EPIZOOTOLOGY OF WORM INFECTION.
(With special reference to worms of domestic animals.)

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It has long been recognized that preventive measures against worm parasites, based on a knowledge of their life-histories and bionomics, are much more expedient than the treatment of infected animals—although the latter may form an important part of such preventive measures. Consequently, in recent years much attention has been directed to the detailed study of life-histories, in the widest sense of the word.

The following types of life-histories, arranged from the epizoological point of view, are found (a few special cases are not included in this scheme):

I. Eggs leave the host (in faeces, urine, etc.).
   (i) Eggs hatch in the free state:
      (a) Larvae become infective, without intermediate host, e.g., most Strongyles.
      (b) Larvae pass into an intermediate host (Trematodes) and enter the final host after leaving the intermediate host (Fasciola, Schistosomum) or with a second intermediate host (Paragonimus, Clonorchis).
   (ii) Eggs do not hatch in the free state:
      (a) Eggs become infective, without intermediate host, e.g., Ascarids.
      (b) Further development in and entrance into final host with intermediate host, e.g., Tapeworms, Spirurids (Nematoda).

II. Larvae leave the host, usually intermediate host necessary, e.g., Habronemias of Horse.

III. Larvae remain in host, transmitted by blood-sucking Arthropoda, e.g., Filarias, or transmitted in other ways, e.g., Trichinella.

The factors which control the incidence of worm infection are:
(1) those operating on the free stages of the parasite or on its intermediate host; these are chiefly climatic;
(2) those influencing the chances of the parasite’s gaining entrance into the host, which are numerous and widely different in nature;
(3) those acting for or against the successful establishment of the infection, i.e., the conditions which the parasite finds in the host.

These factors apply to any special case in a degree depending on the nature of the life-history; e.g., those with a life-history of Group I11 type are not affected directly by factors of the first group, only their intermediate hosts may be affected.

These controlling factors, since an accurate knowledge in the combat against them is so enormously wide, that only a reading of the following pages.

Climatic Condition—A living part of a worm life-history, other than the parasitic host, may be considered as a simple organism, with the free state and the larval stage (parasitic) the third stage (infective) and the intermediate hosts cannot be included in the period is effected by reactions to temperature, humidity and viviparity or viviparity of the free-living form or of the intermediate host, or accidental cause, or result, is coupled with the other stages. The eggs and larvae, for instance, have a very wide range of temperature that are not suitable for hatching. Anomalies exist in cases of Acanthoecauleus, where the free-living stage is not known and none of the free-living forms capable of hatching; or the case of Achiellostrongylus that are very nearly in the same way (Cameron, 1927) and its effect on development.

The most important factors are temperature and moisture, realized, some concrete results from the more clearly established temperature. Temperature—Apart from the known fact that a small number of cases of worm life-histories is an optimal temperature for that stages. This temperature is probably near 25°C. Above that temperature the organism, and with considerably lower temperatures, usually takes place, so that the organism is not reached at all, or at least not for more rapid development of the parasite and may not be detrimental; but to the same end. As a frequent development, often death is as a rule not possible. Strongylus type of life-history of Trichostrongylus in 60 hours (Mönning, 1924) is the stage at a low (winter) temperature, and is the case with most such stages, on which such climatic...
These controlling factors can now be considered in greater detail, since an accurate knowledge of them is of paramount importance in the combat against worm infection. But this subject is so enormously wide, that only the main points can be touched on in the following pages.

**Climatic Conditions.**—The longer the non-parasitic or free-living part of a worm’s life is, the less the worm has given itself over to the parasitic habit, the nearer it is still to the free-living forms and the more resistant to the effects of adverse climatic conditions. This is quite true in cases like those of *Haemonchus contortus* and *Oesophagostomum columbianum*, in which the eggs hatch in the free state and the larvae are free-living up to and including the third stage (infective larva), although even in these cases the pre-infective stages cannot resist desiccation. Shortening the free-living period is effected by remaining a longer time in the host (ovoviviparity or viviparity) or in the egg-shell, or by making use of an intermediate host, or a combination of these; but this, either as cause or result, is coupled with loss of resistance of the free-living stages. The eggs and miracidia respectively of *Fasciola hepatica*, for instance, have a very short span of life if climatic conditions are not suitable for hatching or a suitable snail cannot soon be found. Anomalies exist in cases like those of the lungworms, e.g. *Dictyocaulus filaria*, where the eggs hatch immediately after being laid and none of the free-living stages is resistant to desiccation, although the life-history is of the Strongyle type (Daubney, 1920). These worms seem to be badly in need of an intermediate host and are apparently on their way to develop that habit, as is seen from the case of *Aelurostrongylus abstrusus* of the cat; in this case, larvae that are very nearly infective to the cat, still find shelter in mice (Cameron, 1927) and it is conceivable that this is a relatively recent development.

The most important climatic factors affecting worm parasites are temperature and moisture. Although this is usually vaguely realized, some concrete facts may be necessary to make their importance more clearly evident.

**Temperature.**—Although the fact has been definitely established in a small number of cases only, it may be said that in general there is an optimal temperature for the development of the non-parasitic stages. This temperature varies slightly with the species and lies near 25°C. Above this optimum, development is not so successful and with considerably higher temperatures (say 40°C) degeneration usually takes place, so that the infective stage is either of low vitality or is not reached at all. The high temperature may act by causing more rapid decomposition of the medium in which the worms develop and may not be detrimental in itself, but in practice as a rule, this comes to the same. At lower temperatures, which are met with more frequently, development is slower or may even practically stop, but death is as a rule not the result, especially in worms with the Strongyle type of life-history. Whereas the infective stage of e.g. *Trichostrongylus instabilis* is reached under an optimal temperature in 60 hours (Mönig, 1927), it may take several weeks to reach this stage at a low (winter) temperature. The infective stages of this same species, frozen hard for 14 days, are still infective. The same is the case with most species that have this type of life-history and on which such climatic factors chiefly operate. As an exception,
the sheep hookworm, *Bunostomum trigonocephalum*, must be mentioned (Cameron, 1923). Temperature alone is thus not a very important controlling factor, but it becomes important in combination with the moisture factor.

*Moisture* is usually an absolute essential to the free-living, pre-infective stages. These, in the case of *Haemonchus contortus*, *Oesophagostomum ostertagi*, and other species die immediately on drying. Rare exceptions occur even here; Looss (1911) mentions that eggs of the Strongyles and Trichonema (Cyclocoptera) of the horse, containing complete embryos, developed further on moistening, after they had been dry for six months, but not after nine months. The writer has found a similar resistance in the case of *Trichostrongylus* species of sheep; eggs containing complete embryos are at the moment of wetting still able to revive, after having been dry in faeces for over nine months; this is the only pre-infective stage of these worms that is so resistant.

The infective stages of the strongyles usually resist drying to a marked degree; 0.1 per cent. of *H. contortus* larvae revive after having been dry on glass slides in the laboratory for six months. Also the cercariae of *Fasciola hepatica* have recently been shown to live in hay for about eight months (Marek, 1927). Exceptions occur, which are important to note, e.g. the infective stages of *Bunostomum trigonocephalum* (see Cameron, 1923), *B. phlebotomum* (see Schwartz, 1924), and *DactylogyrhusSharpei* (see Dunbar, 1926), do not survive drying, and hence infections with these worms are acquired only on moist pastures.

The length of life of the infective larvae in a pasture, which is an important factor, depends to a great extent upon their power of resistance against drying. It is well known that the infective larvae of many Strongyles live in the herbage and the surface soil while there is moisture, penetrating deeper down during dry periods. A large proportion will, however, be caught by rapid drying and die unless they are resistant. It is usually stated that the infective larvae of *Haemonchus*, *Oesophagostomum*, and *Trichostrongylus* of sheep, for instance, can live about a year in a pasture, while it is understood that favourable conditions are necessary to attain the maximum period. Recent experiments have qualified this statement to some extent by showing that a year of life can be reached only under the most favourable conditions, that this probably happens rather rarely in nature and that the type of soil also plays an important part. It was found that a few weeks of summer temperature would suffice to kill off all the larvae of these species in a very heavily infected plot of black turf soil, while they lived slightly longer in a plot of light, red soil and about 10 months in pots of the same soil which were sheltered and kept moist. (The experimental data underlying this and several other statements made in this article will be published in the Reports of the Director of Veterinary Services). Drying, undoubtedly, plays an important part in those cases, but the high temperature of the soil must be an important factor, stimulating the larvae to greater activity and consequently exhausting their food reserves, since they do not feed.

In connection with the moisture factor, the conformation of the country is important. It will generally be found that hilly country is more worm-infested than flat country, other things being equal, since the valleys between the hills receive little or no rainfall, while the hills support less moisture in the lower parts.

In South Africa the helminthologist must have noticed the effect of moisture in the low veld on the infectivity of worms in the dry veld. Stockmen who change from a low veld to a drier veld remain in the same locality, the stockfarmers change their herds. In any case, everyone finds that the dry season stops and the wet season starts again. During dry years and in the wet season, the worms are usually forgotten again.

The greater part of the year is at any rate given the best conditions for the development of worms. The summers are warm, while the dry winter months do not last for an occasional shorter period. In the winter, development of the infective larvae is generally arrested before they are infective, and the worm eggs are returned to the soil, which are thus destroyed by the process of maturation. The best place in which the worms are found is in the soil, and it is no wonder that when the worms are no longer found in the dung and are not left there for several months. The dry season is a time of great danger to the worms, for although the worms can live in the soil, they cannot survive drying, and are readily picked up and killed by the grasshopper or other insects.

The winter rains are also very dry, although worm infection would certainly be higher during this period as the other is in the summertime. Winter rains fall over large stretches of country, while the summer rains over a much smaller area.

A highly interesting stretch of country, viz. a region that is considered to be a desert and consequently dry at least in parts, a region where rainfall is 20 to 25 per cent. of the total rainfall in the summer months, and the remainder is supplied by springs and streams. Such a region can be divided into two parts, viz. the uplands and the lowlands. The uplands are usually covered with grassland, while the lowlands are often covered with water. The uplands are usually covered with scrub and thorn bushes, while the lowlands are usually covered with grassland.

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valleys between the hills are usually moist and concentra-
tion of infection also results here on account of the transport of
larvae to the lower levels by rains.

In South Africa wet years and dry years occur frequently, and
the helminthologist can find no better lesson on the important role
of moisture in the life-history of worms than what he can learn by
observing the effects of these climatic ups and downs on the incidence
of worm infection in the livestock of the country. During wet years
the stock farmers clamour for remedies, and when the dry season
comes, everyone finds a "remedy," which "cures," because infection
stops and the worms concerned do not live long in the animals.
During dry years all the advice given on preventive measures is
usually forgotten and the next wet cycle starts the whole problem
again.

The greater part of South Africa has a summer rainfall which
gives the best conditions, warmth and moisture, for the development
of worms. The summer, in this area, is, therefore, the wormy season,
while the dry winter is practically a safe period for stock. Even
if occasional showers of rain or a heavy dew or frost may fall in
winter, development proceeds so slowly that drying overtakes the
larvae before they reach the infective stage. Since the pasture in
general is, therefore, safe during the winter, one's attention is
focused on a few unsafe places. These are dams and drinking pools,
which are unsafe all the year round. In the first place, they contain
the washings of the countryside and the larvae can live in the water
for several months. Secondly, at the edges of the water where there
is constant moisture and sufficient oxygen, development can proceed,
though slowly, and since the animals come frequently to drink and to
feed on the grass that grows here, infection is concentrated
and readily picked up.

The winter rainfall area of South Africa, is relatively small and,
although worm infection is here not as serious as in the other part,
it would certainly be much less if this area were as dry in summer
as the other is in winter. Summer rains are more frequent here
than winter rains in the other part and, besides, the country is
mountainous with many small streams.

A highly interesting condition is found in Beleruanalnd. This
stretch of country, bordering on the Kalahari desert, and generally
considered to be a dry region, is nevertheless heavily worm infested,
at least in parts, and even hookworms are quite common. If this
region be visited during the dry winter, when many sheep die of
worms, it would be difficult to conceive how this is possible. During
the summer, when it rains, numerous small, shallow pools or "pans"
fill up and hold water for some time. Around these pools the grass
remains green when the rest of the pasture dries up, the sheep graze
here and drop worm eggs, which find suitable conditions for develop-
ment, and the resulting conditions are those of an oversown, wet
pasture. When everything is dry again, the sheep begin to
suffer from want of food, the effects of worm infection become evi-
dent, but the source of infection is then rather obscure.

The Chances of Reaching the Host.—(i) Moisture and light
control to a great extent those larvae of the Strongyle type which
migrate up the grass in a dull light and go down for shelter when
the surface of the grass dries and the light becomes strong. It is
hence a good practice to allow animals to graze only during that
time of the day when the sun is well up. The dry winter drives the
larvae into the soil and so keeps them away from a host.

(ii) Insanitary conditions are well known to favour worm in-
fection. As examples may be mentioned Ascaris infection of pigs,
for which a remedy has been devised in the McLean County system
of swine sanitation with the purpose of rearing pigs free of infection
(Raffensperger 1927, Hall 1928); Ascaris in poultry kept in unclea-
pens; hookworms in dogs kept in kennels as compared to dogs running
free; infection of horses with Habronema, which are transmitted
through the agency of flies breeding in horse manure and which can
be remedied by suitable manure disposal; finally, the watering of
animals from dams and pools, which have been mentioned above.
It is certain that watering animals from dams is responsible for a
large proportion of the worm infection in South Africa. If pure
water cannot be given, it is simple enough to fence in a dam and to
lead the water into troughs by means of pipes placed not too near
the bottom of the dam; this would improve the position considerably.
Under insanitary conditions can also be grouped overstocking and
permanent pastures. These both tend to concentrate infection and
are so obviously favourable to the parasites that they need not be
further discussed. It may, however, be interesting here to refer to
the findings of Hall (1927) in Central America, where Haemonchus
contortus and related Nematodes were found to be practically absent
owing to wide range grazing and an annual dry, hot season. As a
remedy for these evils, methods of pasture rotation have been re-
commended for many years, which implies that the farm must not be
overstocked.

(iii) The ways of grazing of different animals influence the
possibility of their becoming infected. The cercariae of Fasciola
hepatica are known to settle on plants at about water level, and it is
recognized that close grazing animals like sheep, are more liable to
become infected on moist, where infected pastures, than are cattle,
which have the habit of grazing high. The same holds in the case
of H. contortus and related worms, whose larvae hide near the ground
in the dense grass for the greater part of the day, while the sunlight
is strong.

(iv) The presence and frequency of intermediate hosts, where
these are necessary, is obviously of great importance, not only to
make development possible, but also to assist the parasite in reaching
the final host. As a practical example may be mentioned the fact
that fowls running on free range are usually more heavily infected
with tapeworms than are fowls kept in in only moderately clean
pens, because in the former case the birds have greater opportuni-
ities of feeding on the intermediate hosts.

(v) The action of mechanical vectors is important in certain
cases. It is well known that earthworms frequently swallow the eggs
of fowl Ascaris and tapeworms (Syngamus trachea) and, since they
are readily eaten by fowls, they serve to bring the parasite to its
host. In the case of Syngamus this appears to be such an important
factor, that earthworms were at one time considered to be necessary
and true intermediate hosts of this worm.

(vi) Nematodes like Ascarids and hookworms, which migrate in
the body of the host, may cause prenatal infection, and in this way
reach a susceptible host and not be very susceptible to expul-
sion, especially in the progressive young. The more and more, and it has
be fatially infected at birth.

The Chances of Success of the Host, there are several
will be successfully established.

(i) The host may be resistant; this must happen

(ii) Many species of Nematodes are known to have
hosts, but usually one species will be the host, and the best develop-
of Echinococcus granulosus are not always fertile, i.e., sterile.
The pig Ascaris (A. suum) is fully mature in sexual maturity and is the

(iii) In some cases infection is
not acceptable, but even then the tissue damage and consequent
symptoms, such as ruptures, may be very severe. In some cases
those that reach the central nervous system, are distal to any
further.

(iv) The number of eggs passed in the feces may have a bearing on
the infection, as a heavy faecal loading may be a matter of the
liver to the abdomen, and

(v) The existence of immunity is well known, but it is rather obscure. In general, immunity does not exist, but there are some experiments
which prove that immunity may be possible. This is an interesting point,

if the cause of the results. Fernandez-Nunez (1927) found that
coelomederus vulpis became infected after 7-12 months. The injection
of O. felineus by the

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not be very susceptible herself. The importance of prenatal infec-

in the case of Ascaris of dogs, is being realized

more and more, and it has been found that whole litters of 

fertility of birth (Shillinger, 1923).

The Chances of Successful Infection. When the parasite reaches

The host may be or an unsuitable species, and no infection 

results; this must happen very frequently.

(iii) Many species of worms can live in several different host 

species, but usually one of the latter is the most normal or natural 

host, and the best development is obtained in it; e.g. the cystic form 

of Echinococcus granulosus occurs in many mammals, but the cysts 

are not always fertile, i.e. develop tapeworm heads. In cattle usually 

80 per cent. are sterile, while in sheep they are as a rule fertile. 
The pig Ascaris (A. suum) may develop in sheep, but does not attain 

sexual maturity and is thus infertile in this host.

(iv) In some cases the host species may be correct and sus-

ceptible, but even then a large number of parasites do not succeed 

because they fail to reach the correct organ. In larvae of Multiceps 

multiceps, which enter the bloodstream of the sheep from the ali-

mentary tract, are distributed to all parts of the body, but only 

those that reach the central nervous system can successfully develop 

further.

The number of parasites entering the host simultaneously may 

have a bearing on the success of the infection. When a sheep 

swallows a few eggs of Trichurus suis the larvae pass through 

the liver to the abdominal cavity and grow into the Cysticercus tenui-

colis, but when the infection is heavy, the liver may be so damaged 

that the host dies while the parasites are still quite immature. If 

lamb becomes heavily infected with O. columbianum, the worms 

returning from the intestinal wall into the lumen cause such a marked 

irritation, that diarrhoea results and the majority of the young 

worms are expelled; this is seen in lambs on the sixth day after 

infection and the diarrhoea has a typical dark-green colour.

(v) The existence of a resistance to worm infection, also called 

immunity, is well known, but the exact nature of this quality is 

rather obscure. In general, it is believed to contain an age factor, 

but this may possibly only mean that a previous infection has existed, 

though some experiments seem to contradict this (Herrick, 1925).

This is an interesting problem and may in future become important 

if the cause of the resistance can be more definitely determined. 

Fernán-Núñez (1927) found that dogs infected with eggs of Tricho-

cephalus vulpis became resistant to infection with that parasite for 

7-12 months. The injection of lambs with saline filtrates of dried 

O. columbianum by the writer did, however, produce no resistance. 

Ackert and Herrick (1928) showed that chickens become progressively 

resistant to infection with Ascaridia lineata as they grow older and 

that one infection produces a strong resistance against a subsequent 

infection. Sandground (1928), working with species of Strongylodes, 

found that dogs were refractive to reinfection for over six months 

after having lost a previous infection and that they became refractive
to superinfection a few weeks after beginning of the primary infection and before the latter had disappeared. In the case of *O. columbianum* Voglia (1924) found that the development of the parasite in the susceptible lamb differed greatly from its development in the more resistant adult sheep. In lambs the larvae stay in the intestinal wall for about 5 days and then return to the lumen of the intestine, usually without causing any nodule formation. In adult, resistant sheep, a large nodule develops around the larva and many larvae never leave these nodules; the writer found larvae in such nodules more than three months after infection. When the contents of the nodule later become cheesy, and then calcify, the larvae either die there or leave the nodule and wander about between the muscular coats of the intestine, leaving behind them a trace of pus similar to that found in nodules, and only rarely do they pass into the lumen. It appears from most of the available evidence, that, in the case of intestinal worms, the immunity is a local one of the intestinal mucosa and not a general body immunity.

(vi) The general condition of the host is very important in determining the success of the infection and the length of its duration. No better example can be quoted than that of *Trichostrongylus* in sheep; it has been found to be quite impossible to infect good-conditioned, but otherwise perfectly susceptible lambs, with this parasite. Also, if sheep are infected and are allowed to improve in condition the infection is lost immediately. Natural *Trichostrongylus* infection is, therefore, found only in sheep that are underfed or infected with other more virulent worms like *H. contortus*. Although general experience from the realm of bacterial diseases would lead one subconsciously to expect greater resistance in strong, healthy animals, it is difficult to understand this in the case of worms, since the parasite should find more and better food in a healthy host than in a weak one. Possibly it is here, as in the bacterial diseases, a question of the production of antibodies, even though immunity may be only local.

The practical application of this knowledge should be to prevent worm infection by aiming at good condition of the animals, by proper feeding as well as by keeping them free of the most injurious parasites, external and internal, which pave the way for others.

LITERATURE.


Paper No. 10.

THE PREVENTION AND TREATMENT OF ASCARIS.

By P. L. De Roux, B.I.

Officer, Department of Agriculture, Capetown.

For the control and treatment of *Ascaris* (or Distomiasis) from our primitive species should be acquainted with the habits of water, and to these parasites but present in Africa, it is practically non-pathogenic.

I. THE INVESTITION.

Fasciolaria among the large areas where the mollusca abound. This mollusca is said to be an extant under many names. *F. gigantea.*


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Paper No. 10.

THE PREVENTION AND TREATMENT OF FASCIOLIASIS IN CATTLE.

By P. L. Le Roux, B.Sc. (Edin.), M.R.C.V.S., Veterinary Research Officer, Department of Agriculture, Union of South Africa.

For the control and the complete eradication of Fascioliasis (vel Distomiasis) from our herds and flocks it is firstly essential that we should be acquainted with the habits and biometrics of the fresh water snails which may act as intermediate hosts of Fasciola hepatica and F. gigantica and, secondly, that we should have a drug lethal to these parasites but practically non-toxic to the vertebrate host.

Dicrocoelium lanceolatum will not be considered because, if present in Africa, it is not of common occurrence and is regarded as practically non-pathogenic to its definitive host.

I. THE INVERTEBRATE HOSTS AND THEIR HABITS.

Fascioliasis amongst cattle and sheep in South Africa is limited to those areas where the freshwater snail Lymnaea natalensis (Krauss) abounds. This mollusc is confined to Africa, south of the Sahara. It is said to be an extremely variable snail and has been described under many names. This species transmits both F. hepatica and F. gigantica.