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A FIELD STUDY OF SOME NEMATODE PARASITES OF BOVINES IN A SEMI-ARID AREA, WITH SPECIAL REFERENCE TO THEIR BIOLOGY AND POSSIBLE METHODS OF PROPHYLAXIS

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DEDICATION

To the Memory of My Late Father Leopold Reinecke, Ph.D., Geologist

CONTENTS

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Summary

Preliminary field investigations revealed the presence of *Cooperia pectinata*, *C. punctata*, *Haemonchus placei*, *Oesophagostomum radiatum* and *Bunostomum phlebotomum* as the most common parasites of bovines in the North Western Cape.

Experiments on the ecology and epizootology of these parasites were carried out under field conditions, at the Armoedsvlakte Research Station near Vryburg in the North Western Cape.

Possible methods of prophylaxis based on experimental observations are described, and the possible use of strategic drenching, using anthelminthics which gave promising results, is included.

Introduction

(1) *North Western Cape*

The North Western Cape, formerly part of Bechuanaland, is a vast, semi-arid cattle ranching area. The annual rainfall varies from 10 inches in the West to 20 inches in the East, occurring mainly from mid-summer to autumn with very little, if any, rain in the winter and spring. At the Armoedsvlakte Research Station (27 S, 25 W, altitude 4,000 ft.) near Vryburg, Cape Province, the average annual rainfall is 431·0 mm. (16·9 inches) and marked diurnal temperature variations occur from a mean maximum of 19·8 C (67·6 F) to a mean minimum of −0·5 C (31·1 F) in July and from a mean maximum of 32·1 C (89·8 F) to a mean minimum of 16·3 C (61·3 F) in January. Mean Relative Humidities vary from 36 per cent in September to 59 per cent in March and sunshine hours from 8·5 to 9·9 hours. Rates of evaporation are high.

The area lacks surface water of any kind. Fountains are few and far between; rivers fail to run other than for short periods in times of flood. Boreholes, powered by windmills and Diesel pumps, must supply all water requirements. Subterranean water supplies are very deep, often brackish, and frequently only 2–3 gallons a minute can be pumped up from 400–600 ft. or more underground. Frequently on farms of 5,000 morgen* there is only one water supply and cattle must walk miles from their grazing to the drinking troughs.

The veld is a mixture of sweet grasses, mainly annuals, and edible bushes and trees, e.g., *Grewia* spp., *Tarchonanthus major* and *minor*, *Acacia giraffae*, etc., etc. After the rains in summer and autumn, the grass makes a natural hay in the veld in the winter. The edible bushes provide a protein supplement. Once the rains start, grass seeds germinate and the growth is phenomenal (up to 5 inches in a week).

The grazing is of good quality but due to annual droughts of at least six to nine months or longer, light stocking of one head per 5 morgen in the eastern to one per 15 morgen in the drier western areas is necessary.

(2) *Farming Methods.*

There are two main and modified methods of farming in the district.

(*a*) *Dairy Ranching*

On these farms cows are milked for cream and, in some cases, milk for cheese factories. Calves are confined to calf-pens and kraals† at birth and are separated from their dams. These calf-pens are small, fenced-off enclosures within or adjacent to the kraal, and connected to it by a wire gate. Both calf-pens and kraals have floors of manure accumulated over many years.

Cows graze in the veld at night and return to the kraal from 7 to 10 a.m. in the morning. Milking is commenced by moving the calf from its pen into the kraal and, once it has started suckling, by securing the cow's hind legs with a leather thong (riem), pushing the calf away and milking two or three teats. Thereafter the calf is allowed to suckle and left in the kraal with the cow until 2 p.m., when they are separated, the calf remaining in the kraal and the cow returning to the veld. Calves from two weeks to four months of age are allowed into a small camp at night to graze with the older calves.

(*b*) *Beef Ranching*

Cows graze with the herd in the veld, calve there and are not separated from the calves until they are weaned. The herd grazes from the late afternoon to the following morning, and comes to the drinking trough at about 8 a.m. The animals lie down near the water supply during the heat of the day, drink again from 2 to 3 p.m. or later and return to the veld. In most cases cows on beef ranches are not milked.

A more detailed description of these farming methods has recently been given by du Toit (1958) who modifies this classification.

(3) *History of Verminosis in the North Western Cape*

Farmers have stated that many sheep were kept in Bechuanaland 20 to 30 years ago but that the presence of worms forced them to abandon sheep farming in favour of cattle farming.

* 1 morgen = 10,000 sq. yards = approx. $2\frac{1}{6}$ acres.
† Kraals are cow yards, or cattle pens.

In 1930 a severe outbreak of gastro-intestinal nematodes in bovines occurred at Armoedsvlakte (Mönnig, 1931). Fourie (1942) described outbreaks in the district during 1939 to 1941. In the annual reports of the State Veterinarian (Vryburg), verminosis was considered serious in 1946, 1947, 1950 and 1951. In 1954 another extensive outbreak of helminthiasis in cattle occurred. This outbreak reached a crisis in the spring and summer under conditions of severe drought. The State Veterinarian instituted a dosing campaign and the Stock Inspectorate Staff dosed 150,888 bovines with tetrachlorethylene emulsion with excellent results. Prior to dosing, stock died off at an alarming rate, but as soon as dosing was instituted, stock losses stopped immediately; stock began filling themselves in four to five days and milk yields improved.

In view of the critical position, the Director of Veterinary Services gave instructions that a full scale investigation of bovine verminosis with headquarters at Armoedsvlakte be carried out in semi-arid areas. The work commenced in January, 1955 and some of the investigations are reported in this paper.

Review of the Literature

Veglia (1928) considered the rainfall of 7·87 inches in 1922 at Armoedsvlakte to be insufficient for the development to the infective stage of *Oesophagostomum columbianum* larvae in the faeces. According to Mönnig (1931), P. L. le Roux in 1930 diagnosed *Haemonchus contortus* (= ? *H. placei*), *Cooperia* spp., *Bunostomum phlebotomum* and *Oesophagostomum radiatum* in cattle. At the time the climatic conditions were those of severe drought. In this same article, Mönnig showed that despite the absence of rain there was sufficient moisture in a dung heap for larvae to reach the infective stage. Furthermore, he recovered larvae from the soil next to the dung heap and suggested that grass growing around and through dung heaps may carry a severe infestation of worms into the animal.

Fourie (1942) described outbreaks of verminosis along the Malopo River in the Mafeking and Vryburg areas. After floods in January and February of 1941, pools and vleis had remained which, he considered, assisted the spread of verminosis. Furthermore, he suggested that sprouting green grass near dung heaps, while usually not grazed, would be grazed during times of drought, and that sandy soils and the prevailing phosphate deficiency may have facilitated the spread of verminosis.

The embryonated eggs and infective larvae of *Trichostrongylus* spp. are very resistant to desiccation (Mönnig, 1930; Crofton, 1948b). Sprent (1946b) showed that desiccation was the most important inhibitory factor in the development of *Bunostomum phlebotomum* and that, in the dry season, these larvae could not develop in pastures, apart from permanent swamps. Seddon (1950) reported that wet conditions were not essential for the development of heavy investations in sheep. Although pasture was dry and scanty, green grass could grow due to subterranean moisture. Leaking drinking troughs, dampness under troughs lying on the soil, frontages on streams, etc., provided sufficient moisture for the spread of verminosis.

Roberts (1951b) working in Queensland, Australia, stated that verminosis was absent in areas with less than 30 inches of annual rainfall, except during abnormally wet years. Later investigators confirmed Mönnig's (1931) observations, namely that sufficient moisture was present in dung for larvae to reach the infective stage (Roberts, O'Sullivan & Riek, 1952). Roberts (1951b) stated that once dung pads had hardened 5 inches of rainfall a month was necessary for *H. contortus* (= ? *H. placei*) to escape from dung pads, but that *Cooperia spp.* and *O. radiatum*

needed less rainfall. However, in later investigations it was found that, under drought conditions, when livestock concentrated on small areas in the vicinity of the waterholes, calves became infested with *H. contortus* (= ? *H. placei*), *T. axei*, *Ostertagia ostertagi*, and *Cooperia* spp. (Riek, Roberts & O'Sullivan, 1953.) They stated that under drought conditions selective grazing could not take place, and the animals fed to soil level and right up to the dung pad. Under such conditions larval migration became less important, but some migration was essential and this could be assisted by heavy dews which occurred in the winter. The absence of *Bunostomum phlebotomum* infestation of calves led them to the conclusion that the distribution of this parasite was governed by rainfall, and that it would not survive in areas with less than 24–25 inches annually.

From the above review it will be seen that some investigators (Veglia, 1928; Sprent, 1946b; Roberts, 1951; Roberts *et al.*, 1952) mentioned that verminosis could not be spread under drought conditions; other workers (Mönnig, 1931; Fourie, 1942; Seddon, 1950; Riek *et al.*, 1953) showed that verminosis did occur under severe drought conditions; the reasons for this occurrence were not investigated. Such arid conditions occurred in the North Western Cape. It would appear that certain species of worms had found local conditions in which they were able to thrive and cause serious infestations of stock.

Preliminary Investigations

Before embarking on experimental work at Armoedsvlakte it was essential that the species of worms in cattle in the area be diagnosed; the prevalence of these species under different methods of animal husbandry be investigated; attempts be made to ascertain at what season and age stock become infested, and which age groups suffered most from the effects of verminosis.

Species of Helminths Concerned

The following species were diagnosed at post-mortems on farms in the district, at Armoedsvlakte and at the Vryburg Abattoir:—

(1) *Haemonchus placei* (Place, 1893) Ransom, 1911. The name *H. placei* has recently been resuscitated by Roberts, Turner & McKevett (1954) who have shown that this species in bovines is morphologically distinct, both in adults and infective larvae, from *Haemonchus contortus* (Rud. 1803) Cobb 1898 in ovines. The parasites found by the author at post mortem examinations and the infective larvae were compared with the descriptions of Roberts et al. and were found undoubtedly to be *H. placei;* this name will in future be used when referring to this parasite in bovines.

(2) *Cooperia pectinata* Rans. 1907.

(3) *Oesophagostomum radiatum* (Rud. 1803) Raill. 1898.

(4) *Bunostomum phlebotomum* (Raill. 1900) Raill. 1902.

These four species were the most commonly recovered in order of their prevalence. Frequently, however, *Cooperia pectinata* was present in larger numbers than *Haemonchus placei*. *Cooperia punctata* (v. Linst. 1907) was occasionally present and, on rare occasions, *Trichuris globulosa* (v. Linst. 1901) Rans. 1911. The only Cestode of note was *Moniezia benedini* (Moniez, 1899) which was fairly prevalent in calves. Trematodes were never recovered.

Field Observations

Farms scattered over an area of 200 miles from east to west and 280 miles from north to south were visited. Post mortem examinations were carried out where farmers were prepared to sacrifice stock, and faeces were collected from different age groups. Notes were made on the size of the farm, stocking rate, available water supplies, systems of animal husbandry, etc.

It soon became evident that calves and weaners were more heavily infested than adult stock, with the odd exception of the old cow. After weaning, young stock lost condition rapidly and only improved at about 18 to 24 months of age, after the change of teeth, if suitable grazing was available.

On dairy ranches calves were more heavily infested than on beef ranches. Even calves confined to calf-pens and kraals were severely infested with a mixed infestation of parasites. On beef ranches *Cooperia* spp. and *H. placei* were present with little other infestation. The infestations were usually milder than on the dairy ranch, and calves were in better condition. On farms with as little as 7 to 10 inches annual rainfall, where dairy ranching was practised, stock were more heavily infested than their counterparts on the beef ranch, under the same climatic conditions.

Helminthiasis at Armoedsvlakte

This research station consisted of two farms, 11 miles apart, known as Armoedsvlakte (3,800 morgen), and Biesjesvlakte (3,200 morgen), stocked with approximately 1,000 head of cattle. Water supplies from boreholes were plentiful and both farms well divided into camps. The former was a dairy ranch stocked with Red Poll and Fries, the latter a beef ranch stocked with Afrikaner and Sussex cattle. Calving took place from 1 November to 31 January. At Armoedsvlakte calves were separated from their dams at birth, and during the twice daily milkings, were allowed two teats on which to suckle; the other two were milked. Cow-byres, kraals and calf-pens had concrete floors which were cleaned regularly. Three small camps were set aside for the calves and grazing alternated irregularly, according to the state of the pasture. These calves had a mild infestation of *Cooperia* spp., *H. placei* and *O. radiatum.*

Biesjesvlakte on the other hand was run as a beef ranch. Cows calved in the veld and the calves ran with the dams until weaning. The dams were herded daily into kraals and crush-pens to be dosed with bone meal.* During the breeding season, from February to April, cows were herded into small kraals to be served and were left with the respective bulls for three hours every morning. The calves accompanied the cows both to the crush and kraals. The calves were more severely infested than their counterparts at Armoedsvlakte, not only with the same species but with *B. phlebotomum* as well. Diametrically opposed results were observed when comparing the different worm burdens of stock on the farms with those on the experimental station.

The preliminary investigations had shown what species of nematodes were common in the district, and had proved that calves and weaners were more heavily infested than adult animals.

* NOTE.—Due to the prevailing phosphate deficiency in the grazing all stock except suckling calves were dosed with bone meal every day.

ECOLOGY

Before any rational means of prophylaxis could be attempted, the ecology and epizootology of these parasites had to be investigated.

A.—Hatching of Eggs and Development of Larvae to the Infective Stage under Field Conditions

Materials and Methods

(1) Faeces were collected per rectum from six or more head of cattle suffering from a mixed nematode infestation. The faeces were well mixed and the number of eggs per gram established by taking the mean of two or more separate specimens, using Roberts & O'Sullivan's (1950) technique—with one modification: A 40 per cent sucrose solution was used instead of a NaCl solution. It was noted that a sucrose solution gave better egg counts and that eggs were easier to see than was the case with a salt solution. More air bubbles were formed, however, with a sucrose solution than with a salt solution. This was overcome by adding a few drops of amyl alcohol as advocated by Roberts *et al.* (1951a).

(2) Seventy-five grams of the dung was used for a control culture which was incubated for eight days at 26° C.

(3) The remainder of the dung was divided into equal quantities of 400 grams each. In two experiments, however, quantities of 1 Kg. each were used. These specimens were shaped into heaps similar to cattle dung pads and placed in a row next to each other in a paddock which had been ungrazed for years. They were placed on the bare ground and the surrounding grass was cut off to a height of 5 cm. In a few experiments the dung pads were placed in the shade of a large bush. Due to the activities of dung beetles during summer, it was found necessary to protect the dung pads with wire gauze (mosquito netting) cages. These allowed free passage of air, light and rain and only termites and ants could get at the dung; this did not have much effect on the dung itself.

(4) At intervals, dung pads were collected, weighed and the dung broken into small pieces and well mixed; sufficient dung was taken for egg counts and the remainder placed in the Baermann Apparatus for 24 hours. The maximum weight placed in any funnel was 50 grams, so that the thickness of dung did not exceed 1·5 to 2 cm. Poor results were obtained when this thickness was exceeded.

When the outer crust and the depth of the dung were examined separately, dung pads were weighed as before, the crust and depth separated, both weighed separately and kept apart for the rest of the examination.

(5) After 24 hours 50 c.c. of fluid was tapped from the bottom of the funnels, the dung removed, mixed with dry sterile cattle faeces and incubated for eight days at 26° C. The larvae recovered from the funnels were allowed to settle int he collecting tubes for two to three hours, the supernatant fluid siphoned off and the sediment examined for larvae in the counting chambers of the Roberts & O'Sullivan (1950) counting slides. If larvae were present in large numbers in the sediment a dilution count technique was employed and the total number of larvae in 2 or 4 c.c. of a 50 or 100 c.c. dilution were counted in the counting slides as follows:—

> The larval suspension in the dilution tubes was shaken, and 0·5 c.c. pipetted into one of the chambers of the counting slide. The process of shaking and pipetting was repeated until all the chambers had been filled.

A drop of sterile water was added to each chamber to give convex menisci on the outer edges of the fluid on the verandah of the counting chamber. If infective larvae were present they tended to swim towards the menisci and microscopy was facilitated thereby.

The chambers were examined microscopically with the low magnification (30 diameters) and the larvae were counted. As many larvae as were necessary were transferred from the sediment in the dilution tube onto glass slides, heat killed, and the species of infective larvae were identified on a percentage basis. No attempts were made to identify the species of pre-infective larvae which were merely counted.

(6) Larvae from control cultures and incubated dung were collected as follows:—

A Baermann funnel was filled with water up to 2 inches from the brim. The lid of the culture jar was washed into this funnel to remove any larvae present. The culture jar was filled with water at 40° C, a piece of plastic sheeting placed over the mouth of the jar and held firmly in position with the hands; the jar was turned upside down and placed in the Baermann funnel containing water. The jar was then picked up slightly, the plastic sheeting gently removed and the jar allowed to reseat itself in the funnel. While the plastic sheet was being removed care was taken that the mouth of the culture jar was below the level of the water in the funnel. The plastic sheet was washed into a beaker to remove any larvae adherent to it and the contents of the beaker poured into the funnel next to the culture jar.

The larvae were collected 20 to 24 hours later, by tapping the lower 50 c.c. into test tubes. Thereafter the larvae were examined in the same fashion already described for larvae recovered from dung with the Baermann Apparatus.

(7) Prevailing climatic conditions.

The daily variations in the climatic conditions were recorded for the experimental period.

Experimental Observations

The observations are summarised in Table No. I, in the Appendix. Unless otherwise stated, wherever experimental numbers are referred to, the results will be found in this table. A series of 22 groups of dung pads was placed in the veld from 15 August, 1956 to 3 June, 1957. Some of the data shown in the table were unreliable and have not been taken into account for the following reasons:—

(1) Control culture of No. 3 and incubated culture from dung in No. 1 (*c*), 5 (*c*), 21 (*e*), 22 (*d*) were not made.

(2) Dung pads were damaged by dung beetles in No. 7, 9, 10 and 11.

(3) Original egg per gram counts of No. 17 and 18 were obviously incorrect.

(*A*) *Hatching of eggs in the field*

From September to March all eggs hatched within four to eight days; on the average more than half the eggs (61 per cent) hatched within two days and nearly all (87·8 per cent) had hatched by the sixth day. In August all the eggs hatched within eight to nine days, but from April to June, with one exception, 58 to 96·3 per cent

of eggs hatched after the dung had been in the veld for periods of two to three weeks. In this one exception all the eggs hatched within 13 days in May (No. 19b).

The rate of hatching is summarised in Table No. 1.

TABLE NO. 1

Rate of Egg Hatching in Relation to Atmospheric Temperatures

Percentage Hatched	Time in Days	Maximum Temperatures		Minimum Temperatures	
		Mean °C	Range °C	Mean °C	Range °C
%					
100.....	4– 8	31·1	28·4–32·6	12·8	10·1–15·2
100.....	9–13	24·3	22·7–26·7	2·6	2·6– 3·6
58–96·5.....	14–21	22·6	18·0–27·2	3·2	1·5– 4·4

At higher temperatures the eggs hatched rapidly; at lower temperatures, however, there was a certain amount of inconsistency. This was probably due to:—

(1) Marked diurnal fluctuations in temperature, particularly in the winter, when differences of 21° C between the daily maximum and minimum temperatures were not unusual.

(2) Thermograph readings give a truer picture of temperature fluctuations during the day than the mere recording of maximum and minimum temperatures. In the summer, temperatures at Armoedsvlakte remained high for long periods and only fell below 20° C for a few hours, i.e. from about 11 p.m. to sunrise. In the winter, however, temperatures rose above 15° C from about 10 a.m. to 4 p.m. and remained at a low level for the rest of the day. Whereas, in summer, temperatures exceeded 20°C for 18 hours every day, only for six hours daily did temperatures exceed 15° C in mid-winter, i.e. only from 10 a.m. to 4 p.m. During summer temperatures fell below 20° C for only six hours per day; in winter temperatures below 15° C prevailed for 18 hours daily. The inconsistencies of the rate of egg-hatching in the winter is explained by the fact that temperatures were much lower for longer periods.

Eggs hatched more quickly in the sunlight than in the shade. In the winter dung pads were placed in shade or exposed to sunlight, but were otherwise identical. Those in the shade hatched and the larvae developed more slowly than those in the sun (compare No. 19 with No. 20 and No. 21 with No. 22). Ground temperatures were frequently 2 to 3° C higher in the sunlight than in the shade.

Eggs hatched more rapidly in the crust of the dung pads than in the deeper lying parts. Wherever the crust and depth were examined separately lower egg counts were recorded in the former than in the latter [No. 16 (*d–j*), 19a, 20 to 22]. This indicated more rapid hatching of eggs in the crust. Temperatures in the depth were often 1 to 2° C lower than in the crust.

Since evaporation of water was more marked from the outer surface of the dung, air was probably more plentiful in the crust and possibly assisted in egg hatching.

(*B*) *The morphology of pre-infective larvae*

It was very important to distinguish the larval stages of these parasites from those of free-living worms. Pure cultures of the different species were examined microscopically at regular intervals after incubation of eggs recovered from adult gravid female worms.

Little difficulty existed in distinguishing infective larvae from free-living Nematodes. These have been adequately described by Keith (1953). The pre-infective larvae, however, were considerably more difficult to differentiate, and the following salient points were used to distinguish them from free-living Nematodes:—

(1) *First stage larvae.*—Morphologically the larvae belonged to the rhabditoid type. The form of the body was cylindrical, gradually decreasing in size from the base of the oesophagus, to the tail and, to a lesser extent, to the head. The length of all the species of larvae fell in the range of 292 to 500 microns; the maximum breadth at the base of the oesophagus was 19 to 21 microns.

The main point of differentiation was the oesophagus and the best description which the author encountered in the literature of this differentiation was that given by Loos (1911) in his epic work on *Ancylostoma duodenale.*

The description (on page 349 of his publication) is quoted:—

> " The oesophagus presents division into three sections which is characteristic of the *Rhabditidae.* This fact has already been pointed out by the earlier writers; but in the *Ankylostoma* larvae the three sections are not nearly so sharply marked off, as in the *Rhabditidae.* The anterior section is more uniform in thickness (ca. 0·009 mm.) throughout its length, not distinctly conical as in the free living Nematodes, or even the non-parasitic generation of *Strongyloides stercoralis.* The transition to the thinner part takes place fairly gradually, as does the broadening to the terminal bulb, which is on the whole more slender and weaker than *Rhabdites.* If these differences are observed, confusion between young *Ankylostoma* larvae and those of *Strongyloides stercoralis* should hardly be possible ".

Similarly Mönnig (1926) made the observation that the first stage larvae of *T. rugatus* and *T. instabilis* had " an oesophagus which is of the usual rhabditiform shape, but that the three regions are not as sharply marked off as e.g. in the larvae of *Strongyloides papillosis* ".

These observations were confirmed. First stage larvae of the species of parasitic worms studied had an oesophagus of the rhabditoid shape, but the three regions were not as sharply marked off as those of the larval stages of free-living worms. This information, combined with the size and shape of the larvae described above, facilitated in making a diagnosis.

(2) *Second Stage Larvae.*—These were more easily differentiated from the free-living nematodes than the first stage larvae. Second stage larvae of parasitic worms were cylindrical in shape, of equal diameter from the base of the oesophagus to the anus (20 to 21 microns); narrowed sharply to the tail and the sheath of the tail, which was similar to the infective larvae, particularly when the development of the second stage was more advanced. The larval length depended on the stage of development and varied with the individual species, the maximum in *B. phlebotomum* being 500 microns, while the other species exceeded 700 microns.

The oesophagus became elongated, the corpus and isthmus more difficult to delineate and the bulbus more spatulate than in the first stage. The cellular elements of the intestine became opaque, being usually dark brown in colour. The larvae were more active.

The species of larvae of the parasitic worms were only differentiated from each other in their infective stages; for counting purposes the pre-infective stages were differentiated from free-living worms.

(*C*) *The development and survival of larvae*

Larvae developed rapidly to the infective stage from August to April, being recovered after a minimum period of five days and more regularly within eight days. In early winter they were recovered after 14 days but had not yet developed in mid-winter after 21 days.

TABLE NO. 2

Mean Percentages of Larvae recovered from August to April

No. of Days in the Field	Mean Percentages Recovered from Field Specimens			Mean Percentages Recovered after Incubation
	1st Stage	2nd Stage	3rd Stage	3rd Stage
	%	%	%	%
1	0·32	—	—	30·7
2	0·69	0·07	—	15·8
3	2·96	0·63	—	19·8
4	1·18	1·08	—	6·1
5	1·9	4·13	0·52	5·6
6	0·8	1·47	1·03	2·3
7	0·21	0·68	4·74	2·3
8	0·5	1·00	1·40	3·8
9	0·41	0·77	2·79	1·2
30	—	—	1·01	0·5

The difference between the numbers of eggs per gram, as revealed by egg counts on fresh faeces, and the numbers after various periods in the field were considered to represent the numbers of eggs which had hatched, i.e. the number of larvae in the dung. The mean percentages of these larvae as recovered with the Baermann Apparatus and again after a period of eight days incubation are shown in Table No. 2.

This table is of particular interest in that it reveals the very small percentage of larvae which reach the infective stage under field conditions. This was probably due to a very high mortality of the pre-infective larvae. From the table it will be noted that first, second and third stage larvae were at their optimum on the third, fifth and seventh days respectively. Further, after the collection of larvae with the Baermann Apparatus, the incubation of the dung indicated that there was a dramatic drop in the percentage of infective larvae recovered after three days in the field.

The Baermann Apparatus is not as efficient in extracting pre-infective as infective larvae and this may account to some extent for the poor recoveries of the former. When this extracted dung was incubated, both unhatched larvae and unrecovered pre-infective larvae were given ample chance to develop to the infective stage and these were then more easily recovered.

Egg hatching and the development of larvae to the infective stage were slower and more protracted in winter. In May and June first stage larvae were recovered from the fourth to the twenty-first days; second stage larvae from the fourth to the twenty-sixth day and infective larvae were not yet present even after 21 days. The number of specimens examined in winter was not sufficient to establish when the pre-infective larvae reached optimal development.

(*D*) *Climatic factors affecting survival of larvae*

(1) *Evaporation.*—Due to lack of equipment, evaporation could not be measured in the standard fashion. Dung pads were protected from the activities of beetles and, since they were weighed before placing in the field and at the time of collection, the weight loss was probably due to evaporation. This is expressed as a percentage in Table No. 3, in which three experiments were selected to indicate the effect of evaporation and other climatic factors on the percentages of hatched larvae recovered from dung pads exposed to field conditions. The poor larval recoveries in experiment No. 14 when compared with No. 12, was due to desiccation of the larvae, brought about by water-loss from the dung pad. In the period August to April, if dung pads lost 65 per cent of their weight by evaporation in the first six days in the field, less than 0·27 per cent of the hatched larvae reached the infective stage. The higher moisture content contributed markedly to the better larval recovery rates in No. 12 and 21, but it was noticeable that larval recoveries were falling off after three weeks in the latter when evaporation caused a 62·5 per cent decrease in the weight of the dung.

In experiments summarised in Table No. I (Appendix) it was a marked feature that larval recoveries from the crust of the dung were poor in spite of more rapid egg hatching [No. 16 (*d–j*), 19a, 20 to 22]. Due to evaporation the crust was drier than the depth, and probably accounted for the poor larval recovery rates caused either by the death of the larvae or possibly by the migration of the larvae to the moister depth of the dung pad.

(2) *Temperature.*—In the period August to April infective larvae were recovered within five to eight days. In June they were not yet present in dung after 21 days; if Table No. I (Appendix) is consulted it appears that the infective larvae were not only conspicuous by their absence, having not yet developed after three weeks, but that specimens in the shade showed lower larval recovery rates than those in the sun, due to colder conditions there. In No. 20a (Table I) the mean maximum was 22·0° C. and the mean minimum 2·8° C over a period of 20 days and infective larvae had not yet developed. The maximum temperatures should have been adequate for larval development to the third stage. However, as previously mentioned when egg hatching results were being described, temperatures in the winter remained below 15° C for most of the day and higher temperatures applied only for the briefest periods. Thus both egg hatching and larval development could proceed for short periods only in the winter.

Conversely higher temperatures applied for longer periods in the summer and probably accounted for the rapid development to the infective stage.

The few larvae recovered in No. 21 (Table No. 3) appeared to be due, therefore, to a combination of low temperatures, retarding development, and to the slowly increasing evaporation, causing larval death by desiccation.

TABLE NO. 3

Climatic factors affecting the percentage of larvae recovered from hatched eggs

Experimental No.	No. of days in field	Total percentage of larvae recovered	Percentage weight loss of dung pads due to evaporation	Mean maximum temperature.	Mean minimum temperature	Mean relative humidity	Total rainfall	Days on which rain fell
		%	%	°C	°C	%	m.m.	
*12—								
a	2	2·9	36	—	—	—	—	—
b	3	5·4	34	—	—	—	24·5	3rd
c	4	8·0	30	31·5	16·7	37·5	3·5	4th
d	5	9·3	49	—	—	—	—	—
e	6	3·2	47·5	—	—	—	—	—
f	7	14·9	37·5	—	—	—	21·5	7th
*14—								
a	2	0·66	50	—	—	—	—	—
b	4	0·11	62·5	33·1	12·7	41	0	0
c	6	0·02	79	—	—	—	—	—
d	8	0·02	84	—	—	—	—	—
†21—								
a	4	1	42·5	—	—	—	—	—
b	8	2·17	42·5	—	—	—	1·4	6th
c	10	0·02	35	18	1·5	65	21·6	9th
d	14	1·01	51	—	—	—	—	—
e	21	0·33	62·5	—	—	—	—	—

* No. 12 and 14, January and February, respectively.
† No. 21, June.

(3) *Relative humidity*.—There appeared to be little correlation between relative humidity of the atmosphere and larval survival if the results of Table No. 3 are consulted.

(4) *Rainfall*.—In the summer the best recoveries of larvae occurred when rain fell during the first five days the dung was in the field. The distribution seemed to be important. Optimal results were obtained when rain fell on the third and fourth, or second and fifth days, followed by a further fall of rain (No. 8, 12, 13 and 15, Table No. I—Appendix).

The absence of rain probably accounted for the poor results in No. 14 (Table No. 3).

In autumn this did not appear to be so important, since rain only fell after nine days and larval recoveries were reasonable (No. 16, Table No. 1—Appendix).

In winter, in spite of rainfall within the first ten or 11 days, larval recoveries remained at a low level (No. 19, 20, 21, 22, Table No. I—Appendix and No. 21, Table 3).

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In spring, rainfall on the first and third day, but none thereafter, assisted larval development to the sixth day, but thereafter larvae decreased rapidly (No. 4, Table No. I—Appendix). Rain falling for the first time on the sixth day in spring was too late to have any effect on the survival of larvae (No. 6, Table No. I—Appendix).

(5) *Shade and sunshine.*—Unfortunately this was only tested in the winter and eggs and larvae developed more rapidly in the sun than in the shade due to higher temperatures in the sunlight. Experiments described elsewhere (*vide infra*), however, showed better results in the summer with specimens in the shade than those in the sun as far as the recovery of infective larvae was concerned.

Temperatures and rates of evaporation were thus intimately linked with shade and sunlight, the former lowering, the latter exaggerating the effects of both temperature and evaporation.

(*E*) *Effects of environment on the different species*

The effects, of exposure to field conditions on the different species dealt with are summarised in Tables No. 4 and 5. The percentages of infective larvae recovered, both from dung in the Baermann Apparatus and after further incubation, were averaged out in seven experiments for the period September to April and compared with the mean percentages of the control cultures. These are summarised in Table No. 4. Similarly larvae recovered from five experiments in the winter (May and June) were averaged out and compared with the mean of the controls and summarised in Table No. 5.

On examination of Table No. 4 species exposed to field conditions in dung pads showed little change after two days, but marked changes occurred after four days. *Cooperia* spp. showed a marked increase while *H. placei* decreased. This tendency continued until the eighth day, while *O. radiatum* and *B. phlebotomum* remained at almost the same level as the original controls.

In Table No. 5, *Cooperia* spp. and *H. placei* acted in the same fashion, but *B. phlebotomum* decreased rapidly, and *O. radiatum* not so markedly over a 14 day period when the larval species were compared with the controls.

TABLE NO. 4

The effects of exposure to field conditions from spring to autumn on different species (see text)

Days in field	Mean larval species variations			
	Cooperia spp.	*H. placei*	*O. radiatum*	*B. phlebotomum*
	%	%	%	%
Controls	46	35	12	7
2	44	33	13	10
4	57	20	14	9
6	60	15	11	14
8	72	8	11	9

FIG. NO. 1 DAILY VARIATIONS IN THE CLIMATIC CONDITIONS AT ARMOEDSVLAKTE FROM 1/6/55 — 31/8/56

TABLE NO. 5

The effects of exposure to field conditions in winter on different species (see text)

Days in field	Mean larval species variations			
	Cooperia spp.	*H. placei*	*O. radiatum*	*B. phlebotomum*
	%	%	%	%
Controls	36	44	13	7
4	45	35	16	4
8	62	20	15	3
10	59	23	15	3
14	68	25	6	1

Before further elaboration of these results, two points had to be cleared up:—

(*a*) Infective larvae may have migrated from the dung pads before they were collected. This was not possible before the fifth day, because no infective larvae were recovered before five days exposure. As shown later on, migration could only occur after the fifth day, provided adequate rain had fallen. This was possible in only two of the seven experiments, from which the data in Table No. 4 were calculated. The rainfall, however, fell only on the seventh and eighth days respectively in sufficient quantities to cause migration. By this time the species fluctuations were already marked and would not have materially affected the results.

(*b*) The Baermann Apparatus was possibly more efficient in the collection of pre-infective larvae of *H. placei* than of the other species. Since the pre-infective larvae were merely counted and not identified this could be presumed. There was, however, no evidence to prove this. The low efficiency of the Baermann Apparatus in collecting pre-infective larvae is shown by the usually larger numbers of infective larvae recovered from incubated dung, after it had been in the Baermann Apparatus, than could be accounted for by the unhatched eggs present in dung exposed for a few days in the field. Furthermore in critical tests there was no evidence that infective *H. placei* larvae were more efficiently collected than the other species in the Baermann Apparatus. It was thus unlikely that less active pre-infective larvae would exhibit this tendency. There is, therefore, little likelihood that the results shown in Tables No. 4 and 5, are false reflections of the effects of environmental conditions on the pre-infective stages of the life cycle.

It appeared that *Cooperia* spp. were best adapted to the environment. In the summer pre-infective stages of *O. radiatum* and *B. phlebotomum* were more resistant than *H. placei* (Table No. 5). However, in the winter, *B. phlebotomum* particularly, rapidly decreased even after four days in the field, whereas *O. radiatum* could withstand cold conditions for ten days and showed a sharp drop by the fourteenth day in the field. *Haemonchus placei* appeared to be more resistant to cold, but *Cooperia* spp. again were predominant.

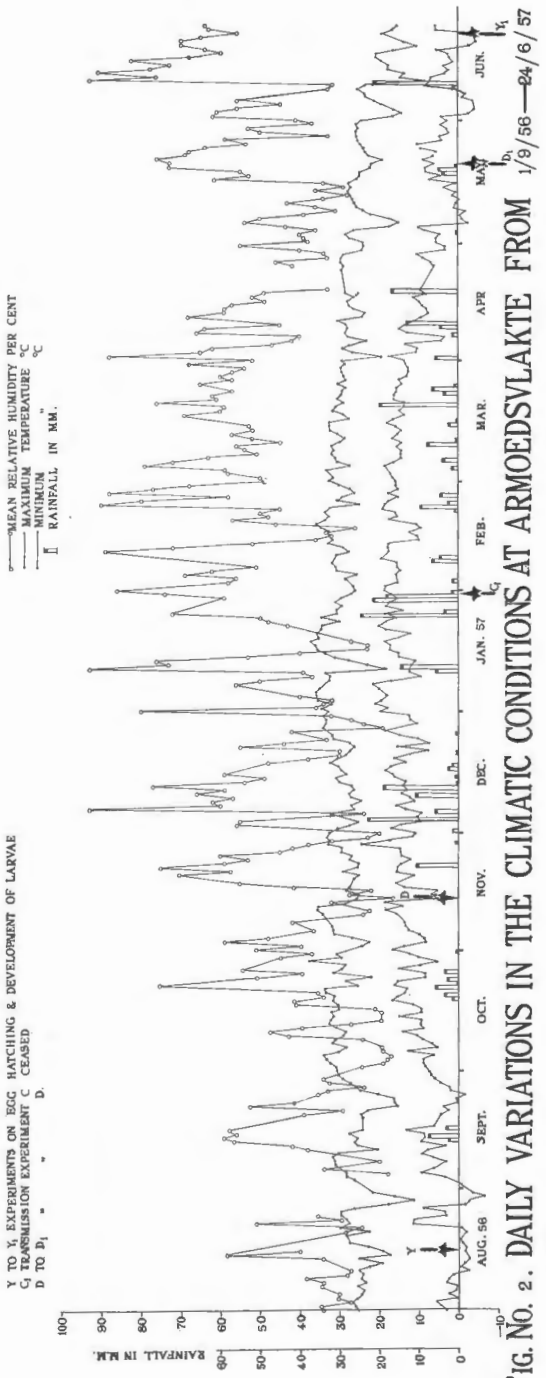

FIG. NO. 2. DAILY VARIATIONS IN THE CLIMATIC CONDITIONS AT ARMOEDSVLAKTE FROM 1/9/56—24/6/57

Climatic conditions.—Daily variations in the climatic conditions from 15 August, 1956 to 23 June, 1957 are shown in Fig. 2. Climatic data were important in these experiments while eggs were hatching and larvae developing to the infective stage. In summer, hatching and development were completed in seven to ten days, but in winter this process continued for longer than three weeks. The climatic data for the various experiments are summarised in Table No. 6: periods of six to ten days from spring to autumn and 14 to 26 days in winter were used, to show prevailing climatic conditions during periods of egg hatching and larval development.

TABLE NO. 6

Prevailing Climatic Conditions during the Periods of Egg Hatching and Larval Development

Experimental No.	Days in field	Mean maximum temperature	Mean minimum temperature	Mean relative humidity	Total rainfall	Days on which rain fell
		°C	°C	%	mm.	
1	9	26	2·6	35	0	0
2	8	27	3·0	33·5	0	0
3	10	26·8	3·5	36	0	0
4	9	23·7	5·7	49	10·9	1st, 3rd.
5	9	23·4	3·6	33·4	0	0
6	6	31·6	12·6	28·5	1·5	6th.
*8	7	28·9	15·6	59·5	24·8	1st, 2nd, 3rd, 4th, 6th, 7th.
*12	7	31·5	16·7	37·5	49·5	3rd, 4th, 7th.
13	8	31·3	16·7	39	51·3	3rd, 4th, 7th, 8th.
14	8	33·1	12·7	41	0	0
15	9	31·8	15·2	52	23·5	3rd, 4th, 8th.
16	9	24·8	4·4	43	0·3	9th.
†17	14	25·1	3·5	52	9·7	9th, 10th, 11th.
18	26	23·3	3·8	52	23·0	18th, 19th.
19	19	22·7	2·2	51	23·0	18th, 19th.
20	20	22·0	2·8	52	23·0	18th, 19th.
21	21	18·0	1·5	65	23·0	6th, 9th.
22	21	18·0	1·5	65	23·0	6th, 9th.

* Experimental No. 7, 9, 10 and 11 not included—due to effect of dung beetle activity.
† No. 17 to 22 were carried out during the winter, hence the longer periods.

Discussion

The results shown on the previous pages and summarised in Table No. I (Appendix) were generally poor. The climatic extremes under which these experiments were conducted were a marked feature of the investigations. While the different species of worms were undergoing the free-living stages of their life cycle in dung they were subjected to marked diurnal temperature variations, the mean relative humidities were generally low, rainfall was either absent, sparse or fairly well distributed and adequate (Table No. 6). In addition, high rates of evaporation were common when dung lost up to 70 per cent of its moisture in less than a week, particularly in spring and summer. It was, therefore, not surprising that results varied from one extreme to the other but were generally poor and indicative of unfavourable environmental conditions.

Temperature appeared to play an important role in egg hatching and larval development. It has been stated by Dinaburg (1944) that *H. contortus* eggs and larvae did not develop below a mean maximum temperature of 65° F (18·3° C) in the United States of America. In Australia Gordon (1948) stated that a mean maximum temperature of 63·9° F (17·7° C) was essential for larval development of this parasite. A similar temperature was given by Roberts *et al.* (1952) for *H. placei* of cattle. Crofton (1948b) has shown that all eggs of *T. retortaeformis* parasitic in rabbits will hatch within eight days at temperatures of 55° F (12·8° C) or more.

The author's findings did not confirm these observations. At mean maximum temperatures of 25·1° C (77·2° F) infective larvae took two weeks to develop (No. 17, Table No. I—Appendix). At a mean of 18° C (64·4° F) and even 22° C (71·6° F) larvae had not yet reached the infective stage, nor had all the eggs hatched after 21 and 20 days respectively (No. 21, 22 and 20, Table No. I); the mean maximum temperatures, however, were on an average 16·5° C to 21·6° C higher than the mean minimum temperatures (Table No. 6, Experiments 17 to 22).

Recently work in Kenya has shown that *H. contortus* will develop to the infective stage in eight to 12 days if the mean maximum air temperatures are 74° F (23·4° C) or more and the mean minimum temperatures are not less than 52° F (11·1°C) (Dinnik & Dinnik, 1954–55). These workers pointed out that in the United States of America and Australia, which are countries with generally temperate climates, the limit of temperatures of 64° F (17·8° C) can generally be applied, but this was not the case in the Kenya Highlands, where there were marked diurnal temperature fluctuations. This was more in agreement with the observations at Armoedsvlakte than with those of the Australian, American and British workers.

In Experiment No. 1, the mean maximum temperature was 26° C and mean minimum temperature 2·6° C whereas in Experiment No. 20 the mean maximum and minimum temperatures were 22·0° C and 2·8° C, respectively (Table No. 6). In the former, larval development was completed in eight days whereas in the latter no infective larvae were present after 20 days (Table No. I—Appendix). There are several possible reasons for this:—

(*a*) Thermograph readings in the winter showed prolonged periods of 16 to 18 hours a day when air temperatures were below 15° C. In spring, thermographs showed a more even distribution of maximum and minimum temperatures.

(*b*) Grass minimum temperatures were 3 to 5° C lower than minimum air temperatures in the winter, but seldom more than 2° C lower in spring.

(*c*) Temperatures in the depth of the dung were usually 2° C lower than temperatures at the surface of the dung.

In spring, therefore, warmer conditions prevailed for a longer period and heavy frosts were infrequent; egg hatching and larval development were thus able to proceed for almost 12 hours a day. In the winter, enough warmth for larval development to proceed, existed for only six to eight hours a day on the surface of the dung and for even shorter periods in the colder depth of the dung.

Actual freezing of first and second stage larvae probably also occurred during the heavy winter frosts. This freezing probably killed pre-infective larvae as was shown for other species by Ransom (1906), Veglia (1915), Schwartz (1924) and Mönnig (1930). In the winter, grass minimum temperatures of −7·3° C (18·8° F) were recorded, thus giving some idea of the severity of the frost.

At the other extreme all stages of the free-living life cycle were completed in five days when the mean maximum temperature was 32° C (89·6° F) and the mean minimum 16·8° C (62·3° F). Many other workers investigating a wide variety of parasitic nematodes have found rapid egg hatching and larval development at high temperatures (Theiler & Robertson, 1915; Veglia, 1915; de Blieck & Baudet, 1926; Ortlepp, 1925 and 1937; Mönnig, 1930; Crofton, 1948b, etc.). In the summer months minimum temperatures were approached for only a few hours in the early morning, and temperatures stayed above the minimal level for larval development throughout the rest of the day.

Drying and desiccation has been shown to be a major cause of larval death, particularly of the pre-infective larval stages (Veglia, 1915 and 1923; Mönnig, 1930; Ortlepp, 1937; Crofton, 1948b; Dinnik & Dinnik, 1954–55, etc.). Dung pads that lost more than 65 per cent of their moisture in the first five to seven days in the field, gave poor larval recoveries; in the period spring to autumn, should rapid desiccation have occurred accompanied by no rainfall, only 0·27 per cent or less infective larvae were recovered. Eggs hatched during this period, but few larvae were able to reach the infective stage. First and second stage larvae reached optimal development on the third and fifth days respectively. If moisture was inadequate during this period larval death was very marked. Observations that enough moisture exists in a dung pad for larvae to reach the infective stage have been made by various workers (Mönnig, 1931; Roberts, 1951; Roberts *et al.*, 1952 and Riek *et al.*, 1953). These workers, however, did not show what percentage of hatched larvae reached the infective stage, although Mönnig only recovered a few larvae. This was probably also due to mortality of pre-infective larvae.

When the effect of evaporation was decreased by rainfall, particularly when pre-infective larvae were present in large numbers (i.e. third to fifth day), the percentage of larvae which reached the infective stage was considerably increased. When rates of evaporation were high the best results were obtained when on at least one, but preferably on two separate days, rain was recorded during the first five days in the field, optimal results being obtained when rain fell from the second or third day onwards.

In winter, due to extremely low temperatures and in spite of much lower rates of evaporation, pre-infective larvae seldom developed to the infective stage. The effects of desiccation were also observed in winter, where, although egg hatching occurred more rapidly in the crust of the dung, fewer larvae were recovered there than in the moister depth of the dung pad. This may be due either to the mortality of pre-infective larvae or to their migration to the moister deeper layers.

Some interesting observations were made on reactions of the different species to the invironment.

The pre-infective stages of *Cooperia* spp. were best adapted to withstand environmental extremes of heat and cold, and dry and comparatively dry conditions. *Haemonchus placei* on the other hand was much less resistant to heat, cold and arid conditions. In summer its pre-infective stages decreased even more rapidly than those of *O. radiatum* and *B. phlebotomum*, but during the cooler winter months conditions were more favourable and this species was able to maintain itself better. Once it had reached the infective stage, however, it certainly was more resistant than either *O. radiatum* or *B. phlebotomum*. This was also confirmed in experiments described elsewhere.

Oesophagostomum radiatum, while maintaining itself fairly well in the summer months, was apparently sensitive to cold conditions and fewer larvae were able to reach the infective stage in experiments conducted over periods of longer than ten days in the winter, than the larvae of *Cooperia* spp. or *H. placei*.

Bunostomum phlebotomum maintained itself fairly well in the warmer months of the year but was sensitive to cold conditions. According to Schwartz (1924) and Sprent (1946b) this species is also very sensitive to desiccation. This was not entirely confirmed in the author's experiments, as infective larvae were present when no rain was recorded and the dung very dry [2 (*b*) and (*c*), 5 (*d*), Table No. I—Appendix]. However, with well distributed rainfall over the first five to seven days, many more larvae reached the infective stage. Although dung pads yielded few of these larvae when the Baermann Apparatus was used, incubated dung showed the presence of large numbers of larvae. Possibly under flood conditions the eggs did not hatch as readily as those of the other species, due perhaps to increased moisture of the dung depriving the eggs of air. This could not be confirmed but, according to Sprent (1948b), eggs of this species need air to hatch. Although this hypothesis may be feasible, it was more likely that pre-infective larval stages, being very sensitive to desiccation, survived under wet conditions and were recovered as infective larvae after incubation in the laboratory. Experiments on infective larvae described elsewhere (*vide infra*) tended to confirm the latter view.

Summary

Investigations were carried out on the hatching of eggs and development to the infective stage of larvae of *Cooperia* spp., *H. placei*, *O. radiatum* and *B. phlebotomum* under field conditions.

The following observations were made:—

(1) Eggs hatched within eight days and infective larvae were recovered after a minimum period of five days in summer, but more frequently at seven days from spring to autumn. First and second stage larvae reached their optimum development on the third and fifth days respectively, and infective larvae on the seventh day.

(2) In winter 42 per cent of eggs had not yet hatched after 21 days in the field and no larvae had reached the infective stage when temperatures ranged from a mean minimum of 1·5° C to a mean maximum of 18° C. Protracted development of the free-living stages was possibly due not only to diurnal temperature fluctuations but also to the long duration of cold conditions; lower temperatures in the shade than in the sun; in the depth of dung than on the surfaces; grass minimum temperatures as much as 3 to 5° C lower than air temperatures; heavy frosts possibly causing freezing and death of pre-infective stages.

(3) Marked evaporation occurred from spring to autumn. When moisture loss, due to evaporation, caused a decrease of 65 per cent or more in weight of dung within the first five to seven days, very few larvae reached the infective stage.

(4) Eggs hatched more rapidly in, but less infective larvae were recovered from, the crust than from the depth of the dung.

(5) Rainfall on one, but particularly on two separate days from the second to the fifth or sixth day, caused optimal conditions for larval development from spring to autumn. In the winter, rainfall made little difference to larval development and temperatures appeared to be more important.

(6) No correlation existed between relative humidity of the atmosphere and larval development. The influence of shade compared with that of sunlight in the winter had its main effect in the modification of temperatures and rates of evaporation.

(7) *Cooperia* spp. were well adapted to extremes of heat and cold, dryness and desiccation. *H. placei* were more sensitive to hot, arid conditions but more resistant to cold. *O. radiatum* was resistant to hot, dry conditions but more sensitive to cold winter conditions.

B. phlebotomum, although occasionally recovered under very dry conditions at high temperatures, was very sensitive to cold and only present in large numbers when well distributed rains provided adequate moisture for larval development in the summer.

B.—Activity and Survival of Infective Larvae under Field Conditions

Materials and Methods

(1) Infested dung was collected from the rectum of two or more infested animals, shaped into dung pads and placed in various positions in the veld to simulate natural defaecation. Since dung beetles were very active from November to April, most dung pads were placed in a protected position in the open for four to five days to harden before being placed in the veld. In the hard dry state the dung did not attract the beetles so readily.

(2) To trace migrations, both the infested dung pad and the surrounding habitat were examined for larvae. Specimens were therefore, collected and placed in separate labelled containers as follows:—

(A) Dung pad.

(B) Soil to a depth of 2 cm. under the dung pad.

(C) Grass adjacent to the dung pad.

(D) Grass roots adjacent to the dung pad.

(E) Soil 2 cm. deep, adjacent to the dung pad. The order of collection was (C), (D), (E), (A), (B).

(3) Notes were made on the day of collection as follows:—

(*a*) Date the dung pad was placed in the veld and the date specimens were collected.

(*b*) Number of days in the veld.

(*c*) The dung was measured and expressed in terms of the maximum and minimum diameters on the lower surface and the maximum height, e.g. $20 \times 18 \times 8$ cm.

(*d*) The surrounding vegetation, height of grass, bushes, etc., were noted.

(*e*) Since dung beetles often removed manure to the underlying soil, and dung and soil could not be separated, it was included in the specimen (B).

(*f*) Where horizontal or lateral migration was being investigated, the grass and soil furthest from the dung pad were collected first, followed by specimens nearer the dung pad.

When vertical migration was being investigated, the tops of the grass were cut off first, thereafter grass was cut at various heights above the soil surface to ground level.

(4) After transfer to the laboratory, specimens were:—

(*a*) Weighed and placed in the Baermann Apparatus, using a technique similar to that advocated by Mönnig (1930). This technique was modified as follows:—

(i) Dung was broken into small pieces with a pestle and mortar; no specimen in any funnel exceeded 50 grams in weight, nor did the thickness of dung exceed 2 cm. Similar remarks applied to the humus, but the sand was not weighed and the thickness of the material only, was taken into consideration.

(ii) Large funnels with a 20 cm. diameter were used and mutton cloth replaced linen.

(iii) Grass roots were cut into small pieces and only 30 grams were placed in funnels.

(*b*) After 24 hours in the funnels, 25 c.c. of fluid was withdrawn from the bottom of the funnels and left for two to three hours to settle in the collecting tubes. The supernatant fluid was then siphoned off and 2 to 3 c.c. of the sediment left for examination.

(*c*) The methods of examination of larvae have already been described in the previous experiment.

(5) Prevailing climatic conditions.

The daily variations in the climatic conditions from June, 1955, to August, 1956, were recorded.

Experimental Observations

A total of fifty-eight experiments was carried out over the period 23 June, 1955 to 7 August, 1956 and dung pads were left in the veld for periods varying from seven to 105 days.

The results of these experiments are summarised in Table No. II in the Appendix, and wherever reference is made to experimental numbers, the results of these experiments will be found in this table, unless otherwise mentioned.

(*A*) *Development of larvae to the infective stage*

This has been more fully dealt with elsewhere (*vide supra*) but two important points were noted here as an addendum to those experiments.

In the summer months more larvae reached the infective stage in dung protected from the sun by the surrounding vegetation than those exposed to the direct sunlight.

Poor recoveries of larvae invariably occurred from dung pads that had been attacked by dung beetles; possible due to the effects of increased evaporation, giving rise to desiccation and death during the pre-infective larval stages (No. 24–28, 30–33 and 35).

(*B*) *The distribution of infective larvae in the dung pad*

In experiments described elsewhere (*vide supra*), it was shown that more larvae reached the infective stage in the depth of the dung pad than in the crust. In 25 experiments the hard outer crust and the moister, deeper layers were examined separately. In 22 of these experiments considerably more larvae were recovered from the depth than the crust, thus confirming the observations in the experiments previously described. In three cases, however, the opposite was true (No. 12, 51 and 55). A further experiment also yielded more larvae in the crust than the depth but in this case a large proportion of the depth was included with the crust (No. 58). Most of the specimens with more larvae in the crust were collected in the winter.

A further subdivision of dung pads was made in five experiments. The crust was examined as before and the centre portion or depth divided into two layers, viz. upper and lower.

In four of the experiments the largest number of larvae were recovered in the upper layer, i.e. the portion lying just under the crust (No. 17, 19, 38 and 48). In three experiments the lower layer had more larvae than the crust (No. 17, 38 and 48), but in one case the opposite was true (No. 19). The latter was artificially moistened by having water dripping next to it.

In one experiment, most of the larvae were recovered from the crust, fewer from the upper layer and least from the lower layer. In this experiment active vertical migration had taken place; the crust was very soft due to the influence of heavy rains (No. 42).

(*C*) *Migration of infective larvae from the dung pads*

Larval migration was governed by rainfall. In the absence of rain or where rainfall was very limited, no migration occurred (No. 5, 12, 26, 52 and 56). Little or no migration occurred under the influence of 14·0 mm. (0·55 inches) of rain which had been preceded by a comparatively dry spell (No. 22 and 23).

Larval migration occurred when 32 mm. (1·26 inches) of rain fell in the first 48 hours, followed by 6·5 mm. (0·26 inches) on the tenth day when specimens were collected (No. 29). Similarly when 55·8 mm. (2·19 inches) fell on the second day, followed by 11·1 mm. (0·43 inches) from the eighth to the eleventh day when specimens were collected, larval migration was found to have occurred (No. 43).

In these two experiments most of the larvae migrated to the soil, but some vertical migration on grass blades also occurred. In an experiment conducted over a period of seven days where 19 mm. (0·75 inches) fell on the fifth day, the rain caused migration, mostly to the soil under the dung pad (No. 39).

Extensive migration occurred for limited periods in December, February and March. Well-distributed heavy rains occurred during these periods. In all cases rain fell on one, two or three days in the first eight days the dung was in the veld. In one of these experiments conducted over a period of eight days, rain fell on the fifth, sixth and eighth days, a total of 116·0 mm. (4·6 inches) being recorded, and 83 per cent of all the larvae recovered were from the grass. In addition, horizontal migration of over 50 cm. from the edge of the pad had occurred to the grass and soil (No. 42). In another four experiments where rains were well distributed, and

totals varying from as little as 40·4 mm. (1·59 inches) to as much as 127·7 mm. (5·04 inches) over the whole period the experiments were conducted, massive larval migration had occurred, and 41 to 90 per cent of all larvae recovered were on the grass (No. 30, 41, 44 and 45).

An experiment which ran for nine days, where the rainfall recorded from the fourth to the sixth day was 26·0 mm. (1·02 inches) followed by 25·5 mm. (1·01 inches) on the ninth day, did not cause more than 17 per cent of all the larvae to migrate. However, a few larvae were recovered from the grass and soil 80 cm. from the dung pad (No. 46).

Larvae were recovered from grass 20 cm. above the soil surface in an experiment which ran for 41 days. All the rainfall, a total of 172·0 mm. (6·78 inches), fell during the first 24 days, there being no rain recorded during the last 17 days of the experiment (No. 49).

(D) Migration of larval species

The results of species migration are summarised in Table No. 7.

TABLE NO. 7

Percentage of experiments in which larval migration occurred

Species	Site of Larval Migration			
	B	C	D	E
	%	%	%	%
Cooperia spp.	53·5	40·3	27·6	43·1
H. placei	32·7	25·9	20·7	24·1
O. radiatum	25·9	17·2	12·1	27·6
B. phlebotomum	12·1	—	—	5·2

B = Soil under the dung pad.
C = Grass adjacent to the dung pad.
D = Grass roots adjacent to the dung pad.
E = Soil adjacent to the dung pad.

Cooperia spp.—These species were the most active migrators from the dung under extremes of heat, cold and drought. They were the most frequently recovered larvae of all the species dealt with and were recovered from 80 cm. in the soil, 70 cm. on the grass, from the edge of the dung pad (No. 46) and had migrated more than 20 cm. vertically on grass (No. 49, Table II).

Haemonchus placei.—As can be seen in Table No. 7, this species was not as active a migrator as *Cooperia* spp. When good rains fell this species was particularly prominent, but it was also found to have migrated under less favourable conditions. Horizontally, it was recovered from grass 80 cm. and from soil 70 cm. away from the edge of the dung pad (No. 46). Vertically it had migrated over 20 cm. on grass (No. 49).

Oesophagostomum radiatum.—This species did not migrate as frequently as the species mentioned earlier but it was recovered more frequently than *H. placei* from the soil next to the dung pad (Table No. 7). However, it only migrated horizontally for 30 cm. in the soil (No. 41) but was recovered from grass 50 cm. from the edge of the dung pad (No. 41 and 42). Vertically this species only migrated up to 5 cm. on grass (No. 35 and 43).

Bunostomum phlebotomum.—This species was not really an active migrator from the dung and was only recovered in the soil, more frequently beneath, and less often adjacent to, the dung pad (Table No. 7). The larvae, although recovered from the soil adjacent to the dung pad, were confined to the soil right next to the dung pad (No. 30, 33 and 42). This species was never recovered from grass or grass roots.

(*E*) *The role of insects in larval migration*

Under field conditions coprophagous beetles, termites, ants, etc., frequently attacked dung pads and removed the faeces to the underlying and adjacent soil. These small pieces of manure could not be separated from soil specimens. It is possible that infective larvae developed in these small pieces of dung. Where dung beetles had been active, soil beneath the dung yielded infective larvae when climatic conditions were unfavourable for migration (No. 13, 18, 24, 48 and 57), as well as in the adjacent soil (No. 18 and 57). There was possibly enough moisture, even when minute quantities of rain fell to stimulate larval migration from the underlying soil containing this manure, and this would account for the recoveries of larvae on the grass under extremely unfavourable conditions (No. 10, 11 and 18). Under slightly more favourable conditions of rainfall for larval migration, it was difficult to assess whether rainfall or beetles, or both, were responsible for migration (No. 20, 27, 28, 33 and 35).

(*F*) *The survival of infective larvae*

The maximum number of days the larvae survived after infested dung was placed in the veld is summarised in Table No. 8.

Cooperia spp. were the most resistant larvae, regardless of the site of larval recovery, followed by *H. placei*, *O. radiatum* and *B. phlebotomum*, in that order. It was interesting to note the similarity between *H. placei* and *O. radiatum* in the maximum survival rates on grass, and the longer period *O. radiatum* survived on grass roots as compared with *H. placei*.

TABLE NO. 8

Maximum number of days infective larvae were recovered after experiments commenced

Species	Site of Larval Recovery				
	A	B	C	D	E
Cooperia spp.	*105	105	93	104	105
H. placei	105	104	41	28	104
O. radiatum	105	42	41	84	67
B. phlebotomum	24	25	—	—	25

A = Dung pad
B = Soil under dung pad
C = Grass adjacent to dung pad
D = Grass roots adjacent to dung pad
E = Soil adjacent to dung pad
* = Days.

Tables No. 7 and 8 were compared and it was noted that migration and survival followed essentially the same pattern, with a few minor differences when *H. placei* and *O. radiatum* were compared. In this connection the frequency of larval migration was more important than the actual survival rates in isolated cases.

Poor recovery rates of larvae occurred when experiments were conducted over long periods (No. 9, 16, 21, 32 and 57), with the exception of two experiments; in one the dung mass was fairly large and rainfall was well distributed; the other was conducted in autumn and winter, under colder conditions (No. 38 and 58).

Apart from the two exceptions mentioned, larvae were recovered in large numbers only when the experimental period did not exceed 24 days (No. 14, 17–20, 23, 29, 36, 40, 42–44, 46–48 and 53). A fair number of larvae were recovered in two experiments which lasted 40 and 41 days (No. 22 and 49, respectively).

In experiments described elsewhere (*vide supra*), the minimum period in which infective larvae developed in dung pads was five days. The results of these experiments indicate good recoveries of infective larvae up to the twenty-fourth day, i.e. after infective larvae had been present for a maximum period of 19 days. After this period the mortality rate increased sharply and larvae were rarely recovered in large numbers after the twenty-fifth day, except in isolated dung pads or in small numbers where migration has occurred.

(*G*) *Migration of infective larvae to grass*

Distribution of rainfall has already been mentioned as an important factor in larval migration. Since five days is the minimum period required for infective larvae to develop to the infective stage, rainfall in this period would assist larval development to the infective stage and thereafter assist larval migration.

In Table No. 9 four experiments, where larval migration to the grass occurred, are compared. Heavy rainfall, particularly after the fifth day, explained the excellent migration in Experiment No. 42. Although the actual total amount of rainfall for the period was less in No. 44 than in either No. 29 or 46, a higher percentage of larvae migrated in the former than in the latter experiments.

TABLE NO. 9

Distribution and amount of rainfall required for optimal larval migration to grass

Experiment No.	Up to Five Days		After Five Days		Larvae on Grass		No. of Days in Field
	No. of Days Rain fell	Total Rainfall in mm.	No. of Days Rain fell	Total Rainfall in mm.	Total No. Recovered	Percentage of Total No. from all Sources	
						%	
42.....	1	27·5	2	89·3	6,118	83	8
44.....	2	3·6	4	36·9	586	46	12
29.....	2	38·5	1	6·5	125	10	10
46.....	2	24·8	2	26·7	266	10	9

Apparently the rainfall that fell after the fifth day accounted for better migration of the larvae to the grass, although in this period only 10·2 mm. (0·40 inches) more

was recorded in No. 44, than in No. 46. It was interesting to note that as little as 6·5 mm. (0·26 inches) in No. 29 after the fifth day, was probably responsible for the migration of 10 per cent of the infective larvae to the grass.

In experiments where horizontal migration was measured the largest percentage of larvae was recovered within 10 to15 cm. from the edge of the dung pad (No. 41, 42, 44, 45–47). It was also noted that the largest proportion of larvae was recovered at heights of less than 10 cm. on the grass and decreased in numbers the higher the grass was cut off from the soil surface (No. 41, 44, 45, 47 and 49). Whereas in one experiment 50 per cent of the larvae were recovered below 10 cm. and a further 28 per cent between 10 and 20 cm., only 22 per cent were found 20 cm. or higher on the grass (No. 49). Migration over the grass was most marked where the grass was thick and formed a " mat ".

(H) Prevailing climatic conditions

The climatic conditions prevailing during the experimental period (26 June, 1955 to 7 August, 1956) are shown in Fig. No. 1. The monthly rainfall is included in Table No. 10, and in Table No. II, Appendix; relevant climatic data for the period each experiment ran are also shown.

TABLE No. 10

Monthly rainfall at Armoedsvlakte from July, 1955 to June, 1957

Month	Number of Days Rain fell	Total Rainfall	
		mm.	Inches
July, 1955	0	0	0
August	0	0	0
September	1	0·2	0·01
October	6	16·5	0·7
November	6	40·4	1·6
December	10	127·9	5·0
January, 1956	9	38·3	1·5
February	7	140·3	5·5
March	15	175·6	6·9
April	0	0	0
May	5	9·4	0·4
June	0	0	0
TOTAL	59	548·6	21·61
July, 1956	0	0	0
August	0	0	0
September	3	13·4	0·53
October	6	18·3	0·72
November	2	11·5	0·45
December	11	67·4	2·66
January, 1957	7	82·7	3·26
February	7	29·9	1·18
March	10	47·7	1·88
April	5	41·0	1·61
May	4	10·0	0·39
June	2	23·0	0·91
TOTAL	57	344·9	13·59

It will be noted that during the experimental period little or no rain fell except for three months, in December, 1955, February and March, 1956, when rainfalls were good. Marked diurnal temperature variations occurred. In July the mean minimum was 0·3° C (32·5° F) and the mean maximum 20·7° C. (69·2° F). In January the mean minimum was 15·9° C (60·6° F) and the mean maximum 31·6° C (88·8° F). Mean relative humidity varied from 31·5 per cent in September to 70·4 per cent in March.

Discussion

Generally speaking the results of these experiments were disappointing. No larvae were recovered in 12 per cent, less than a hundred in 35 per cent, and between a hundred and a thousand in 19 per cent of the experiments, respectively. Only in 34 per cent of the experiments were more than one thousand larvae recovered, of which 24 per cent had one to ten thousand, and 10 per cent more than ten thousand larvae respectively. The poor results were probably due to adverse climatic conditions, the surrounding habitat, survival of larvae and secondary causes (e.g. dung beetle activities).

It has been shown in experiments described elsewhere that no larvae reach the infective stage in the cold winter months at temperatures varying from a mean minimum of 2·6° C (36·7° F) to a mean maximum of 22·7° C (72·9° F). When temperatures in spring were adequate for hatching and larval development, drying and desiccation due to evaporation caused death, particularly of the pre-infective larvae. Similar results were obtained in summer when no rain fell during the first six to seven days dung pads were placed in the field. The negative and poor results in spring and during the hot, dry periods in summer were probably due to death by desiccation of the pre-infective larvae. This has been the experience of many other workers investigating different species of strongyloid worms (Ransom, 1906; Veglia, 1915; Theiler & Robertson, 1915; Schwartz, 1924; Mönnig, 1930; Ortlepp, 1937; Crofton, 1948b; Dinnik & Dinnik, 1954–5, etc.).

It was noticed that dung which had no protection from the sun during the day gave very poor results. Partial and deep shade yielded more larvae under similar conditions. This was probably due to the temperature causing higher rates of evaporation in exposed dung pads. Dinnik & Dinnik (1954–5), working with *Haemonchus contortus* found similar results in the dry season. In one experiment conducted in winter, however, large numbers of larvae were recovered from a dung pad exposed to the sun (No. 53) and only one larva was recovered from dung lying in the shade (No. 52). In these cold conditions, exposure facilitated development whereas shade retarded it. This was probably due to higher temperatures in the former, assisting development to the infective stage, whereas temperatures the in the shade were too low to allow the pre-infective stages to reach the infective stage.

Poor recovery rates were recorded when experiments continued for long periods, with one major exception: the last experiment conducted over 105 days from April to August (No. 58). In this experiment larvae developed to the infective stage in autumn, i.e. they survived the whole winter, practically all being confined to the dung pad. The life expectation of larvae in other experiments throughout the year appeared to decrease sharply after the twenty-fourth day of exposure to field conditions. This observation is of importance in that it indicates how long heavy infestation can remain in a pasture, and will have to be taken into account in the prophylaxis of verminosis by pasture management.

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Dung beetles are undoubtedly the ally of the cattle rancher in the control of verminosis. Wherever these beetles had been active larval recoveries from dung pads were very poor, due doubtless to the aeration of the dung assisting evaporation and accelerating the desiccation and death of pre-infective and infective larvae. By the mechanical removal of the dung, particularly from the lower surface, to the underlying and also adjacent soil, these beetles probably accounted for the large number of experiments in which larvae were present in the soil, particularly underneath, but also next to the dung pad. It was a feature of these experiments that wherever dung pads were hollowed out by beetles, larvae were recovered from the soil beneath the dung. Dung pads protected from beetles did not show this phenomenon to the same extent, unless rainfall had occurred. It is suggested that beetle activity, and not the migratory habits and positive heliotropism of the larvae as suggested by Mönnig (1931), was the main reason why larvae were recovered from soil. In most cases Mönnig found more larvae in the soil next to, rather than underneath, the dung pad. This observation was not confirmed in most cases in the experiments described above; in fact the reverse was observed.

From the observations that larvae could be recovered from the soil underneath and adjacent to dung pads, it appeared reasonable to assume that a few would be found near the basis of grass tufts. This was actually the case. Very little rain would then be necessary to stimulate larvae to migrate on to the grass, as shown in certain experiments (No. 10, 11 and 18).

In the dung pad itself most moisture is retained in the so-called depth of the dung pad, and more larvae were recovered there than elsewhere. This was possibly due either to the death of the pre-infective larvae in the drier crust or to the migration of these larvae to the moister and deeper layer.

Migration of larvae in the dung pads was, however, interesting. Only in one experiment was it noticed that active vertical migration was taking place in the dung pad, viz. where rainfall had been very heavy indeed and the crust of the dung pads had thus been softened (No. 42). In most of the cases where active migration occurred under the influence of rainfall, larvae were recovered in large numbers in the soil, particularly beneath the dung pad. Possibly the hard crust of the dung did not allow the passage of infective larvae from the depth but, since the soil surface layers were softer, they could escape to the ground. This migration did not include the effects of dung beetles, since it occurred even when dung beetle activity had been excluded. In one experiment, which ran over seven days and in which 19·0 mm. of rain was recorded on the fifth day, only downward migration occurred (No. 39). In two other experiments a rainfall range of 11·1–19·0 mm. after the fifth day caused most of the infective larvae to migrate to the soil beneath the dung pad (No. 38 and 40). With slightly higher rainfall larvae were also recovered from the grass, but the larger percentage of migrated larvae was still found in the soil under the dung pad. It appeared, therefore, that a rainfall range of 11 to 19 mm. (0·43 to 0·77 inches) stimulates downward migration of larvae into the soil although some larvae were found on the adjacent grass. Marked larval migration to the grass was only noted when heavier and well distributed rains fell.

A significant observation was that, in the absence of rain, even heavy dews failed to cause larval migration to the grass, although 0·3 per cent of the larvae were found under the dung pad (No. 48). This is not in agreement with the views of Australian investigators who stated that heavy dew would assist migration from dung pads (Riek, Roberts & O'Sullivan, 1953). However, once the larvae had migrated from dung pads, dew would undoubtedly assist further migration.

Of great practical importance are the amount and distribution of rainfall necessary for significant larval migration to the grass. The amount of rainfall necessary for significant larval migration was from 40·4 mm. upwards. Of greater significance, however, was the distribution of rainfall. It has already been shown that rainfall during the first five to six days assisted larval development. Once infective larvae were present, further rainfall would assist larval migration. The important rainfall for larval migration would thus occur after the fifth day. This point is shown in Table No. 9. A rainfall range of 6·5 mm. to 26·7 mm. after the fifth day caused only 10 per cent of the larvae to migrate to the grass, whereas 36·9 mm. falling after the fifth day caused the migration of 45 per cent of the larvae to the grass, i.e. a mere 10·2 mm. of extra rain falling when infective larvae were freely available increased larval migration to the grass by 35 per cent.

According to Rogers (1940), light intensities of 62 f.c. have been shown to be optimal for larval activity. These intensities exist, under English conditions, from half-way down the grass to the base, depending on the brightness of the day (Crofton, 1948a). Light intensities at Armoedsvlakte during summer, apart from cloudy days, which were rare, were probably high due to the fact that grass tufts were scattered. Consequently specimens were collected from dawn to 7 a.m. which, according to Rogers (1940), would be nearly optimal. However Crofton (1949) found more larvae on the grass from 12 noon to 5 p.m. than in the early morning when dew was present. He stressed the fact that migration of larvae was impossible below 10° C (50° F) and that it was fallacious to assume that moisture only could control larval activity. In the summer months at Armoedsvlakte, minimum daily temperatures were usually above 12° C (53·6° F) and as high as 20° C (68° F), so that temperatures at dawn were adequate for larval migration. Apparently this is not the case in England.

The *vertical* distribution of larvae on grass generally agreed with the experience of other investigators, who found most of the larvae near the base, i.e. the lower two to three inches of grass (Taylor, 1938; Crofton, 1948a). In these experiments more larvae were recovered in the lower 5 to 10 cm. of grass than higher up, although in one case a few larvae were found to have migrated as much as 20 cm. vertically. The number of larvae recovered from grass appeared to be greater where the grass was thicker. This agreed with Kauzal's (1941) observation. On the other hand, where optimal larval migration was taking place in five of these experiments (No. 30, 41, 42, 44 and 45), 41 to 90 per cent of available larvae were recovered from the grass. This percentage is much higher than the 16 per cent observed by Kauzal.

The *horizontal* distribution of larvae on grass showed that 72 to 100 per cent of the larvae were recovered within 15 cm. of the dung pad. The number of larvae decreased rapidly as the distance from the dung pad increased. The maximum horizontal migration of *H. placei* on the grass was over 80 cm., whereas *Cooperia* spp. were only found up to 70 cm. from the dung pad, i.e. within a radius of 89 and 79 cm. respectively from the centre of the dung pad (No. 46).

In this particular experiment the grass was fairly dense but did not form a continuous thick mass around the dung pad. Most of this migration was influenced by the rainfall of 25·5 mm. (1·0 inches) which fell during the last 24 hours before the specimens were collected. This may possibly have caused a little flooding and assisted in disseminating the larvae over a large area.

The behaviour of the various species of larvae differed in certain important aspects.

Cooperia spp.

These larvae were the most drought resistant, lived longer under various climatic conditions in the dung, soil, grass and grass roots, and migrated and survived when no other species was found. This observation confirms work done in Australia (Roberts, Riek & O'Sullivan, 1952). Since almost a pure *Cooperia pectinata* infestation was present it can be stated that this species can withstand cold better than *H. placei.*

Haemonchus placei.

Although not as resistant to drought as the previous species, it was recovered from grass in small numbers under very unfavourable circumstances.

In comparison with *Cooperia* spp., it survived as long in dung and soil, although not as frequently, but died off more rapidly in the grass and grass roots. When conditions were optimal for larval migration it was, however, more prominent than the former species.

Oesophagostomum radiatum.

For unavoidable reasons both this species and *B. phlebotomum* were not available initially to the same extent in infested dung as the first two species mentioned. It would be wise therefore to treat the results of the behaviour of the infective larvae of these latter two species with reserve.

It was found that *O. radiatum* did not migrate as readily as either *Cooperia* spp. or *H. placei*, but was recovered more frequently than the latter from the soil adjacent to the dung pad, although less frequently elsewhere. It survived longer on grass roots, the same length of time on grass and dung but shorter periods in the soil than *H. placei.*

Bunostomum phlebotomum.

This species was the most sensitive to adverse climatic conditions. It neither lived as long as nor migrated to any appreciable extent when compared with the other species. Its maximum survival rate from the time the dung was placed in the veld, was 24 days in the dung pad and 25 days in the soil. It was recovered on a few occasions from the soil beneath the dung pad, and only rarely from the soil next to the dung. It did not migrate to the grass, an observation also made by Sprent (1946b), who stated that it remained in the dung. He did not mention whether it migrated to the soil. His first observation was confirmed by these observations, but although more frequent in dung, larvae were also recovered from the soil in these experiments.

Australian workers have stated that *B. phlebotomum* will not survive in areas with an average annual rainfall of less than 24 to 25 inches (Riek *et al.*, 1953). This observation was not confirmed. Over a 14-month period during these experiments 21·6 inches of rain fell. This species was recovered in 25·8 per cent of the experiments from October to May, inclusive, in which period monthly rainfall varied from nil to 6·9 inches.

Summary

Studies were carried out on the activity and survival of infective larvae of *Cooperia* spp., *H. placei*, *O. radiatum* and *B. phlebotomum* under field conditions. The following observations were made:—

(1) Fifty-eight experiments were carried out over a period of 14 months. Eleven of these months had little or no rain. Three months had monthly rainfalls varying from 127·9 to 175·6 mm. (5 to 6·9 inches).

(2) Only 34 per cent of the experiments gave satisfactory results. In most cases these experiments were carried out in summer, during periods when rainfall was adequate; dung pads were placed in areas partially or wholly protected from the sun, the experimental periods were short and dung beetle activity excluded.

(3) Sixty-six per cent of the experiments gave unsatisfactory results due to one or more of the following factors:—
   (*a*) adverse climatic conditions;
   (*b*) over-exposure to sunlight;
   (*c*) long-term experimental periods;
   (*d*) dung beetle activity.

(4) In dung pads larvae were usually recovered in greater numbers from the depth, which lay between the outer crust and ground surface layers, than from either the crust or ground surface layers.

(5) Migration from the dung was influenced by rainfall as follows:—
   (*a*) under the influence of 14·0 mm. (0·55 inches) of rain after a fairly dry period, larvae failed to migrate;
   (*b*) when rainfall occurred in the first five days dung was in the field, a rainfall range of 11 to 19 mm. (0·43 to 0·77 inches) thereafter stimulated migration of larvae mainly to the soil;
   (*c*) in experiments which ran over periods of 9 to 12 days and rainfall had been recorded in the first five days, subsequent rainfall caused greater or lesser migration to the grass. When 6·5 to 26·7 mm. (0·26 to 1·05 inches) of rain fell after the fifth day, only 10 per cent of the larvae migrated to the grass, but if 36·9 mm. (1·45 inches) of rain fell in this period, 46 per cent of the larvae migrated to the grass.

(6) *Cooperia* spp. larvae migrated horizontally 70 cm. on grass, 80 cm in soil and 20 cm. vertically on grass. Under field conditions they migrated more frequently and survived longer than any other species.

(7) *Haemonchus placei* larvae migrated horizontally 80 cm. on grass, 70 cm. in soil and 20 cm. vertically on grass. They migrated less frequently and survived as long in dung, almost as long in soil, but for much shorter periods on grass and grass roots than *Cooperia* spp.

(8) *Oesophagostomum radiatum* larvae migrated horizontally 50 cm. on grass, 30 cm. in soil and 5 cm. vertically. They migrated less frequently, survived as long in dung as the previous species, and were recovered from grass for the same maximum period as *H. placei*. Otherwise their survival rate was lower.

(9) *Bunostomum phlebotomum* larvae did not migrate on to the grass but only to the soil underneath or right next to the dung pad. Their survival rate was extremely low in comparison with the other species.

(10) Horizontal migration was more marked within 15 cm. of the dung pad. Vertical migration was more noticeable on grass within 5 to 10 cm. of the soil surface.

(11) Dung beetles decreased the larval recoveries from dung pads by increasing aeration and evaporation, causing death by desiccation of pre-infective larvae. At the same time they assisted migration by their mechanical movement of the dung to soil, where some larvae could reach the infective stage.

C.—Insect Activities under Natural Conditions

Introduction

During the course of these investigations marked insect activities, especially of dung beetles, were noted in the dung. In most cases dung was attacked during the first few days in the field, with resultant greater or lesser dung pad destruction. It was, therefore, considered essential to ascertain what effects these insect activities had on the developmental stages in the life cycles of the helminths studied.

Experimental Observations

A.—Hatching of eggs and development of larvae to the infective stage

These results have been summarised in Table No. I in the Appendix and the experimental numbers referred to will be found in this table.

Dung beetles and other insects attacked dung pads during November, 1956 and again from January to April, 1957. Although afforded no protection against dung beetles, dung pads placed in the field from August to October, in December, 1956, and in May and June, 1957 were not attacked.

During November, 1956, in Experiment No. 7 (*a* to *f*), six dung pads were placed in the field. The first dung pad, 7 (*a*), was collected after one day's exposure to field conditions, and had not been attacked by dung beetles. The other five dung pads, 7 (*b* to *f*), collected subsequently, had been hollowed out by beetles. Two days after exposure to field conditions 7 (*b*) and 7 (*c*) were collected; the former weighed 150 gm. the latter 100 gm., the difference in weight being due to increased insect activity; egg counts were 120 and 20 eggs per gram, respectively, indicating more rapid hatching of eggs in the latter. Only 25 first stage and 12 second stage larvae were recovered in the former, while 256 first stage larvae and no second stage larvae were recovered in the latter after extraction with the Baerman Apparatus. However, after a further eight days' incubation in the laboratory the specimens yielded 10,000 and 3,500 larvae, respectively. In comparison with the latter more than twice the number of infective larvae were recovered from the former, although the weight of the dung in the latter at collection was two-thirds of the former.

Another dung pad, 7 (*d*), was examined on the third day; the dung only weighed 67 gm. and both egg counts and larval examination after extraction with the Baerman Apparatus were negative. After a further eight days' incubation in the laboratory only 550 infective larvae were recovered. This dung pad had been extensively hollowed out by insects and although it was 67 per cent of the weight of 7 (*c*) when

collected in the field, the number of larvae collected from this specimen was only 15·7 per cent of the number collected the previous day in 7 (*c*). The activities of dung beetles, as well as the longer exposure to field conditions, were responsible for the marked drop in larval recoveries.

The remaining dung pads, 7 (*e*) and 7 (*f*), exposed to field conditions for 30 and 64 days, respectively, were also extensively damaged by dung beetles and yielded few larvae on examination.

In Experiment No. 9 six dung pads were placed in the field on 11 January, 1957. Three days later 9 (*a*) was collected and examined. It was extensively hollowed out by beetles, and weighed 113 gm.: egg counts were negative: two first stage larvae were recovered with the Baerman Apparatus and 825 infective larvae after eight days' incubation.

The other five dung pads in this experiment were almost completely destroyed. Small heaps of loosened soil covered with one or two pieces of dung, the largest of which was 2 cm. in diameter, indicated where the dung pad had been. On examination of these heaps, minute pieces of manure were found to be inextricably mixed with the soil.

A large mass of dung, 3 lb. in weight, was also placed in the field on 11 January, 1957. This experiment, No. 10, suffered the same fate as the five dung pads in No. 9. In experiment No. 11, four dung pads were placed in the field on 17 January, 1957. Within 48 hours only four small heaps of loosened soil indicated the site of these dung pads.

It was important to know whether infective larvae could develop in the small pieces of dung removed to the soil by these insects and whether they could be recovered from the soil. This was included in the study of infective larvae in the previous year and is reported hereunder.

B.—The activity and survival of infective larvae under field conditions

These results have been summarised in Table No. II in the Appendix and the experimental numbers referred to will be found in this Table.

In 16 experiments (No. 7, 10, 11, 13, 18, 20, 24, 25, 26, 27, 28, 30, 31, 32, 33 and 35) dung beetles had been active to a marked degree. In the remnants of the dung pads infective larvae were recovered in large numbers in only one experiment (No. 18); in ten experiments (No. 11, 13, 20, 26, 27, 28, 30, 32, 33 and 35) from one to 388 larvae were recovered, while no larvae were present in five experiments (No. 7, 10, 24, 25 and 31).

Dung beetles removed manure to the soil underlying and adjacent to the dung pads. It was impossible to separate these small pieces of dung from the soil and they had to be examined together.

It was interesting to compare the number of infective larvae recovered from the soil beneath the dung pad with that in the dung pad itself. More larvae were recovered from the soil beneath the dung pad in five experiments (No. 20, 28, 30, 33, and 35) and less in four experiments (No. 13, 18, 27, and 32). In two experiments (No. 24 and 31) a few larvae were recovered from the soil, while none was present in the dung pad. In two other experiments (No. 13 and 18) rainfall was inadequate for any migration; in a further three experiments (No. 20, 27, and 28), the amount of rainfall only partly assisted downward migration from the dung, which would

account for some of the infective larvae found there. Where rainfall had been adequate, it was impossible to assess whether the presence of larvae in the soil was due to migration from the remnants of the dung pad, or whether they had developed in the small pieces of dung removed to the soil by dung beetles (No. 30, 31, 32, 33 and 35).

Larvae were recovered from the soil adjacent to the dung pad in nine experiments (No. 18, 20, 27, 28, 30, 31, 32, 33 and 35). In one experiment (No. 18) rainfall had been inadequate for this migration from the dung pad. In the other eight experiments the same remarks in relation to rainfall and beetle activity apply as mentioned in the previous paragraph, to account for the presence of larvae in the soil.

Larvae were recovered from the grass next to the dung pad in ten experiments (No. 10, 11, 18, 27, 28, 30, 31, 32, 33 and 35). The most interesting observations were made in three of these experiments (No. 10, 11 and 18). The rainfall recorded during all these experiments was less than 0·5 mm. for the periods of exposure to field conditions. Experiments described elsewhere showed that this amount of rain was inadequate for larval migration from the dung pad itself. Dung beetles had removed small pieces of the dung to the soil at the base of the grass. It is more than likely that even very little rain was sufficient to cause migration on to the grass of infective larvae from these small particles.

In only four experiments (No. 28, 30, 33 and 35) were larvae recovered from grass roots adjacent to the dung pad. They were usually present in smaller numbers than those recovered from other sources.

On examination of the results of the 12 experiments which ran over short periods of seven to 19 days, it was interesting to note that in only two experiments (No. 18 and 20), were large numbers of larvae recovered. In similar experiments (No. 15, 17, 23 and 29), conducted during the same period, when dung beetles had not been active, considerably larger numbers of larvae had been recovered. These parallel experiments, carried out under the same climatic conditions, afforded evidence that the end result of dung beetle activity was a marked reduction in the number of infective larvae.

C.—The effect of low level phenothiazine dosing on dung beetle activity

Introduction.—The observations previously reported showed that dung beetles were important in reducing the number of available infective larvae. Phenothiazine, when dosed to stock in small quantities, is excreted with the faeces and has been extensively used to control the pasture stages of the life cycle of round worms. It was important to know whether this drug, when excreted in faeces during low level phenothiazine dosing, had any deleterious effect on dung beetles. If this were the case low level phenothiazine dosing would counteract the insect activities in dung and could not be recommended. For this reason low level dosing of phenothiazine was carried out on two animals whose faeces were collected, and dung beetle activities in these faeces were compared with their activities in faeces derived from an undosed control animal.

Materials and Methods.—Two cows were daily dosed with two and five grams of phenothiazine, respectively. Three days after commencement of dosing, faeces were collected from these two animals, as well as from an undosed control cow. From each of these animals dung weighing 1 Kg. was placed in the field. These dung pads were collected after exposure to field conditions for periods of three to six days. In the laboratory they were weighed and the number of dung beetles in each specimen

counted. In addition, each dung pad was examined to see how extensively they had been hollowed out by insects. The insects collected were placed in bottles to see how long they would survive after removal from the dung. Dosing continued and specimens were collected over a period of two weeks.

TABLE 11

A comparison between the activity and the number of dung beetles recovered from 1 Kg. samples of dung exposed to field conditions

No. of Days in Field	No. of Insects Recovered from Dung of—			Remarks
	*(*a*) Cow No. 1	*(*b*) Cow No. 2	*(*c*) Cow No. 3	
3	172	134	13	Dung in specimen (*c*) was more hollowed out by beetles than either (*a*) or (*b*).
3	260	70	174	Little damage was done to any of the dung pads by beetles.
3	174	48	12	More evidence of dung beetle activity in (*b*) and (*c*) than in (*a*).
4	74	55	8	Dung in (*c*) more extensively hollowed out than either (*a*) or (*b*).
5	18	32	5	Dung of (*a*) and (*b*) more hollowed out by beetles than (*c*).
6	35	18	3	All specimens extensively hollowed out by dung beetles.

*(*a*) Cow No. 1 dosed daily with 2 grams of phenothiazine.
*(*b*) Cow No. 2 dosed daily with 5 grams of phenothiazine.
*(*c*) Cow No. 3 undosed control.

Experimental Observations

In Table 11 the number of insects recovered from the various specimens showed no correlation whatever. Dung pads were frequently extensively hollowed out but very few insects were recovered in such specimens. In most cases more dung beetles were recovered from the dung pads derived from cows receiving low level phenothiazine dosing than from the dung of the control cow. The evidence that insects had been active varied to such an extent between the specimens that, although they were not necessarily still present when searched for in the dung in the laboratory, their absence did not indicate that other dung beetles had not been active prior to collection and had subsequently left the dung pad. There was no evidence that insect activity was more marked in dung from the undosed control than either of the dung pads from the two cows receiving daily doses of phenothiazine.

The insects that were recovered from these dung pads were placed in bottles in the laboratory. They lived for two to three days before they started dying, regardless of whether they were derived from dung from the dosed cattle or from the undosed control. They lived as long as six days before dying when dung was placed in the bottles, regardless of the presence or absence of phenothiazine in the dung which was added.

From these observations it is clear that low level phenothiazine dosing of cattle had no apparent effect on the activity of the insects that attacked their dung, nor did it cause the death of any dung beetles. Since it had no deleterious effects on dung beetle activity, this drug can safely be used in the control of verminosis in stock, as is at present advocated in many parts of the world.

Discussion

The observations on the hatching of eggs and the development of larvae to the infective stage in dung pads in the field, indicated that dung beetles caused increased aeration of dung pads, which speeded up the tempo of egg hatching. This confirms Mönnig's (1931) observation. In spite of the more rapid hatching of eggs, the recovery of larvae from such dung pads after incubation in the laboratory, was considerably less than from those dung pads in which the insects, although present, had not hollowed out the dung pad to the same extent. The death of the larvae was probably due to increased aeration, giving rise to more rapid desiccation and death during the pre-infective larval stages.

During January, 1957, 11 dung pads were placed in the field. Ten of these were completely destroyed within 48 to 72 hours, leaving only small heaps of soil covered with a few small pieces of dung. The one dung pad left was extensively hollowed out and was examined as previously reported.

Throughout the rest of the summer and autumn of that year repeated attempts to study the pre-infective stages of the life-cycle, under completely natural conditions, met with a similar fate. Once the dung beetles had destroyed the dung pads egg counts and the recovery of the various developing larval stages were impossible. Since the author was also studying the effects of other environmental factors on these stages of the life-cycle at the same time, he was compelled, albeit reluctantly, to protect the dung pads with wire gauze. Fortunately dung beetle activity ceased at the end of April, so that it was unnecessary to protect the dung pads in the winter and they could be studied under completely natural conditions.

In the previous year dung beetles had also been active, but not nearly to the same extent as in the autumn of 1957. The poor recoveries of larvae as a result of dung beetle activity reaching a peak in the autumn, offset to a marked degree the beneficial effects of increased rainfall on the development of infective larvae.

The poor recoveries of infective larvae, in 14 of the 16 experiments on infective larvae, substantiated the statement made above, viz. that insect activity facilitated the death of the pre-infective larval stages. Dung beetles, are attracted to fresh manure only, while it is still soft and very moist, i.e. during the first four days it is in the field. They burrow into the dung pads and remove manure to the soil particularly beneath, but also next to, the dung pad. These small pieces of manure were seen in the soil. The recovery of fairly large numbers of larvae in the soil mixed with manure granules below the remnants of the dung pad, under conditions where rainfall was inadequate for larval migration from the dung pad, must have been due to the presence of larvae in these small pieces of manure. Since they had been removed within the first few days the dung was in the field, it is only reasonable to assume that they must have developed to the infective stage after being removed by dung beetles to the soil. The movement of dung beetles in the soil loosens it, thereby introducing air and probably also increasing the rate of evaporation. Although stimulating egg hatching, this would also increase the death rate by desiccation of the larvae. This possibly accounts for the poor larval recoveries from soil samples in most of the experiments where dung beetles had been active.

During the two year period of these investigations, from July, 1955 to June, 1957, it was noted that dung beetles were most active from January to April, in both seasons.

Rainfall data at Armoedsvlakte over a period of more than 30 years indicated that the rainy season was from December to April, the best month being March. Experiments described elsewhere showed that these months were the most optimal for the free-living stages of the nematode parasites. Furthermore, experiments on the transmission of verminosis proved that stock only became infested during this period.

It was very significant that during this same period dung beetles were most active. While other environmental factors facilitated the propagation of infestation in the late summer and autumn, the burrowing habits of insects in the dung had the opposite effect. Within two or three days of being in the field dung pads were frequently destroyed. Only the presence of rain would save any remaining larvae from desiccation and death.

The presence of frequent rains and nocturnal dews would be necessary to prevent death during the pre-infective stages. Although dew was a nightly occurrence, it would only moisten the surface of the soil and any remnants of dung pads above the soil. Below the surface of the soil rain would be required to supply sufficient moisture for larval survival. In this respect the erratic distribution of the rain meant that few larvae had this benefit and therefore died in the frequent, relatively dry periods between rainfalls. Only at those periods when rainfalls were regular would more larvae reach the infective stage. Thus insect activity would be balanced out to a certain extent by the moisture supplied by rain. The interim periods between days on which rain fell would allow the full effects of dung beetle activity to be felt. Since these periods were more frequent than the days on which rain fell, few larvae would reach the infective stage during this period. In other words, it was only during rainfall periods that the larvae really had a chance to survive and develop to the infective stage.

Dung beetle activity can safely be stated to be an important method of biological control of worm infestation in the field and an important ally of the farmer in worm control.

Summary

1. Four experiments on the hatching of eggs and development of larvae under field conditions where insects attacked dung pads are described.

2. In November, 1956, five dung pads in one experiment were attacked by dung beetles. These insects caused increased aeration, stimulating egg hatching, but larval recoveries after incubation in the laboratory were considerably less in dung pads where insect activity was most marked, indicating increased larval mortality.

3. In three experiments in January, 1957, 11 dung pads were placed in the field; of these only one was suitable for examination after three days. The other ten were completely destroyed within 48 to 72 hours, leaving small heaps of sand containing a few small pieces of manure inextricably mixed with the soil. No semblance of dung pads was left to examine for egg hatching or for the recovery of larvae.

4. The effects of dung beetles were observed in 16 experiments in which the activity and survival of infective larvae were being studied. In two experiments larvae were recovered in fairly large numbers. In 14 experiments, larvae were either absent, or present in small or very moderate numbers.

5. The presence of infective larvae in soil underlying and next to dung pads, was concluded to be partly due to their development in the small pieces of manure mixed with the soil. These pieces of dung had been removed from the dung pad by insects during the first few days it had been in the field, and before infective larvae were present in the dung pads.

6. Where rainfall was inadequate to cause larval migration, the presence of larvae in the soil was probably due to the mechanical removal of dung by beetles.

7. Low level phenothiazine dosing has no deleterious effects on the activities of dung beetles.

Conclusions

Dung beetles hollow out dung pads, which gives rise to increased rates of evaporation. This leads to the death of the pre-infective larvae. In the late summer and autumn, when climatic factors are optimal for larval development, these insects are most active and frequently destroy dung pads. Their activities are therefore an important method of biological control of infestation in the field. The administration of small doses of phenothiazine to cattle does not affect the subsequent activities of beetles in dung.

EPIZOOTOLOGY

Introduction

Based on field observations reported elsewhere (*vide supra*), four experiments were carried out on the transmission of verminosis to susceptible calves reared by the various methods of animal husbandry practised in the district.

The experiments were as follows:—

A.—Case report on calf No. 7180.

B.—Four groups of calves reared by different methods of animal husbandry from mid-summer to winter.

C.—Five groups of calves reared by different methods of animal husbandry from autumn to mid-summer.

D.—Seven groups of calves reared by different methods of animal husbandry from summer to early winter.

Note.—In Experiments C and D the work done in Experiments A and B was repeated, with the addition of extra groups.

A.—Case Report on Calf No. 7180

Materials and Methods

1. Two oxen suffering from a severe mixed infestation of *Cooperia* spp., *H. placei*, *O. radiatum* and *B. phlebotomum*, were introduced into a small camp, 5·4 morgen (about 11½ acres) in extent, in May, 1955, followed by three artificially infested calves, in October.

2. A kraal with a surface area of approximately 1,500 sq. ft. was constructed and the infested stock herded into this kraal from 7 a.m. to 2 p.m. every day.

The grass growing in the kraal and in a 3 ft. strip around the kraal was removed with a hoe. The kraal contained a raised water-trough from which no leakage was allowed.

3. Calf No. 7180 was born on 15 November, 1955 and *confined to the kraal* from 19 November, 1955 until it was slaughtered on 2 August, 1956. *Its dam* grazed elsewhere but *was allowed into the kraal from 7 a.m. to 2 p.m. daily to allow the calf to suckle.* This was the calf's only food supply until February, when it was allowed access to an adjacent calf pen to feed on chaffed lucerne in a special stanchion constructed to prevent spillage on the ground. This calf pen will be described in Experiment B.

4. Twice weekly initially, but thereafter once a week, faeces were collected from the calf per rectum and examined for worm eggs. At first a centrifugal flotation technique using $ZnSO_4$, S.G. 1·4 was employed, but as soon as the faeces were positive, egg counts, using the technique of Roberts & O'Sullivan (1950), were carried out. Positive faeces were mixed with sterile cattle dung, incubated for eight days at 26° C and the larvae were collected, heat killed and identified on a percentage basis.

5. Manure was collected in the kraal at regular intervals in the following fashion: An area of 10 sq. cm. was marked out on the surface and the manure was removed to a depth of 2 cm. and placed in a container. A further specimen immediately below this specimen to a further depth of 2 cm., was removed and placed in a separate container. Specimens were taken to the laboratory, weighed and placed in Baermann funnels for 24 hours; the larvae were collected and examined as described in previous experiments (*vide supra*).

6. Prevailing climatic conditions were recorded daily.

7. At the conclusion of the experiment in August, 1956, the calf was slaughtered and the worms identified and counted.

Experimental Observations

This experiment is called a case report since only one calf was involved. The experimental period was from 19 November, 1955 to 2 August, 1956, when the calf was slaughtered. Due to circumstances beyond the author's control the post mortem examination was carried out four weeks after the faeces examination had been concluded.

(*a*) *Development of Infestation.*—(For results see Fig. No. 3).

Six weeks after the calf had been placed in the kraal faeces examinations were negative, but the following week, on 7 January, 1956, a sudden rise to 1,460 e.p.g.* was observed. The egg counts reached their peak on 6 March, 1956 when 6,810 e.p.g. were noted, and thereafter fell until at the end of the experiment in July, 240 e.p.g. were recorded.

* e.p.g.—eggs per gram.

Larval cultures unfortunately were unsuccessful until 17 January, 1956 when *Cooperia* spp., *H. placei* and *Trichostrongylus* spp. were diagnosed, followed five weeks later by *O. radiatum* and *B. phlebotomum*. As the experiment progressed *Trichostrongylus* spp. larvae disappeared, *Cooperia* spp. and *H. placei* decreased, *O. radiatum* increased slightly and *B. phlebotomum* became the predominant species of larvae until the faeces examination was concluded in July.

(*b*) *Post Mortem Results*

At the post mortem examination of this calf on 2 August, 1956, five species

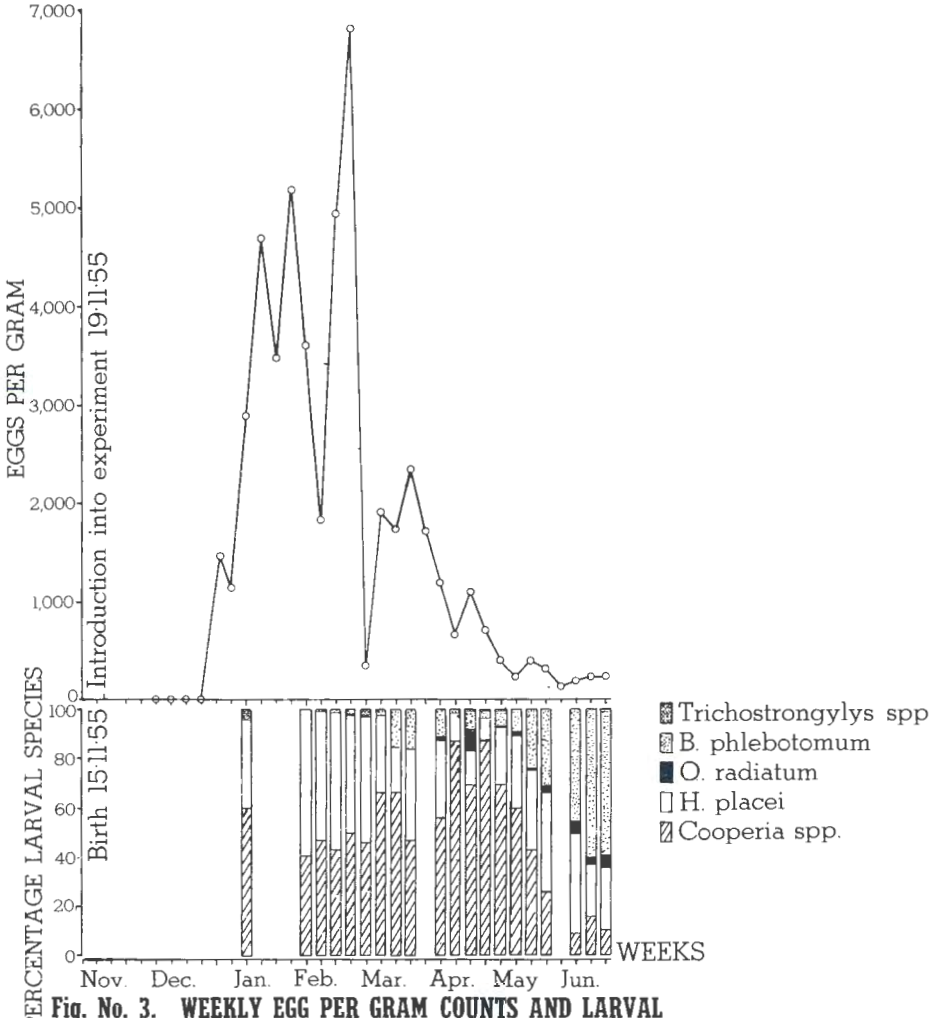

Fig. No. 3. WEEKLY EGG PER GRAM COUNTS AND LARVAL SPECIES VARIATIONS OF No. 7180

of worms were recovered. The species and their number are recorded in Table No. 12. Although larval culture results had revealed the presence of *Trichostrongylus* spp. until a few months before the post-mortem, these were not recovered at post-mortem.

TABLE NO. 12
Number of worms recovered at post-mortem of calf No. 7180

Date of Post-Mortem	*Cooperia pectinata*	*Cooperia punctata*	*Haemonchus placei*	*Oesophagostomum radiatum*	*Bunostomum phlebotomum*
2/8/56.....	504	*	†35	‡24	140

* There were only a few *C. punctata* worms present at post-mortem examination and the total number of *Cooperia* spp. worms present is included under *C. pectinata.*
† Including five immature *H. placei.*
‡ Including 12 immature *O. radiatum.*

(*c*) *Examination of Kraal Manure*

The results are summarised in Table No. III in the Appendix, along with results pertaining to subsequent experiments. It will be noted that infective larvae of all four genera were recovered and were more frequent in March. During this month rainfalls were heavy.

(*d*) *Prevailing Climatic Conditions*

Daily variations in the climatic conditions are shown in Figure No. 1. Monthly rainfalls for the period are included in Table No. 10.

From Figure No. 1 and Table No. 10, it will be noted that heavy rainfalls were recorded in December, February and March. During, or just after these rains larvar were recovered from kraal manure. The role which the dams' teats and the haie at the base of the teats plays in the transmission of verminosis to calves will be brought out in the discussion at the end of these experiments.

B.—FOUR GROUPS OF CALVES REARED BY DIFFERENT METHODS OF ANIMAL HUSBANDRY FROM MIDSUMMER TO WINTER

Materials and Methods

1. The same camp and kraal as described in the previous experiment were used in this experiment. However, three calf pens were built next to the kraal in the paddock as follows:—

(*a*) A small calf pen (10 ft. × 15 ft.) was built next to the kraal. It had a ground floor and a gate leading into the kraal. In the calf pen a special stanchion and trough was built in February, 1956. Once the calves' heads were secured in the stanchion, wetted chaffed lucerne was placed in the trough and there was no possibility of spillage on to the ground floor.

(*b*) and (*c*) Next to the calf pen (*a*) two additional calf pens were built, with concrete floors. The former (*b*) was 15 ft. × 20 ft. while the latter (*c*) was 10 ft. × 15 ft. in size. Both had gates communicating with the paddock and lucerne and water troughs were provided.

2. Introduction of susceptible stock was unfortunately delayed while awaiting the construction of the calf pens. Ten calves born between 8 November, 1955 and 22 December, 1955 were placed on concrete floors at the laboratory on 22 December, 1955.

Unfortunately seven of these calves had already become mildly infested and were treated with phenothiazine on 10 January, 1956 at the rate of 10 grams/100 lb. live weight, with subsequent negative faeces. Before the calf pen construction had been completed three more calves were born and placed with the other ten calves on concerte floors. The calf pen construction having been completed on 3 January, 1956, the calves were placed in various groups. Calves born after the third of January were introduced into their groups at birth and by 3 February, 1956, 19 calves were in the experiment. The calves were divided into groups as follows:—

Group A

Five calves (No. 7176, 7216, 7290, 7329 and 7379) were introduced into calf pen (*a*). These calves were *confined to the calf pen* from 7 a.m. until 2 p.m.; from 2 p.m. until 7 a.m. the following morning they had *access to the infested kraal* through the communicating gate and mixed with calf No. 7180 in Experiment A. Milk was fed to the calves twice daily in buckets and in February additional feed in the form of chaffed lucerne was fed in the special stanchion mentioned earlier.

Group B

Five calves (No. 7177, 7178, 7188, 7214 and 7331) were introduced into calf pen (*b*). *These calves were confined to the calf pen and never allowed out.* The concrete floor was washed and scrubbed daily with brooms and water. The calves suckled their dams early in the morning in the calf pen for about 15 to 20 minutes. Thereafter the dams were herded into the infested kraal from 7 a.m. until 2 p.m. and returned to the calf pens to allow the calves to suckle for a further 15 to 20 minutes. After the calves had suckled, the cows were herded into a separate camp to graze overnight, returning to the calf pen just before 7 a.m. the following morning. These calves were also fed chaffed lucerne in troughs.

Group C

Five calves (No. 7193, 7227, 7292, 7234 and 7400) were introduced into calf pen (*c*). This was the control group. *The calves were confined to the calf pen and never left it.* The concerte floor was scrubbed daily with brooms and water. Calves were fed milk in buckets twice daily as well as chaffed lucerne in troughs.

Group D

Four calves (No. 7207, 7262, 7353 and 7375) were introduced into the infested paddock in which the kraal and calf pens were situated. They grazed with the infested stock at night and suckled their dams at 7 a.m. and 2 p.m. for about 15–20 minutes in each case. *The calves remained in the infested paddock constantly*, apart from a short period of about 20 minutes once a week when they were herded into a crush adjacent to the kraal for faeces collection per rectum. The dams grazed elsewhere and were never allowed into the kraal.

3. The technique employed in the faeces examination of the calves and the kraal manure examination was identical to the one already described in the previous experiment.

4. Larval infestation of herbage was investigated from 29 February, 1956 onwards at regular intervals. Grass was collected from two plots, one adjacent to the kraal, the other 300 yards away. The plots were labelled 1 and 2 and the grass was collected and examined according to Taylor's (1939) technique except that, in the laboratory, Baermann funnels were used for larval collection and only 30 grams of grass placed in each funnel. Larval counts were carried out using the technique already described in previous experiments. The formula, as described by Taylor, was used to estimate the number of larvae per lb. of grass.

5. Prevailing climatic conditions were recorded daily.

6. At the conclusion of the experiment in July, 1956, ten calves were slaughtered for worm examination.

Experimental Observations

The experiments were conducted over the period 3 January, 1956 to 2 July, 1956. Due to circumstances beyond the author's control post-mortem examinations were delayed for three weeks after the faeces examinations had been concluded; however, all the calves used in post-mortems were confined to their groups until slaughtered.

(*a*) *Development of Infestation*

Group A consisted of five hand-reared calves confined to the infested kraal and adjacent calf pen. (For results see Fig. No. 4.)

Calves in this group developed infestation slowly and only after 20 weeks in this experiment did the majority of the group have egg counts exceeding 100 e.p.g. The highest individual egg count was 690 e.p.g., observed in calf No. 7176 after 22 weeks exposure to infestation.

Larval culture results revealed the presence of *Cooperia* spp., *H. placei*, *O. radiatum* and *Trichostrongylus* spp. before the average egg counts exceeded 100 e.p.g. It was significant that only when *B. phlebotomum* was well established did the egg counts for the majority of the group rise to a level in excess of 100 e.p.g.

Group B.—Five suckling calves confined to a concrete floored pen; the dams were kept in the infested kraal from 7 a.m. to 2 p.m. (For results see Fig. No. 4.)

Infestation developed slowly, but a sudden rise in the e.p.g. counts was noted 13 weeks after the experiment had commenced and four weeks later all the calves had egg counts in excess of 100 e.p.g. One calf had 1,960 e.p.g. at this stage (viz. No. 7214). A week after the egg counts had reached their peak, i.e. 18 weeks after the

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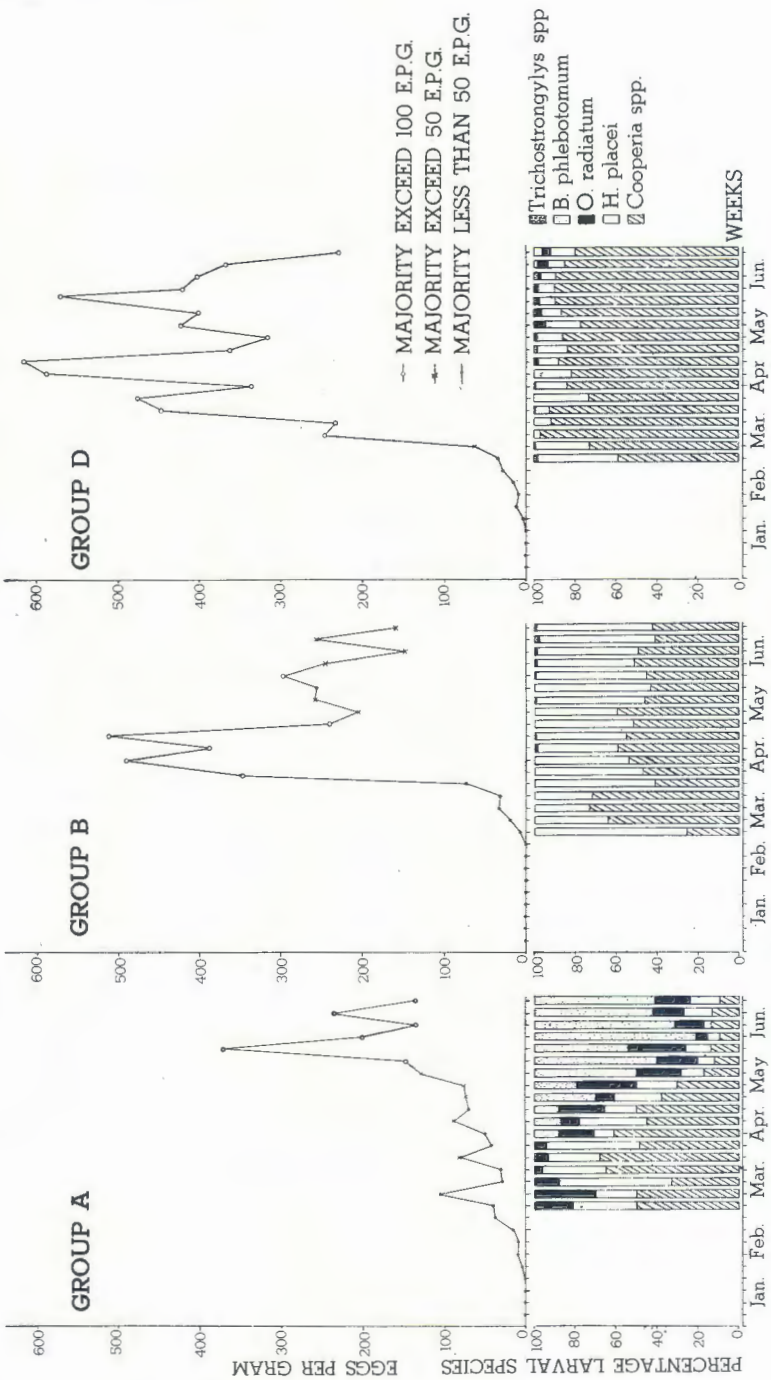

Fig. No. 4. WEEKLY MEAN EGG PER GRAM COUNTS AND LARVAL SPECIES VARIATIONS OF GROUPS A, B AND D.

experiments commenced, egg counts fell dramatically and remained at a low level, most of the calves having egg counts between 50 and 100 e.p.g. until the experiment was concluded.

Larval culture results revealed a predominant *Cooperia* spp. and *H. placei* infestation. When egg counts were high, more *H. placei* larvae were recovered from cultures but the reverse was the case when egg counts fell. Larval cultures revealed very little *O. radiatum* and even less *B. phlebotomum* infestation.

Group C.—Five hand-reared calves in a concrete floored pen.

Only one calf in this group developed infestation of any note (calf No. 7193), reaching a peak of 140 e.p.g. in May and falling to 20 e.p.g. at the end of the experiment. Another calf developed a very mild infestation and faeces examinations were negative for five weeks before the experiments ceased in July. The rest of the calves were negative throughout.

Larval cultures of calf No. 7193 revealed the presence of *H. placei*, *Cooperia* spp. and *O. radiatum*. The cultures in most cases were very poor indeed and seldom yielded enough larvae to differentiate the species on a percentage basis.

The chaffed lucerne fed to these calves was found to have become infested with the species found in calf No. 7193 and this was probably the source of infestation; chaffed lucerne fed to other groups was not infested.

Group D.—Four suckling calves confined to the infested paddock. (For results, see Fig. No. 4.)

Eleven weeks after the experiment commenced all the calves in this group had egg counts exceeding 100 e.p.g., rising to a mean of 650 e.p.g. six weeks later and remaining at a high level, only falling to 255 e.p.g. at the end of the experiment. *Cooperia* spp. larvae were dominant in cultures although the other species were also recovered.

(*b*) *Post Mortem-Results*

The results of the post mortems are summarised in Table No. 13, and confirmed the findings and observations of faecal examinations of the various groups.

TABLE No. 13

Number of worms recovered at post-mortem of calves in Experiment B

Group	Calf No.	Date of Post-Mortem	*Cooperia pectinata*	*Haemonchus placei*	*Oesophagostomum radiatum*	*Bunostomum phlebotomum*	*Trichuris globulosa*
A.....	7216	24/7/56	5	—	4	2	2
	7290	26/7/56	—	6	—	22	2
	7329	26/7/56	—	—	—	98	—
B.....	7177	31/7/56	29	1	—	1	—
	7178	31/7/56	9	10	—	—	—
	7188	31/7/56	8	9	—	—	—
C.....	7193	8/8/56	30	5	5	—	—
D.....	7262	3/8/56	742	—	5	25	—
	7353	7/8/56	900	1	10	19	—
	7375	8/8/56	425	—	8	58	—

(*c*) *Examination of Kraal Manure*

The results of these examinations are summarised in Table No. III in the Appendix; larvae of all four genera were recovered particularly in March.

(*d*) *Larvae per Pound of Herbage*

These results are summarised in Table No. IV in the Appendix. It will be noticed that larvae were recovered in large numbers in February, March and up to 24 April, particularly in Plot No. 1 next to the kraal. Larval recoveries in the winter months were very sporadic.

(*e*) *Prevailing Climatic Conditions*

These are shown in Fig. No. 1 and Table No. 10. Heavy rainfalls were recorded in February and March, less rain in January and little or no rain from April to May. Kraal manure and grass were more heavily infested with larvae in the months when rainfalls were good and calves showed evidence of increased egg counts in faeces examination a month or so after rains had started at the end of February.

C.—Five Groups of Calves reared by Different Methods of Animal Husbandry from Autumn to Midsummer

Materials and Methods

1. The same paddock, kraal and calf pens were used as in the previous experiment and examination of calf faeces, kraal manure and grass was carried out as mentioned previously. Climatic data were also recorded.

2. Introduction of the calves into the groups in this experiment was carried out in a different fashion than in Experiment B. Calves were not available from the large breeding herd on the station in the autumn because the breeding policy at Armoedsvlakte only made provision for summer calving. The author, however, had been given 50 cows for another experiment in April of the previous year. Two bulls were allowed to run alternately with the cows, each bull being with the herd for one month and resting for the following month until January, 1956. This led to irregular calving of the cows over a period of nearly seven months (i.e. from February to September, 1956). At birth the calves were introduced into the various groups and ran with the calves in the previous experiments, and by the time the previous experiments (A & B) were brought to a conclusion 75 per cent of the calves used in this experiment were already born and placed in their respective groups.

3. Twenty-six calves, divided into five groups, were used in this experiment; there were five calves in each group, apart from group No. 3 in which there were six calves. The division into groups No. 1 to 4 and the treatments were the same as in the previous experiments. Groups No. 1, 2 and 3 were the same as groups A, B and D in Experiment B, while group No. 4 was a duplication of Experiment A.

Group No. 5 was a new group. Five calves were *confined to the infested kraal* along with the calves in Group No. 4 *from 7 a.m. to 2 p.m. and were allowed to suckle their dams there. From 2 p.m. to 7 a.m. they grazed with the infested stock* and calves in Group No. 3 *in the infested paddock*. Their dams grazed elsewhere. The full details of the division into groups is shown in Table No. V in the Appendix.

Note.—Due to the shortage of calves, the approach of winter conditions and the fact that only two calves became mildly infested in Experiment B, in the control group [Group (C)], it was felt that no useful object would be served in continuing with a similar group in this experiment.

4. Four calves (No. 7176, 7207, 7214 and 7379) that became infested in Experiment B were not slaughtered for post-mortem examination in July, when the other calves in that experiment were autopsied. They were kept to act as infested stock along with the other infested stock mentioned under materials and methods (No. 1 and 2) in Experiment A. They ran with the older infested stock in the paddock and kraal and remained there until May of the following year (1957).

Experimental Observations

The experimental period was from February, 1956, to January, 1957. The first calf (viz. No. 8227) was born on 29 February, 1956 and the last post-mortem carried out on 30 January, 1957. Negative calves were, however, discharged on 15 January, 1957. In addition, post-mortems were also carried out in October and November,

(*a*) *Development of Infestation*

Group No. 1.—Five hand-reared calves confined to the infested kraal and adjacent calf pen. (For results see Fig. No. 5.)

Of the five calves in this group, one (No. 8237), born in March, became positive on faeces examination in the winter, egg counts reaching a peak in October and November. This calf was slaughtered in November for a post-mortem examination. The balance of the group was born from July to September and only three of the calves became mildly infested in the summer, the maximum egg counts for any one calf being 22 e.p.g., in Calf No. 8246. One calf was negative throughout (No. 8244).

Larval cultures of the calf showing infestation in winter were predominantly *B. phlebotomum*, while *O. radiatum* was the most common larval species recovered from cultures of the calves that became infested in summer.

Group No. 2.—Five suckling calves confined to a concrete-floored pen; the dams were kept in the infested kraal from 7 a.m. to 2 p.m. (For results, see Fig. No. 5).

Only two calves born in March in this group became infested, the other three being negative throughout, i.e., calves born from May until September. The two infested calves had very low egg counts, reaching their peak in October when one calf became negative, the other maintaining its infestation until slaughtered in November.

Larval cultures showed a predominant *B. phlebotomum* infestation.

Group No. 3.—Six suckling calves confined to the infested paddock. (For results, see Fig. No. 6.)

Two of the six calves in this group, born before the end of March, became infested at six to seven weeks of age, their egg counts rising until June and then falling, to show another rise in October and November. These two calves were slaughtered at the peak of their egg production (viz. No. 8227 & 8229). The other two calves, born in September, showed a very low egg count in December and January.

Larval cultures from the calves infested in autumn showed the presence of *Cooperia* spp. at first, followed by *H. placei*. By August *H. placei* and *B. phlebotomum* were predominant. *O. radiatum* was diagnosed in September. Larval cultures of the two calves that became infested in the summer indicated the presence of *H. placei* and *Cooperia* spp.

Group No. 4.—Five suckling calves confined to the infested kraal and adjacent calf pen. (For results see Fig. No. 6.)

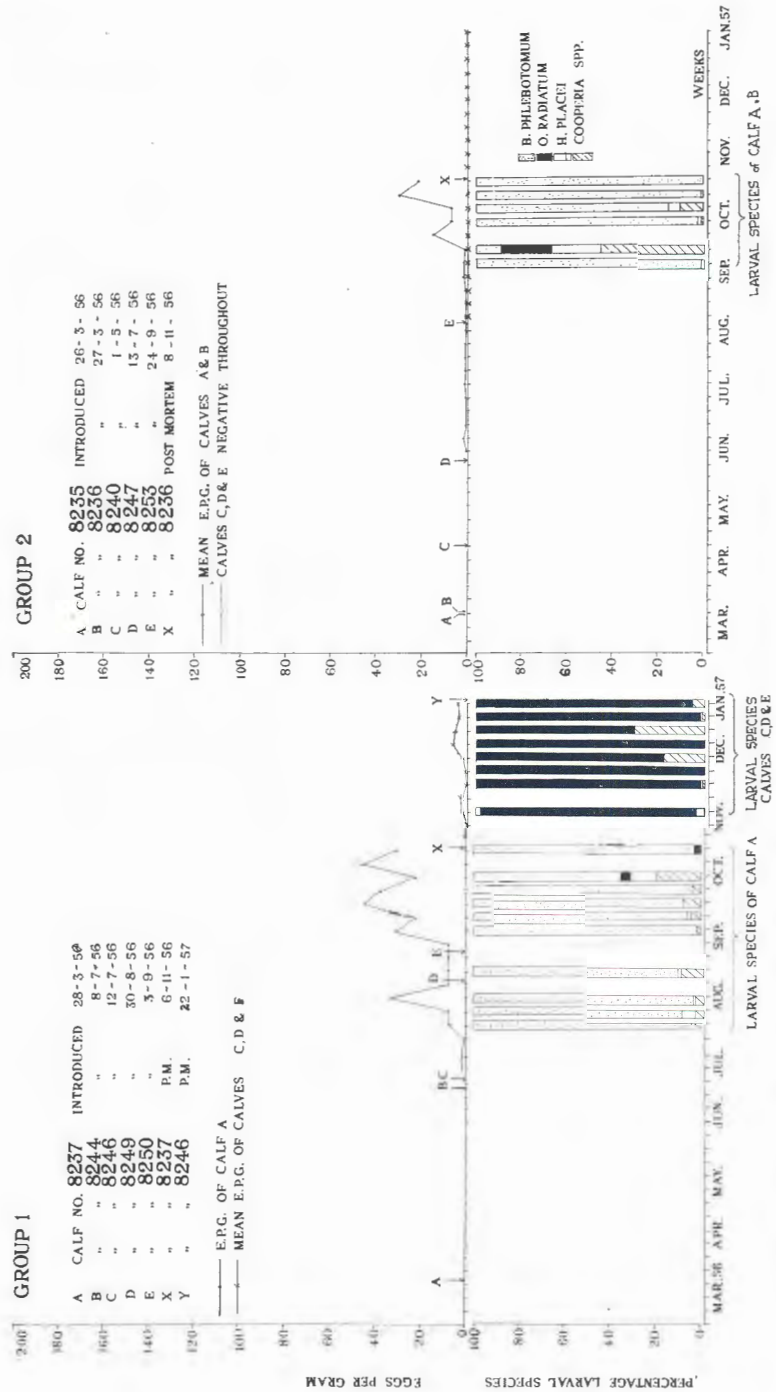

FIG. NO.5. WEEKLY MEAN EGG PER GRAM COUNTS & LARVAL SPECIES VARIATIONS OF GROUPS 1 & 2

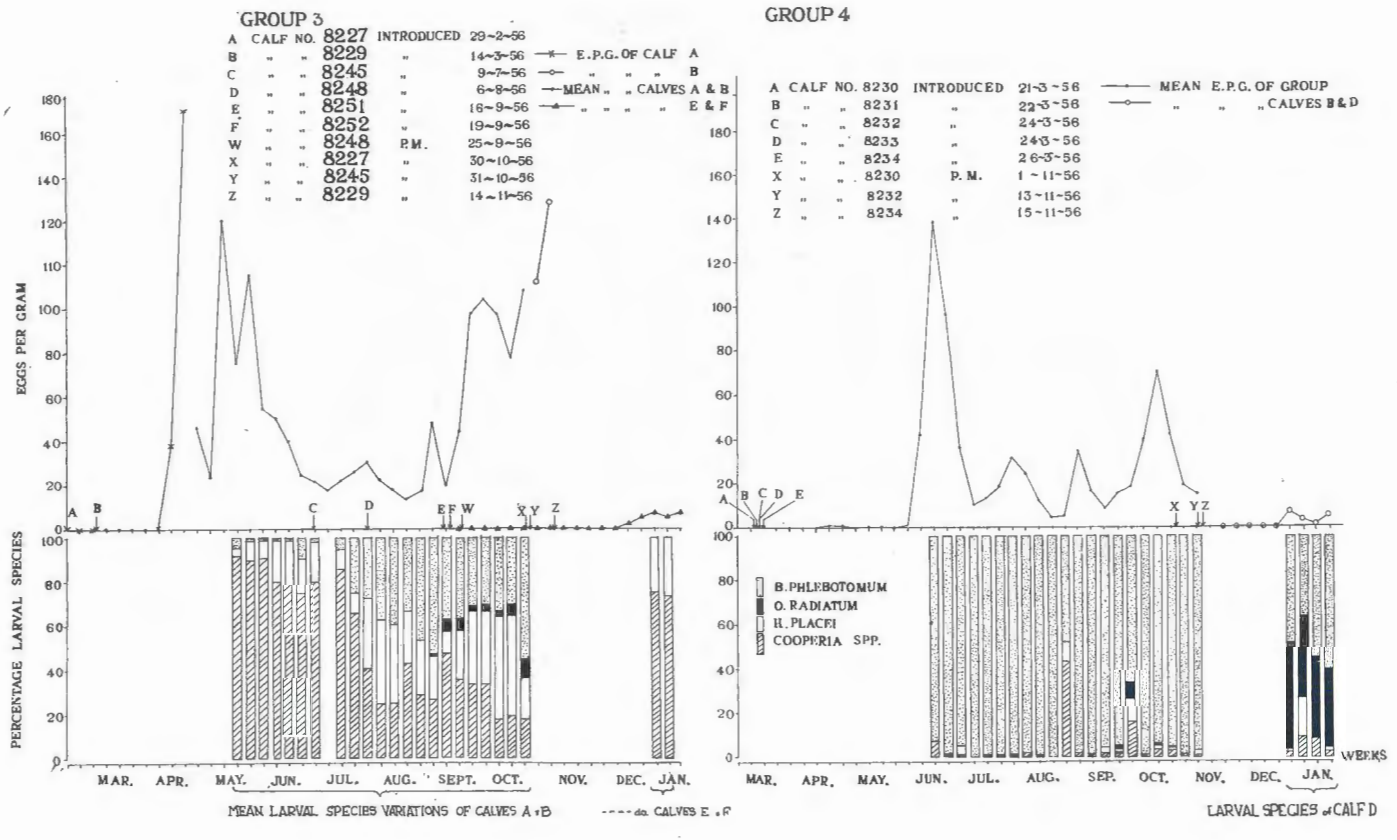

FIG. NO. 6 WEEKLY MEAN EGG PER GRAM COUNTS & LARVAL SPECIES VARIATIONS OF GROUPS 3 & 4

All five calves in this group were born in March and all of them became infested, the egg counts showing a sharp rise in July followed by another peak in October. However, two of the calves became negative in October and November (No. 8231 & 8233); in one calf (No. 8231) this was maintained until the experiment was concluded, while the other calf (No. 8233) again became positive in December and January although the egg counts remained at a low level.

Larval cultures consisted almost entirely of *B. phlebotomum* in the winter but *O. radiatum* and other species of larvae were also recovered from the faeces of No. 8233 in the summer.

Group No. 5.—Five calves that suckled in and were confined to the infested kraal from 7 a.m. to 2 p.m. and grazed in the infested paddock from 2 p.m. to 7 a.m. The dams grazed elsewhere. (For results see Fig. No. 7.)

The calves in this group were born from 14 April, 1956 to 6 June, 1956. They were negative throughout the winter but all of them became infested within a short period of each other from 18 December onwards. Egg counts showed a steady rise until the experiments were concluded in January.

Larval cultures revealed the presence of *Cooperia* spp. initially which were soon followed by *H. placei; O. radiatum* only made its appearance in January.

(*b*) *Post-Mortem Results* (cf. Table No. 14).

From the results summarised in Table No. 14 the most striking observations are those made on calves No. 8227 and 8229 (Group No. 3). Although all four species were recovered from these calves at post-mortems the presence of immature *H. placei* worms was particularly interesting. The finding of these immature worms led to the slaughtering of calf No. 8245 which had been negative on faecal examination. This calf, in spite of diligent search, including microscopical examination of mucosal scrapings of the abomasum, was negative for parasites (Table No. 14). Another calf (No. 8248) in this group had died of torsio colon in September and was also negative at post-mortem. Both these calves were born in July and August, respectively (Table No. V in the Appendix). The calves that showed both mature and immature *H. placei* worms at post-mortem were born in February and March (Table No. V in the Appendix). The remaining two calves (No. 8251 and 8252) in this group, born in September, were negative for *H. placei* until 31 December.

Since only the calves that were born before the end of March showed immature worms at post-mortem in October and November, whereas the other calves, under identical conditions but born later, showed no worm infestation either by faecal examination or at the post-mortem, it would appear that the immature worms had been acquired prior to winter and had remained immature until the post-mortems were carried out. Furthermore, five calves in Group No. 5, born from April to June, were negative for *H. placei* until the end of December. These calves grazed in the same paddock as those in Group No. 3. Their freedom from infestation substantiated the supposition that the paddock was free of infestation from April to November.

(*c*) *Examination of Kraal Manure.*

These results are summarised in Table No. III in the Appendix. Larvae were consistently recovered from kraal manure in March and up to 19 April. Thereafter results were inconsistent; from the end of November to the early part of January, larvae were recovered every week.

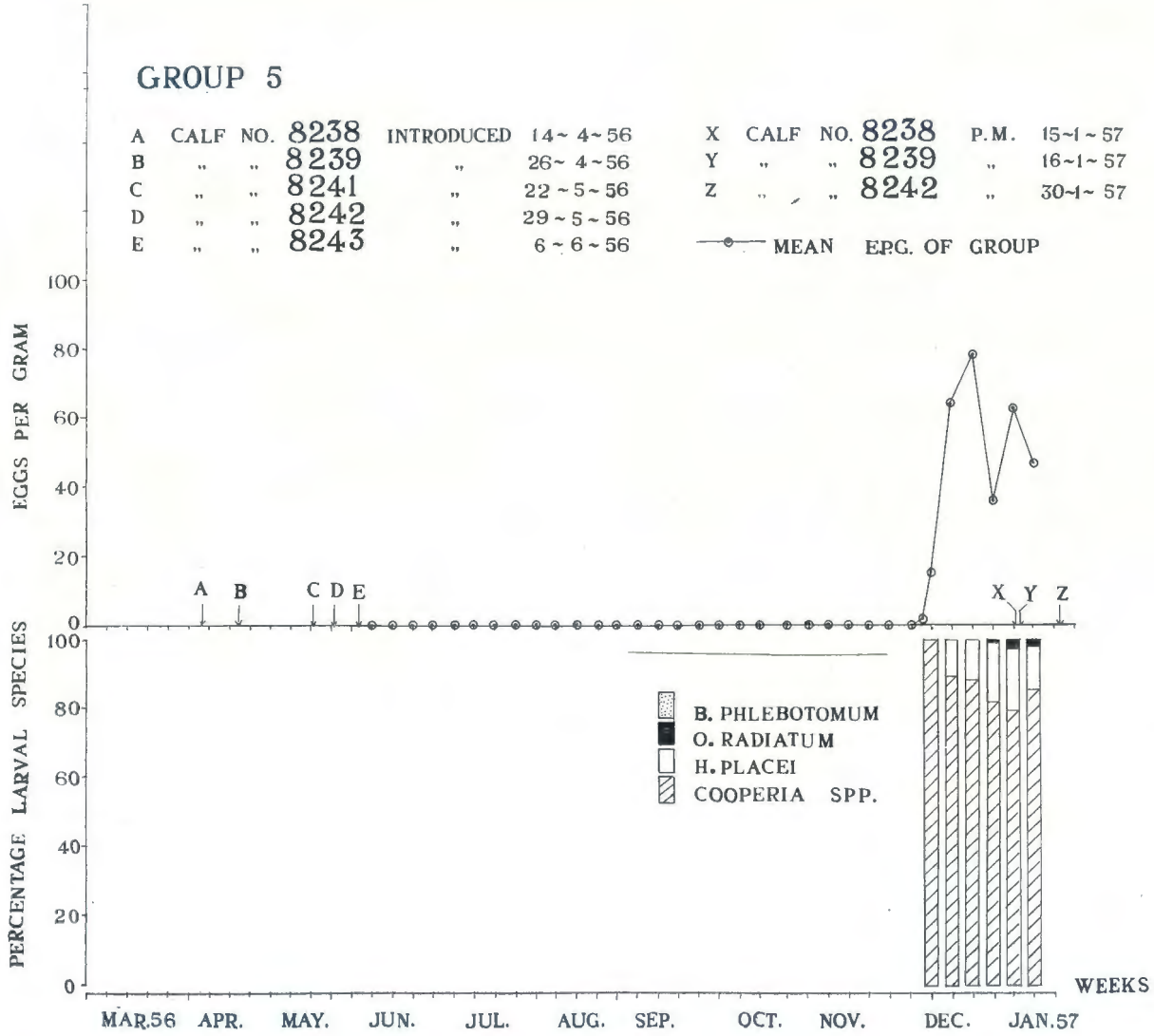

FIG. NO. 7. WEEKLY MEAN EGG PER GRAM COUNTS & LARVAL SPECIES VARIATIONS OF GROUP 5

TABLE NO. 14

Number of worms recovered at post-mortem of calves in Experiment C.

Group	Calf No.	Date of Post Mortem	*Cooperia pectinata*	*Haemonchus placei*	*Oesophagostomum radiatum*	*Bunostomum phlebotomum*	*Trichuris globulosa*
1.....	8237	6/11/56	—	—	—	28	1
	8246	22/ 1/57	3	—	35	1	—
2.....	8236	8/11/56	—	—	—	34	—
3.....	8248	25/ 9/56	—	—	—	—	—
	8227	30/10/56	2	*341	11	32	—
	8245	31/10/56	—	—	—	—	—
	8229	14/11/56	97	†667	9	60	—
4.....	8230	1/11/56	—	—	—	27	—
	8232	13/11/56	—	—	—	74	—
	8234	15/11/56	—	1	—	32	—
5.....	8238	15/ 1/57	27	171	—	—	—
	8239	16/ 1/57	228	6	25	2	—
	8242	30/ 1/57	280	24	3	9	—

* Including 50 immature *H. placei.*
† Including 36 immature *H. placei.*

(d) Larvae per Pound of Herbage

These results can be seen in Table No. IV in the Appendix. The periods when infective larvae were more plentiful were similar to those mentioned under kraal manure investigations, but the summer period was shorter; consistent results were only obtained for three weeks after 20 November, and, rarely thereafter until the end of January.

(e) Prevailing Climatic Conditions

The daily variations in the climatic conditions will be noted in Fig. No. 1 and 2 and the monthly rainfalls for the period of this experiment are included in Table No. 10.

It will be noted that the only months the rainfall exceeded 50 mm. in the experimental period were March and December, 1956, and January, 1957.

D.—SEVEN GROUPS OF CALVES REARED BY DIFFERENT METHODS OF ANIMAL HUSBANDRY FROM SUMMER TO EARLY WINTER

Materials and Methods

1. The same paddock, kraal and calf pens were used as in previous experiments; grass was similarly examined and climatic data recorded daily.

2. Thirty-five calves were used. Those born from 31 October, 1956 to 13 November, 1956 were confined to concrete-floored pens at birth and placed in their various groups on 13 November, 1956. Calves born after 13 November, 1956 were

immediately placed in their various groups. By 13 December, 1956 all the groups were complete. Information concerning the date calves were born and placed in groups, etc., is given in Table No. VI in the Appendix. Each group contained five calves.

(*a*) Groups No. 1 to 5 were the same as Groups No. 1 to 5 in Experiment C. Calves of similar groups in both experiments ran together until the end of January when Experiment C was concluded.

(*b*) Group No. 6, the control group, was a duplication of Group C in Experiment B.

(*c*) Group No. 7: The calves in this group were *confined to a calf pen with a concrete floor* near the stables, away from the infested paddock. *The dams' udders were washed before the calves were allowed to suckle at 7 a.m. and 2 p.m.* This was regarded as an additional control group.

3. Faeces collections were carried out as previously described, but the laboratory techniques were modified in that a 40 per cent sucrose solution was used for both centrifugation and egg counting instead of $ZnSO_4$ and NaCl solutions. Eggs were easier to see microscopically and higher egg counts were obtained when a sucrose solution was compared with a NaCl solution on the same faeces. However, more air bubbles were trapped in the emulsion after shaking when sucrose was used, but with the addition of a little amyl alcohol this was overcome. Before counting it was essential that slides be left for at least three minutes to allow the eggs to rise to the top. Larval examinations were carried out as described previously.

4. The examination of kraal manure was carried out as before until February. Thereafter the technique was modified as follows:—

(*a*) Manure was collected as described previously.

(*b*) Specimens were brought to the laboratory, hard lumps broken into small pieces, and each specimen thoroughly mixed; two samples, weighing 50 grams each, from each specimen were placed in separate Baermann funnels.

(*c*) Twenty grams of the residue of each specimen were thoroughly mixed; 50 grams of this mixture were well mixed with 1,000 active infective larvae and placed in a Baermann funnel to act as a control.

(*d*) The larvae were collected and examined by the microscopical technique described in previous experiments.

(*e*) The number of larvae per Kg. of manure was estimated, using the same formula advocated by Taylor (1939) for the estimation of larvae per lb. of herbage.

5. Larvae adhering to the teats of cows and to hairs at the base of teats were recovered in the following fashion:—

The teats and hair at the base of the teats of six cows in the infested kraal were wiped off with a sterile cloth into a recently boiled container. Thereafter another sterile cloth was used to wash the teats into another sterile container. Both dry material and teat washings were placed in separate Baermann funnels and the larvae were collected and examined in the manner described previously.

Experimental Observations

The experimental period lasted from 13 November, 1956 to 20 May, 1957.

(*a*) *Development of Infestation*

Group No. 1.—Five hand-reared calves confined to the infested kraal and adjacent calf pen. (For results see Fig. No. 8.)

Infestation developed extremely slowly in this group and only after 11 weeks in the experiment were all the calves infested. One calf died of hoven on 27 February, 1957 and only a single hookworm was recovered from it. Egg counts reached their peak in March and by the end of April two of the calves were negative.

Larval cultures indicated the presence of four genera of Nematodes.

Group No. 2.—Five suckling calves confined to a concrete-floored pen; the dams were kept in the infested kraal from 7 a.m. to 2 p.m.

The calves in this group remained negative throughout and were discharged in May.

Group No. 3.—Five suckling calves confined to the infested paddock. (For results see Fig. No. 8.)

Worm eggs were noticed in the faeces of two calves six weeks after the experiment had commenced; four weeks later all the calves were infested; egg counts reached their peak at 14 weeks, remaining high until the experiment was concluded.

Cooperia spp. and *H. placei* larvae were the first species recovered from cultures and only towards the end of the experimental period were larvae of *O. radiatum* and *B. phlebotomum* recovered.

Group No. 4.—Five suckling calves confined to the infested kraal. (For results see Fig. No. 8.)

Infestation developed very slowly in this group, only two calves being infested after the first six weeks; nine weeks later all the calves were infested. Egg counts never reached a high level although a slight rise was recorded a few weeks before the termination of the experiment.

Larval cultures at first only contained *Cooperia* spp.; these were followed by *H. placei;* a few weeks later *B. phlebotomum* and finally *O. radiatum* larvae were also present.

Group No. 5.—Five calves that suckled in and were confined to the infested kraal from 7 a.m. to 2 p.m., and grazed in the infested paddock from 2 p.m. to 7 a.m. The dams grazed elsewhere. (For results see Fig. No. 9.)

The infestation of calves in this group was first noted in two calves after five weeks; within another month all the calves were infested. Egg counts reached their peak after 14 weeks and fell slowly until the experiments were concluded in May.

Cooperia spp. larvae were the first species recovered in cultures made on 18 December, 1956 from two calves; cultures made ten days later showed *H. placei* larvae. *O. radiatum* and *B. phlebotomum* larvae were recovered from cultures on 7 January, 1957 and 28 January, 1957, respectively.

N.B.—The mean e.p.g. counts of this group were more than double those of any other infested group

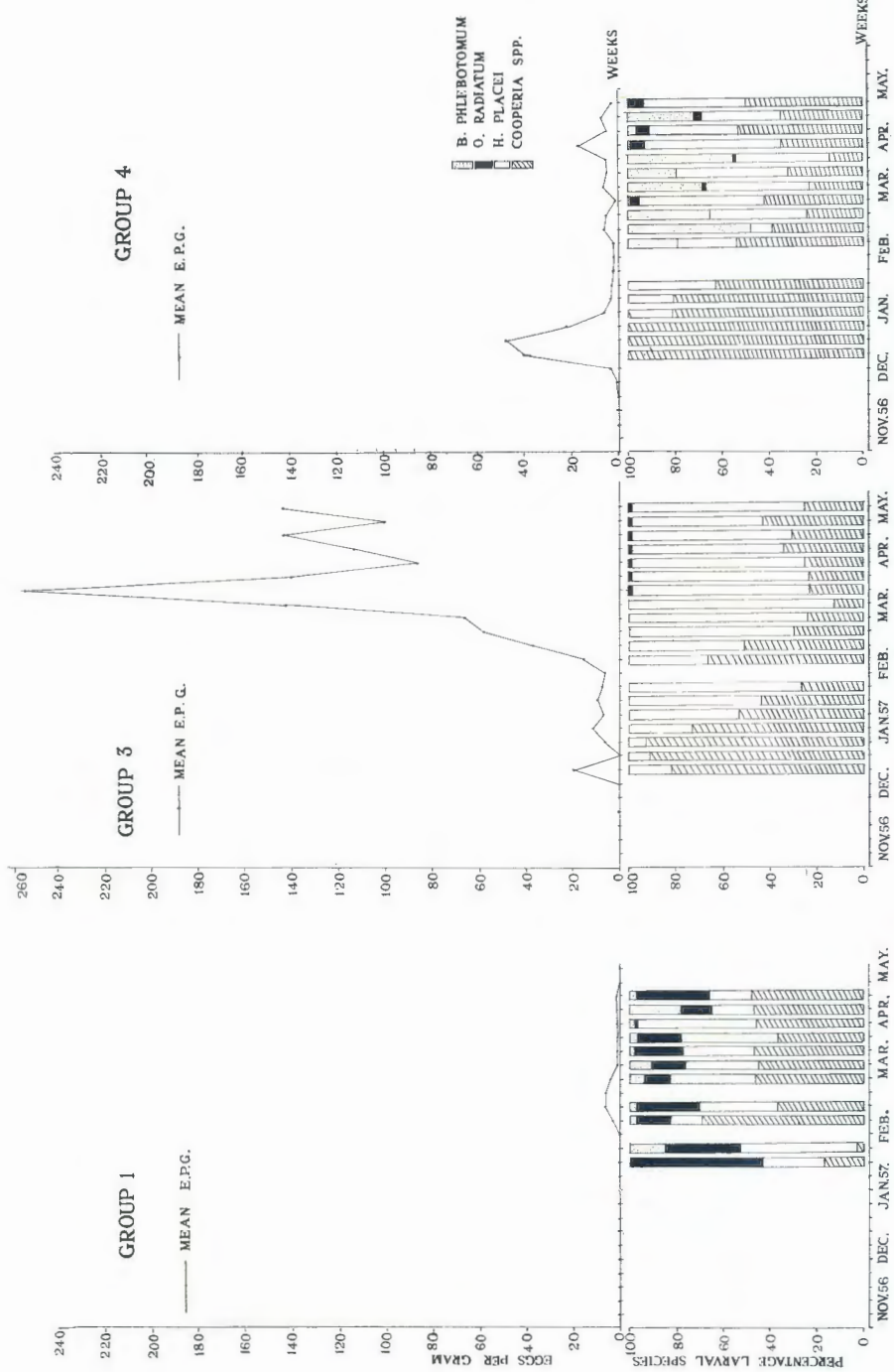

FIG. NO. 8. WEEKLY MEAN EGG PER GRAM COUNTS & LARVAL SPECIES VARIATIONS OF GROUPS 1 3 & 4

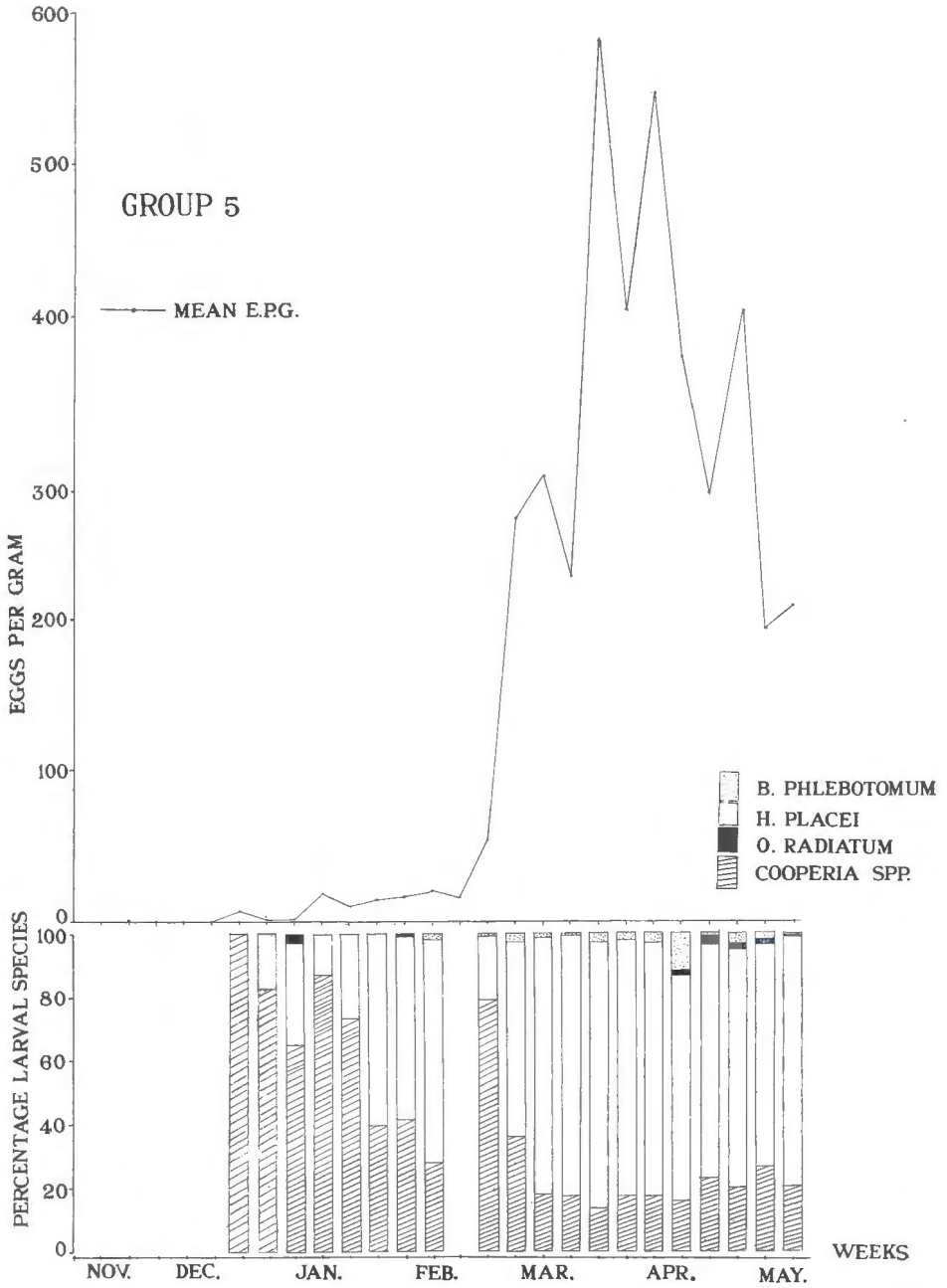

FIG. NO. 9. WEEKLY MEAN EGG PER GRAM COUNTS & LARVAL SPECIES VARIATIONS OF GROUP 5.

Groups No. 6 and 7.—There were five calves in each group, confined to concrete floors. Calves in the former groups were hand-reared; the latter suckled on previously washed udders.

Calves in these groups were negative throughout and were discharged in May at the conclusion of the experiment.

TABLE NO. 15

Number of worms recovered at post-mortem of calves in Experiment D

Group	Calf No.	Date of Post-mortem	*Cooperia pectinata*	*Haemonchus placei*	*Oesophagostomum radiatum*	*Bunostomum phlebotomum*	*Trichuris globulosa*	*Moniezia benedini*
1.....	14	27/ 2/57	—	—	—	1	—	—
	15	1/ 5/57	—	—	1	4	1	—
3.....	51	2/ 5/57	173	162	7	1	—	—
	52	8/ 5/57	13	29	—	—	—	—
	36	14/ 5/57	69	187	1	1	—	1
	59	15/ 5/57	308	164	3	2	—	—
	25	16/ 5/57	133	173	5	3	—	1
4.....	50	1/ 5/57	3	1	—	19	1	—
	24	7/ 5/57	10	7	—	1	—	—
	26	8/ 5/57	7	8	5	4	—	—
5.....	27	30/ 4/57	950	535	7	3	—	1
	6	6/ 5/57	95	478	2	12	—	—
	60	9/ 5/57	144	188	22	2	—	—
	87	13/ 5/57	103	169	3	18	—	—
	17	20/ 5/57	68	97	—	11	—	—

(*b*) *Post-Mortem Results*

These results are summarised in Table No. 15.

Apart from Calf No. 14 that unfortunately died of hoven in February, all the calves whose faeces were positive at the end of the experiment were slaughtered It is not necessary to elaborate on these results as the table clearly indicates the severity of infestation in the various groups, viz. Groups No. 5, 3, 4 and 1, respectively, in order of severity.

(*c*) *Examination of Kraal Manure*

The results of these investigations, using the old technique until the end of January, are summarised in Table No. III in the Appendix. Larvae were recovered regularly every week from specimens collected from the end of November to the middle of January.

From February the modified technique as described earlier was used and the results are summarised in Table No. IIIA in the Appendix. Weekly examinations were carried out during the period 5 February, 1957 to 30 April, 1957, the mean number of larvae per Kg. of kraal manure varying from 0 to 986.

(d) Larvae per Pound of Herbage

These results are summarised in Table No. IV in the Appendix.

Infective larvae were only recovered from herbage irregularly in November and December, and from February to April.

(e) Recovery of Infective Larvae from the Teats of Cows

TABLE NO. 16

Infective larvae recovered from the teats of cows that had been confined to the infested kraal from 7 a.m. to 2 p.m.

Date Specimens collected	No. of Larvae recovered from dry Material on the Teats	No. of Larvae recovered from Teat Washing	*Cooperia* spp.	*H. placei*	*O. radiatum*	*B. phlebotomum*
22/11/56....	0	0	—	—	—	—
30/11/56....	2	0	—	1	1	—
5/12/56....	7	2	1	1	—	7
12/12/56....	0	0	—	—	—	—

Some of the results of this examination are shown in Table No. 16. Seven further examinations at weekly intervals after 12 December, 1956 were negative and are not shown. However, all four species of infective larvae were recovered from the teats, as shown in the table. This point, viz. that larvae can adhere to teats, being proved, it was not necessary to continue this examination.

(f) Prevailing Climatic Conditions

Daily variations in climatic conditions are shown in Fig. No. 2 and monthly rainfalls are included in Table No. 10. The total rainfall from 30 October, 1956 to 20 May, 1957, the complete period over which this experiment was conducted, was 290·2 mm. (11·43 inches).

(g) The Effect of Rainfall on the Transmission of Verminosis

An excellent opportunity existed, when this experiment began, to study the effects of rainfall on the transmission of verminosis, for the following reasons:—

(i) Prior to the commencement of this experiment on 13 November, 1956, conditions were very dry and only 13·4 mm. and 18·3 mm. of rain had been recorded for the months of September and October, respectively (Table No. 10).

(ii) The presence of calves born in the winter and early spring which were still worm-free when this experiment commenced and remained worm-free on faecal examination until 18 December (Experiment C).

(iii) The introduction of 26 newly-born calves between 13 November, 1956 and 21 November, 1956 in a dry period, before the summer rains began on 22 November.

(iv) The fact that some of the worm-free calves of the previous experiment (C) and a few newborn calves of this experiment (D) became positive, on faecal examination, on the same day, and with the same succession of species thereafter.

The above-mentioned reasons showed that conditions must have been favourable to set up infestation.

The minimum period necessary for the infective larvae of the different species to reach maturity in the host, i.e. the prepatent period, was known (Table No. 17); consequently the probable date of infestation could be determined. The rainfall recorded after the calf's birth and before the day the calf became infested, would then give the amount of rainfall necessary to render infective larvae available to the host in numbers large enough to cause infestation (Table No. 18).

Discussion

(1) *Animal Husbandry Methods*

The transmission experiments were conducted in a manner as closely allied as possible to the methods of animal husbandry practised in the district. The various groups were attempts at separating the various facets thought to be possible sources of infestation to calves. The experiments showed that the sources of infestation were:—

(*a*) Herbage.

(*b*) Kraal manure adhering to teats.

(*c*) Kraal manure by direct contact.

(*a*) *Herbage.*—The paddock was the most constant source of infestation, both during wet and comparatively dry years (Group D, Expt. B, and Group No. 3, Expt. C and D). At post-mortem examination *C. pectinata* and *H. placei* were the most common species recovered, and to a lesser extent *B. phlebotomum* and *O. radiatum.*

TABLE NO. 17

The minimum period for infective larvae to reach maturity in calves

Species	No. of Days that Infective Larvae require to develop to Adults in Calves — Prepatent Period	Authority
**Cooperia punctata*	11	Bailey (1949).
Cooperia pectinata	16	†Own observations.
Haemonchus placei	19	Roberts (1957).
Haemonchus placei	26–28 (average)	Roberts (1957).
Haemonchus placei	14	Mayhew (1941).
Haemonchus placei	23–26 (average)	Mayhew (1941).
Oesophagostomum radiatum	35	Mayhew (1948).
Bunostomum phlebotomum	52	Mayhew (1948).
Bunostomum phlebotomum	56	Sprent (1946a).

* At post-mortems of calves in experiments (C) and (D) no *C. punctata* worms were recovered.

† Minimum period between dosing pure cultures of *C. pectinata* larvae to calves at Armoedsvlakte and appearance of worm eggs of this species in faeces. The calves were worm-free prior to dosing and kept under worm-free conditions until faeces were positive.

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TABLE NO. 18

The minimum rainfall necessary at Armoedsvlakte for infective larvae to be present, in numbers large enough to infest calves

Species	Total Rainfall from Date of Calf's Birth to Probable Date on which the Calf became infested		Date on which Infestation Probably Occurred	Minimum Pre-patent Period in Days	Date on which Eggs were first detected in Faeces of Calves
	mm.	Inches			
C. pectinata	13·3	0·52	2/12/56	16	18/12/56
**H. placei*	13·3	0·52	2/12/56	26	28/12/56
**H. placei*	42·3	1·59	9/12/56	19	28/12/56
**H. placei*	72·8	2·87	14/12/56	14	28/12/56
O. radiatum	13·3	0·52	3/12/56	35	7/ 1/57
†*B. phlebotomum*	42·3	1·59	7/12/56	52	28/ 1/57

* Three alternatives given for *H. placei*, see discussion.

† NOTE.—Sprent's (1946a) observations shown in Table No. 17 not included in this table - see discussion.

(*b*) *Kraal manure adhering to teats.*—*Cooperia* spp., *H. placei*, *O. radiatum* and *B. phlebotomum* larvae were recovered from both dry material on and washings of the teats of cows that had been lying in the infested kraal (Table No. 16). Larvae adhering to the teats transferred infestation from the infested kraal to suckling calves in a nearby concrete-floored pen during a particularly wet autumn (Group B, Expt. B.; Group No. 2, Expt. C), but not during a dry summer and autumn (Group No. 2, Expt. D). Although all species of larvae were recovered from cultures (Fig. No. 4) only *C. pectinata*, *H. placei* and *B. phlebotomum* were recovered at post-mortem (Group B, Table No. 13), and in a later experiment (C) only *B. phlebotomum* (Group No. 2, Table No. 14).

(*c*) *Kraal manure by direct contact.*—Hand-reared calves with access to the calf-pen and infested kraal were predominantly infested with *B. phlebotomum* (Group A, Table No. 13; Group No. 1, Tables No. 14 and 15) and only mildly infested with *C. pectinata*, *O. radiatum* and *H. placei* (Group A, Table No. 13).

Suckling calves in the infested kraal not only walked in infested manure all day, but were forced to suckle on their dams' teats after the cows had been lying in the infested kraal during the morning, i.e. the combined effects of (2) and (3) above. At post-mortem examinations, they had heavier worm burdens (Group No. 4, Tables No. 14 and 15) when compared with hand-reared calves in the infested calf pen and kraal (Group No. 1, Tables No. 14 and 15). Under the influence of particularly good rains in summer and autumn, one suckling calf (viz. No. 7180), confined to the infested kraal, acquired a heavy mixed worm burden (Expt. A, Figure No. 3 and Table No. 12).

Roberts *et al.* (1952) mentioned that infestation could occur at a very early age through the contamination of the teats of cows or through the calves' habit of sucking various objects, but that infestation in this manner does not appear to be of any significance. This view was not confirmed, but it must be mentioned that the average kraal in the North Western Cape and the kraal created in these experiments

had a layer of at least six inches of manure as a floor. In the rainy season particularly, wet and semi-dry manure adhered very easily to the udder and the ventral surface of the abdomen. In addition, calves had the habit of licking themselves and each other, particularly about the navel. These unhygienic conditions probably did not apply to the farms which Roberts and his co-workers investigated and possibly this was not an important source of infestation there.

When all the sources of infestation were combined and calves grazed in the infested paddock and suckled in the infested kraal, it was not surprising that at post-mortem experiment (D) indicated mean egg counts (Fig. No. 9) and worm burdens of all species (Group No. 5, Table No. 15), more than double those of any other group. This practice was the most popular method of rearing calves in the district.

The provision of clean concrete floors in calf pens made a big difference to the incidence of verminosis in hand-reared calves. Only two calves out of five became mildly infested in one experiment (Group C, Expt. B) and none in other experiments (Group No. 6, Expt. D). Although suckling calves on a clean concrete floor became infested in two experiments (Group B, Expt. B; Group No. 2, Expt. C), this was due to their dams lying in kraal manure during a particularly wet autumn and transporting the infestation to them via the teats. In a dry summer and autumn the same group did not become infested (Group No. 2, Expt. D.), nor did calves suckling on previously washed udders become infested when kept on clean concrete floors. Calf pen hygiene was responsible for their freedom from parasitism.

(2) *Seasonal Incidence*

These experiments indicated that parasitism in calves was seasonal. During the summer and autumn, depending on the rain and husbandry methods, stock became infested to a greater or lesser degree. During the dry months, i.e. from April to November, with one exception (Calf No. 8246, Group No. 1, Expt. C.), stock did not become infested. Calves born between April and November (Expt. C and D) only became infested in December.

Since rainfall played an important role in rendering infective larvae available in numbers large enough to infest the host, it was important to know the minimum amount of rainfall necessary to create these conditions.

In Table No. 18 three minimum prepatent periods are given for *H. placei* larvae to reach maturity in the host and, using this information, a rainfall range of 13·3 to 72·8 mm. over periods of ten to 22 days was shown to be the amount of rainfall necessary. However, these larvae were recovered from kraal manure (Table No. III, Appendix) and grass before this amount of rain had fallen at the end of November. Roberts (1957), although giving a minimum prepatent period of 19 days, reports an *average* period of 26 to 28 days for *H. placei* larvae to reach maturity in the host. Similarly Mayhew's (1941) results showed that in eight out of 13 cases tested, prepatent periods varied from 23 to 26 days. Both these workers showed an average of 26 days as the prepatent period. Since, in the author's observations, larvae of *H. placei* were diagnosed in faeces collected on 28 December, 1956 for the first time, it is reasonable to assume that infestation took place 26 days prior to this, i.e. on the same day *Cooperia pectinata* larvae infested calves. If that were the case, only 13·3 mm. of rain distributed over *ten days was necessary to render enough larvae available to infest the host.

* The first rain was recorded on 22 November, 1956, giving a ten day period until 2 December, 1956.

In Table No. 17 two minimum prepatent periods of 52 and 56 days are shown for *B. phlebotomum*, according to Mayhew's (1948) and Sprent's (1946a) observations, respectively. In Table No. 18, however, only the period given by Mayhew (1948) was used, and it was shown that 42·3 mm. of rain was necessary to render enough infective larvae available to infest calves. This was done in view of the fact that observations reported elsewhere, as well as observations by other workers (Schwartz, 1924: Sprent, 1946b), showed that the larvae of this species were very sensitive to drying and desiccation, and were therefore unlikely to be available in large enough numbers to infest the host when only 13·3 mm. of rain had fallen, which would be the case if the prepatent period of 56 days was correct.

Nocturnal dews in April and May, 1956 were extremely heavy and no rain fell in April and only 9·4 mm. in May. Five calves born in this period failed to become infested (Calf No. 8240, Group No. 2, and Calves No. 8238, 8239, 8241 and 8242, Group No. 5, Expt. C). Experiments reported elsewhere showed no larval migration from dung under the influence of dew so that the observation that calves failed to become infested was understandable. Riek *et al.* (1953) and Roberts (1957), however, stated that heavy dew would assist in the migration of larvae from dung pads. Previous observations (*vide supra*) and failure of calves to become infested in April did not confirm their observations.

(3) *Fluctuations in Worm Egg Counts*

Worm egg counts in faecal samples rose to a peak from March to May in calves born from November to January (Fig. No. 4 and Fig. No. 8 and 9). Sudden rises in egg counts in summer and autumn were noted in certain groups of calves three to five weeks after well-distributed, heavy rains fell (Groups B and D, Fig. No. 4). A spectacular rise from a negative examination the previous week to 1,460 e.p.g. was noted in one calf (No. 7180) on 7 January, 1956, five weeks after the rains had started in the previous month (Fig. No. 3).

Egg counts in calves born in February and March showed two peaks, the most prominent one being in June and July, followed by a secondary peak in October and November (Fig. No. 6). Calves born after the rains had ceased at the end of March, i.e. April to September calves, and kept under similar conditions, did not show infestation on faecal examination until *December and January (Group No. 3, Fig. No. 6; Group No. 5, Fig. No. 7). The calves born in February and March, therefore acquired their infestation before the rains ceased at the end of March; the variations in the worm egg counts were due to that infestation and not to infestation acquired during the winter and early spring.

Post-mortem results in the winter, spring and summer showed that worm egg counts were not a reliable index of the worm burdens in calves.

Roberts (1957) stated that " egg counts may be regarded as a reasonably accurate index of the population during the period of susceptibility to infestation, but they are of doubtful value when the animal has acquired, or is acquiring, resistance. In other words, it would seem that whereas high egg counts are a safe index of heavy infestations, low egg counts do not necessarily imply that only a few worms are present."

* There was one exception, viz. Calf No. 8246 (Group No. 1, Expt. C) which was born in July and became infested at the end of November.

The observations in these experiments are in complete agreement with Roberts' statement. Most calves were slaughtered when they were over seven months of age and had been infested with worms for periods of four months or longer. Some resistance to infestation must have been acquired by the host since post-mortem results were very variable when compared with worm egg counts.

4. *Immature* H. placei *Worms at Post-Mortem*

The post mortem results of Experiment C revealed the presence of mature and immature *H. placei* worms in two autopsies done in October and November (Table No. 14).

The nearest description of these immature *H. placei* which the author found in the literature, was that by Roberts (1957) in his paper on reactions of calves to *H. placei* as " small adult worms with few or no eggs in the females." The females in the author's experiments had no eggs and both males and females were small. Roberts furthermore showed that immature worms, in the fourth and fifth stage particularly, could live in the host for long periods. This has been observed by various workers with other species of nematodes (Taylor & Michel, 1952, 1953: Gibson, 1953; Soulsby, 1957). On the other hand, other workers stated that the presence of immature worms at post-mortem was due to continual infestation (Mönnig, 1931; Morgan, Parnell & Rayski, 1951).

In the description of these post-mortem results under the experimental observations of Experiment C, it was shown that the presence of these immature worms must have been due to infestation acquired in March, i.e. seven months previously. This conclusion was drawn from the fact that a winter-born calf from the same group was negative at autopsy. Furthermore, seven other calves born between April and September, grazing in the same paddock, remained negative on faecal examination for this species at that time and for a further six to eight weeks.

Summary

Four experiments are described on the transmission of *Cooperia* spp., *H. placei*, *O. radiatum* and *B. phlebotomum* to susceptible calves, reared by different methods of animal husbandry. The following conclusions are drawn:—

(1) Calves become infested in the summer and autumn only and fail to become infested in the winter and spring.

(2) A minimum of 13 to 40 mm. of rain over a period of ten to 15 days is necessary for infective larvae to become available in numbers large enough to infest the host.

(3) It is shown that the sources of infestation are—

(*a*) infested herbage;

(*b*) infested kraal manure adhering to cows' teats;

(*c*) infested kraal manure by direct contact.

(4) Different systems of calf rearing facilitate the spread of verminosis, not only when rainfall increases the availability of infective larvae but even when little rain falls in summer and autumn. In order of their importance, the transmission of verminosis is facilitated by the following systems of calf rearing:—

(*a*) calves suckling in the infested kraal and grazing in the infested paddock;

(*b*) suckling calves grazing in the infested paddock;

(*c*) suckling calves confined to the infested kraal and adjacent infested calf pen;

(*d*) hand-reared calves confined to the infested kraal and adjacent infested calf pen.

(5) Under the influence of *heavy autumn rains* calves reared on clean concrete floors also become infested. The manner in which they became infested is—

(*a*) suckling on teats of cows that became contaminated in the kraal;

(*b*) accidental infestation of lucerne-hay fed to hand-reared calves.

(6) During a comparatively *dry summer and autumn* calves confined to clean concrete-floored pens fail to become infested when reared as follows:—

(*a*) by hand;

(*b*) suckling on previously washed or unwashed udders.

(7) Post-mortem results confirmed the results already mentioned under the transmission of verminosis. Although four species of worms were recovered at post-mortem in all the groups, the order of numerical predominance of the species was as follows:—

(*a*) *Cooperia pectinata* and *Haemonchus placei;* where the source of infestation was the herbage these species were recovered in large numbers;

(*b*) *Bunostomum phlebotomum;* this species was predominant where kraal manure was the source of infestation;

(*c*) *Oesophagostomum radiatum;* this species was recovered in small numbers where both the herbage and kraal manure were the source of infestation.

PROPHYLAXIS

In his paper on the epidemiology of parasitic nematodes of sheep, Gordon (1948) divided the life cycle of parasitic nematodes into two stages and two phases. "The stages are: *Parasitic*—the worms in the host animal, and *Free-living*—eggs and larvae in faeces on the ground. The two phases are: *Contamination*—eggs passing from the host to the pasture, and *Infection*—larvae passing from the pasture to the host".

The emphasis during the expriments described above has been on the free-living stage and the contamination and infection phases. Control measures described below are therefore mainly a description of improved methods of animal grazing management based on experimental observations, and, to a lesser extent, the role anthelmintics might play in controlling the parasitic stage of the life cycle.

Prophylaxis can therefore be viewed from two angles which will be discussed separately. They are:—

1. Animal and grazing management.
2. The use of anthelmintics.

1. Animal and Grazing Management

Since two systems of farming, i.e. dairy and beef ranching, are practised in this area they will be discussed separately.

(1) *Dairy Ranching*

As mentioned earlier, calves on dairy ranches are separated from their dams at birth and placed in calf pens. When the cows come into the kraal in the morning from 9 a.m. onwards, two teats are milked and the calves allowed to suckle on the other two. After the cow returns to the grazing between 3 and 4 p.m., calves are herded into a small camp or, if very young, left in the kraal.

These calves are invariably in extremely poor condition, due not only to verminosis and various gastro-intestinal disorders, but also to the fact that they are starved because the dam's milk supply in inadequate and the grazing in the calf camp usually very inferior. On many farms the calf camp is grazed by sheep during the day, with the result that very little good grazing is available for calves.

It has been shown that calves kept under unhygienic conditions in kraals and grazing on infested pastures become infested with heavier worm burdens than calves reared by other methods. The provision of a concrete floor in the calf pen was sufficient to reduce the worm burden to low levels and even to the state where calves were free from parasites. It is not only necessary to improve the hygiene in the calf pen and kraal, but also to provide good quality, uninfested grazing for calves; attempts should be made to improve the nutritional state of these calves by allowing them adequate milk, higher quality grazing in the form of improved pastures, or at least enough good quality veld grazing by providing more than one calf camp. According to Dr. C. E. M. Tidmarsh of the Division of Crops and Pastures (personal communication), veld in the North-Western Cape should be allowed a rest in late summer, followed by a rest in early summer, once every four or five years. The important period to rest the pastures is during the growing season and Tidmarsh suggests the following rotation on a four camp system:—

Year	Season	Camps			
		A	B	C	D
1	E.S.....	G	G	G	R
	L.S.....	G	G	R	G
	W.....	G	G	G	G
2	E.S.....	G	G	R	G
	L.S.....	G	R	G	G
	W.....	G	G	G	G
3	E.S.....	G	R	G	G
	L.S.....	R	G	G	G
	W.....	G	G	G	G
4	E.S.....	R	G	G	G
	L.S.....	G	G	G	R
	W.....	G	G	G	G

Note.—Tidmarsh divides the year into three seasons: E.S. is early summer, i.e. from mid-September to mid-December. L.S. is late summer, i.e. from mid-December to the end of April. W. is winter, i.e. from May to mid-September. Furthermore, G stands for graze and R for rest.

As can be seen from the schedule, three camps are grazed in the summer and four in the winter. Each camp is grazed for two and rested for four weeks in the summer, whereas each camp is grazed for two and rested for six weeks in the winter. If more than 40 mm. of rain falls during any fortnight, calves must be moved every week to another camp, and returned to a fortnight rotation when drier conditions return. This would assist in verminosis control without detriment to the veld.

The size of these camps would be determined by the carrying capacity of the veld, the number of calves on the farm, the available water supplies, etc., and in each case the farmer would have to be guided by the advice of the local Agricultural Extension Officer.

On farms where dairy ranching is practised, bulls run with the cows constantly in attempts to make the cows calve throughout the year. Bonsma (1939) has shown that the main calf crop is in mid-summer—from November to January—and to a lesser extent in mid-winter—June and July. It is suggested therefore that cows be served only in February, March and April for the summer calf crop and from the middle of August to the middle of October for the winter calf crop.

If these calves are allowed to graze in special camps by themselves, it is highly desirable to wean the summer calf crop by the end of August and the winter calf crop by the end of February. It was shown in experiments on the epizootology of verminosis that calves carried worm burdens from autumn through to the following summer. In spite of these calves being reared together with winter and spring calves, the younger calves remained free of infestation until the rains started in December. *It is therefore important that the calves born in the previous summer be weaned and separated from calves born during or after June before the rains start in December.* If calves born in summer are weaned at the end of August and given good grazing in a separate camp, they will not carry infestation to calves born in the winter because they will have left the calf camps in the dry season, at least two months before the rains start. Furthermore, it is desirable that winter-born calves, when weaned at the end of February, do not graze before the following winter with calves weaned at the end of the previous August.

This, therefore, entails at least four calf camps and two weaner camps. In brief, summer calves may become infested in summer and autumn but will not infest winter calves if the latter are born after June and if the summer calves are weaned in August. Calves born in winter will be free from infestation and may run with calves born in the following summer until the former are weaned in February. If both August and February weaners are kept separate until the rains cease in autumn, they may join the main herd the following summer. By this time their ages will vary from 18 to 24 months, the older heifers may join the breeding herd and both groups will be fairly worm free; if not resistant to verminosis, at least the effect of verminosis on them will not be so marked if they become infested thereafter.

Riek *et al.* (1953) have suggested that the low incidence of verminosis in calves at Maleny, Queensland, Australia, where annual rainfalls are high (average 68 inches), was due to improved ley pastures, rotated every few months, and to other nutritional considerations, as well as to the provision of concrete-floored calf pens and cow yards.

The dairy herd at Armoedsvlakte was similarly lightly infested. Calves were born in summer only, kept in three camps that were rotated every six to eight weeks, and, after weaning in August, kept in separate camps for another year. No sheep grazed in any of these camps. The calf pens, kraals and cow byres had concrete floors and calves suckled on their dams after the udders had been washed. All these calves received more milk than was the practice in the district. Hygiene, improved nutrition and the separation of age groups all contributed to the low incidence of verminosis.

(2) *Beef Ranching*

On farms where beef ranching is practised, cows calve in the veld and the calf is not separated from its dam until weaning time. The incidence of verminosis on these farms is much lower than on the dairy ranch and calves are more healthy and better fed than their counterparts on the dairy ranch.

On these ranches it would be advisable to keep the breeding herd in separate camps from the rest of the herd. Furthermore, since milk is not the farmers' source of income, there is no object in having more than one calving season for more efficient management of the herd unless the fertility of the cows is at a low level. Since most calves are born in the summer, cows should be served from February to April so that calving can occur in November, December and January. This is unfortunate from the verminosis control point of view and winter calving would be preferable, but calf crops in winter are seldom as plentiful as summer calf crops; management is also simplified with one calf crop.

All calves should be weaned in August and placed in their own camps. Since calves will normally lose condition at this time of the year after weaning, the best available grazing should be set aside for the weaned calves and, if at all possible, weaners should be separated from the rest of the herd until they have reached the age of two years, when the heifers join the breeding herd and the oxen join the older stock for fattening prior to slaughter. From the management point of view it would be desirable to separate heifers and oxen at weaning, if separate camps are available for both groups.

It can be assumed that calves born in summer will become infested with parasites before the rains cease in autumn. Apart from the use of anthelmintics in worm control, which will be dealt with later, two additional methods are suggested for consideration. These methods are:—

(*a*) *Grazing Rotation*

Grazing rotation, as advocated for dairy calves, would be highly desirable for the breeding herd on beef ranches. However, this may entail considerable expense both in fencing material and the provision of water supplies, particularly if the breeding herd is large. Where a four camp system is impracticable, Tidmarsh (personal communication) suggests the following rotation on a three camp system:—

Year	Season	Camps		
		A	B	C
1	E.S.....	G	G	R
	L.S.....	G	R	G
	W.....	G	G	G
2	E.S.....	G	R	G
	L.S.....	R	G	G
	W.....	G	G	G
3	E.S.....	R	G	G
	L.S.....	G	G	R
	W.....	G	G	G

NOTE.—E.S. is early summer, i.e. from mid-September to mid-December; L.S. is late summer, i.e. from mid-December to end of April; W. is winter, i.e. from May to mid-September. G. stands for graze and R for rest.

In the summer, camps are grazed for three weeks and rested for three weeks; in winter, camps are grazed for three and rested for six weeks. Verminosis control under these conditions is almost impossible and much less satisfactory than the four camp system mentioned earlier.

Due to the general lack of water in the North-Western Cape it is difficult to supply water to separate camps. This can be overcome by extending existing water supplies and providing separate troughs for each camp. Division into camps would, therefore, entail fences meeting at or near a central point and water troughs being placed in each camp; or using the fence between the camps to divide the trough as well, so that stock have water in each camp. On many farms water troughs are divided in the manner suggested. By various methods, existing reservoir tanks can supply more than one water trough, or the water can be pumped from tanks to other reservoirs, to extend the distribution of existing water supplies. Provision is made, under the Soil Conservation Act, for the subsidising of fencing material and piping for the extension of existing water supplies, from boreholes to additional watering points.

(*b*) *Removal or Disinfestation of Kraal Manure*

(i) *Removal of manure.*—Conditions, similar to those existing in the kraals, are common around every drinking trough on farms owned by European farmers in the district. Accumulated manure of many years is found around watering points on almost every farm.

On the trust farms of the Native Affairs Department no such manure accumulations exist, because the Native stockowners collect dung pads while still fresh and place them in heaps next to their huts, for use as fuel when dry or even for building purposes. It was noted that Native-owned stock were practically worm-free, although calves were allowed to run with their dams in a similar fashion to European-owned stock. In view of the investigations previously described, the lack of manure at watering points must have been largely responsible for their freedom from parasitism.

Since cattle tend to congregate near the water troughs during the heat of the day and deposit a high concentration of manure there, it would be advisable to remove manure regularly, particularly in the rainy season, from the vicinity of water troughs. This is not practical where the soil is very sandy since the manure becomes well mixed with the sand and it is impossible to separate them.

(ii) *Disinfestation.*—The disinfestation of kraals was attempted in a kraal on a farm* in the district, using the delta isomere of benzine-hexachloride. There were two adjacent kraals, used by two different herds, and kraal manure examination indicated that both kraals were infested. The one kraal was left as a control and the other kraal dusted with 25 lb. of a 5 per cent delta BHC powder. The area of the treated kraal was approximately 20,000 sq. ft. and the treatment was carried out in March, 1956, when rainfalls were particularly heavy, i.e. 120·0 mm. for the month. Subsequent examinations showed that infective larvae were absent from the treated kraal for a period of two weeks only, whereas the control kraal remained infested throughout. This insecticide was therefore of temporary value only in decreasing the number of infective larvae in kraals.

Laboratory trials of the effects of various chemicals as larvicides were carried out and the results of some of these trials are shown in Table No. 19.

* Buckshee—owner Mr. Rex Butler.

TABLE NO. 19.

The effect on infective larvae of various compounds at concentrations of one part per million in aqueous solutions.

Compound	Percentage mortality of infective larvae after— (*a*) 24 hours	(*b*) 48 hours
	Per cent	Per cent
*Malathion 25 per cent	70	80
† Chlorthion 20 per cent	40	90
Phenothiazine	35	40
gamma Benzine-hexachloride	30	40
delta Benzine-hexachloride	5	20
‡Polybor	8	10

* Malathion is O. O-dimethyl-dithiophosphate of diethyl-mercapto-succinate.
† Chlorthion is O. O-dimethyl-0-3 chloro-4-nitrophenyl thiophosphate.
‡ Polybor's active ingredients are sodium pentaborate tetrahydrate 77 per cent and sodium tetraborate pentahydrate 18 per cent.

Trials conducted by Levine *et al.* (1956) showed that malathion and chlorthion killed or prevented the development of horse strongyle larvae at concentrations of 0·02 and 0·06 per cent respectively. The results summarised in Table No. 19 showed that these compounds were also very effective larvicides against infective bovine nematode larvae. The results with polybor were unsatisfactory (Table No. 19) although Hoerlein (1950, 1951) showed that this compound destroyed *Ancylostoma caninum* larvae.

The effect of malathion on the development of larvae in cattle dung was tested by dosing three infested year-old cattle with this drug, much on the same principle as low level phenothiazine dosing. The toxicity of this drug was unknown and it was decided to incorporate toxicity trials with tests of the effects on the worms. The three animals were dosed with 5, 10 and 20 mgm. per Kg. body weight of malathion respectively every day for three months. Although this drug had no apparent toxic effect on the three animals tested, it was also of no value as a vermicide, and apparently not enough malathion passed through the alimentary canal with the faeces to act as a larvicide. When mixed with infested faeces in cultures, both malathion and chlorthion, at one part per 10,000 parts of faecal culture medium, caused a 50 per cent reduction in the development of larvae to the infective stage when compared with controls.

These drugs may be of value in disinfesting kraal manure but were unfortunately not tested in the field. Malathion appears to be non-toxic for stock even at dosage rates of 20 mgm. per Kg. body weight for a period of three months. Before its use as a larvicide is attempted in kraals, its toxicity should be tested on new-born calves, which are usually more susceptible to the effects of any poison than older stock.

At the moment, all that can be said is that the use of certain insecticides as larvicides in kraal manure needs further investigation before recommendations can be made.

Apart from these methods of decreasing the danger of manure as a potential source of infective larvae to susceptible calves, concrete floors can be laid around water troughs and regularly cleaned. It is doubtful whether any farmer will be able

to carry this out with the scarcity of labour, or whether it is practical to surround every trough in the various camps with large areas of concrete which must be cleaned regularly. It is as well to mention that all water troughs should be well constructed and leak-proof and that at least a small area of concrete flooring should be built next to the trough in case of an overflow of water. It was frequently noted that, due to leaking drinking troughs or the overflow of water caused by faulty ball valves, the area adjacent to the trough was a mixture of soft mud and manure. Such artificially created conditions obviously supplied more than enough moisture for larval development and were dangerous, potential sources of infestation.

The remarks on leaking drinking troughs also apply to dairy ranches.

2. The Use of Anthelmintics

The author having tested only two drugs, viz. phenothiazine and tetrachlorethylene for their efficiency as anthelmintics, the recommendations made below are based on the observations of other workers as well. Recent investigations show that the following drugs are of value: –

(*a*) *Toluene*

According to Riek & Keith (1957a) this drug is an effective anthelmintic against *H. placei*, *B. phlebotomum* and *Cooperia* spp. Cattle must be starved overnight and, immediately prior to treatment, 60 c.c. of a 10 per cent sodium bicarbonate solution given to close the oesophageal groove (Riek, 1954). The drug is then dosed at the rate of 10 c.c. per 100 lb. body weight in an emulsion prepared by the addition of an emulsifying agent. Apart from temporary anaesthetic effects this drug is relatively non-toxic, according to these authors.

(*b*) *1:8 *Dihydroxyanthraquinone*

Riek & Keith (1957b) have shown that this drug was highly efficient against *H. placei*, *Cooperia* spp. and *O. radiatum*, administered *per os* as a suspension in water at 2·5 grams per 100 lb. body weight. No premedication to close the oesophageal groove nor starvation prior to dosing is necessary.

(*c*) *Phenothiazine*

This drug is effective against *H. placei* and *O. radiatum*, according to various workers (Sprent, 1946c; Riek, 1951; Roberts, 1955). These results were confirmed at Armoedsvlakte. The usual dosage rate is 0·2 grams per lb. body weight, according to Riek (1951) and Roberts (1955). The usual maximum dose is 40 grams for an adult.

(*d*) *Tetrachlorethylene*

This was mixed with an *emulsifying agent and one part of C_2Cl_4, was well shaken with two parts of water to make an emulsion. Immediately after dosing with 60 c.c. of a 10 per cent sodium bicarbonate solution, 25 c.c. of this emulsion per 100 lb. body weight were dosed, to a maximum of 100 c.c., i.e. 33·3 c.c. of C_2Cl_4. Results were not very satisfactory although the drug was effective against *H. placei*.

* This drug is sold under the proprietary names "Diaquone", "Altan", "Istin" and "Istizin".

When larger doses of 60 c.c. of emulsion were used, i.e. 20 c.c. C_2Cl_4 per 100 lb. body weight, after premedication with 10 per cent sodium bicarbonate solution, this drug was highly efficient against *H. placei*, but not very effective against other worms.

The most efficient drugs against the parasitic nematodes in cattle would appear to be toluene and 1: 8 dihydroxyanthroquinone, although these were not personally tested. The price of the latter, unfortunately, is too high for it to be used where large herds have to be treated. The disadvantages of toluene are that animals must be starved overnight and that this drug must pass directly into the abomasum to be efficient. It is effective against *H. placei*, *Cooperia* spp. and *B. phlebotomum*, however, according to Riek & Keith (1957a), and, since it is cheap, its use on a large scale is recommended. Phenothiazine appears to be the drug of choice for the treatment of *O. radiatum* and *H. placei*.

Strategic drenching

It has been shown that stock only become infested in summer and autumn and that different species of worms are present in stock in significant numbers at different times. Each species will be dealt with separately.

Cooperia spp.—Egg counts reach a maximum, on faecal examination, in autumn and post-mortems of calves in the winter showed large recoveries of *C. pectinata*.

H. placei.—There were two peaks in the egg counts of this species, the most marked being in autumn and a secondary rise in spring. More worms of this species were recovered at post-mortem in the winter and spring than in the summer.

O. radiatum.—Egg counts only reach their maximum in winter and at post-mortem this species was more plentiful in the winter than at any other time.

B. phlebotomum.—Egg counts of this species were at their maximum in winter after which they fell, to show a secondary rise in the spring. More worms were recovered in the winter and spring than in mid-summer, at post-mortem.

It is therefore suggested that strategic drenching of stock be carried out on all stock, apart from calves younger than two months of age or winter-born calves. The best time to dose and the drugs of preference would then be as follows:—

(1) *February:* This drenching is aimed at *Cooperia* spp. and *H. placei*, before the rise in egg output in autumn. Toluene would be the drug of preference.

(2) *May:* This treatment is aimed at *Cooperia* spp., *H. placei* and *B. phlebotomum* which will be present in fair numbers by this time. Toluene would be the drug of choice.

(3) *July:* This treatment is aimed at *O. radiatum*, and phenothiazine would be preferable.

(4) *August:* This treatment is aimed at the spring rise in the egg output of *B. phlebotomum* and *H. placei*, and toluene would be the drug of choice.

To summarise, toluene would be dosed in February, May and August and phenothiazine in July.

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* Triton × 100.

Calves born in the winter need not be dosed until February and, since they will be weaned in February, they must be dosed before going to the weaner camps. There is no object in dosing summer-born calves before they are two months of age, since their worm burdens are very low before this age.

Ranch cows, due to calve in summer, should be dosed in October. Since they seldom have more than a mild infestation of *H. placei* and very few other parasites, phenothiazine should be used. In these animals it may be advisable to incorporate a low level phenothiazine treatment from November to May by adding 10 per cent of this drug to the lick. The expense of low level phenothiazine dosing would hardly be warranted with other stock.

In the event of heavy rains occurring at any time, tactical drenching with toluene four to six weeks after the rains commence would be advisable.

Summary

Possible methods of prophylaxis, based on experimental observations, are described and the possible use of strategic drenching, using anthelmintics which gave promising results when tested by other workers, is included.

The recommendations made are as follows:—

(1) Separation of calves born before the winter from younger calves born before the following summer.

(2) The provision of concrete-floored calf-pens and kraals on dairy ranches, as well as four separate grazing paddocks for calves, the paddocks to be regularly rotated.

(3) The separation of breeding stock from the rest of the herd on beef ranches, and the provision of camps which are regularly rotated, for these animals.

(4) The provision of separate camps for weaners.

(5) Strategic dosing of stock with anthelmintics, using toluene in February, May and August, and phenothiazine in July.

(6) Wherever possible, improving the nutritional state of calves and weaners.

ADDENDUM

After completion of this paper the author obtained the following reference— RIEK, R. F. & KEITH, R. K. (1958). "Studies on antelminthics for cattle: IV. The organic phosphorus compound O, O-dimethyl-2, 2, 2,-trichloro-1-hydroxyethyl phosphonate (Bayer L.13/59)". *Aust. Vet. J.* Vol. 34, No. 4, pp. 93–103.

This drug is known by the trade name of "Neguvon". Rick & Keith observed no significant difference between the anthelminthic efficiency of the aqueous solution and a 50 per cent emulsion, when tested at the same dosage rates.

They found the drug highly effective against *H. placei* and *O. radiatum*, at dosage rates of 2 grams per 100 lb. body weight; at dosage rates of 5 grams per 100 lb. body weight it was effective against *Cooperia* spp., *B. phlebotomum* and even *T. axei*.

An extremely important observation was that this drug proved effective against the immature stages of most of the common nematodes of cattle.

Although relatively non-toxic at the dosage rates recommended, calves on high protein diets showed severe symptoms, and these authors advise the use of this drug under veterinary supervision until more experience has been gained as regards its use.

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APPENDIX

Contents

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TABLE NO. I

Results of Experiments on Egg Hatching and Development of Larvae to the Infective Stage under Field Conditions

Experimental Number	Position of Dung Pads in Veld	Date Experiment Commenced	Number of Days in Veld	Specimens Examined	Original Weight of Dung in Grams	Weight of Dung at Collection in Grams	Eggs per Gram	Larvae Recovered with the Baermann Apparatus			Third Stage Larvae Recovered after Incubation	*Cooperia* spp.	*H. placei*	*O. radiatum*	*B. phlebotomum*	Remarks
								1st Stage	2nd Stage	3rd Stage						
1	Exposed to sun	15/8/56		*F †X	75		160	— —	— —	— —	— 3,200	% 72·5	% 8	% 9·5	% 10	1 (*b*) No cultures; results from incubated dung
(*a*)	,,	,,	7	‡E	400	100	20	8	16	—	40	33	—	—	7	
(*b*)	,,	,,	8	E	,,	110	20	11	100	13	—	13	—	—	—	
(*c*)	,,	,,	9	E	,,	100	0	1 —	31 —	10 —	— 9	10 7	— —	— 1	— 1	
(*d*)	,,	,,	35	E	,,	130	0	— —	— —	2 —	— 87	2 87	— —	— —	— —	
2	Exposed to sun	16/8/56		F X	75	—	110 —	— —	— —	— —	— 2,550	— 71·5	— 3	— 12·5	— 13	
(*a*)	,,	,,	4	E	400	175	10	150	50	—	812	83	2	15	—	
(*b*)	,,	,,	6	E	,,	140	20	11	33	—	125	89	4	7	—	
(*c*)	,,	,,	8	E	,,	100	0	— —	29 —	9 —	— 16	9 13	— —	— 1	— 2	
3	Exposed to sun	18/8/56		F			130	—	—	—	—	—	—	—	—	
(*a*)			2	E	400	195	40	12	—	—	5,250	93	2·5	2·5	2	No control culture made
(*b*)	,,	,,	10	E	,,	85	0	11 —	100 —	13 —	— 36	13 33	— 1	— —	— 2	
(*c*)	,,	,,	60	E	,,	65	0	— —	— —	4 —	— 8	4 8	— —	— —	— —	

* F.—Fresh faeces examined for eggs before dung pads were placed in the field.
† X.—Control cultures incubated in the laboratory.
‡ E.—Entire dung pad.

TABLE NO. I (*continued*)

Experimental Number	Position of Dung Pads in Veld	Date Experiment Commenced	Number of Days in Veld	Specimens Examined	Original Weight of Dung in Grams	Weight of Dung at Collection in Grams	Eggs per Gram	Larvae Recovered with the Baermann Apparatus			Third Stage Larvae Recovered after Incubation.	*Cooperia* spp.	*H. placei*	*O. radiatum*	*B. phlebotomum*	REMARKS
								1st Stage	2nd Stage	3rd Stage						
4	Exposed to sun	13/9/56		F. X	75		410	— —	— —	— —	— 2,375	% 48	% 5	% 8	% 39	
(*a*)	,,	,,	6	E	400	195	10	500	2,500	—	5,000	71·5	6·5	9	13	
(*b*)	,,	,,	7	E	,,	155	0	40 —	200 —	250 —	— 437	45 88	— 5	5 1	50 6	
(*c*)	,,	,,	9	E	,,	125	0	— —	350 —	1,100 —	— 1,600	84 88	1 —	2 3	13 9	
(*d*)	,,	,,	30	E	,,	95	0	— —	— —	455 —	— 1,050	90 94·5	6 2·5	4 3	— —	
(*e*)	,,	,,	60	E	,,	75	0	— —	— —	800 —	— 2,270	69 95	1 2	30 3	— —	
5	Exposed to sun	22/9/56		F X	75		410	— —	— —	— —	— 2,175	— 38	— 34	— 15	— 13	Incubated dung culture in 5 (*c*) accidentally discarded before examination
(*a*)	,,	,,	2	E	400	210	20	1	1	—	15,720	60	9	22	9	
(*b*)	,,	,,	4	E	,,	190	60	900	37	—	11,575	90·5	2	7	0·5	
(*c*)	,,	,,	6	E	,,	105	20	250	388	—	—	—	—	—	—	
(*d*)	,,	,,	9	E	,,	75	0	—	4	44	— 175	38 91	2 —	— 7	4 2	
6	Exposed to sun	13/10/56		F X	75	—	360 —	— —	— —	— —	— 13,500	— 57	— 37	— 5	— 1	
(*a*)	,,	,,	2	E	400	225	100	480	—	—	31,250	37	48	12	3	
(*b*)	,,	,,	4	E	,,	140	45	104	260	—	1,630	37	32	27	4	
(*c*)	,,	,,	6	E	,,	132	0	— —	— —	200 —	— 550	85 36	5 63	7 1	3 —	
(*d*)	,,	,,	30	E	,,	100	0	— —	— —	250 —	— 300	86 97	2 —	12 3	— —	

TABLE NO. I (*continued*)

Experimental Number	Position of Dung Pads in Veld	Date Experiment Commenced	Number of Days in Veld	Specimens Examined	Original Weight of Dung in Grams	Weight of Dung at Collection in Grams	Eggs per Gram	Larvae Recovered with the Baermann Apparatus			Third Stage Larvae Recovered after Incubation	*Cooperia* spp.	*H. placei*	*O. radiatum*	*B. phlebotomum*	Remarks.
								1st Stage	2nd Stage	3rd Stage						
7	Exposed to sun	12/11/56		F X	— 75	— —	90 —	— —	— —	— —	— 6,875	% 52·5	% 16·5	% 17·5	% 13·5	No. 7 (*b*) and (*c*) partially destroyed by dung beetles. No. 7 (*d*) to (*f*) extensively damaged by dung beetles
(*a*)	,,	,,	1	E	400	210	80	37	—	—	40,600	55	26	14	5	
(*b*)	,,	,,	2	E	,,	150	120	25	12	—	10,000	50	30	13·5	6·5	
(*c*)	,,	,,	2	E	,,	100	20	256	—	—	3,500	65	13·5	12·5	9	
(*d*)	,,	,,	3	E	,,	67	0	—	—	—	550	80	6	12·5	1·5	
(*e*)	,,	,,	30	E	,,	75	0	— —	— —	162 —	— 137	78 80	1 10	2 10	— —	
(*f*)	,,	,,	64	E	,,	111	0	— —	— —	10 —	— 5	9 5	1 —	— —	— —	
8	Exposed to sun	11/12/56		F X	 75		120	— —	— —	— —	— 6,916	— 24	— 53·5	— 16·5	— 6	Infective larvae recovered with Baermann Apparatus in 8 (*e*) not identified
(*a*)	,,	,,	1	E	400	350	100	12	—	—	22,500	41	50	8	1	
(*b*)	,,	,,	2	E	245	80	—	4	—	—	9,200	21	61	13	5	
(*c*)	,,	,,	3	E	400	220	80	100	25	—	15,000	17	69	8	6	
(*d*)	,,	,,	7	E	,,	147	0	400 —	350 —	350 —	— 3,270	50 89	33 4	5 2	6 5	
(*e*)	,,	,,	31	E	,,	160	0	— —	— —	100 1	— 12	— 4	— 8	— —	— —	
9	Exposed to sun	11/1/57		F X	 75	—	200 —	— —	— —	— —	— 8,125	— 29	— 39	— 15	— 17	No. 9 (*a*) badly damaged by dung beetles, the other dung pads, destroyed by dung beetles
(*a*)	,,	,,	3	E	400	113	0	2	—	—	825	32	38	7	23	
10	Exposed to sun	11/1/57		F X	 75	—	40 —	— —	— —	— —	— 3,125	— 52	— 19	— 23	— 6	Dung pads destroyed by dung beetles

TABLE NO. I (*continued*)

Experimental Number	Position of Dung Pads in Veld	Date Experiment Commenced	Number of Days in Veld	Specimens Examined	Original Weight of Dung in Grams	Weight of Dung at Collection in Grams	Eggs per Gram	Larvae Recovered with the Baermann Apparatus			Third Stage Larvae Recovered after Incubation.	*Cooperia* spp.	*H. placei*	*O. radiatum*	*B. phlebotomum*	Remarks.
								1st Stage	2nd Stage	3rd Stage						
11	Exposed to sun	17/1/57		F X	75		200	— —	— —	— —	— —	% — 28	% — 72	% — —	% — —	Although dung pads weighed 1 Kg. they were destroyed by dung beetles.
12	Exposed to sun	22/1/57		F X	75		140	— —	— —	— —	— 7,500	— 39·5	— 24·5	— 20	— 16	All dung pads placed in field from No. 12 onwards protected by wire gauze cage from dung beetles. Compare No. 12 with No. 13. Dung pads were derived from identical faeces but dung pads weighed 400 gm. in No. 12 and 1 Kg. in No. 13 when placed in the field.
(*a*)	,,	,,	2	E	400	255	15	1,550	—	—	15,875	28	20	15	37	
(*b*)	,,	,,	3	E	,,	265	75	1,237	772	—	10,000	32·5	19·5	14	34	
(*c*)	,,	,,	4	E	,,	280	45	1,225	1,862	—	7,500	29	12·5	17	41·5	
(*d*)	,,	,,	5	E	,,	205	30	625 —	3,750 —	250 —	— 4,750	54 28	14 26	30 9	2 37	
(*e*)	,,	,,	6	E	,,	210	15	150 —	312 —	1,250 —	— 1,175	72 30	10 18·5	18 13.5	— 38	
(*f*)	,,	,,	7	E	,,	250	0	100 —	750 —	7,500 —	— 1,000	55 30	25 18·5	18 13.5	2 38	
(*g*)	,,	,,	30	E	,,	85	0	— —	— —	450 —	— 437	60 83	5 8	35 9	— —	
(*h*)	,,	,,	60	E	,,	95	0	—	—	662	—	72	7	21	—	
13	Exposed to sun	22/1/57		F X	75		140	— —	— —	— —	— 7,500	— 39·5	— 24·5	— 20	— 16	Compare with No. 12. (See remarks No. 12.)
(*a*)	,,	,,	8	E	1,000	650	0	1,575 —	3,150 —	2,500 —	— 8,175	61 28	12 20	21 12	6 40	
(*b*)	,,	,,	30	E	,,	215	0	— —	— —	565 —	— —	59 86	5 4	36 10	— —	

TABLE NO. I (*continued*)

imental Exper Number	Position of Dung Pads in Veld	Date Experiment Commenced	Number of Days in Veld	Specimens Examined	Original Weight of Dung in Grams	Weight of Dung at Collection in Grams.	Eggs per Gram	Larvae Recovered with the Baermann Apparatus			Third Stage Larvae Recovered after Incubation	*Cooperia* spp.	*H. placei*	*O. radiatum*	*B. phlebotomun*	Remarks.
								1st Stage	2nd Stage	3rd Stage						
14	Exposed to sun	12/2/57		F X	75		140	— —	— —	— —	— 1,500	% — 56	% — 36	% — 3	% — 5	
(*a*)	,,	,,	2	E	400	200	90	250	—	—	1,850	49	41·5	6·5	3	
(*b*)	,,	,,	4	E	,,	150	0	63	—	—	100	85	12	3	—	
(*c*)	,,	,,	6	E	,,	85	0	— —	— —	12 —	— 13	12 12	— 1	— —	— —	
(*d*)	,,	,,	8	E	,,	65	0	— —	— —	9 —	— 27	9 26	— 1	— —	— —	
(*e*)	,,	,,	30	E	,,	70	0	— —	— —	2 —	— 15	2 15	— —	— —	— —	
(*f*)	,,	,,	60	E	,,	85	0	— —	— —	105 —	— 7	100 7	— —	— —	— —	
15	Exposed to sun	12/3/57		F X	75		400	— —	— —	— —	— 400	— 40	— 48	— 9	— 3	
(*a*)	,,	,,	1	E	400	340	360	—	—	—	20,000	51	46·5	2	0·5	
(*b*)	,,	,,	2	E	,,	240	60	1,350	—	—	33,125	52·5	43·5	3·5	0·5	
(*c*)	,,	,,	3	E	,,	200	285	9,700	1,150	—	7,175	41·5	54	4·5	—	Small number of larvae recovered in control culture.
(*d*)	,,	,,	4	E	,,	205	195	3,025	2,825	—	2,500	57	31	9	3	
(*e*)	,,	,,	5	E	,,	180	150	1,200 —	5,400 —	700 —	— 1,375	65 58	33 30	1 12	1 —	
(*f*)	,,	,,	6	E	,,	135	120	800 —	2,850 —	2,300 —	— 2,500	71 86	19 12	7 2	3 —	
(*g*)	,,	,,	7	E	,,	125	30	— 250	— 1,150	— 7,500	— 2,250	69 71	18 20	12 9	1 —	
(*h*)	,,	,,	8	E	,,	215	0	150 —	200 —	8,750 —	— 14,765	75 78	6 16	18 4	1 2	
(*i*)	,,	,,	9	E	,,	185	0	— —	36 —	6,875 —	— 3,162	41·5 74	14 20	43 5	1·5 1	
(*j*)	,,	,,	30	E	,,	105	0	— —	— —	5,000 —	— 1,250	85 96	4 1	11 3	— —	

TABLE NO. I (*continued*)

Experimental Number	Position of Dung Pads in Veld	Date Experiment Commenced	Number of Days in Veld	Specimens Examined	Original Weight of Dung in Grams	Weight of Dung at Collection in Grams.	Eggs per Gram	Larvae Recovered with the Baermann Apparatus			Third Stage Larvae Recovered after Incubation	*Cooperia* spp.	*H. placei.*	*O. radiatum.*	*B. phlebotomum.*	Remarks
								1st Stage	2nd Stage	3rd Stage						
16	Exposed to sun	24/4/57		F			390	—	—	—	—	% —	% —	% —	% —	All dung pads collected from 16 (*d*) onwards were divided into the crust or upper layers and depth or lower layers as indicated by C. (crust) and D. (depth) in the fifth column of the table. The crust and depth were weighed and examined separately.
				X	75			—	—	—	28,750	43	31	19·5	6·5	
(*a*)	,,	,,	1	E	400	385	260	200	—	—	50,000	49	31	15	5	
(*b*)	,,	,,	2	E	,,	325	240	750	—	—	50,000	34	37·5	19·5	9	
(*c*)	,,	,,	3	E	,,	280	250	1,250	—	—	40,000	43	40	12	5	
(*d*)	,,	,,	4	*C	,,	90	30	100	—	—	7,500	42	32·5	20·5	5	
				†D		180	375	425	125	—	20,000	49	23·5	20·5	7	
(*e*)	,,	,,	5	C	,,	75	0	—	5	—	15	6	4	4	1	
				D		130	285	3,750	1,005	—	12,400	14	10	55	21	
(*f*)	,,	,,	6	C	,,	45	0	—	1	—	280	17	12	16	55	
				D		130	375	3,750	4,750	—	12,500	6·5	1·5	43·5	48·5	
(*g*)	,,	,,	7	C	,,	35	0		1	—	23	—	—	4	19	
				D		105	270	100	1,400	—	5,000	2·5	3	45	49	
(*h*)	,,	,,	8	C	400	10	0	1	—	1	—	1	—	—	—	
								—	—	—	5	5	—	—	—	
				D		100	120	800 —	4,900 —	1,850 —	— 6,250	72 24	20 —	6 39	2 37	
(*i*)	,,	,,	9	C	,,	58	0	—	—	1	—	1	—	—	—	Infective larvae accidentally discarded in the incubated dung of the depth in 16 (*j*) before identification.
								—	—	—	18	10	—	1	7	
				D		92	75	1,200 —	5,000 —	3,700 —	— 4,000	78 11	14 2	7 38	1 49	
(*j*)	,,	,,	14	C	,,	74	0	—	—	21	—	16	—	5	—	
								—	—	—	—	—	—	—	—	
				D		42	15	—	—	4,350 —	— 1,000	86 —	9·5 —	2·5 —	1·5 —	

* C.—Crust of the dung pad.
† D.—Depth of the dung pad.

TABLE NO. I (*continued*)

Experimental Number	Position of Dung Pads in Veld	Date Experiment Commenced	Number of Days in Veld	Specimens Examined.	Original Weight of Dung in Grams	Weight of Dung at Collection in Grams	Eggs per Gram	Larvae Recovered with the Baermann Apparatus			Third Stage Larvae Recovered after Incubation	*Cooperia* spp	*H. placei*	*O. radiatum*	*B. phlebotomum*	Remarks
								1st Stage	2nd Stage	3rd Stage						
17	Exposed to sun	9/5/57		F X	75		200				20,000	% 44·5	% 32·5	% 13	% 10	The results in No. 17 should be compared with those in No. 18. Dung was identical except that the former was placed in the sun while the latter was placed in the shade. No notice should be taken of the egg per gram counts of the fresh faeces which were incorrect.
(*a*)	,,	,,	2	C D	400	104 176	270 310	500 15	— —	— —	6,200 25,000	44 51	39 40·5	16·5 6·5	0·5 2	
(*b*)	,,	,,	4	C D	,,	70 120	30 190	100 275	— —	— —	5,000 31,250	41·5 42·5	40 40	14·5 16	4 1·5	
(*c*)	,,	,,	6	C D	,,	65 105	15 210	125 4,350	— 3,100	— —	350 5,000	36 25	44 22	8 45	12 8	
(*d*)	,,	,,	8	C D	,,	60 90	15 90	— 2,250	— 2,250	— —	50 750	30 50	17 22	3 24	— 4	
(*e*)	,,	,,	10	C D	,,	145 60	0 10	40 1,250	90 2,250	— —	90 175	45 60	10 30	27 10	8 —	
(*f*)	,,	,,	11	C D		110 85	0 15	— 500	— 1,500	— —	12 525	8 46	4 22	— 30	— 2	
(*g*)	,,	,,	14	C	,,	75	0	1	2	9	250	7 70	2 30	— —	— —	
				D		80	15	75	2,000	3,500	1,250	80 70	13 20	6·5 10	0·5 —	

TABLE NO. I (*continued*)

Experimental Number	Position of Dung Pads in Veld	Date Experiment Commenced	Number of Days in Veld	Specimens Examined	Original Weight of Dung in Grams	Weight of Dung at Collection in Grams	Eggs per Gram	Larvae Recovered with the Baermann Apparatus			Third Stage Larvae Recovered after Incubation	*Cooperia* spp.	*H. placei*	*O. radiatum*	*B. phlebotomum*	Remarks
								1st Stage	2nd Stage	3rd Stage						
18	In shade...	9/5/57		F X			200				20,000	% 44·5	% 32·5	% 13	% 10	
(*a*)	,,	,,	2	C	400	125	315	—	—	—	3,250	49	36	13	2	
				D		200	315	—	—	—	21,750	43·5	39	13·5	4	
(*b*)	,,	,,	4	C	,,	95	225	1	—	—	7,500	14·5	59·5	21	5	Compare with No. 17. Ignore original egg per gram counts of fresh faeces which were obviously incorrect
				D		200	570	1	—	—	20,000	32	42	25	1	
(*c*)	,,	,,	8	C	400	75	30	50	—	—	450	38	48	6	8	
				D		125	255	850	50	—	3,100	33	44	21	2	
(*d*)	,,	,,	11	C	,,	125	30	5	20	—	675	50	46	10	4	
				D		135	75	1,250	1,250	—	750	32	12	48	8	
(*e*)	,,	,,	14	C	,,	85	0	77	41	7	487	3 40	4 54	— 4	— 2	
				D		130	30	2,250	1,250	3	1,325	3 41	50	— 5	— 4	
(*f*)	,,	,,	18	C	,,	60	0	—	—	—	3	2	1	—	—	
				D		110	30	1,520	750	—	1,137	65·5	28·5	4	2	
(g)	,,	,,	26	C	,,	55	0	—	—	1	0	1	—	—	—	
				D		55	0	—	50	225	375	76 90	24 10	— —	— —	

TABLE NO. I (*continued*)

Experimental Number.	Position of Dung Pads in Veld.	Date Experiment Commenced.	Number of Days in Veld.	Specimens Examined.	Original Weight of Dung in Grams.	Weight of Dung at Collection in Grams.	Eggs per Gram	Larvae Recovered with the Baermann Apparatus			Third Stage Larvae Recovered after Incubation	*Cooperia* spp	*H. placei*	*O. radiatum*	*B. phlebotomum*	Remarks
								1st Stage	2nd Stage	3rd Stage						
19	Exposed to sun	22/5/57		F X	75		305				21,745	% 34	% 45·5	% 17·5	% 3	Compare the results of No. 19 with those of No. 20, the dung being similar in every respect except that the former was exposed to the sun and the latter was in the shade
(*a*)	,,	,,	5	C D	400	65 130	90 855	500 1,825	— —	— —	3,675 46,250	34 55·5	29 27·5	20 14·5	17 2·5	
(*b*)	,,	,,	13	C D	,,	40 45	0 0	— 100	— —	— —	8 262	7 80	1 20	— —	— —	
(*c*)	,,	,,	19	C D	,,	45 40	0 0	— 2	— —	— —	18 13	16 13	2			
20	In shade...	22/5/57		F X	75		305				21,750	34	45·5	17·5	3	Compare with No. 19
(*a*)	,,	,,	20	C D	400	100 100	0 150	— 1,050	— 100	— —	75 975	75 71	23	4	2	
21	Exposed to sun	3/6/57		F X	75		140				9,350	28	55	8	9	Compare No. 20 and No. 21. The former dung pads were exposed to the sun, the latter were in the shade
(*a*)	,,	,,	4	C D	400	95 135	150 180	— 150	25 —	— —	3,000 18,750	79 59	13 29	8 11	— 1	
(*b*)	,,	,,	8	C D	,,	95 155	60 180	55 375	5 50	— —	300 2,575	77 76	2 11·5	18 12	3 0·5	
(*c*)	,,	,,	10	C D	,,	105 155	30 195	— —	5 —	— —	100 3,750	65 62	10 25	20 12	5 1	
(*d*)	,,	,,	14	C D	,,	70 125	0 120	1 200	1 212	— —	50 1,450	50 63	— 18	— 18	— 1	Incubated dung cultures of 21 (*e*) were unfortunately not examined
(*e*)	,,	,,	21	C D	,,	65 85	0 90	62 100	— —	— —						

TABLE NO. I (*continued*)

Experimental Number	Position of Dung Pads in Veld	Date Experiment Commenced	Number of Days in Veld	Specimens Examined	Original Weight of Dung in Grams	Weight of Dung at Collection in Grams	Eggs per Gram	Larvae Recovered with the Baermann Apparatus			Third Stage Larvae Recovered after Incubation	*Cooperia* spp	*H. placei*	*O. radiatum*	*B. phlebotomum*	Remarks
								1st Stage	2nd Stage	3rd Stage						
22	In shade...	3/6/57		F X	75		104				9,350	% 28	% 55	% 8	% 9	Compare with No. 20 (see remarks above)
(*a*)	,,	,,	8	C	400 400	100	120	—	—	—	1,925	89	2·5	7·5	1	
				D		180	225	—	—	—	3,500	83	8·5	8·5	—	
(*b*)	,,	,,	10	C	,,	115	150	—	—	—	2,200	77	19	3	1	Unfortunately incubated dung cultures of 22 (*e*) were not examined
				D		175	195	—	—	—	6,300	67	21	11	1	
(*c*)	,,	,,	14	C	,,	95	30	8	—	—	1,150	98	—	1	1	
				D		155	225	5	10	—	6,200	81	18	1	—	
(*d*)	,,	,,	21	C	,,	90	15	—	—	—						
				D		120	195	40	—	—						

TABLE No. II

Results of Experiments on the Activity and Survival of Infective Larvae under Field Conditions

Experimental No.	Date of Collection of Specimens in Veld	No. of Days in Veld	Dung Pad's Size in cm. and Position in the Veld	Climatic Conditions: Mean Maximum Temp. in Degrees C.	Climatic Conditions: Mean Minimum Temp. in Degrees C.	Climatic Conditions: Mean Relative Humidity per cent	Climatic Conditions: Total Rainfall in Millimetres	Third Stage Larvae Recovered: A Dung Pad: Part Examined	A Dung Pad: *Cooperia* spp.	A Dung Pad: *H. placei*	A Dung Pad: *O. radiatum*	A Dung Pad: *B. phlebotomum*	A Dung Pad: Total No. of Larvae Recovered	B Soil under the Dung Pad: *Cooperia* spp.	B Soil under the Dung Pad: *H. placei*	B Soil under the Dung Pad: *O. radiatum*	B Soil under the Dung Pad: *B. phlebotomum*	B Soil under the Dung Pad: Total No. of Larvae Recovered	C Grass Surrounding the Dung Pad: Distance from A in cm.	C Grass Surrounding the Dung Pad: Height above Soil in cm.	C Grass Surrounding the Dung Pad: *Cooperia* spp.	C Grass Surrounding the Dung Pad: *H. placei*	C Grass Surrounding the Dung Pad: *O. radiatum*	C Grass Surrounding the Dung Pad: Total No. of Larvae Recovered	D Grass Roots Around the Dung Pad: Distance from A in cm.	D Grass Roots Around the Dung Pad: *Cooperia* spp.	D Grass Roots Around the Dung Pad: *H. placei*	D Grass Roots Around the Dung Pad: *O. radiatum*	D Grass Roots Around the Dung Pad: Total No. of Larvae Recovered	E Soil Next to the Dung Pad to a Depth of 2 cm.: Distance from A in cm.	E Soil Next to the Dung Pad to a Depth of 2 cm.: *Cooperia* spp.	E Soil Next to the Dung Pad to a Depth of 2 cm.: *H. placei*	E Soil Next to the Dung Pad to a Depth of 2 cm.: *O. radiatum*	E Soil Next to the Dung Pad to a Depth of 2 cm.: *B. phlebotomum*	E Soil Next to the Dung Pad to a Depth of 2 cm.: Total No. of Larvae Recovered	Total No. of Larvae Recovered from all Sources	Remarks
1	19/7/55	26	Size: 17 × 9 × 1. Exposed to sun	19·9	0·1	49·9	0	*E.	–	–	–	–	0	–	–	–	–	0	0–15	–	–	–	–	0	0–15	–	–	–	1	0–15	–	–	–	–	0	1	Atmospheric conditions were unsuitable for development
2	19/7/55	12	Size: Not measured. Exposed to sun	21·7	3·9	44·5	0	E.	–	–	–	–	0	–	–	–	–	0	0–15	–	–	–	–	0	0–15	–	–	–	0	0–15	–	–	–	–	0	0	Atmospheric conditions were unsuitable for development
3	19/7/55	12	Size: 9 × 8 × 6. In partial shade	21·7	3·9	44·5		E.	–	–	–	–	0	–	–	–	–	0	0–15	0–10	–	–	–	0	0–15	–	–	–	0	0–15	–	–	–	–	0	0	Atmospheric conditions were unsuitable for development
4	12/8/55	36	Size: 13 × 9 × 2–5. Exposed to sun	19·1	0·5	47	0	E.	–	–	–	–	0	–	–	–	–	0	0–15	–	–	–	–	0	0 15	–	–	–	0	0 15	–	–	–	–	0	0	Atmospheric conditions were unsuitable for development
5	18/8/55	8	Size: 20 × 42 × 5. In partial shade	20·0	0·6	35	0	†C. ‡D.	+ –	+ –	+ –	– –	67 0 67	–	–	–	–	0	0–15	0–6	–	–	–	0	0–15	–	–	–	0	0–15	–	–	–	–	0	67	The first signs of the presence of larvae. The number of larvae recovered is not very significant
6	20/8/55	26	Size: Not measured. In partial shade	19·9	−0·8	30·5	0	E.	–	–	–	–	0																							0	No larvae recovered in the dung pad due to unfavourable atmospheric conditions. Specimens B, C, D, and E, accidentally discarded before examination
7	8/9/55	12	Size: 12 × 7 × 4. In partial shade	25·6	2·0	37	0	E.	–	–	–	–	0	–	–	–	–	0	0–15	0–20	–	–	–	0	0–15	–	–	–	0	0–15	–	–	–	–	0	0	The dung pad was hollowed out by dung beetles which may have accounted for the lack of development
8	24/9/55	14	Size: 19 × 7 × 2–5. Exposed to sun	28	6·2	30	0	C. D.	+ 95%	+ 1%	– 4%	– –	16 193 209 99·5%	–	–	–	–	1 1 ± 0·5%	0–15	0–5	–	–	–	0	0–15	–	–	–	0	0–15	–	–	–	–	0	210	Atmospheric conditions were more favourable for larval development *N.B.*—More larvae were present in the depth of the dung pad than in the crust
9	29/9/55	84	Size: 15 × 6. In partial shade	23·3	0·0	40	0·2	E.	–	–	–	–	0	–	–	–	–	0	0–10	0–20	–	–	–	0	0–10	–	–	+	1	0–10	–	–	–	–	0	1	The long period of exposure to field conditions as well as the unsuitable atmospheric conditions, when dung was placed in the veld in the winter probably accounted for the almost negative results
10	3/10/55	16	Size: 17 × 12 × 7. In deep shade	27·6	8·6	29	0·4	E.	–	–	–	–	0	–	–	–	–	0	0–10	0–2 2–50	+ –	+ +	– –	3 4 7	0–10	–	–	–	0	0–10	–	–	–	–	0	7	Dung beetles had been active. In spite of very little rain larvae were recovered on the grass
11	4/10/55	7	Size: 18 × 2–5. Exposed to sun	26·2	8·0	19·5	0·2	C. D.	– +	– +	– –	– –	0 2 2	–	–	–	–	0	0–10	0–2 2–50	+ +	+ +	– –	0 2 2	0–10	–	–	–	0	0–10	–	–	–	–	0	4	As in No. 10
12	6/10/55	49	Size: 28 × 26 × 10. In partial shade	25·5	4·8	33·5	0·4	C. D.	+ +	+ –	+ –	– –	71 1 72	–	–	–	–	0	0–10	0–5	–	–	–	0	0–10	–	–	–	0	0–10	–	–	–	–	0	72	The number of larvae recovered in the dung pad was not very significant
13	11/10/55	7	Size: 12 × 6. In partial shade	27·5	6·9	33·5	0·4	C. D.	+ 72%	– 17%	– 11%	– –	11 377 388 91%	+	+	–	–	38 38 9%	0–10	0–5 0–50	– –	– –	– –	0 0	0–10	–	–	–	0	0–10	–	–	–	–	0	426	The soil under the dung pad included small pieces of manure left there by dung beetles. This may have accounted for the presence of larvae in the Specimen B

*E.—Entire dung pad. †C.—Crust of the dung pad. ‡D.—Depth of the dung pad.

TABLE NO. II (*continued*)

Experimental No.	Date of Collection of Specimens in Veld	No. of Days in Veld	Dung Pad's Size in cm. and Position in the Veld	CLIMATIC CONDITIONS: Mean Maximum Temp. in Degrees C.	Mean Minimum Temp. in Degrees C.	Mean Relative Humidity per cent	Total Rainfall in Millimetres	THIRD STAGE LARVAE RECOVERED.	A DUNG PAD: Part Examined	*Coeoperia* spp.	*H. placei*	*O. radiatum*	*B. phlebotomum*	Total No. of Larvae Recovered	B SOIL UNDER THE DUNG PAD: *Coeoperia* spp.	*H. placei*	*O. radiatum*	*B. phlebotomum*	Total No. of Larvae Recovered	C GRASS SURROUNDING THE DUNG PAD: Distance from A in cm	Height above Soil in cm.	*Coeoperia spp.*	*H. placei*	*O. radiatum*	Total No. of Larvae Recovered	D GRASS ROOTS AROUND THE DUNG PAD: Distance from A in cm.	*Coeoperia* spp.	*H. placei*	*O. radiatum*	Total No. of Larvae Recovered	E SOIL NEXT TO THE DUNG PAD TO A DEPTH OF 2 CM.: Distance from A in cm.	*Coeoperia* spp.	*H. placei.*	*O. radiatum.*	*B. phlebotomum.*	Total No. of Larvae Recovered	Total No. of Larvae Recovered from all Sources	REMARKS
23	6/11/55	24	Size: 13 × 14 × 9. In partial shade	27·3	10·8	44	16·9		C. D.	90% 90%	4% 4%	5% 5%	1% 1%	630 6,750 7,380 ±99·4%	+	+	+	−	42 42 0·6%	0–10	0–15 15–60	+ 1	− −	− −	1 0 1 0·01%	0–10	−	−	−	0 0	0–10	−	−	−	0 0	7,423	Rainfall was again insufficient to cause larval migration of any note
24	21/11/55	16	Size: 18 × 16 × 6. In partial shade	30·8	11·2	31	0		E.	−	−	−	−	0	+	−	−	−	1	0–10	0–10 10–65	− −	− −	− −	0 0	0–10	−	−	−	0	0–10	−	−	−	0	1	Dung beetles attacked the dung pad to such an extent that only a thin crust remained, probably accounting for the poor recovery of larvae
25	23/11/55	9	Size: 12 × 8 × 6. In deep shade	30·1	11·4	32	9·5		C. D.	− −	− −	− −	− −	0 0	−	−	−	−	0	0–10	0–10 10–40	− −	− −	− −	0 0	0–10	−	−	−	0	0–10	−	−	−	0	0	As in No. 24
26	23/11/55	9	Size: 11 × 10 × 5. In deep shade	30·1	11·4	32	9·5		C. D.	− +	− −	− −	− −	0 1 1	−	−	−	−	0	0–15	0–10 10–20	− −	− −	− −	0 0	0–15	−	−	−	0	0–15	−	−	−	0	1	As in No. 24 and 25
27	29/11/55	7	Size: 20 × 20 × 5. In partial shade	27·6	15·2	54·5	16·3		E.	7%	47%	46%	−	112 79%	−	+	+	−	25 17·5%	0–15	0–5 5–60	+ −	− −	− −	1 0 1 0·7%	0–15	−	−	−	0	0–15	−	−	+	−	5 5 2·8%	143	As in No. 24 to 26, although more larvae were recovered
28	29/11/55	7	Size: 21 × 21 × 4. In partial shade	27·6	15·2	54·5	16·3		E.	24%	38%	37%	1%	112 112 44%	16%	36%	42%	6%	140 140 55%	0–15	0–5 5–75	− −	+ −	+ −	2 0 2 ± 0·8%	0–15	+	−	−	1 1 ± 0·2%	0–15	+	−	+	−	2 2 ± 0·8%	257	As in No. 27
29	13/12/55	10	Size: 10 × 10 × 4. In deep shade	27·9	14·2	46	38·5		E.	22%	62%	14%	2%	350 350 29%	28%	48%	24%	−	112 112 9%	0–10	0–5	45%	42%	13%	125 125 10%	0–10	+	+	+	12 12 ± 1%	0–10	12%	20%	68%	−	622 622 51%	1,221	This was the first experiment in which any migration of note had taken place to the grass. Of the total of 38·5 mm. of rain recorded, 32 mm. fell in the first 48 hours and only 6·5 mm. the last 24 hours before collection
30	19/12/55	25	Size: 5 × 4 × 4. In partial shade	27·4	14·1	54	127·7		E.	+	−	+	−	8 8 5%	+	+	+	+	25 25 14%	0–10	0–10	+	+	+	75 75 41%	0–10	+	+	+	24 24 13%	0–10	+	+	+	+	50 50 27%	182	Under the influence of good rains, most of the larvae had migrated from the dung. The long period in the veld possibly accounted for the relatively poor recoveries of larvae. Dung beetles had also been active
31	19/12/55	67	Size: 14 × 5 × 4. Exposed to sun	28·2	12·3	43·5	164·1		E.	−	−	−	−	0	+	−	−	−	12	0–15	0–10	+	−	−	12	0–15	−	−	−	0	0–15	+	−	+	−	3	27	Dung beetles had been active and probably accounted for the poor recoveries of larvae. All the larvae had migrated from the dung due to good rains.
32	19/12/55	93	Size: 10 × 8 × 4. In deep shade	28·2	10·9	39·5	168·5		E.	+	−	+	−	4	+	−	−	−	2	0–10	0–5 5–20	+ +	− −	− −	4 6 10	0–10	−	−	−	0 0	0–10	+	−	−	−	1 1	17	Due to the long period of exposure most of the larvae had probably died. Although *Coeperia* spp. were the only larvae recovered on the grass, both *H. placei* and *O. radiatum* larvae were present in the dung pad. Dung beetles had also been active

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TABLE NO. II (*continued*)

Experimental No.	Date of Collection of Specimens in Veld	No. of Days in Veld	Dung Pad's Size in cm. and Position in the Veld	CLIMATIC CONDITIONS: Mean Maximum Temp. in Degrees C.	Mean Minimum Temp. in Degrees C.	Mean Relative Humidity per cent	Total Rainfall in Millimetres	THIRD STAGE LARVAE RECOVERED. A DUNG PAD: Part Examined	*Cooperia* spp.	*H. placei*	*O. radiatum*	*B. phlebotomum*	Total No. of Larvae Recovered	B SOIL UNDER THE DUNG PAD: *Cooperia* spp.	*H. placei*	*O. radiatum*	*B. phlebotomum.*	Total No. of Larvae Recovered	C GRASS SURROUNDING THE DUNG PAD: Distance from A in cm.	Height above Soil in cm.	*Cooperia* spp.	*H. placei*	*O. radiatum*	Total No. of Larvae Recovered	D GRASS ROOTS AROUND THE DUNG PAD: Distance from A in cm.	*Cooperia* spp.	*H. placei*	*O. radiatum*	Total No. of Larvae Recovered	E SOIL NEXT TO THE DUNG PAD TO A DEPTH OF 2 CM.: Distance from A in cm.	*Cooperia* spp.	*H. placei*	*O. radiatum*	*B. phlebotomum*	Total No. of Larvae Recovered	Total No. of Larvae Recovered from all Sources	REMARKS
41	25/2/56	28	Size: 18 × 18 × 5. In deep shade	29·6	13·2	50·0	84·5	E.	+	–	+	–	39	–	–	–	–	10	0–15 0–15 15–50 50–55	0–10 10–50 0–50 0–50	+ + + +	+ + + +	– – – –	39 25 4 10	0–15	–	–	–	4	0–15 30–33 50–55	+ – –	– – –	– + –	– – –	1 2 0	134	On 22 and 23 February, two days before the collection of specimens 61·0 mm. of rain fell. Marked horizontal migration took place and more larvae were recovered on grass than elsewhere
													39 29%					10 8%					78 58%					4 3%						3 2%		
42	26/2/56	8	Size: 21 × 20 × 8. In partial shade	25·8	15·9	61·5	116·8	C. U.D. L.D.	20% 30% +	68% 58% +	4% 4% –	8% 8% –	260 150 25	30%	40%	20%	10%	125	0–15 15–30 30–50 50–53	0–15 0–15 0–15 0–15	17% 28% 42% 38%	83% 72% 58% 60%	– – – 2%	5,000 730 251 137	0–15	22%	77%	1%	237	0–15 *(1) †(2) 30–33 50–53	39% 40% + +	55% 57% – +	5% 3% – –	1% – – –	300 103 1 6	7,325	In addition to the rain mentioned in No. 41, another 55·8 mm. of rain fell the night before specimens were collected. Massive vertical and horizontal migration occurred. Although most of the migration on to grass took place within 15 cm. of the edge of the dung, larvae were recovered more than 50 cm. away. The diameter of the infested area including the dung pad's diameter was 126 cm. (2 × 53 plus 20 cm.) or 4′ 1½″
													435 6%					125 2%					6,118 83%					237 3%						410 6%		
43	7/3/56	11	Size: 18 × 18 × 4. Exposed to the sun	28·6	15·3	63	66·9	C. D.	+ 45%	+ 53%	– –	+ 2%	93 725	42%	53%	2%	3%	1,700	15–30 30–50	0–15 0–15	+	+	+	5 0	15–30			–	0	0–15 15–30 30–33 50–53 60–63	+ – – – –	+ + + + +	+ – – – –	– – – – –	62 2 0 1 0	2,588	There was no grass within 15 cm. of the edge of the dung pad and very little migration to the grass further away occurred. Most of the rain (55·8 mm.) fell in the first 24 hours and only a little rain (11·1 mm.) fell the last three days before specimens were collected. The distribution of rain probably accounted for the fact that most of the larvae migrated to the soil
													818 31%					1,700 66%					5 ± 0·2%					0						65 3%		
44	12/3/56	12	Size: 18 × 18 × 5. Exposed to the sun	29·5	15·7	60	40·4	C. D.	55% 44%	20% 32%	10% 20%	15% 4%	100 450	–	–	+	–	14	10–15 15–30 15–30 30–50 30–50 50–60 60–63	0–40 0– 5 5–40 0– 5 5–40 0–40 0–40	23% 22% + + + + –	77% 78% + + + + +	– – – – – – –	425 125 13 12 5 5 1	10–30		+	–	3	0–15 15–18 30–33 50–53 60–63	+ + + – –	+ + + – –	+ + – – –	– – – – –	90 31 2 0 0	1,276	The last 48 hours before specimens were collected 28·7 mm. of rain fell. Marked horizontal and vertical migration occurred although not to the same extent as in No. 42. The infested area including the dung pad's diameter was 144 cm. (2 × 63 plus 18 cm.) or 4′ 9″
													550 43%					14 ± 1%					586 45%					3 ± 0·2%						123 ± 10%		
45	19/3/56	23	Size: 21 × 15 × 5. In partial shade	28·5	15·9	65	96·6	E.	+	+	–	–	36	+	+	–	–	10	0–15 0–15 15–30 15–30 30–50 30–50 50–60 50–60 60–70 60–70 70–73	0– 5 5–30 0– 5 5–30 0– 5 5–30 0– 5 5–30 0– 5 5–30 0–30	39% 40% + + – – – – – – –	59% 60% + + – – + – – – +	2% – – – – – – – – – –	300 185 9 5 0 0 0 1 0 0 3	0–15		+	–	3	0–15 30–33 50–53 60–63 70–73	+ + + – –	+ + + – –	– – – – –	– – – – –	2 1 3 1 0	559	Similar remarks as made in No. 42 and 44 apply in this case
													36 6·5%					10 2%					503 90%					3 ± 0·5%						7 ± 1%		

*(1)—Soil adhering to roots.
†(2)—Loose soil.

TABLE No. II (*continued*)

Experimental No.	Date of Collection of Specimens in Veld	No. of Days in Veld	Dung Pad's Size in Cm. and Position in the Veld	Climatic Conditions: Mean Maximum Temp. in Degrees C.	Mean Minimum Temp. in Degrees C.	Mean Relative Humidity per cent	Total Rainfall in Millimetres	Third Stage Larvae Recovered: Part Examined	A Dung Pad: *Cooperia* spp.	*H. placei*	*O. radiatum*	*B. phlebotomum*	Total No. of Larvae Recovered	B Soil under the Dung Pad: *Cooperia* spp.	*H. placei*	*O. radiatum*	*B. phlebotomum*	Total No. of Larvae Recovered	C Grass Surrounding the Dung Pad: Distance from A in cm.	Height above Soil in cm.	*Cooperia* spp.	*H. placei*	*O. radiatum*	Total No. of Larvae Recovered	D Grass Roots Around the Dung Pad: Distance from A in cm.	*Cooperia* spp.	*H. placei*	*O. radiatum*	Total No. of Larvae Recovered	E Soil Next to the Dung Pad to a Depth of 2 cm.: Distance from A in cm.	*Cooperia* spp.	*H. placei*	*O. radiatum*	*B. phlebotomum*	Total No. of Larvae Recovered	Total No. of Larvae Recovered from all Sources	Remarks
53	28/5/56	17	Size: 13 × 12 × 8. Exposed to the sun	20·4	2·4	58	4·6	C. D.	83% 72%	14% 13%	3% 7%	— 8%	600 2,750 3,350 + 100%	+	—	—	—	1 1 0·003%	0–15	0– 5	—	—	—	0 0	0–15	+	—	—	1 1 0·003%	0–15	—	—	—	—	0 0	3 352	In contradistinction to No. 52, large numbers of larvae were recovered. This was possibly due to the exposure of the dung pad to the sun where temperatures were higher than in the shade
54	13/6/56	25	Size: 18 × 13 × 7. Exposed to the sun	18·1	2·2	59	4·0	C. D.	+ +	+ +	— —	— —	7 8 15	—	—	—	—	0 0	0–15	3– 7	—	—	—	0 0	0–15	—	—	—	0 0	0–15	+	—	—	—	2 2	17	In spite of exposure to sunlight atmospheric temperatures were too low to allow any appreciable development to the infective stage
55	14/6/56	63	Size: 15 × 11 × 10. In partial shade	22·5	4·2	54·5	9·4	C. D.	+ +	— —	+ —	— —	4 2 6	—	—	—	—	0 0	0–15	0–25	—	—	—	0 0	0–15	—	—	—	0 0	0–15	+	—	—	—	2 2	8	The long period of exposure to field conditions may have accounted for the poor larval recoveries
56	26/6/56	32	Size: 20 × 13 × 8. In partial shade	19·5	0·9	57	0	C. D.	— +	— —	— —	— —	0 8 8	—	—	—	—	0 0	0–15	0– 5	—	—	—	0 0	0–15	—	—	—	0 0	0–15	—	—	—	—	0 0	8	As in No. 52
57	18/7/56	104	Size: 18 × 14 × 4. In deep shade	22·5	3·8	47	9·4	C. D.	— —	— —	— —	— —	0 0 0	+	+	—	—	7 7	0–10	0–25	—	—	—	0 0	0–10	+	—	—	5 5	0–10	+	+	—	—	10 10	22	Dung beetles had been active which may have accounted for the presence of larvae in the soil and on the roots of grass. Note the long period of exposure to field conditions
58	7/8/56	105	Size: 16 × 14 × 12. Exposed to the sun	21·4	1·9	50	9·4	C. & U.D. L.D.	42% +	5% +	53% +	— —	1,375 5 1,380 99·6%	+	—	—	—	4 4 0·28%	0–10	0–18	—	—	—	0 0	0–10	—	—	—	0 0	0–10	+	—	—	—	2 2 0·14%	1,386	This was the longest period of exposure to field conditions and a fairly large number of larvae were recovered, most of them being confined to the dung pad. The dung pad was very thick in the centre and possibly this assisted in keeping the upper layer of the depth moist.

TABLE NO. III

Infective Larvae Recovered from Kraal Manure

Date	Number of Larvae Recovered from each Specimen				Total	*Cooperia* spp.	*H. placei*	*O. radiatum*	*B. phlebotomum*
	A	B	C	D					
29/ 2/56	0	0	0	3	3	—	x	—	—
9/ 3/56	8	5	0	—	13	x	x	x	x
22/ 3/56	3	9	29	3	44	x	x	x	—
28/ 3/56	3	2	3	6	14	x	x	—	—
3/ 4/56	24	1	2	1	28	x	x	—	—
12/ 4/56	0	0	0	0	0	—	—	—	—
19/ 4/56	12	8	1	0	21	x	x	—	—
25/ 4/56	0	0	0	0	0	—	—	—	—
4/ 5/56	0	0	0	0	0	—	—	—	—
9/ 5/56	0	0	2	18	20	x	x	—	—
16/ 5/56	0	0	1	0	1	x	—	—	—
25/ 5/56	0	0	0	0	0	—	—	—	—
30/ 5/56	0	0	0	1	1	x	—	—	—
14/ 6/56	0	2	3	1	6	x	—	x	—
4/ 7/56	0	0	0	6	6	x	—	x	—
19/ 7/56	0	0	0	3	3	x	—	x	—
9/ 8/56	0	0	0	0	0	—	—	—	—
28/ 8/56	0	1	1	0	2	x	—	—	—
12/ 9/56	1	1	0	5	7	x	—	—	—
19/ 9/56	0	0	0	0	0	—	—	—	—
25/ 9/56	0	0	0	0	0	—	—	—	—
2/10/56	0	0	0	0	0	—	—	—	—
11/10/56	0	0	12	0	12	x	—	—	—
23/10/56	12	18	12	0	42	x	—	—	x
31/10/56	0	0	0	0	0	—	—	—	—
7/11/56	0	0	0	0	0	—	—	—	—
20/11/56	25	0	0	0	25	x	—	—	—
30/11/56	0	7	10	5	22	x	x	x	—
5/12/56	2	300	250	0	552	x	x	x	x
11/12/56	0	2	0	1	3	x	—	x	—
19/12/56	1	0	0	4	5	x	x	x	—
26/12/56	0	0	2	1	3	x	x	—	—
1/ 1/57	0	0	3	7	10	x	x	—	—
8/ 1/57	0	2	0	1	3	x	x	—	—
15/ 1/57	0	0	0	0	0	—	—	—	—
22/ 1/57	0	0	0	0	0	—	—	—	—
27/ 1/57	0	0	0	0	0	—	—	—	—

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TABLE NO. IIIA.

Mean Number of Infective Larvae per Kg. of Manure in the Infested Kraal

Date	No. of Larvae per Kg. of Manure	*Cooperia* spp.	*H. placei*	*O. radiatum*	*B. phlebotomum*
5/2/57.....	380	x	x	—	—
12/2/57.....	6	x	—	—	—
19/2/57.....	0	—	—	—	—
26/2/57.....	88	x	—	—	—
5/3/57.....	0	—	—	—	—
12/3/57.....	0	—	—	—	—
19/3/57.....	10	—	—	—	—
26/3/57.....	40	x	—	x	—
2/4/57.....	0	—	—	—	—
9/4/57.....	30	x	—	—	—
16/4/57.....	986	x	x	x	x
23/4/57.....	17	x	—	—	—
30/4/57.....	9	—	x	—	—

TABLE NO. IV

Mean Number of Larvae per Pound of Herbage. Plot No. 1 was next to the Kraal and Plot No. 2 was approximately 300 Yards from the Kraal

Date	No. of Larvae per lb. of Herbage		Date	No. of Larvae per lb. of Herbage	
	Plot No. 1	Plot No. 2		Plot No. 1	Plot No. 2
29/ 2/56.....	223	0	12/12/56....	214	0
6/ 3/56.....	99	21	19/12/56....	0	0
14/ 3/56.....	270	54	26/12/56....	0	0
21/ 3/56.....	180	51	2/ 1/57....	0	0
28/ 3/56.....	28	23	8/ 1/57....	0	0
3/ 4/56.....	98	30	15/ 1/57....	0	0
10/ 4/56.....	43	18	22/ 1/57....	0	0
17/ 4/56.....	63	25	29/ 1/57....	0	0
24/ 4/56.....	48	0	5/ 2/57....	0	974
12/ 5/56.....	0	0	12/ 2/57....	0	0
23/ 5/56.....	51	0	19/ 2/57....	0	0
28/ 5/56.....	0	19	26/ 2/57....	104	0
7/ 6/56.....	0	0	5/ 3/57....	0	0
22/ 6/56.....	0	0	12/ 3/57....	0	0
4/ 7/56.....	0	0	19/ 3/57....	28	0
31/ 7/56.....	0	0	26/ 3/57....	0	0
6/ 9/56.....	0	0	2/ 4/57....	133	17
19/ 9/56.....	0	0	9/ 4/57....	0	0
26/ 9/56.....	0	0	16/ 4/57....	36	25
9/10/56.....	0	0	23/ 4/57....	15	0
11/10/56.....	0	0	30/ 4/57....	0	0
17/10/56.....	0	0			
23/10/56.....	0	0			
31/10/56.....	0	0			
7/11/56.....	0	0			
20/11/56.....	16	0			
30/11/56.....	20	0			
5/12/56.....	0	0			

TABLE NO. V

Five Groups of Calves used in Experiment C

Group	No. of Calf	Date of Birth and Introduction into Group	Method Calves were Reared from Birth
1	8235 8244 8246 8249 8250	28/3/56 8/7/56 12/7/56 30/8/56 3/9/56	Hand-reared and allowed access to the infested kraal from 2 p.m. to 7 a.m. From 7 a.m. to 2 p.m. confined to an adjacent calf pen with a ground floor covered with manure.
2	8235 8236 8240 8247 8253	26/3/56 27/3/56 1/5/56 13/7/56 24/9/56	Confined to a calf pen with a concrete floor which was cleaned twice daily. Suckled on dams at 7 a.m. and 2 p.m. Dams confined to the infested kraal from 7 a.m. to 2 p.m.
3	8227 8229 8245 8248 8251 8252	29/2/56 14/3/56 9/7/56 6/8/56 16/9/56 19/9/56	Grazed in the infested paddock and suckled on dams there at 7 a.m. and 2 p.m. Dams grazed elsewhere. Once a week calves were herded into the crush next to the kraal for faecal collections.
4	8230 8231 8232 8233 8234	21/3/56 22/3/56 24/3/56 24/3/56 26/3/66	Confined to the infested kraal with access to the calf pen used by calves of Group No. 1 from 2 p.m. to 7 a.m. Suckled on dams in the infested kraal at any time from 7 a.m. to 2 p.m.
5	8238 8239 8241 8242 8243	14/4/56 26/4/56 22/5/56 29/5/56 6/6/56	Grazed in the infested paddock from 2 p.m. to 7 a.m. and suckled on dams in the infested kraal at any time from 7 a.m. to 2 p.m.

TABLE NO. VI

Seven Groups of Calves used in Experiment D

Group	No. of Calf	Date of Birth	Date of Introduction into Group	* Method of Calf Rearing from Birth
1	13	5/11/56	13/11/56	As in Group No. 1, Experiment C.
	14	6/11/56	13/11/56	
	15	7/11/56	13/11/56,	
	21	10/11/56	13/11/56	
	31	13/11/56	13/11/56	
2	10	4/11/56	13/11/56	As in Group No. 2, Experiment C.
	12	5/11/56	13/11/56	
	18	9/11/56	13/11/56	
	28	12/11/56	13/11/56	
	92	23/11/56	25/11/56	
3	25	7/11/56	13/11/56	As in Group No. 3, Experiment C.
	36	14/11/56	14/11/56	
	51	13/11/56	13/11/56	
	52	14/11/56	14/11/56	
	59	21/11/56	21/11/56	
4	24	11/11/56	13/11/56	As in Group No. 4, Experiment C.
	26	10/11/56	13/11/56	
	50	20/11/56	20/11/56	
	81	21/11/56	21/11/56	
	99	29/11/56	29/11/56	
5	6	31/10/56	13/11/56	As in Group No. 5, Experiment C.
	17	8/11/56	13/11/56	
	27	11/11/56	13/11/56	
	60	22/11/56	22/11/56	
	87	22/11/56	22/11/56	
6	16	7/11/56	13/11/56	Hand-reared on concrete floors that were cleaned twice daily with water and brooms. Lucerne in stanchions was also fed to the calves. This was a control group and similar to Group C. Experiment B.
	19	9/11/56	13/11/56	
	20	9/11/56	13/11/56	
	23	11/11/56	13/11/56	
	32	13/11/56	13/11/56	
7	88	22/11/56	22/11/56	Suckling calves kept on concrete floors which were cleaned twice daily with water and brooms. Before the calves suckled at 7 a.m. and 2 p.m. the dams' udders were washed. This was also a a control group.
	110	6/12/56	6/12/56	
	119	11/12/56	11/12/56	
	121	13/12/56	13/12/56	
	124	13/12/56	13/12/56	

* NOTE.—Calves born prior to 13 November, 1956, were placed on concrete floors and then placed in groups. Calves born after 13 November, 1956, were placed into groups at birth.