per cent.

Seven species of *Myriapoda* (excluding *Symphyla*) occurred in this plot, and thirteen species of *Arachnida*.

10. Comparison of the Faunas of the Two Plots.

It is noticeable that in both the plots the *Oligochaeta* (*Limicolae*), *Formicidae* and *Collembola* were much the most abundantly represented groups, and that the *Diplopoda*, *Oligochaeta* (*Terricolae*) and *Acarina* were also very numerous in both plots. There was not very much difference between the numbers of *Elateridae* larvae in the two plots, the numbers being 198,653 per acre in plot 2, and 164,983 per acre in plot 3. It is also noticeable that the numbers of *Tipulidae* larvae and *Hepialidae* larvae are the same for both plots.

Other groups showed considerable difference in numbers between the two plots. *Diplopoda* occurred at the rate of 1,367,002 per acre in plot 2 and 595,959 per acre in plot 3, while *Trichocera* larvae occurred at the rate of 367,002 per acre in plot 2, but only at the rate of 23,567 per acre in plot 3, and *Chironomidae* larvae, which were found at the rate of 515,151 per acre in plot 2, were only found at the rate of 26,936 per acre in plot 3.

Most of the other groups occurred in somewhat greater numbers in plot 2: only one or two groups were found to be more plentiful in plot 3. Amongst the latter were the *Cecidomyidae* (larvae), 212,121 per acre in plot 3 and 195,286 per acre in plot 2, and the *Chilopoda*, 215,488 per acre in plot 3 and 208,754 per acre in plot 2, although the differences in these cases are not large enough to be of importance.

The equal or almost equal numbers of *Elateridae*, *Tipulidae* and *Hepialidae* larvae appears to show quite clearly that the continued use of farmyard manure does not cause an appreciable increase in the numbers of these injurious species although this manure appears to introduce or attract the injurious *Diplopoda* and certain non-injurious

species such as *Trichocera* and *Chironomidae* larvae, which probably are of some service in helping to open up the soil.

11. Distribution in Depth.

The depth at which the different organisms occurred was of considerable interest, and the samples were taken in five separate layers in order that their distribution might be accurately determined. This distribution was considerably affected by the ploughing of the plots, but seemed to be very little influenced by the operations of cultivation, harrowing and drilling.

In taking a sample of soil it was usually quite clear to what depth the ploughing had affected the soil, and as a rule a distinct change in the character of the soil was noticed in the fourth layer, taken between the five and seven-inch levels.

Of the total number of insects present, taking the whole period of the investigation, in plot 2, 78·7 per cent., and in plot 3, 50·3 per cent., occurred in the first two layers of soil, that is, between the surface and a depth of three inches. The percentages at the different depths were, for the manured plot: I 51·5; II 27·2; III 11·0; IV 6·4; V 3·8; and for the control plot: I 25·3; II 25·0; III 33·0; IV 11·1; V 5·5. Taking only the period from the commencement of the investigation in February until the plots were ploughed on October 13th, the percentages at the different depths were, for the manured plot: I 58·0; II 27·7; III 9·6; IV 2·5; V 2·2, and for the control plot: I 26·0; II 25·0; III 33·9; IV 10·2; V 4·8. Similarly, from the time of ploughing to the end of the investigation (October to January), the percentages at the different depths were, for the manured plot: I 8·7; II 24·3; III 20·0; IV 32·3; V 15·0, and for the control plot: I 16·6; II 24·0; III 22·2; IV 22·2; V 14·8.

It must be borne in mind, in comparing the percentages in the uppermost layer with those in the other layers, that the volume of soil in this top layer was considerably less than in the other layers, as it consisted of the soil between the surface and a depth of one inch below the surface only, while the remaining layers consisted of the soil for a depth of two inches.

Most groups of insects, etc., considering the period of the investigation as a whole, occurred in the largest numbers in the second layer, with a rather lower percentage in the first. The third usually contained a distinctly smaller percentage than the second, quite commonly being from one-half to one-third the number, while the fourth layer usually stood in about the same relation to the third, the difference being in

some cases even greater. The same relation existed again between the fifth and fourth layers. The fact that the figures given above do not coincide with this is due chiefly to the distribution of the ants, which occurred on two occasions in large numbers, owing to the sample containing part of a nest. One of these nests occurred in the first layer of a sample from the manured plot, and the other in the third layer of a sample from the control plot, before the plots were ploughed.

In Fig. 7 the *Formicidae* have been omitted. This diagram indicates very clearly that the *Insecta*, "*Myriapoda*" and *Oligochaeta* (*Terricolae*) probably penetrate to a greater depth than nine inches.

A few groups showed noticeable variations from the above general rule. The *Acarina*, *Cecidomyidae* (larvae), *Chironomidae* (larvae) and *Trichocera* (larvae) were found to occur in much larger proportions in the upper layer than in the second, and very few occurred below the five-inch level. With the *Symphyla* the usual proportions per layer were practically reversed, much the greatest proportion of this group occurring in the fourth and fifth layers.

After the plots had been ploughed the effect of the ploughing on some of the groups of invertebrates was very clear for some time. Taking the numbers of *Collembola* for example, from the beginning of the investigation in February to the time of ploughing in October, the percentages in the five layers were: I 29·0; II 44·0; III 19·8; IV 3·0; V 4·1 in the manured plot, and I 28·6; II 46·8; III 16·1; IV 4·6; V 3·6 in the control plot.

For the period from the time of ploughing to the end of the investigation, the percentages were: I 2·1; II 12·2; III 20·1; IV 44·6; V 20·9 in the manured plot, and I 14·3; II 14·3; III 28·6; IV 28·6; V 14·3 in the control plot.

In the case of the *Elateridae* larvae, taking the whole period of the investigation, the percentages at the different depths were, in the manured plot: I 1·7; II 18·6; III 20·3; IV 32·2; V 27·1; and in the control plot: I 12·2; II 18·4; III 26·5; IV 32·6; V 10·2. Taking only the period from the commencement of the investigation to the time of ploughing the percentages at the different depths were, for the manured plot: I 2·8; II 30·5; III 27·8; IV 22·2; V 16·7; and for the control plot: I 11·6; II 20·9; III 27·9; IV 34·9; V 4·7. After the plots had been ploughed, taking the period from the time of ploughing to the end of the investigation, the percentages at the different depths were, for the manured plot: I nil; II nil; III 8·7; IV 47·8; V 43·5; and for the control plot: I 16·7; II nil; III 16·7; IV 16·7; V 50·0.

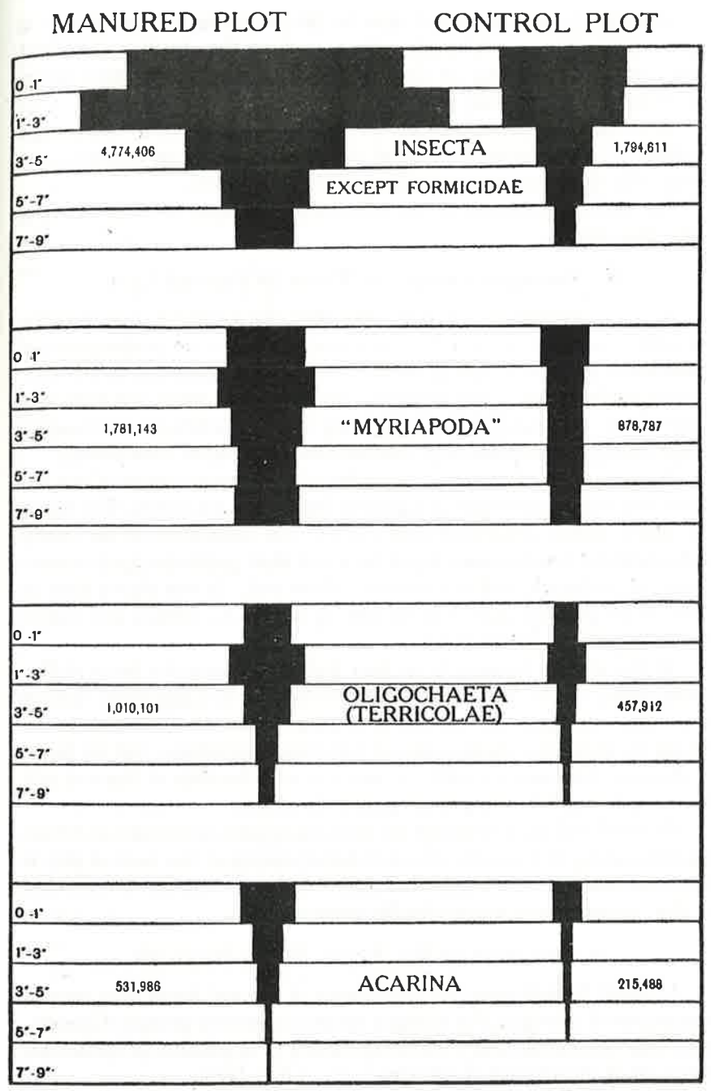


Fig. 7. Distribution in depth of the more important groups in the manured and control plots.

Effects of a similar nature due to the ploughing were observed in some other groups, while with others, such as the *Acarina*, the effect was very little marked, as they appeared to regain the upper layers after being buried by the plough.

Although the percentage at the different depths varied somewhat between the two plots, the general distribution of the insects, etc., was very little different in one plot from that in the other.

No seasonal variation in the distribution in depth of the soil fauna was observed.

12. Comparison with Soil Fauna of Pasture Land.

It is not possible to compare very fully the soil fauna found in the present investigation with that previously found in the examination of permanent pasture(10) owing to the considerable difference in the conditions under which it was existing. The localities in which the work was carried out are widely separated, being in Hertfordshire and Cheshire respectively, and the soil and weather conditions differ considerably.

In pasture land few insects were found at a greater depth in the soil than two inches, and none at a greater depth than six inches. The depth to which insects penetrated into the soil was considered to be chiefly influenced by four factors—depth to which their particular food occurs; aeration; moisture; and temperature of the soil. It was shown that in permanent pasture these four factors all tended to restrict the insects to the superficial layers of soil.

In the present instance these four factors influence the fauna differently, owing to the field being under cultivation. The periodical turning over and stirring of the soil makes it fairly certain that the soil, to the depth to which the implements of cultivation penetrate, will be fairly uniform in composition, and the aeration and drainage of the soil will be more favourable owing to its greater looseness.

In arable soil the conditions are thus much more favourable to deeper penetration by the insects. The number of insects in the control plot is less than was found in the pasture (3,586,088 per acre), but the number in the manured plot is considerably greater.

13. Relation of Soil Fauna to Soil Nitrogen.

In order to determine the importance of the soil fauna as a reserve and source of nitrogen, the nitrogen content of several groups of insects, etc., was estimated, and from these figures it is possible to obtain an estimate of the amount of nitrogen in the whole fauna.

The nitrogen content of the following groups was obtained: *Elateridae* larvae, *Collembola*, *Formicidae*, *Oligochaeta* (*Terricolae*), *Myriapoda* and *Oligochaeta* (*Limicolae*), the percentage of nitrogen in the dry weight being: *Elateridae* larvae 10·65 per cent.; *Collembola* 11·18 per cent.; *Formicidae* 10·92 per cent.; *Oligochaeta* (*Terricolae*) 9·4 per cent.; *Myriapoda* 4·88 per cent.; *Oligochaeta* (*Limicolae*) 6·26 per cent.

The total weight of nitrogen per acre contained in the bodies of the above groups in the manured plot is approximately: *Elateridae* larvae 206·0 gm.; *Collembola* 8·5 gm.; *Formicidae* 306·6 gm.; *Oligochaeta* (*Terricolae*) 4626·0 gm.; *Oligochaeta* (*Limicolae*) 97·0 gm.; *Myriapoda* 1864·9 gm.

Assuming that the remaining insects are of the same average nitrogen content, the total nitrogen of all the insects in an acre of the manured plot is 687·7 gm.

The nitrogen contained in the *Oligochaeta* (*Terricolae* and *Limicolae*) and *Myriapoda* is 6587·9 gm. per acre of the manured plot. These groups include 6,400,668 of the 7,373,730 invertebrates other than insects, the remaining 973,062 consisting chiefly of *Arachnida*, with some *Isopoda* and a few *Gastropoda*. Assuming their nitrogen content to be the same as that of the same number of insects, it would be 74·0 gm. giving a total of 6661·9 gm.

The total nitrogen of the fauna of an acre of the manured plot is thus 7349·6 gm. or 16·2 lbs.

In the control plot the nitrogen contained in the bodies of the same groups is: *Elateridae* larvae 169·0 gm.; *Collembola* 2·4 gm.; *Formicidae* 71·5 gm.; *Oligochaeta* (*Terricolae*) 2128·0 gm.; *Oligochaeta* (*Limicolae*) 21·4 gm.; *Myriapoda* 920·1 gm.

Again assuming that the remaining insects are of the same average nitrogen content, the total nitrogen of all the insects in an acre of the control plot is 313·3 gm.

The nitrogen contained in the *Oligochaeta* (*Terricolae* and *Limicolae*) and *Myriapoda* is 3069·5 gm. per acre of the control plot.

These groups include 2,131,311 of the 2,478,112 invertebrates other than insects in an acre of the manured plot. Assuming that the remaining 346,801 invertebrates have the same nitrogen content as the same number of insects, their nitrogen content is 26·4 gm.

The total nitrogen contained in the bodies of the fauna of an acre of the control plot is thus 3409·2 gm. or 7·5 lbs.

These amounts of nitrogen are equivalent to the nitrogen contained in 103·6 lbs. and 48·0 lbs. of nitrate of soda in the manured and control plots respectively.

It appeared possible that the introduction of insects, etc., in an application of farmyard manure, and their subsequent death and decay with gradual liberation of nitrogen, might account for the effects of an application of farmyard manure being noticeable for a considerable time afterwards. The quantity of nitrogen contained in the fauna seems, however, to be too small to be of great importance in this way, even although the manured plot in this case had received farmyard manure annually for 77 years.

Although the bodies of the invertebrate fauna of the soil contain quite an appreciable amount of nitrogen, there can scarcely be any loss or gain of nitrogen due to them. The *Oligochaeta*, *Myriapoda* and other groups which live and die in the soil, eventually return to it, at their death, all they have taken from it. Although winged insects may leave a plot in which their larvae have fed, this is probably balanced by other insects migrating to the plot and dying there, whose larvae have fed elsewhere.

14. The Function of the Invertebrate Fauna in the Soil.

Since the work of Darwin (1) and others (6), (14) the importance of the earthworms in the soil has been widely recognised, the uniformity and loose texture of the surface soil being attributed largely to them. By means of their burrows air and water are enabled to penetrate the soil, and their habit of drawing leaves, blades of grass and other vegetable remains into their burrows adds to their importance.

A considerable proportion of the damage done to land by floods is considered to be due to the flooding out of the earthworms, so that the surface soil remains compacted and vegetation languishes until a new immigration of earthworms has restocked the soil.

Some authors (3), (6), (7), (13) consider that, in addition to the mechanical work of loosening the soil and assisting aeration and drainage, the earthworms, by the passage of considerable quantities of soil through their bodies, render the mineral substances more readily available for plants. On the other hand, the results of other experiments have tended to disprove this theory (12).

It has also been stated that by following the burrows of earthworms, the roots of plants are able to penetrate to a greater depth than would otherwise be the case, although this is denied by other workers (2).

The work of insects, insect larvae and other invertebrates in the soil is probably similar to that of the earthworms (7) in assisting in the aeration and drainage of the soil. Since they pass smaller quantities of soil through their bodies than in the case of earthworms, they probably do not affect the soil to the same extent.

Kostitcheff, in his work on the Russian "Black earth" (8), states that the action of worms and insects in the soil is of great importance in assisting in the breaking down of vegetable matter and the formation of humus. In damp places where worms and insects are unable to live, the vegetable matter is broken down very much more slowly, and peat, in which the vegetable matter still retains a certain amount of structure, is formed instead of an amorphous humus. He does not agree with Darwin with regard to the importance of earthworms in bringing soil from the lower levels to the surface.

In experiments carried out on earthworms, millepedes and *Sciara* larvae Kostitcheff (9) found that they had little effect in accelerating the decomposition of dead leaves, but he considers that after being once passed through the animal, the material is then acted on by fungi and bacteria, and again made available as food for the worms and insects, and in this way the vegetable matter is eventually completely broken down.

Darwin estimated that earthworms brought to the surface of the soil, in their "casts," sufficient earth to form annually a layer 0·2 inch in depth, or dry earth weighing ten tons per acre, and that in 50 years the upper ten inches of soil is completely turned over by them.

Hensen, quoted by Darwin, calculated that there were 53,767 earthworms in an acre of garden soil, and found open burrows to the number of 196,020 per acre, although Darwin states that he has seen them much more numerous. Hensen estimated that there would be half as many earthworms in an acre of cornfield as in garden soil. Darwin, who obtained the number and weight of the "worm-casts" over certain areas, did not give any relation between the number of "casts" and the number of worms present.

In the present investigation the numbers of worms found, 1,010,101 and 457,912 in the manured and control plots respectively, are very much above Hensen's estimates.

Summary.

1. Samples of soil were taken from two of the plots at the Rothamsted Experimental Farm and all insects and other invertebrates were recorded together with the approximate depths at which they occurred.

2. One of these plots (plot 2) has received 14 tons of farmyard manure per acre per annum since 1843; the other (plot 3) has received no manure of any kind since 1839. This difference in treatment had a very marked effect on the number of insects present.

3. Twenty-three samples of soil were examined from each plot, each sample being a cube $9 \times 9 \times 9$ inches. The soil in each sample was removed in five layers, so that it was possible to determine the approximate depth at which the specimens occurred.

4. There were, in round numbers, 15,100,000 invertebrates per acre, of which 7,720,000 per acre were insects, in plot 2, and 4,950,000 invertebrates per acre, of which 2,470,000 per acre were insects, in plot 3.

5. The greatest number, both of insects and of other invertebrates, occurred in the upper three inches of the soil, but some species were found in larger numbers at a greater depth, the greatest number of *Elateridae* larvae being found at a depth of five to seven inches, and of *Symphyla* at a depth of seven to nine inches.

6. Some species, such as the larvae of *Chironomidae* and *Trichocera*, were practically confined to the plot which had received farmyard manure, plot 2, while other species, such as the *Collembola*, *Onychiurus ambulans* and *O. fimetarius*, although they occurred in both plots, were considerably more numerous in plot 2.

7. Injurious insects, such as the larvae of *Elateridae*, *Tipulidae* and *Hepialidae*, appeared to be little affected by the different manurial treatment of the two plots, and occurred in practically equal numbers in the two plots.

8. Although 198,653 and 164,983 *Elateridae* larvae per acre occurred in plots 2 and 3 respectively, they did not produce any appreciable effect on the crop.

9. An attempt was made to estimate the amount of nitrogen contained in the bodies of the soil fauna, and it was found to be 7349·6 gm. or 16·2 lbs. and 3409·2 gm. or 7·5 lbs. in plots 2 and 3 respectively. It is unlikely that there is any appreciable loss of nitrogen from the soil due to the migration of winged members of the fauna.

10. The worms, insects and insect larvae are beneficial in loosening the soil and facilitating aeration and drainage.

11. The net results of these observations show that, although the introduction of farmyard manure greatly increases the invertebrate population of the soil, the latter organisms are saprophagous and are not directly injurious to the growing crop. Such injurious organisms as are present occur in approximately equal numbers whether the land be manured or not. The most notable exception to this generalisation is met with in the *Diplopoda*, whose numbers are increased by about 200 per cent. in the manured plot.

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