THE EFFECT OF THE STOMACH WORM, *HAEMONCHUS CONTORTUS*, ON THE NUTRITION OF SHEEP

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INTRODUCTION

The role that internal parasites play in the nutrition of sheep has been investigated by many workers. However, the specific effects that pure cultures of parasites have on the nutrition of sheep has received little attention. Flock owners have observed that lambs are very susceptible to parasitism during periods of stress such as weaning and castration. Large losses attributed to parasites are also observed during the latter part of the summer when most of the forage is of low nutritive value.

Numerous species of internal parasites infect sheep. The common ones are: the stomach worm (Haemonchus contortus), intestinal worms, nodular worms, whipworms, tapeworms and liver flukes. The most common of these in Oklahoma is the common stomach worm.

Digestion studies have been reported where pure cultures of relatively non-pathogenic parasites were experimentally administered to lambs. Other digestion studies have been reported where mixed cultures of parasites were used.

This study was undertaken primarily to find out what effect a pure culture of a pathogenic type of parasite, Haemonchus contortus, would have on the nutrition of sheep as determined by the following: (1) apparent digestibility of the various constituents of the ration; (2) hemoglobin content and red cell volume levels of the blood; (3) growth and (4) general performance.

Another purpose of this experiment was to determine the value of increasing levels of protein in the ration of infected sheep.

Various hypotheses have been advanced to explain the manner in which parasites living in the alimentary tract harm their hosts. The following hypotheses have been formulated. (1) The worms produce a toxic substance which is absorbed by the host and causes the resulting pathological condition. (2) The ingestion of blood by the parasites and the loss of blood from the wounds produces primarily an anemia. (3) The parasites produce an anti-enzyme which inhibits the action of digestive enzymes in the digestive tract of the host. This action may produce a chronic state of malnutrition. (4) The nervous excitation of the host due to the irritation of the intestinal mucosa by the parasites produces an increased energy metabolism.

The diseases which are caused by the nematode family, Trichostrongylidae, are called trichostrongylidoses. When parasitic disturbances are caused by relatively pure infection of one genus, they are named for that genus. Thus we have haemonchosis, a disease caused by a relatively pure infection of Haemonchus.

LITERATURE REVIEW

Very few studies have been reported on the specific effects of internal parasites on the nutrition of sheep. Apparently internal parasites have varied effects on the nutrition of sheep, and this review of literature is limited to the controlled experiments reported on this subject.

Digestion and Metabolism Studies

Andrews (1938) made a detailed study at the Agricultural Research Center at Beltsville, Maryland, of the effect of nematode infection on the nutrition of lambs. The nematode used in this experiment was Cooperia curticei, a relatively non-pathogenic parasite. This parasite rarely produces clinical disturbances in sheep in the United States. The purpose of his experiment was to explain the manner in which parasites living in the alimentary tract of sheep harm their hosts.

Four pairs of cross-bred Hampshire-Southdown wether lambs were used in this work. Andrews used only the nematode, Cooperia curticei, in the experiments that were conducted. Specimens of Cooperia curticei were collected from the small intestine of sheep slaughtered at a slaughterhouse in Washington,D. C. The females were cut up, and the eggs that were liberated were incubated for seven days in petri dishes. The larvae that developed from the eggs were administered to a lamb that was parasite-free. This lamb began to pass eggs on the eighteenth day after the administeration of the larvae. The larvae obtained from the feces of this lamb were used to infect the experimental lambs. These lambs were four months of age when the first doses of infective larvae were administered. The number of larvae administered daily varied from 250 to 5,000 larvae per lamb. The total number of larvae administered to the lambs varied from 63,000 to 135,000.

The lambs on experiment received the following ration: alfalfa meal, 27 pounds; ground oats, 10 pounds; corn meal, 5 pounds; and bran, 3 pounds. Quantitative analyses were made of the feed, feces, and urine samples and of the right femur of each lamb. The results indicated that although the infected and control lambs of each pair consumed approximately the same quantity of feed, the control lambs gained approximately 4 pounds more than the infected lambs. Furthermore, the infected lambs required an average of 76.7 pounds more feed than the control lambs to produce a gain of 100 pounds. The average apparent digestibility coefficients of the different nutrients of the feed were found to be the same for both the infected and the control lambs. There were also no significant differences in the nitrogen metabolism of the two groups. There was no evidence that the calcium and phosphorus metabolism was altered in any of the infected lambs. This evidence was provided by bone analyses which indicated no significant differences as shown by the calcium and phosphorus content of the bones.

The most significant result obtained in the experiment by Andrews was the apparent decrease in the ability of the infected lambs to convert their feed to an increase in weight. This phenomenon could have been produced by a number of factors. Dehydration of tissues was discounted as the causative factor producing this result since the lambs did not develop diarrhea nor did they suffer from hemorrhage in the intestinal tract. The infected lambs were given an abundant supply of water.

Andrews stated that the increased irritation to the intestinal mucosa may have been responsible for the increased energy metabolism of the infected lambs. Also, the increased energy metabolism may have been accounted for by the nervous excitation of the host caused by the production of areas of inflammation in the digestive tract and by the possible, although undemonstrated, accumulation of guanidine in the blood of the infected lambs. Andrews concluded that infections with this relatively non-pathogenic nematode decreases the ability of lambs to utilize their feed even though they show no clinical symptoms of being parasitized.

Digestion trials were conducted by Stewart (1933) who used sheep infected with a natural mixed culture of nematodes. He reported that as the daily average number of worm eggs decreased, the digestibility of the crude-protein and crude-fiber portions of the ration increased.

Shearer and Stewart (1933) found that more calcium and phosphorus were stored by lambs passing relatively small numbers of worm eggs than by those passing relatively large numbers of eggs. Stewart suggested that the inability of the infected lambs to make use of these components of the ration might be due to an anti-enzyme which he demonstrated in the tissues of the parasites. According to Stewart this anti-enzyme may be present in sufficient quantities to impair seriously the function of enzymes in the digestive tract of the host. This may be a factor concerned in the chronic malnutrition seen in heavy parasitic infections.

Tissue Studies and Symptoms Observed in Parasitic Infections of Sheep

Andrews (1937) conducted an experiment using eleven cross-bred Hampshire-Southdown lambs in which he infected them with species of trichostrongylus, (infrequent in the United States): T. vitrinus, T. columbriformis, and a small number of T. axei. Repeated small doses of 1,000 to 3,000 larvae to some of the animals apparently enabled them to build up some resistance and to survive the infection. Evidence that resistance was developed by the surviving animals is shown by the fact that only 1.5 per cent of the larvae administered were recovered from the animals on post mortem; whereas, animals receiving 150,000 to 115,000 larvae in a single dose died from the infection and 41.8 per cent of the larvae administered were recovered in post mortem examinations. Andrews stated that in the cases where several doses of larvae were administered, if the smallest dose was 3,000 larvae or more, the acquired resistance was not sufficient to protect the animal from death resulting from the infection.

The maximum number of eggs per gram of feces appeared in 21 to 81 days after the first administration of larvae. The time necessary for the maximum number of eggs to appear, as well as that necessary for diarrhea to develop and death to occur was directly associated with the severity of the infection and the rapidity with which the infection was acquired. These time intervals were short following a single large dose or a few large doses of larvae.

The maximum number of eggs per gram of feces in fatal cases of trichostrongylosis varied from 1,800 to 54,000. It is obvious that no eggs will be found in the feces if death occurs before the eighteenth day after administrating the larvae. Also, a large number of eggs per gram of feces will be found if the quantity of feces expelled is less than normal.

Andrews reported that diarrhea which is characteristic of trichostrongylosis occurred 13 to 59 days after the first administration of the larvae. Diarrhea usually appeared suddenly and in most cases was continuous until the death of the animal. Animals that harbored fatal infections of trichostrongylus appeared depressed, suffered from abdominal pain and were unable to eat all the feed given to them. Andrews states that the emaciation of these lambs was due to their inability to eat sufficient feed during the period of the infection to keep them in good nutritional condition. The emaciation may have also been due to the dehydration of the tissues brought about by the continuous diarrhea. There was no evidence of anemia due to trichostrongylosis in this experiment. However, the blood examination did indicate a marked increase in the number of leucocytes.

Death occurred in 16 to 88 days after the first administration of larvae and in 3 to 53 days after the onset of diarrhea. Shortly before death the animals became rapidly weaker, went into a state of collapse and died about two hours later.

Andrews found that although there was a reduction in the quantity of feed ingested by most of the animals, the severe emaciation associated with malnutrition was noted only in those animals that survived for a relatively long period of time. Those lambs that received the larvae from day to day, in a manner similar to that in which they would have acquired it from a pasture, developed severe emaciation. Andrews noted, from the post mortem examination of the lambs that died from trichostrongylosis, that there was diffuse eneritis throughout the intestine of all the animals.

Gordon and Ross (1936) in Australia, reported that daily doses of 4,000 trichostrongyle larvae were fatal to their experimental lambs. They reported that diarrhea occurred in their lambs 6 to 7 weeks after daily infection with 4,000 larvae was begun. Monnig (1931) found that the eggs of the Trichostrongylus spp. appeared in the feces of infected sheep 21 days after infection. He also observed a friable condition of the liver and a swelling under the throat of animals suffering from trichostrongylosis.

Bennetts (1933) observed that animals suffering from trichostrongylosis died of malnutrition that resulted from loss of appetite and failure to ingest sufficient feed. Kauzal (1933) found 35,000 to 40,000 worms on post mortem examinations of lambs that died of trichostrongylosis. Gordon and Ross (1936), however, reported only 3,900 to 11,360 worms from their lambs that died from experimental trichostrongylosis.

Edgar (1936) stated that the outstanding feature observed on post mortem examinations was the extremely emaciated condition of the carcass and the presence of fluid in the abdominal cavity. Boughton (1932) reported that the mucous membrane of the entire length of the small intestine of lambs dying of trichostrongylosis was studded with small ulcers.

Weir (1947) at Wisconsin, made a study of the relationship of nutrition to parasite (Haemonchus contortus) infection in sheep. A group of lambs were given an initial dose of 4,000 larvae of Haemonchus contortus on July 14, 1947, and a second dose of 45,000 larvae was given on August 26. The lambs were then divided into four lots. Lot I received the basal ration which was a low protein ration containing iodized salt. Lot II received the basal ration plus additional minerals (bone meal and trace minerals). Lot III received the basal ration plus additional protein, and lot IV received the basal ration plus minerals and additional protein.

The lambs of lot IV receiving the additional minerals plus a high level of protein made the largest gains. Both the infected and control lambs on the basal ration made poor gains. The hemoglobin value of the lambs was determined weekly by the oxyhemoglobin method. Throughout the experiment the lambs receiving the higher level of protein had the higher hemoglobin values.

The hemoglobin values indicated that lambs in lots I and II following the infection with 45,000 larvae became very anemic before death. The hemoglobin level of the controls varied from 8.09 to 13.58 grams per 100 ml. of blood. The hemoglobin values of the lambs dying from the infection were very low, and varied from 3.35 to 2.55. Lambs in lots I and II died 27 to 40 days after the administration of the second dose of larvae. The hemoglobin of all the lambs dropped following this second dose. The drop was most marked in the lambs receiving only minerals as a supplement in their ration. Other blood constituents, blood plasma vitamins A and C, inorganic phosphorus, and total plasma protein, were adversely affected in varying degrees by the Haemonchus contortus infection. The higher level of protein in the ration apparently aided the lambs in maintaining higher hemoglobin values. The lambs were sacrificed for worm counts on November 4. The average number of worms found was 1,804; 8,617; 4,098 and 5,000 for the lambs from lots I, II, III and IV, respectively.

Weir concluded that when the infection reached only moderately high levels as exemplified by the dose of 4,000 larvae, minerals in the ration appeared to aid the host in withstanding the parasitic infection. However, when the infection became very high as when 45,000 larvae were given, the minerals seemed to aid the parasite more than the host. The higher level of protein seemed to aid the sheep in withstanding the parasitic infection as measured by hemoglobin values. Worm eggs were detected in the feces of the lambs in lots II and IV twenty-one days after the administration of the large dose of 45,000 larvae; whereas, the lambs from the non-mineral lots began passing eggs in the feces 26 to 27 days after the infection. More worms were found in the abomasum of lambs which received minerals than in those that did not receive minerals in the ration.

Whitlock (1946) at the Cornell Experiment Station conducted an experiment using two lots of eight lambs each. Both lots had a natural infection of trichostrongyae. The animals were fed clover hay, oats, and a protein supplement. Lot I received dried Brewers' yeast as a protein supplement, and lot II received linseed meal. The protein supplement was fed at a level of 10 to 13 per cent. Whitlock concluded from this experiment that lambs weaned at an early age (two months) may suffer from trichostrongylosis although they are treated with phenothiazine. He also suggested that yeast may have some effect in overcoming the anorexia in trichostrongylosis.

In the summer of 1947 Whitlock conducted a second experiment. The object of this experiment was to reproduce the trichostrongylosis as in experiment I, and to determine the value of yeast and supplemental feeding in controlling the disease. Sixty-five lambs and sixty ewes were used in this experiment.

The entire flock had access to very good pasture. The flock was divided into three groups. One group was grazed druing the day and the lambs were creep fed oats and 10 per cent Brewers's yeast. The second group was grazed during the day and the lambs were creep fed oats and hay during the night. The third group was grazed during the day and fed only grass hay during the night. Each group was kept separate and placed each day in a different lot so that exposure to infected areas was kept uniform. The lambs were treated with phenothiazine during the summer until September 11. On this date they were taken to an infected padlock where they remained for a period of four days.

They were then returned to the previous experimental conditions. On November 3 the lambs in group I had gained 35.8 pounds; those in group II had gained 34.9 pounds and those in group III had gained 30.2 pounds. There were only three cases of trichostrongylosis noted during the experiment. One of these cases was associated with a thyroid deficiency. From this experiment Whitlock concluded that when haemonchosis is controlled by anthelmintics a high rate of stocking will not always produce trichostrongylidoses even when exposed to an area that is known to be infected.

A third experiment was conducted by Whitlock in which four lots of lambs were used. There were 20 lambs per lot, and all the lambs had free access to the same pasture used in experiment II. Lot A was fed a supplement of oats and 10 per cent of Brewers' yeast. The lambs in lot A were treated throughout the experiment with phenothiazine, copper sulphate and tetrachloroethylene. The lambs in lot B were fed the supplement of oats and 10 per cent of Brewers' yeast but were not treated for internal parasites. Those in lot C received no supplemental feeding but were treated for internal parasites in the same manner as lot A. Those in lot D received no supplemental feeding, nor were they treated for internal parasites.

All the animals were allowed free access to a salt mixture containing dicalcium phosphate, iodized salt, ferrous sulfate, cobalt sulfate and copper sulfate. Red cell counts, weights and body measurements were taken. Fecal egg counts were obtained throughout the experiment.

Whitlock concluded from this experiment that lambs in lot B, the supplement-fed, untreated lot, had larger numbers of parasites in the abomasum, but fewer intestinal parasites than those in lot D, the pasture-fed untreated lot. The average net gain in weight of the four groups was as follows:

lot A, 13.4 pounds; lot B, 13.4; lot C, 8.2 and lot D, 6.7 pounds. The supplement-fed, treated lot gained normally, and the physical development was regular and constant. The supplement-fed, untreated lot developed in physique quite different from the lot A. The development of lambs in lot B was characterized by an initial period of rapid growth and a later period of slow growth. Whitlock refers to this as "over-compensation". Since this phenomenon occurred during the period of infection of the host by the parasites, Whitlock postulated that this increase in growth for a short period of time ("over-compensation") was a reaction of the lamb to the infection. The pasture-fed, treated group showed signs of simple malnutrition as indicated by blood counts and body weights and measurements. The pasture-fed, untreated group were not significantly different from the pasture-fed treated group.

Whitlock states that the diet influences the worm burden encountered in sheep. Insufficient caloric intake is a predisposing factor in a large number of cases of secondary trichostronglidoses. Symptoms of secondary trichostrongylidoses are emaciation, diarrhea, and submaxillary edema. Anemia is the principal symptom of a primary trichostrongylidoses. Of all the trichostrongylidae infecting sheep only Haemonchus contortus has thus far been proven capable of producing the primary disease. Diet seems to influence the number and kind of parasites infecting sheep. Deficient caloric intake, thyroid abnormalities, cobalt and protein deficiency are dietary factors shown to have a marked effect on the severity of the trichostrongylidoses affecting sheep.

Wisconsin workers (1947) indicated two ways (other than by hemmorrhage) that stomach worms may cause anemia in lambs. There are lower levels of riboflavin, niacin, thiamin, and pyridoxine in the blood of infected lambs than in the parasite-free lambs of the same lot. This decrease occurred four weeks after the lambs were experimentally infected with *Haemonchus contortus*.

Second, fewer B vitamins were found in the rumen of the parasitized lambs than in the rumen of worm-free lambs. However, the infected lambs fed trace minerals were still able to manufacture more of these vitamins than the infected lambs not given trace minerals. The rumen contents were obtained by the use of a rumen fistula. The Wisconsin workers concluded that the lack of B-vitamin synthesis in the rumen may be indirectly related to the anemia observed in the infections of *Haemonchus contortus*.

General Effects of the Ration on Parasitism in Sheep

Fraser and Robertson (1936) showed that well-fed lambs were more resistant to a pasture infection of stomach worms than were poorly fed lambs. This was shown by the fact that there were more than three times as many worms, on the average, in the poorly-fed group as compared to the well-fed group. Fraser and Ritchie (1936) used 64 lambs, 32 of which were poorly fed and 32 were well fed. All the lambs had access to good pasture. They were grazed for a period of 46 days and at the end of the 46-day grazing period a count was made of the *Haemonchus* species in the abomasum. The poorly fed lambs had from 0 to 222 and the well-fed lambs had only from 2 to 76 worms.

To determine the degree of infection that normal lambs may attain and still show no visual symptoms of being parasitized, Fraser and Robertson examined the abomasum of a large number of lambs that were slaughtered at the average age of six months at a packing house. It was found that they could tolerate up to 2,100 *Haemonchus* and up to 4,670 *Ostertagia* before showing outward symptoms of being parasitized. Fraser and Robertson reported that infection with Haemonchus is usually light until August, and that twin lambs are more highly infected with parasites than singles.

Gordon et al. (1948) reported that they produced an infection of Haemonchus in several poorly fed 18-month-old sheep but they failed to produce an infection on other 18-month-old sheep on an adequate diet.

Threlkeld and Downing (1936) suggested that the high parasite load encountered in late summer and early fall was probably due to three factors. (1) Because of continuous grazing, the pasture becomes heavily contaminated. (2) The pasture usually becomes shorter and the animals graze closer to the ground, thus picking up more larva. (3) The forage is of poorer quality and the animals may suffer from malnutrition.

Taylor (1934) reported an experiment in which lambs were divided into three groups and exposed to the same infection of a species of the smaller stomach worms. Those receiving hay and concentrates had an average worm count of 3,000 per animal. Those on hay alone showed 9,000 and those on straw had on fecal examination a worm count of 14,000. He subsequently divided the parasitized sheep into two groups. One group was fed hay and concentrates, and a reduction was noted in fecal egg count to one-ninth of the original infection. The other group was fed hay alone and the egg count increased to five times the original number.

Ross (1936) demonstrated that it was possible to break down the resistance of old ewes to Haemonchus by feeding a diet consisting mainly of wheat straw. Hawkins and Cole (1945) demonstrated by an immune serum obtained from 3 lambs and an ewe that the resistance of mature sheep is much greater than younger lambs. They showed that antibodies are developed in the serum of the blood that are antagonistic to the parasites when they come in contact with the blood. This was demonstrated by a precipitate being formed around the body of the parasite when the serum of older sheep was used.

Classification, Characteristics and Life-Cycle of the Stomach Worm (Haemonchus contortus)

Classification:

Plylum III - Coelhelminthes

Class A - Nemathelminthes

Order 1 - Nematoda

Family (e) - Strongylidae

Sub-family - Trichostrongylinae

Genus - Haemonchus

Specie - contortus

Characteristics and Life Cycle:

Underhill (1931) describes the parasite, Haemonchus contortus, as having a body that is filiform in shape and is red or white in color. Length of the female is 11/16 to 13/16 inches. Length of the male is 6/16 to 12/16 inches. The eggs contain developing embryos at the time they are passed from the body.

Underhill states that the parasites are taken up as larvae with ingested plants or drinking water. The worms attack the mucosa of the fourth stomach and feed upon the blood of their host. The degree of disturbance which they cause will be proportionate to the number. Heavy infections are accompanied by disorders of digestion and lead through loss of blood to anemia, emaciation and a generalized unthrifty condition of the host.

The symptoms as described by Underhill are those of a pernicious anemia. The infected animal becomes dull and listless. The appetite is diminished and depraved, and the animal frequently seeks water as if to quench an intense thirst. The anemia is evident by the paleness of the skin and the visible mucous membrane and is also evident in the edematous swellings in parts of the body, especially under the lower jaw. In later stages of the infection, a watery dark, putrid diarrhea appears.

The eggs of *Haemonchus contortus* are passed in the feces of the host. The length of time required for incubation depends upon condition of temperature and moisture. Upon hatching the larvae feed upon the fecal material with which it is surrounded. Later the larvae become enveloped by a chitinous sheath, and in this condition it can withstand adverse weather conditions. The larvae crawl onto a blade of grass or other vegetation and are ingested by the host. The larvae reach the abomasum and mature in two to four weeks.

Monnig (1949) describes the *Haemonchus contortus* as follows: The male has an even reddish color, while in the female the white ovaries are spirally wound around the red intestine, producing the appearance of a barber's pole. Monnig states that when the young worms enter the host they cast the sheath and burrow into the mucosa of the abomasum where the third ecdysis occurs. The fourth-stage larvae begin to suck blood and cause the formation of a small blood clot on the mucosa. The larvae live beneath this blood clot. The adult worms live free in the abomasum and attack the mucosa. Probably an anti-coagulatory substance is injected into the wound by the parasite. The mucosa is therefore strongly irritated and the worms deprive the host of a large quantity of blood.

Monnig describes the symptoms in acute cases as anemia and hydraemia. In the more chronic cases anemia is also the main symptom and edematous swellings are frequently seen under the jaw and sometimes along the ventral aspect of the abdomen. Emaciation is as a rule not seen in pure Haemonchosis infections because the body fat is replaced by a gelatinous tissue. The blood shows a marked decrease in erythrocytes and the presence of various abnormal and primitive blood cells.

It is evident from this literature review that although nutrition has an effect on parasitism in sheep, very little specific information is available as to how this takes place.

EXPERIMENTAL

This experiment was designed to study the effect of the stomach worm, *Haemonchus contortus*, on the nutrition of sheep. The technique used was experimentally to parasitize lambs with the larvae of *Haemonchus contortus* and measure the utilization of feed by these animals confined in metabolism stalls. More specifically, different levels of protein were fed to observe the effect of this component of the ration. Eight head of cross-bred Hampshire-Western wether lambs obtained from the college experimental flock were used in the experiment. The lambs were born in March and April of 1950.

General Procedure:

A paired feeding technique was used and the lambs were allotted according to weight. The rations fed the experimental lambs are shown in Table 1. The lots A, B, C, and D refer to the rations containing approximately 7, 10, 13, and 17 per centprotein, respectively. The chemical composition of the ration and the various feeds used in the experiment is given in Tables 2 and 3. The lambs were placed in metabolism stalls, and a ten-day preliminary trial was begun on September 24, 1950.

Lambs No. 1 and No. 6 were paired and placed on ration A. This ration contained 8.17 per cent protein with a daily feed allowance of 667 grams. Lambs No. 9 and 10 were paired and placed on ration B which consisted of 786 grams of feed containing 11.32 per cent protein. Lambs No. 7 and 4 were paired and fed ration C. Ration C consisted of 888 grams of feed with a protein content of 14.38 per cent. Lambs No. 5 and 3 were paired and fed ration D. Ration D consisted of 890 grams of feed with a protein content of 17.73 per cent.

Table 1. Daily Rations Fed Experimental Lambs

Lot and Ration No.	Ration	Amounts Fed Gms.
A Low protein	Prairie hay (poor to medium quality)	285
	Ground yellow corn	357
	Soybean oil meal	12
	*Minerals	13
	Total Amount	667
B Medium low protein	Prairie hay (poor to medium quality)	272
	Ground yellow corn	428
	Soybean oil meal	70
	*Minerals	16
	Total Amount	786
C Medium high protein	Prairie hay (poor to medium quality)	312
	Ground yellow corn	406
	Soybean oil meal	152
	*Minerals	18
	Total Amount	888
D High protein	Prairie hay (poor to medium quality)	312
	Ground yellow corn	328
	Soybean oil meal	232
	*Minerals	18
	Total Amount	890

*The mineral mix contained 1/2 NaCl and 1/2 bone meal.

Table 2. Chemical Composition of Hay, Corn, Soybean Oil Meal and Minerals
(Composition of dry matter)

Feed	Dry Matter %	Organic Matter %	Protein %	Ether Extract %	Crude Fiber %	N-Free Extract %	Ash %	Nitrogen %
Prairie Hay (Glencoe)	91.22	91.81	4.31	2.15	34.75	50.60	8.19	0.69
Ground Yellow Corn	88.20	98.36	10.32	4.76	2.15	81.13	1.64	1.65
Soybean Oil Meal	90.60	93.90	47.60	4.54	6.30	35.46	6.10	7.62
Minerals	100.00	——	——	——	——	——	100.00	——

Table 3. Chemical Composition of Rations

Lamb No.	Ration	Fresh Material: Daily Amt. gms.	Fresh Material: Dry Matter %	Composition of Dry Matter: Organic %	Protein %	Ether Extract %	Crude Fiber %	N-Free Extract %	Ash %	Nitrogen %
*6P, 1	A	667	89.78	93.30	8.17	3.52	16.34	65.27	6.70	1.31
*9P, 10	B	786	89.69	93.42	11.32	3.71	13.95	64.44	6.58	1.81
*4P, 7, 3	C	888	89.91	93.04	14.38	3.68	14.44	60.54	6.96	2.30
*5P, 3, 10	D	890	90.12	92.66	17.73	3.67	14.76	56.50	7.34	2.84

P = Parasitized.

For the purpose of infecting the experimental lambs, specimens of *Haemonchus contortus* were collected from the abomasum of an infected sheep (disposed of at a packing plant). The eggs obtained from the mature female *Haemonchus contortus* were cultured in a mixture of sterile sand and feces. After a period of approximately fourteen days, the larvae obtained were administered to two parasite-free lambs. The two lambs had been raised parasite free as ascertained by fecal analyses. This was necessary in order to develop a pure infection of *Haemonchus contortus*. Parasite eggs were collected from the feces of these two lambs and cultured for a period of approximately two weeks. The larvae obtained from these feces were then given to the four experimental lambs that were used in this study.

The parasitized lamb in each pair was given fifty thousand larvae on September 28. The larvae were placed in a gelatinous capsule and given orally to lambs No. 4, 5, 6 and 9. The parasites for the infection were prepared by Dr. W. E. Brock, veterinarian, at the Oklahoma Agricultural and Mechanical College, Field Laboratory of the Veterinary Research Institute, Pawhuska, Oklahoma.

Three ten-day metabolism trials were conducted. Each of these trials was preceded by a preliminary trial. The first ten-day trial extended from October 5 to October 15, 1950, inclusive. The second trial was conducted during the period between October 15 and October 25, inclusive. The third trial was not begun until November 3 in order to allow an eight-day preliminary trial for lambs No. 3 and 10.

The lambs were fed twice daily in all trials, one-half the daily allowance to a feed. At least two hours were allowed for complete consumption of the allotted ration. After the feed had been consumed, the containers were removed and the lambs were watered in gallon cans.

During the third trial lamb No. 10 (previously pair mate to No. 9 that died) was placed on ration D as the control lamb. Lamb No. 3 (because of refusal of ration D) was placed on ration C as the control lamb. The rations of the infected lambs remained the same throughout the experiment.

Quantitative analyses by the department of Agricultural Chemistry Research were made of the feed, feces, and urine samples. When the analyses were completed, the apparent digestibility coefficients of the dry matter and protein were computed, and the amount of nitrogen stored by each lamb was ascertained. The apparent digestibility coefficients were computed according to the method described by Morrison (1948).

At selected times parasite egg counts were made from the feces collected from the lambs. Post mortem examinations of the parasitized experimental sheep to determine the number of parasites present and parasite egg counts of Haemonchus contortus were made by Dr. Brock at the Pawhuska station.

Equipment:

All collections were made in a type of metabolism stall designed by Briggs and Gallup (1949). Rations and fecal collections were weighed to the nearest gram on a Toledo balance. Fecal and urine aliquots were stored in quart jars under refrigeration. A 1,000 ml. graduated cylinder was used to measure the daily amounts of urine excreted. Readings were made to the nearest .5 ml. and the aliquots measured out in a 50 ml. graduated cylinder.

Collections were made at approximately 5:00 p. m. during all trials. Aliquots of feces and urine were taken for ten days and then analyzed by the Agricultural Chemistry Department. Five per cent aliquots of urine and feces were taken for analysis. The lambs were weighed at the beginning and ending of each ten-day trial at approximately 5:00 p. m.

Blood Analysis:

Blood samples were collected at selected times from each animal for hemoglobin determination and hematocrit value. These samples were collected by puncture of the jugular vein. Heller and Paul's sodium and potassium oxalate mixture as described by Phillips et al (1945) or lithium citrate was used as the anti-coagulant.

The percentage of hemoglobin was determined by a method published by the Rubicon Company (manufacturers of the Evelyn Photoelectric Colorimeter). However, a correction factor based on the method of Wong as described by Hawk (1947) was applied to these values. The Wintrobe and Landsberg method as described by Levinson (1946) was used for the hematocrit determinations.

RESULTS AND DISCUSSION

Weight Changes of the Lambs:

The weight of the lambs at the beginning and at the end of each trial are given in Table 4. In trial I, the infected lambs gained 7.5 pounds while the control gained 7.0 pounds. The only pair of lambs in which the control lamb gained more than the infected lamb was in lot B. The infected lamb in this lot was heavily parasitized as was shown later on post mortem examination. During the second trial the control lambs gained 6.5 pounds while the infected lambs lost 4.5 pounds, a difference in weight of eleven pounds. The large loss in weight was accounted for by lamb No. 9 that died two days after weighing. The post mortem examination of the lamb revealed 32,000 immature *Haemonchus contortus* in the abomasum.

During trial three, the control lambs did not gain weight. The infected lambs in this trial gained a total of 5 pounds. A large gain in weight was observed in lamb No. 5. This lamb was also heavily parasitized during this period as shown by the worm egg count of the feces. This large increase in weight of parasitized lambs has also been noted by Whitlock. This is what he refers to as "over-compensation".

When the weight changes of the three trials are totaled it is noted that the control lambs gained a total of 13.5 pounds; whereas, the infected lambs gained only 8.0 pounds. In trial III there were two control lambs (3 and 7) in lot C. The average gain in weight of these two lambs was used in computing the gain of this trial. This was necessary in order that there would be the same number of control lambs as infected lambs in this trial.

Table 4. Weight Changes of Lambs During the Experiment

Lot No.	Treatment	Lamb No.	Trial I Oct. 5	Trial I Oct. 15	Trial I Change in Wt.	Trial II Oct. 15	Trial II Oct. 25	Trial II Change in Wt.	Trial III Nov. 3	Trial III Nov. 12	Trial III Change in Wt.	Total Change in Wt.
A	Infected	6	72.0	71.5	-0.5	71.5	71.5	0.0	71.5	72.5	+1.0	
	Control	1	58.5	57.5	-0.5	57.5	58.0	+0.5	61.0	61.0	+0.0	
B	Infected	9*	71.0	73.0	+2.0	73.0	65.0	-8.0	--	--	--	
	Control	10	74.5	78.0	+3.5	78.0	78.5	+0.5	--	--	--	
C	Infected	4	73.5	77.5	+4.0	77.5	77.5	+0.0	80.5	80.0	-0.5	
	Control	7**	72.5	75.0	+2.5	75.0	77.0	+2.0	78.5	78.5	0.0	
	Control	3**	--	--	--	--	--	--	83.0	84.0	+1.0	
D	Infected	5	80.5	82.5	+2.0	82.5	86.0	+3.5	83.0	88.5	+4.5	
	Control	3	78.5	79.5	+1.5	79.5	83.0	+3.5	--	--	--	
	Control	10***	--	--	--	--	--	--	80.5	80.0	-0.5	
Total Gain												
	Infected				+7.5			-4.5			+5.0	+ 8.0
	Control				+7.0			+6.5			0.0	+13.5

*Died October 27.
**The average weight of lambs No. 3 and 7 in lot C was used as there were two controls in this lot.
***Lamb No. 10 was used as the control for lamb No. 5 in the third trial.

Apparent Digestibility Coefficients:

The average apparent digestibility coefficients of the dry matter and protein of the feed for both the infected and control lambs are given in Tables 5 and 6. In some trials irregular feed consumption was encountered; consequently, the digestibility data from these trials were not used in the final calculation.

A comparison of the averages given in this table shows that there were no marked differences in the apparent digestibility coefficients except in lot B. In this lot during trial I the infected lamb consumed the same amount of feed as the control lamb; yet the apparent digestibility coefficient for dry matter was 3.6 per cent less for the infected lamb. The apparent digestibility coefficients of the crude protein was 11.0 per cent less for the infected lamb as compared to the control lamb.

In the other 3 lots there was only a slight decrease in digestibility of the nutrients fed the infected lambs as compared to the control lambs except in lot D where the high protein ration was fed.

Nitrogen Metabolism of the Infected and Control Lambs:

The data on the nitrogen metabolism of the infected and control lambs are given in Table 7. In general these data indicate that the control lambs stored more nitrogen than the infected lambs. It is observed that when the average amounts of nitrogen retained for the four lots are combined, the control lots stored 2.28 grams of nitrogen daily as compared to 1.65 for the infected lambs.

Again, the greatest difference occurred in lot B where the heavily parasitized lamb was observed. In this lot the infected lamb stored only 0.72 grams of nitrogen per day as compared to 2.12 for the control lamb. The amound of nitrogen stored appears related to the level of protein in the diet.

Table 5. A Summary of the Average Apparent Digestibility of Dry Matter and Protein by Infected and Control Animals

Lot No.	Treat-ment	Protein in Ration	Dry Matter Offered	No. of Trials	Lamb No.	Feed Intake: Dry Matter	Feed Intake: Protein	Apparent Digestibility: Dry Matter	Apparent Digestibility: Protein
		%	Gms.			Gms.	%	%	%
A	Control	8.17	598.8	II,III	1	598.8	8.17	66.75	46.60
	Infected	8.17	598.8	II,III	6	598.8	8.17	64.60	43.50
Differences								2.15	3.10
B	Control	11.32	705.0	I,II	10	705.0	11.32	74.50	71.20
	Infected	11.32	705.0	I	9	705.0	11.32	70.90	60.20
Differences								3.60	11.00
C	Control	14.38	789.4	I,II,III,III	7,3	777.4	14.52	73.65	73.77
	Infected	14.38	789.4	I,II,III	4	733.9	14.47	72.37	73.47
Differences								1.28	0.30
D	Control	17.73	802.1	II,III	3,10	754.1	17.16	72.00	76.10
	Infected	17.73	802.1	III	5	783.0	18.01	77.50	79.80
Differences								5.50	3.70

Table 6. Apparent Digestibility of Dry Matter and Protein by Infected and Control Lambs

Lot No.	Treat-ment	Lamb No.	Feed Intake: Dry Matter	Feed Intake: Protein	Apparent Digestibility: Dry Matter	Apparent Digestibility: Protein
			gms.	%	%	%
			Trial I			
B	Infected	9	705.0	11.32	70.90	60.20
	Control	10	705.0	11.32	74.00	70.30
C	Infected	4	798.4	14.38	71.30	73.00
	Control	7	798.4	14.38	72.10	72.60
			Trial II			
A	Infected	6	598.8	8.17	66.90	43.00
	Control	1	598.8	8.17	63.40	49.00
B	Control	10	705.0	11.32	75.10	72.10
C	Infected	4	770.0	14.18	72.70	73.70
	Control	7	788.0	14.51	76.40	76.90
D	Control	3	706.2	16.53	75.30	79.80
			Trial III			
A	Infected	6	598.8	8.17	65.80	44.80
	Control	1	598.8	8.17	66.60	44.20
C	Infected	4	626.4	14.19	73.10	73.70
	Control	7	724.9	14.82	74.20	71.90
	Control	3	798.4	14.38	71.90	73.70
D	Infected	5	783.0	18.01	77.50	79.80
	Control	10	802.1	17.76	72.10	78.50

Table 7. Nitrogen Metabolism of the Infected and Control Lambs
(Values in grams per day)

Lot No.	Treat-ment	Lamb No.	Nitrogen Intake	Nitrogen in Urine	Nitrogen in Feces	Total Nitrogen in Excreta	Nitrogen Retained
				Trial I			
B	Infected	9	12.77	6.98	5.07	12.05	+0.72
	Control	10	12.77	6.79	3.79	10.58	+2.12
C	Infected	4	18.36	9.97	4.94	14.91	+3.45
	Control	7	18.36	10.11	5.03	15.14	+3.22
				Trial II			
A	Infected	6	7.83	2.60	4.47	7.07	+0.76
	Control	1	7.83	2.74	4.00	6.74	+1.09
B	Control	10	12.77	7.46	3.56	11.02	+1.75
C	Infected	4	17.44	10.75	4.60	15.35	+2.09
	Control	7	18.32	11.57	4.22	15.79	+2.53
D	Control	3	18.67	10.89	3.77	14.66	+4.00
				Trial III			
A	Infected	6	7.83	2.47	4.32	6.79	+1.04
	Control	1	7.83	2.45	4.36	6.81	+1.02
C	Infected	4	14.24	10.12	3.75	13.88	+0.36
	Control	7	17.20	10.23	4.83	15.06	+2.14
	Control	3	18.37	11.10	4.82	15.92	+2.45
D	Infected	5	22.55	14.99	4.56	19.55	+3.00
	Control	10	22.75	14.93	4.91	19.84	+2.91

Tissue Analysis

Hemoglobin Values:

The hemoglobin values for the lambs during the three trials are presented in Table 8. In general the hemoglobin levels were lower in the infected lambs than in the control lambs. The hemoglobin value of the heavily parasitized lamb (No. 9) that died was 3.0. The hemoglobin values of the control and infected lambs in lot A were normal. Evidence that anemia occurs when the animals are heavily parasitized is shown by the hemoglobin levels of lambs No. 9 and 4.

The high level of protein in the ration of the No. 5 lamb may account for the consistently high hemoglobin values. Worm egg counts of the third trial revealed that this lamb was heavily parasitized. Weir (1947) reported that high levels of protein maintained the hemoglobin levels of parasitized sheep. The normal hemoglobin level as given by Dukes (1947) is 11.18.

Hematocrit Values:

The hematocrit values for the lambs are presented in Table 9. There appears to be a direct relationship between the hemoglobin and hematocrit values. The lowest hematocrit value noted was in lamb No. 9. The parasitized lamb receiving the high level of protein in the ration had higher hematocrit values than the parasitized lambs receiving lower levels of protein.

Post Mortem Examinations and Worm Egg Counts:

The numbers of worm eggs passed per gram of feces by the infected and control lambs are given in Table 10. Large numbers of worm eggs were observed in the feces 26 days after the dose of 50,000 larvae were administered. The maximum number of worm eggs per gram of feces never exceeded 2,250 eggs.

Table 8. Average Hemoglobin Values of Lambs
(Grams/100 ml. Blood)

Lot No.	Treat-ment	Lamb No.	Oct. 5	Oct. 10	Oct. 19	Oct. 26	Nov. 2	Nov. 9	Nov. 16
A	Infected	6	12.2	12.9	9.9	10.6	12.3	10.9	11.7
	Control	1	8.7	10.9	11.9	13.3	12.0	10.5	10.6
B	Infected	9	12.3	10.3	6.1	3.0*	---	---	---
	Control	10	14.1	10.2	9.9	11.8	---	---	---
C	Infected	4	10.4	10.9	10.6	8.9	8.2	5.9	5.6
	Control	7	10.6	11.0	11.5	11.9	10.4	12.1	11.8
	Control	3	---	---	---	---	11.4	11.3	12.6
D	Infected	5	9.3	10.2	9.7	8.7	10.1	8.9	10.9
	Control	3	7.6	11.7	13.1	15.6	---	---	---
	Control	10	---	---	---	---	12.1	11.9	10.4

*Died October 27

Table 9. Hematocrit Values of Lambs

Lot No.	Treat-ment	Lamb No.	Oct. 10	Oct. 26	Nov. 2	Nov. 9	Nov. 16
A	Infected	6	43.0	39.4	47.6	48.5	46.6
	Control	1	37.0	50.0	47.6	41.7	55.3
B	Infected	9	38.8	10.5	---	---	---
	Control	10	33.3	62.8	---	---	---
C	Infected	4	39.4	36.2	30.5	29.8	22.1
	Control	7	37.5	47.6	49.5	59.2	40.8
	Control	3	---	---	60.0	59.8	56.4
D	Infected	5	35.0	46.2	34.7	44.6	53.0
	Control	3	43.6	53.8	---	---	---
	Control	10	---	---	55.2	50.5	51.0

Table 10. The Number of Worms Passed per Gram of Feces by the Infected and Control Lambs.

Treat-ment	Lamb No.	Sept. 28	October 4	10	13	17	20	24	27	31	November 3	10	14
Control	1	12	9	1	1	3	3	5.5	14	9	12	10	---
Infected	6	56	0	0.5	2	1	0.5	1	2.5	5	3	3	9
Control	10	3	4	4	5	5	10	8	5	6	5	4	---
Infected	9	9	1	2	2	2	4	1	9	---	---	---	---
Control	7	---	14	7	6	7	11	10	1	5	8	7	---
Infected	4	12	2	4	3	4	6.5	875	1264	1194	1643	2250	1987
Control	3	56	9	17	17	16	20.5	23	12	15	14	16	---
Infected	5	20	3	10	5	24	45	115.5	971	536	874	986	956

Large numbers of worm eggs were never encountered in the feces of lamb No. 6.

On October 27, twenty-nine days after the administration of the larvae, lamb No. 9 died, apparently from a large infection of parasities as 32,000 immature Haemonchus contortus were found in the abomasum of this lamb. This lamb refused to eat his ration for a period of four days preceeding his death. The skin and eyelids of this lamb had an anemic appearance.

The surviving infected lambs were slaughtered at the Meats Laboratory, Oklahoma A. and M. College. The carcasses were not in an emaciated condition when they were examined. Examination was made by Dr. W. E. Brock, Pawhuska Field Laboratory, on the contents of the abomasum for Haemonchus contortus. Results of this examination revealed that 15,000 mature Haemonchus were present in lamb No. 4; whereas, 5,000 mature worms were found in lamb No. 5. For some undetermined reason, only 20 mature Haemonchus were found in lamb No. 6.

Diarrhea was observed in lamb No. 5 on October 22. This diarrhea was of short duration, lasting only two days. Diarrhea was not observed in the other lambs.

CONCLUSIONS

The effect of internal parasites on the nutrition of sheep, as observed in this experiment, were similar to those observed by other workers. The data presented suggest that a parasitic infection will decrease weight gains. It is not known what is responsible for the failure to gain weight.

Some evidence was observed that the phenomenon of "over-compensation" as observed by Whitlock (1947) may occur. This phenomenon was observed in Trial No. III when lamb No. 5 (heavily parasitized) gained a total of five pounds during a ten-day period. The additional protein afforded in ration D may have enabled lamb No. 5 to withstand the parasites.

There appears to be no significant differences in the apparent digestibility coefficients of the lambs, except in Trial I, lot B. During the trial both lambs in lot B consumed the same amount of feed yet the digestibility coefficients of the dry matter and crude protein were lower in the infected lamb than in the control lamb. It remains to be seen whether the digestibility coefficients would have been lower if the protein level had been higher. The unusually heavy infection of parasites that lamb No. 9 harbored may also have had some effect on the lowered apparent digestibility of the feed.

The nitrogen metabolism of lambs seems to be more adversely affected by parasitism than the digestibility of the rations. Although the differences in the amount of nitrogen stored by the parasitized and non-parasitized lambs were not consistent, these data appear to indicate that a larger amount of nitrogen was stored by the control lambs than by parasitized lambs. A negative nitrogen balance was never encountered in this experiment.

It was noted that a heavy parasitic infection lowers the hemoglobin and hematocrit levels of lambs especially those on a low level of protein. The anemia observed in this experiment was accompanied by a decrease in the blood cell volume as shown by the hematocrit readings.

It was found on post mortem examination that a heavy Haemonchus contortus infection was present in lambs No. 4, 5, and 9. There were 5,000 mature Haemonchus found in the abomasum of lamb No. 5; 15,000 in lamb No. 4; and 32,000 in lamb No. 9. There is no explanation for the fact that Lamb No. 6 was not parasitized.

SUMMARY

An experiment was conducted during the fall of 1950 to determine the effect of the stomach worm, Haemonchus contortus, on the nutrition of lambs. The lambs were placed in metabolism stalls in order that digestion coefficients and nitrogen retention values could be determined. Four levels of protein were fed to determine the effect of different levels of protein in feed on parasitized lambs.

Eight head of cross-bred Hampshire-Western lambs were divided in four lots, A, B, C, and D, with two lambs in each lot. One lamb in each lot was used as the control and the other lamb was infected with the stomach worm larvae (Haemonchus contortus). The four rations contained the following protein levels: lot A, 8.17 per cent; lot B, 11.32 per cent; lot C, 14.38 per cent; and lot D, 17.73 per cent.

On September 28, 1950, fifty-thousand larvae were administered to the lambs to be infected. The lambs were placed in metabolism stalls, and separate daily collections of feces and urine were taken. Three metabolism trials were conducted.

In this study a decrease in body weight was noted in the parasitized lambs on low protein rations. A high protein ration fed to the parasitized lambs seemed to prevent this weight loss.

One lamb died due to the heavy infection of Haemonchus contortus larvae. This lamb had very low hemoglobin and hematocrit values.

The apparent digestibility of the dry matter and the crude protein appeared to be lowered during severe infections. The data suggest that nitrogen retention is reduced during parasitic infections. The high levels

of protein in the diet seemed to reduce the adverse effect that parasites have upon their hosts.

The fast growth rate of lamb No. 5 during trial III may be partially accounted for by the high level of protein in the diet. The phenomenon of "over-compensation" as described by Whitlock (1947) could possibly account for this increase in weight.

The fecal egg count and the examination of the abomasum of the infected lambs indicated that large numbers of parasites were present in three of the infected lambs. These examinations revealed that the lamb on the low protein diet, lamb No. 6, was never parasitized.

The digestion trials in which the lambs consumed unequal amounts of feed were not reported in this study.

The conclusions drawn from this experiment are based upon a limited number of trials where a small number of lambs were used. Further study will be necessary before definite conclusions can be drawn.

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