EARTHWORMS AND SOIL FERTILITY

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In recent years the fauna of the soil has been receiving more attention and interest has centred especially on earthworms and the functions they subserve. A number of experiments have been devised in order to learn more of their influence on the relations between plant and soil, and among the accounts of recent work that of Hopp and Slater (1) is one of the more important. These two workers in a series of five pot experiments showed that with different crops and soils of varying fertility the earthworms consistently increased the plant yields. The increases varied between 43 per cent. for millet in one soil and 350 per cent. for wheat in another. The addition of dead earthworms also significantly increased the yields, but to a less degree than was the case with living ones.

It was shown that in the soils with dead earthworms there was an increase of nitrate nitrogen, which raises the problem of whether the higher fertility was due to the nitrogen so released. This aspect together with the failure by certain other workers (2) to demonstrate positive results has led to some degree of criticism. Thus a highly cautious attitude is adopted by E. W. Russell (3), who says in his book, "Soil Conditions and Plant Growth," "There is still much uncertainty whether earthworms directly affect the fertility of soils. . . . A. C. Evans has recently re-investigated this problem and could not show that living worms increased the green weight of crops growing in the soil, though they appeared to increase its dry weight, a result that is difficult to interpret, but one that could be due to the improved physical condition of the soil."

In spite of some negative results there is a growing body of evidence that the presence of earthworms is reflected in more vigorous plant growth. Generallv speaking, the effects are more apparent when the soil is left undisturbed for some length of time.

It is 'not the purpose of this paper to review. current overseas work, but rather to make a few observations on earthworms under New Zealand grassland conditions.

INTRODUCED EARTHWORMS IN NEW ZEALAND

It has been stated by overseas writers that no observations have been reported which succeed in showing that earthworms increase fertility in the field. The reasons for such a lack of evidence are plain, and reside principally in the fact that in the older lands the various species found there have existed long before the development of agriculture, and probably even before the advent of palaeolithic man. A quite different situation has obtained in New Zealand, where the coming of European civilisation has been followed by the introduction of many animals and plants, some by deliberate human intent, others by accidental means. Our native earthworm fauna is numerous as to species (there being over 110), but contained none of the forms native to the Old World before the first settlers arrived, When European earthworms first reached this country is quite unknown, and the first indication of their presence is given by the account of Captain Hutton in 1876 (4, 5). In spite of faulty identification and mis-naming of species, it is clear that widespread regions in the colony had by that time been populated by the European species *Lumbricus rubellus, Allolobophora caliginosa* and *Eisenia foetida.* By 1922 (6) there were seven such species reported in this country and at the present day we know of twelve of the European Lumbricidae. There are one or two non-European acclimatised worms, but these have no significance in pasture ecology.

The incoming species have obviously found themselves well fitted for New Zealand soil conditions and have spread and adapted themselves very rapidly. From the occasional sporadic immigrant of say 100 years ago, there has developed an extensive population covering millions of acres of our best farm lands and their numbers often reach greater proportions than those attained under permanent pasture in their native habitats. Thus at Rukuhia Soil Research Station, and frequently elsewhere, we have observed earthworm densities over 100 to the square foot or 4,300,000 or so to the acre, whereas the densities as reported for British pastures are generally much lower.

THE EXPERIMENTS OF MR A. S. ASHMORE

It is said that a number of farmers in the hinterland of the North Island were aware some 40 years ago that the fertility of their pastures had improved in a way which was not to be explained by their usual fertiliser treatments. Some of these farmers observed that the higher fertility was apparently associated with the appearance of earthworms in the soil. Unfortunately no systematic observations were then made and it now seems unlikely that we shall ever know the full history of the effects of these spreading animals on our grassland economy. There is, however, one case which has been rather fully investigated, namely the property of Mr A. S. Ashmore in the Raetihi district, Waimarino County. Mr Ashmore was one of the few men who has associated the spread of earthworms with a clearly observable change in soil and sward without the aid of fertilisers. He became sufficiently interested to transplant turves from an original focus containing worms to various parts of his hill-country farm, a holding of some 860 acres. After a time lag of several years, the various small local communities spread over the land and ultimately coalesced. The planting of turves was more or less haphazardly begun in 1925 until in 1930 more systematic efforts were made, so that by 1945 the greater part of the farm had been influenced by earthworm activity.

The changed appearance in the colour of the pasture, the conversion from a predominantly browntop-danthonia association to one containing higher fertility plants such as ryegrass and clovers, and the increased carrying capacity of the farm-these factors have all been described by Hamblyn and Dingwall in the New Zealand Journal of Agriculture for 1945 (7).

The commonest worm species found there in 1945 was identified as ***Allolobophora jassyensis***, which was an unfortunate error. As it had not been reported elsewhere in this country, the feeling arose that this particular worm of Ashmore's had special abilities in its capacity to spread and to raise the fertility of poor hill-country soils. Very soon the Department of Agriculture distributed thousands of these worms over scores of trials in various hilly parts of the North and South Islands. At the same time Sir William Benham re-identified his species as ***Allolobophora caliginosa***, which we now know was present on most of the official trials before the new worms were added.

In August 1949 I visited Ashmore's farm in company with Mr Walsh of the Rukuhia Soil Research Station. By this date practically the whole of the property had been populated by *A. caliginosa* and there was little evidence, at least on the hills, of the changes said to have been wrought consequent upon its introduction. There was one paddock, however, on level ground which showed distinct differences in the pasture. Curiously enough, although almost the easiest ground on the station and readily accessible, it was nearly the last to be planted with worms. It was isolated from neighbouring pastures, being bounded on all sides by a road, a river, and native bush, so that there were excellent conditions here for observing the spread of a local earthworm population.

In 1934 this field of 49 acres was cleared and put down in grass, having previously been covered with scrub and bracken. Chou moellier was grown in 1936 and grass was resown the following year. By 1940 there were signs of deterioration in the pasture and in this year the first worm sod was placed at the northern end. Incidentally the only fertiliser applied over the whole period was 5cwt. of lime per acre in 1949.

At the time of our visit about three-fourths of the field showed signs of worm activity; there was a striking contrast between the fertility of the pasture populated by earthworms and that which *A. caliginosa* had not reached. A narrow zone of intermediate fertility lay between, where the earthworms were few in number. A series of counts produced the figures given in Table I.

TABLE I.

Ashmore's Hay Paddock

Species	Mean Numbers of Earthworms per Square Foot		
	A	B.	C.
A. caliginosa	97	10	—
L. rubellus	15	12	6
Eisenia rosea	1	—	—
Total	113	22	6

A-area populated by earthworms for several years.
B-area near the limit of spread.
C-area no't yet reached by *A. caliginosa.*

Extensive cuts were then taken from the same areas in which the earthworm counts were made. The species analysis by per cent. of oven-dry weight are given in Table II in which the letters A, B, and C have the same meanings as previously :

TABLE II.

Ashmore's Hay Paddock
Botanical Composition

(Per cent. of Oven-dry Weight)

	A	B	C
Ryegrass	42	13	2
Yorkshire fog	18	8	5
White clover	3	1	Trace
Suckling clover	6	8	2
Browntop	19	45	55
Danthonia	—	10	21
Other grasses	6	4	—
Weeds	6	4	5
Moss	—	7	10
	100	100	100

It will be readily seen from Table II that the transition from a browntop-danthonia pasture through an intermediate phase to a ryegrass-dominant one is very marked, and corresponds with the changes in the worm population. One significant point is the high proportion of moss in the unwormed pasture as compared with its total absence in the wormed. The figure of 1.0 per cent. for moss does not represent the real extent of its growth since much of it was at ground level and could not therefore be cut by the shears. In other respects the figures given. in the table reflect fairly accurately the differences presented to the eye (differences which might not unfairly be described as dramatic).

The results of the soil chemical analyses are presented in Table III. (The analyses were done by the quick-test method used by the Department of Agriculture.)

TABLE III

Ashmore's Hay Paddock
Soil Analyses

	pH	Calcium	Potash (as K_2O)	Phosphorus (as P_2O_5)
A-High Worm Count	6.02	14	high	0.9
B-Medium Worm Count	6.21	12	low	1.1
C-*A. caliginosa* absent	6.28	12	medium	0.4

Calcium is expressed as milli-equivalents per cent. of dry soil and phosphate as mg. P_2O_5 per 100g. of dry soil.

From Table III it is seen that the most fertile pasture is somewhat higher in mineral nutrients and. it is possible that given a uniform distribution of earthworms over the whole field, some variations in growth would be seen. It is highly doubtful, however, that the soil analyses shown above could, account for the changes in species composition already indicated in Table II. The soil itself was considerably altered where the worms- had worked in it, being loamy and very plastic to the touch when wet, while the turf was springy underfoot. Where they were absent it was coarser in the texture and seriously root-bound.

The high calcium figures in Table III may offer one reason why the worms spread so rapidly on the farm. A deficiency of potash or of phosphate in the soil will not prevent their establishment, but a shortage of calcium will do so. The lowest safe level of calcium has been estimated to be 5 milli-equivalents per cent (8), so that the Raetihi farm was well supplied in this respect.

It may be safely held that the results of our 1949 examination of this farm fully support the observations made by previous investigators, and by the farmer himself.

FIELD EXPERIMENTS ELSEWHERE

There can be no doubt that at the present day the worms are firmly established over the whole farm, as they are also over most of the adjacent country. This leaves us with the problem of finding other country where the earthworms are spreading so that further observations may be made. We cannot say what tracts of land remain untenanted by such species as *A. caliginosa,* since no overall survey has been.made with this purpose in view. If such a survey were undertaken, it would be necessary to take into account not merely the absence of worms, but the sufficiency of both calcium and soil moisture for these organisms.

When the results of transplanting earthworms on Ashmore's farm. were announced, many farmers obtained turves from him with a view to setting up a colony on their own soils. It is certain that most ,of these efforts were wasted since,, as was indicated earlier, most of our old-established pastures are by now well populated with *A. caliginosa* as well as other species.

The Department of Agriculture has a successful trial near Ohakune, and several others which may yield positive results in the future. Rapid results cannot be expected, since we are dealing not with a fertiliser experiment, but with the problem of inducing an animal population to grow under conditions which are not always favourable; nor can there yet be any complete certainty as to what constitutes a favourable environment.

A POT EXPERIMENT

During the course of a survey of some earthworm trials, a number of turves were collected from different localities. These were taken with a view to setting up a modified pot experiment' for the observation of plant responses to earthworms in different soils. Since the turves were mostly carried by hand from difficult hill country, it was not possible to secure enough material for a properly replicated experiment, but the results obtained from this preliminary trial are sufficiently interesting to indicate the need for further work of this kind.

The following soils were used, there being eight in all.

Soil Type	Description	Source
28H	Waikura sandy loam	Horoeka. H.B.
117A	Moumahaki silt loam	Near Raetihi
114	Kidnappers sandy silt loam	Wanganui district
83	Hamilton clay loam	Hamilton
65	Ohakune silt loam	Ohakune
38H	Okaka silty clay	Rangiahua, Northland
19H	Tarukanga sandy silt	Te Pohue, H.B.
48A	Horotiu sandy loam	Rukuhia

In the case of the soil type 117A, a number of turves were removed from Mr Ashmore's hay paddock to which reference was made earlier. These were set up in duplicate and were kept as nearly as possible in the same condition as when collected. In addition, the Waikura sandy loam type 28H was tested in the form of the original turves taken from an almost pure sward of danthonia. The remaining turves were broken up and both grass and any earthworms present were removed. The soils were heat-treated at 55 degrees to 60 degrees C. to kill any worm cocoons remaining, after which they were carefully divided into two equal portions and placed in wooden boxes 15in. square by 16in. deep. Lime at the rate of 2 tons per acre was added to soil types 48A and 114 only. In each case the soil was laid over about 10in. of subsoil clay collected locally; 100 *A. caliginosa* were added to one box of each pair and all boxes (except the turves) were uniformly sown with a mixture of white clover, ryegrass, cocksfoot, and browntop. The boxes were finally raised about 18in. above ground level on a wooden stand. The trial was begun in November 1949 and was continued for 20 months, during which time there were altogether eight harvests; except for one or two cases the boxes with the earthworms always yielded a greater weight of grass, both wet and dry, than the controls. The total grass growth is summarised in Table IV:'

TABLE IV

Earthworm Box Trial

Soil Type	District	*A. caliginosa* recovered at end of Trial Total Wt. (gms.)	No.	D.M. Yield per acre per year (lb.)	Total D.M. Yield per box (gms.)	Total increase of D.M. in Wormed boxes (per cent.)
Turves						
28H	Horoeka	—	—	2,000	53.9	
28H	„	8.07	28	3,950	106.3	+ 9.7.5
*117A	Raetihi	—	—	3,440.	92.4	
*117A	„	6.75	48	5,430	145.8	+ 58.0
*117A	„	17.09	69	5,750	154.5	+ 67.0
Soils						
117A	Raetihi	—	—	1,530	41.1	
117A	„	0.20	1	2,570	69.0	+ 68.0
114	Wanganui	—		4,930	132.4	
114	„	23.28	281	6,920	185.9	+ 40.5
83	Hamilton	—		8,060	217.4	
83	„	37.50	286	10,350	278.4	+ 28.2
65	Ohakune	—		2,910	78.3	
65	„	15.52	142	4,860	130.6	+ 67.0
38H	Rangiahua	—	—	2,960	79.8	
38H	„	17.98	285	6,250	167.9	+ 110.7
19H	Te Pohue	—	—	3,860	103.7	
19H	„ „	11.20	132	6,160	165.4	+ 59.7
48A	Rukuhia	—		9,640	259.6	
48A	„	21.87	74	12,620	339.6	+ 31.0

*Figures given are means of two; elsewhere only one box used.

Reference to Table IV shows that overall increases in boxes containing ***A. caliginosa*** varied between 28 and 110 per cent. compared with controls. Except for the Hamilton clay loam and the Horotiu sandy loam, which have held worms for probably scores of years, and the oldest wormed Raetihi turves (6 to 8 years), the soils were taken from districts into which

A. caliginosa has spread only in the last 2 or 3 years.

There is little correlation shown between the total weights of earthworms recovered at the end of the experiment and the total dry-matter yields; this fact has little significance, however, since many of them may have died during the previous summer, especially in those soils with a tendency to lose moisture rapidly. So far as seasonal differences are concerned, the greatest increases occurred during spring, followed by winter, with considerably lower increments in the wormed boxes during summer and autumn. One point of interest in this experiment is that there was no tendency for differential encouragement of any species of grass or clover at the expense of the others. Probably the time was too short to allow of any such effect to take place.

CAUSES OF INCREASED FERTILITY

There is no certainty as to the reasons why earthworm activity in the soil tends to promote the growth of grasses and other plants. Doubtless there are several factors involved, and among these increased aeration and improved soil structure would be of some importance, especially the latter, as shown by overseas workers.

One of the suggestions put forward by Hopp and Slater was that earthworms liberate a substance beneficial to plants. They state: "Available evidence suggests that the release of beneficial chemicals occurs principally in the, summer season, when earthworms normally pass through their reproductive period." These authors imply that the earthworms die in summer, thus releasing the unknown substance by decomposition of the bodies. In New Zealand they breed mainly in spring and do not die in summer unless the soil is excessively dry. However, we have given a considerable amount of attention to this. suggestion and are able to report that some earthworms contain in their bodies a substance in minute traces which responds in biological tests in the same way as plant hormones do. Now the term plant hormone, used in its proper context, means a substance formed in and by living plant tissue, therefore the term growth factor will be used to describe the substance in the earthworms.

The chemical tests of my colleague, Mr R. W. Bailey, do not yet indicate the nature of this substance, now show whether there is more than one substance. What can be said, however, is that biological tests indicate the presence of this factor in the bodies of seven species of introduced worms, including *A. caliginosa.* Further, when dead worms were put into the soil, the growth factor was found in the soil for 6 weeks afterwards, while an 'untreated soil gave no positive reaction. In addition to this, there is evidence that. earthworms secrete the growth factor in very small quantities from the living body and hence furnish a constant supply of this material to-the soil round the roots of plants.

There is much conflicting evidence concerning the effects on plants following the experimental addition to the soil of such plant hormones as indoleacetic acid. Whether or not the secretions from earthworms are capable of increasing the growth. of plants is not' known. Only future experiment will determine the importance of this growth factor in the economy of the soil.

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