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Alternative Treatments For Haemonchus Contortus in Sheep: Testing of a Natural Dewormer and Literature Review of Management Methods

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Alternative Treatments for *Haemonchus contortus* in Sheep

Testing of a natural dewormer and literature review of management methods

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The Department of Environmental Studies at Dickinson College hereby accepts this senior honors thesis by Emily Bowie, and awards departmental honors in Environmental Science.

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ABSTRACT

Infestation with the gastrointestinal nematode *Haemonchus contortus* in small ruminants, such as sheep and goats, can cause farmers severe economic losses and endanger animal welfare. Adult *H. contortus* attach to the stomach of a sheep and feed on their blood. Eggs are secreted in the animal's feces, hatch on pasture, and are ingested by the sheep while grazing. Chemical anthelmintics are commonly used to treat *H. contortus*, but the parasite is becoming resistant to these drugs at an alarming rate. This research investigates alternative methods for managing *H. contortus* in two parts. The first part tested a natural dewormer developed by the company Fertrell on ten sheep at the Dickinson College Farm. This experiment used FAMACHA and McMaster's methods to determine responses in anemia and *H. contortus* loads in the animals' feces. The second part investigated the effectiveness of alternative prevention methods in existing literature. The experimental results indicated that the natural dewormer has potential for being effective – the longevity of the effect, however, is uncertain. More research is necessary. The literature review found that selective treatment, pasture rotation, and nutrition supplementation are important and effective ways to increase sheep resistance to and resilience against *H. contortus* and suggests areas for future research.

Introduction

Background

Small ruminant livestock, such as sheep and goats, are extremely susceptible to internal parasites, especially gastrointestinal nematodes. *Haemonchus contortus* (Rudolphi) Cobb, better known as barber pole worm or red worm, is a pathogenic nematode that uses sheep as a host and causes haemonchosis, an infection characterized by anemia and digestive disturbances. *H. contortus* is active mainly in warm, humid climates in the summer months. Adult worms colonize the abomasal mucosa of the sheep and feed on their blood. The eggs they produce are secreted in the feces, hatch, and are ingested by the sheep through the consumption of grasses – especially those that are short and/or covered in dew (Machen *et al.*, 1998; Burke, 2005). *H. contortus,* as the highest egg producer of all sheep worms, is one of the more devastating internal parasites (Besier, 2009). Haemonchosis, if untreated, can lead to protein deficiency, anemia, bottle jaw – the swelling of the lower jaw as a result of anemia, and death (Machen *et al.*, 1998; Williams, 2010). The following report investigates effective management methods for farmers to reduce sheep herd infection by *H. contortus.*

Life Cycle and Infection

The *H. contortus* life cycle takes 21 days to complete. It begins when larvae in the infective (L3) stage are ingested by a sheep on pasture. They then travel to the animal's abomasum, or fourth stomach. Development to the adult stage takes about three weeks in the gut; the worms then attach to the sheep's abomasal mucosa and feed on their blood. The eggs produced during this stage are secreted in the animal's feces, hatch if the conditions are right, and develop through the immature developing (L1 and L2) stages. Once they reach the infective (L3) stage, they travel on to the pasture where they are re-ingested by the sheep through the consumption of grasses (Machen *et al.*, 1998; Hepworth *et al.,* 2006; Besier, 2009). The adult female can lay up to 5,000 eggs daily and together the worms can consume up to 1/10th of an animal's blood in 24 hours (Hepworth *et al.,* 2006).

Young and lactating sheep are the most susceptible to infection by *H. contortus* and *s*tunted lamb growth is the greatest economic loss caused by *H. contortus* (Stear *et al.*, 2007). Young sheep have immunological hyporesponsiveness and lactating ewes experience a temporary loss of immunity for several weeks after they lamb (Besier, 2009; Colditz *et al.*, 1996). *H. contortus* has evolved to respond to the lambing cycle, taking advantage of the temporary lapse in immunity. Responding to environmental changes in the late fall, like changes in forage composition and temperature, the worms go into hypobiosis, a state of metabolic inaction, inside the sheep instead of molting into the adult stage which allows them to overwinter in the animal's intestines. In this state they do not lay eggs and do no damage to their hosts. Several months later, conditions such as the greening of grasses, rain following a drought, and/or increased estrogen levels in females all act as indicators of spring. When these conditions arise, especially when increased estrogen levels indicate the sheep are pregnant, the worm returns to its cycle (Hepworth *et al.,* 2006; Machen *et al.*, 1998). This phenomenon, called the "periparturient rise," immediately exposes vulnerable new lambs to highly infected pastures. The mother ewe is often responsible for much of the larval infection to which her lamb is exposed (Barger, 1999).

Management Methods – Problems with Anthelmintics and Possible Alternatives

Essentially all livestock are exposed to infection by parasites, regardless of whether they are pasture raised or in a confinement setting. *H. contortus* cannot be eradicated. It can, however, be limited so as to not cause economic losses for farmers (Stear *et al.,* 2007; Machen *et al.*, 1998). In discussing the management of *H. contortus* it is important to distinguish between those sheep which are "resistant" and those who are "resilient," because almost every animal is host to the worm. Increased "resistance" in sheep is defined by their ability to expel actively incoming larvae or worms. On the other hand, "resilience" is used to describe an individuals ability to maintain a relatively stable production level while carrying a challenging nematode load (Houtert and Sykes, 1996). Methods to control *H.* contortus must attempt the break the life cycle of the worm, whether through anthelmintics, animal management, or pasture management (Hepworth *et al.,* 2006).

Anthelmintics, drugs that remove the parasite from the intestines, are the most common method for managing *H. contortus.* Chemical anthelmintics are often used to combat haemonchosis, because they are cheap, simple and cost effective; but parasite resistance to them is growing, as seen in Figure 1 (Stear *et al.,* 2007; Yaday *et al*., 1995). Ivermectin as well as albendazole and fenbendezol (both benzimidazoles) have produced the highest levels of resistance, and resistance with levamisole and moxidectin is increasing (Burke, 2005; Schoenian, 2013).

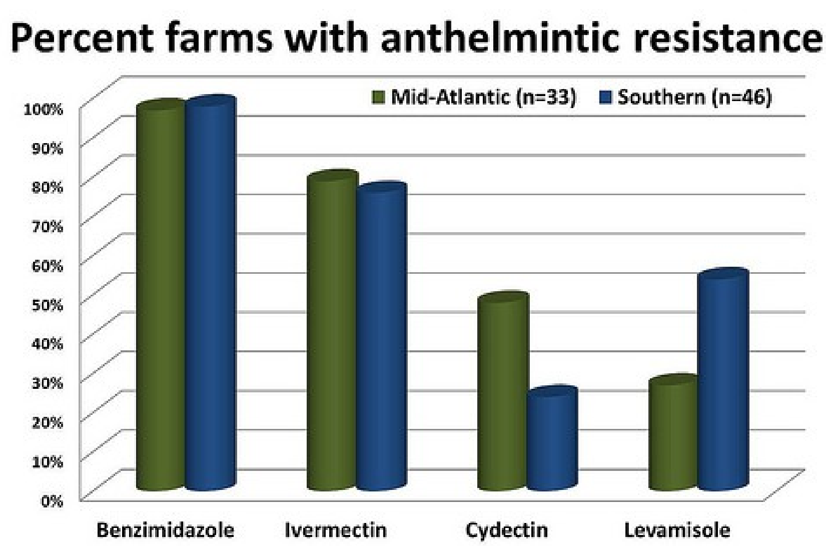

Figure 1. Percent of Mid-Atlantic and Southern farmers in the United States with parasite resistance to anthelmintics used to treat for haemonchosis (Shoenian, 2013)

Resistance to these drugs is high because each one uses a specific mechanistic pathway to kill *H. contortus.* For example, ivermectin binds to glutamate-gated channels in the worm's nervous system, opening them, paralyzing the worm and killing them through starvation (Nolan, 2004). Alternatively, albendazole binds to the parasite's tubulin subunits and interferes with microtubule formation impairing their ability to uptake glucose and therefore maintain energy production, resulting in death (Theodorides *et al.*, 1976). When farmers treat all sheep in a herd with a chemical anthelmintic only the worms that are resistant to its specific mechanism will survive to reproduce. As a result, parasite resistance to the drug grows over time (Burke, 2005). Actions that cause increased resistance include frequent dosing, underdosing to save money, inappropriate administration, wrong anthelmintic choices, and massive reexposure to the parasites (Machen *et al*., 1998).

Responding to chemical anthelmintic resistance, many studies are looking into alternative options for parasite management. The first area of investigation is natural anthelmintics and dewormers. As previously described, chemical anthelmintics utilize specific mechanistic pathways to kill *H. contortus*. Some natural dewormers, like chemical anthelmintics, target and kill the parasite. These natural anthelmintics have the potential to decrease parasite resistance because they likely use non-specific mechanisms to kill the worms (Mali and Mehta, 2008). A study by Sustainable Agriculture Research & Education (SARE) tested pumpkin seeds, garlic, ginger and papaya seeds for anthelmintic properties. Papaya did not show signs of anthelmintic properties. Though garlic and ginger showed traces of success , the data were ultimately inconclusive. Pumpkin seeds were the most promising anthelmintic, especially when administered as a drench – an oral liquid medication (Jackson-O'Brien, 2012). There is little to no scientific data on and investigation into the mechanisms of these natural anthelmintics, especially as they pertain to parasitic nematodes in sheep.

Other natural dewormers build the animal's resistance to the worm, increasing their ability to expel the adult nematodes before they are able to attach to the intestines. *H. contortus* has evolved to thrive in weak intestinal environments and therefore it is harder for the parasite to establish in healthy digestive systems (Wells, 2005). For example, garlic (*Allium sativum*) is a known antibacterial that likely derives its success in treating for *H. contortus* by making the host's digestive tract healthier (Londhe *et al.*, 2011; Noon, 2003). Other studies have shown deworming potential in cayenne pepper (Hart and Dawson, 2010) and diatomaceous earth (Duval, 1994). More research on all of these potential medications is necessary to determine true effectiveness.

Treatment against *H. contortus* using chemical and natural anthelmintics and dewormers is one approach to managing haemonchosis. Another common practice is selective treatment. Some organizations are educating farmers to use the FAMACHA method to identify and treat only those with high haemonchosis levels using their eye color. Farmers can compare the color of their sheep's conjunctivae using a scientifically developed FAMACHA card. Redder eye colors indicate healthier sheep, white colors indicate dangerous anemia levels (Hart and Dawson, 2010; van Wyk and Bath, 2002; Morgan, 2005). Others are promoting the use of the McMaster's method, a veterinary practice for determining *H. contortus* egg counts in sheep feces using microscopes and grid-lined McMaster's slides (Lyndal-Murphy, 1985; Burke, 2005).

Other preventative measures are being investigated to lower exposure to the nematode and to maintain low levels of infection. The application of multiple methods of *H. contortus* management are suggested for achieving the highest rates of resistance and resilience in flocks (Stear *et al.,* 2007). Two of these methods are pasture rotation and nutrient supplementation. Proper pasture rotation allows time for on-pasture larvae to die out before they can be re-consumed and for grasses to grow higher than the larvae can climb (Machen *et al.*, 1998). Studies show that protein and herb supplements improve the health of the digestive tract, lessening the effects of infection and increasing host resilience (Williams, 2010; Parkins and Holmes, 1989; Houtert and Sykes, 1996; Whitlock *et al.*, 1943).

Research goals

The following report identifies possible effective alternatives to chemical anthelmintics for managing *H. contortus* infection in sheep herds. The first part of the research tested the Herbal Supplement Powder (HSP) – a cayenne, garlic, and diatomaceous earth natural dewormer developed by the company Fertrell, based in Bainbridge, PA, for overall effectiveness in reducing anemia and *H. contortus* egg counts among 10 female sheep at the Dickinson College Farm. As a result of the medication, FAMACHA scores and eggs per gram (EPG) counts are hypothesized to decrease steadily over time, with a slight lag in the FAMACHA scores due to the time necessary for the effects of infection to show. The goal of the second phase of the research was to examine the success of three management methods that are practical for the Dickinson College Farm in a comprehensive literature review: (1) selective treatment, (2) pasture rotation, and (3) nutrition supplementation, which are the three approaches that appear most prominently in the literature. Recommendations from this review will help guide future research at the Dickinson College Farm.

METHODS

PART 1: Experimental – Herbal Supplement Powder (HSP) by Fertrell

Medication

One packet of Fertrell's Herbal Supplement Powder (HSP) was administered once a week for three weeks to sheep at the Dickinson College Farm. The HSP mix of cayenne pepper, garlic powder, and diatomaceous earth was mixed in one-third cup of warm water and fed to fifteen infected sheep using the applicator provided by Fertrell. The sheep were continually treated throughout the three weeks testing period. The ten most infected sheep were used in the study described below (5 lambs and 5 adult females) due to time constraints. A control group was not used as a result of ethical concerns. Proportions of the ingredients contained in the medication were not released due to copyright. The sheep did not respond well to the mixture, mostly due to the inefficiency of the applicator and therefore the necessity that they taste the mixture before swallowing. As a result uptake was not 100% but none of the medication was regurgitated.

Testing

Two weeks before the first dose a baseline fecal analysis was conducted on the entire flock of 27 to determine which sheep were infected. This analysis involved a general physical overview of sheep health, a FAMACHA analysis, and fecal egg counts. During the three weeks of dosing and for eleven days afterwards, fecal egg per gram (EPG) counts and FAMACHA scores were collected twice a week. The fecal EPG counts were conducted using the McMaster's Method, a common method used by veterinarians (Lyndal-Murphy, 1985). In this method, a measured fecal sample is suspended in a flotation solution and inserted into a prepared McMaster's slide. Under a microscope *H. contortus* eggs within the grid lines are counted and multiplied by a factor of 50 to calculate the individual sheep's eggs per gram count (EPG).

Analysis

FAMACHA and fecal egg per gram (EPG) data were subjected to graphical and statistical analysis. Graphical analysis investigated visual trends in the data over time. A statistical linear regression was done on FAMACHA score and fecal EPG counts using GraphPad Prism for Macintosh from the first day of treatment to six-eleven days after the last day to treatment to determine the significance of decreases over the testing period. Baseline data was not included in the statistical analysis as it was collected two weeks before the first dosing. Last day of fecal counts was excluded in some analyses due to length of time after treatment to determine statistical significance of effect only *during* treatment. FAMACHA and EPG counts were not statistically analyzed against one another as individual sheep have varying levels of immunity to worm loads and some with heavy loads may show no signs of infections while others with low loads may be highly anemic.

PART 2: Literature Review - Alternative Management

A literature review investigated the effectiveness of selective treatment, pasture rotation, and nutrition supplementation in managing infection by *H. contortus* in sheep. Many studies examined were recipients of Sustainable Agriculture Research and Education (SARE) grants. SARE is a United States Department of Agriculture program that provides money for farmers, ranchers, extension agents and educators, researchers, non-profits, students, communities, and others who are interested in sustainable agriculture projects. Other sources from academic journals were located first using Google Scholar with variations of the search phrases “natural anthelmintics” and “alternative sheep parasite management.” Later sources were located from the references cited in the original sources. Many sources were drawn from the references in Rahmann and Seip (2006).

RESULTS AND DISCUSSION

PART 1: Experimental Results – Fertrell Natural Dewormer

The hypothesis that FAMACHA and EPG counts would decrease over time with a slight lag in FAMACHA scores was partially shown to be true. The FAMACHA scores decreased significantly across the tested sheep from the first date of treatment through eleven days after treatment (linear regression, $r2 = 0.1938$, $F = 16.35$, $df = 1,68$, $P = 0.0001$) (Figures 2 and 3). Collection of these data, however, relied on the perception of color and was based on only a five-point scale. Additionally, FAMACHA measures the level of anemia in each individual sheep. Each individual has a different threshold between egg load carried and resulting anemia. In other words, a weak sheep could have a low egg load but be very anemic. Another may have a high egg load but a strong resistance to showing signs of infection. Both should be treated, the latter, though not sick, will be contributing a large load of eggs to the pasture. Therefore, *H. contortus* eggs per gram were tracked for each sheep to identify the healthy egg carriers (Figure 4 and 5).

Average herd EPG counts decreased overtime in the herd from the first day of treatment to 10/24 but the decrease was not significant (linear regression, $r2 = 0.06808$, $F = 3.287$, df = 1, 45, $P = 0.0765$). Statistical analysis of lamb EPG counts, however, shows a significant decrease (linear regression, $r2 = 0.2303$, $F = 6.881$, df = 1,23, $P = 0.0152$) (Figure 4). Adult EPG counts went up after the second treatment, down after the third, and up with the rest of the herd eleven days after treatment (Figure 5). It is important to note that this statistical analysis is limited in it's ability to determine significant decreases, because as FAMACHA and EPG scores are expected to decrease after treatment they may increase slightly before proceeding treatments bring them down further.

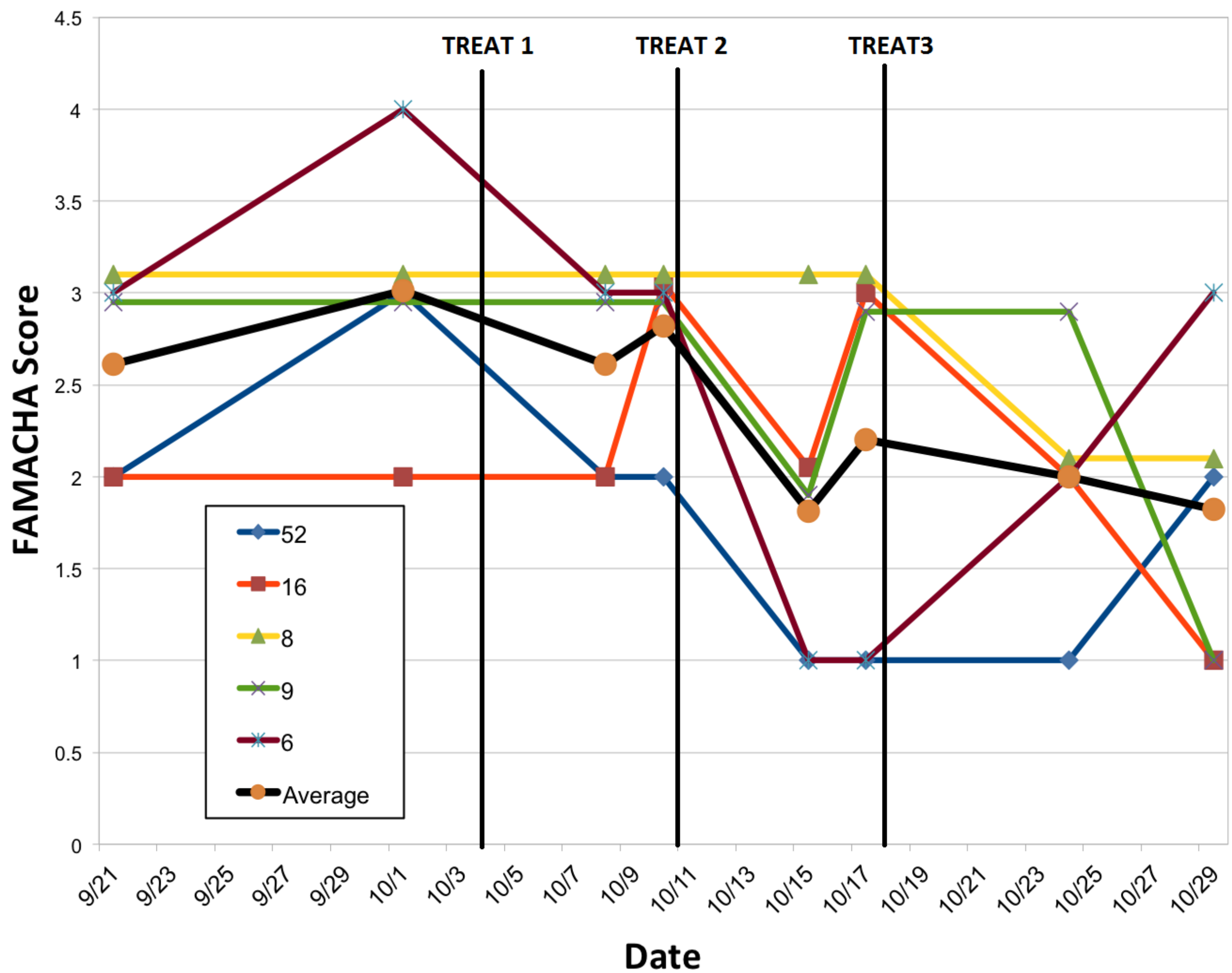

Figure 2. FAMACHA scores for young lambs over three week treatment period.

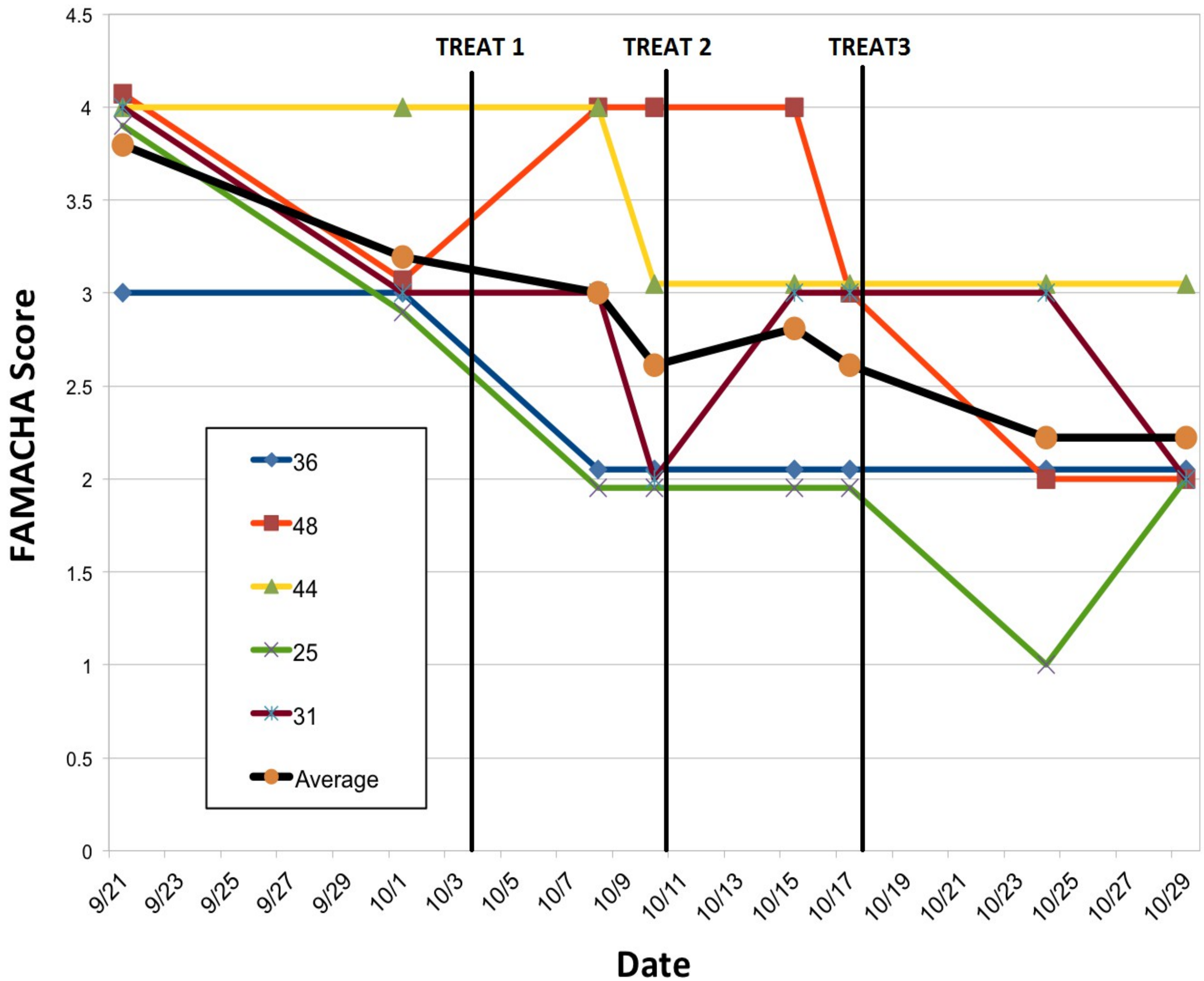

Figure 3. FAMACHA scores for adult sheep over three week treatment period.

Sheep 6, 8, 9, and 16 show patterns with the smallest deviation from the average. These are all lambs and each started with egg counts twice as high as the other sheep. Lambs have a lower tolerance for *H. contortus*, due to undeveloped immune systems (Coldtiz *et al.,* 1996), which would increase the parasite concentration. More research is necessary to determine if age and size influence medication effectiveness. Data collected from lamb 52 and adults 25 and 44 are the opposite of lambs previously mentioned; starting with low EPGs, these sheep had high egg concentrations after the second dose, decreasing significantly after the third and going up slightly with the rest of the herd ten days after treatment suggesting product ineffectiveness. Data gaps for sheep 31 are a result of insufficient amounts of available feces during testing. It is possible that these three individuals had heavy young worm concentrations when baseline data was collected and did not start producing verifiable egg loads until later in the experiment.

Egg counts on 10/24 suggested high effectiveness of the medication. On that day the average egg decrease for the herd from the highest count during the study was 16.69% and 5 of the sheep had decreased to 6-9% of their highest EPG count during the study. Only two sheep (25 and 48) experienced increases in egg counts and they were the adults with the lowest initial egg counts of 0-200 EPG, with the exception of 31, who often did not provide samples large enough to test (Table 1). These data points may also be due to the accuracy limits of the McMaster's method.

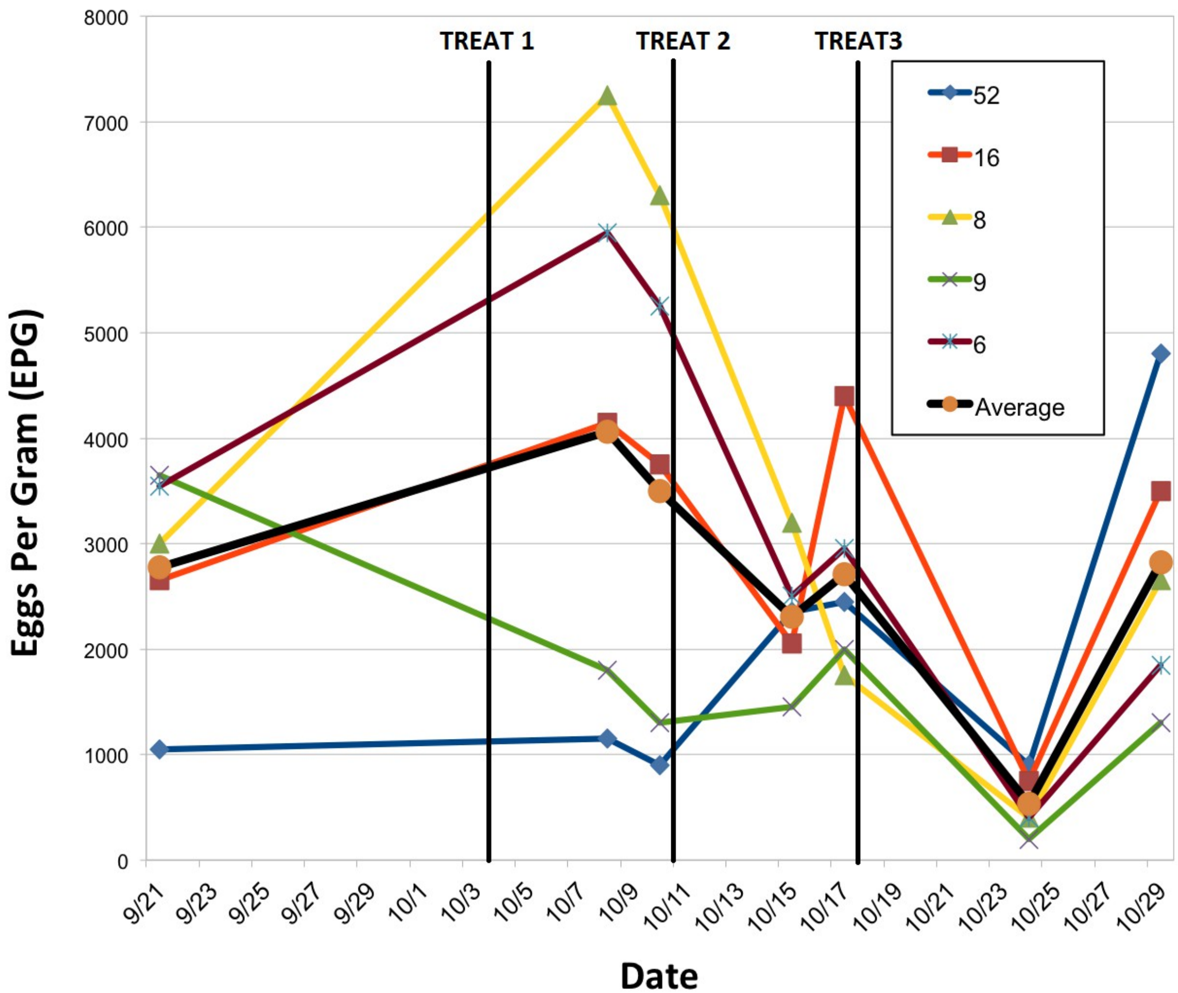

Figure 4. Fecal eggs per gram (EPG) for young lambs over three-week treatment period.

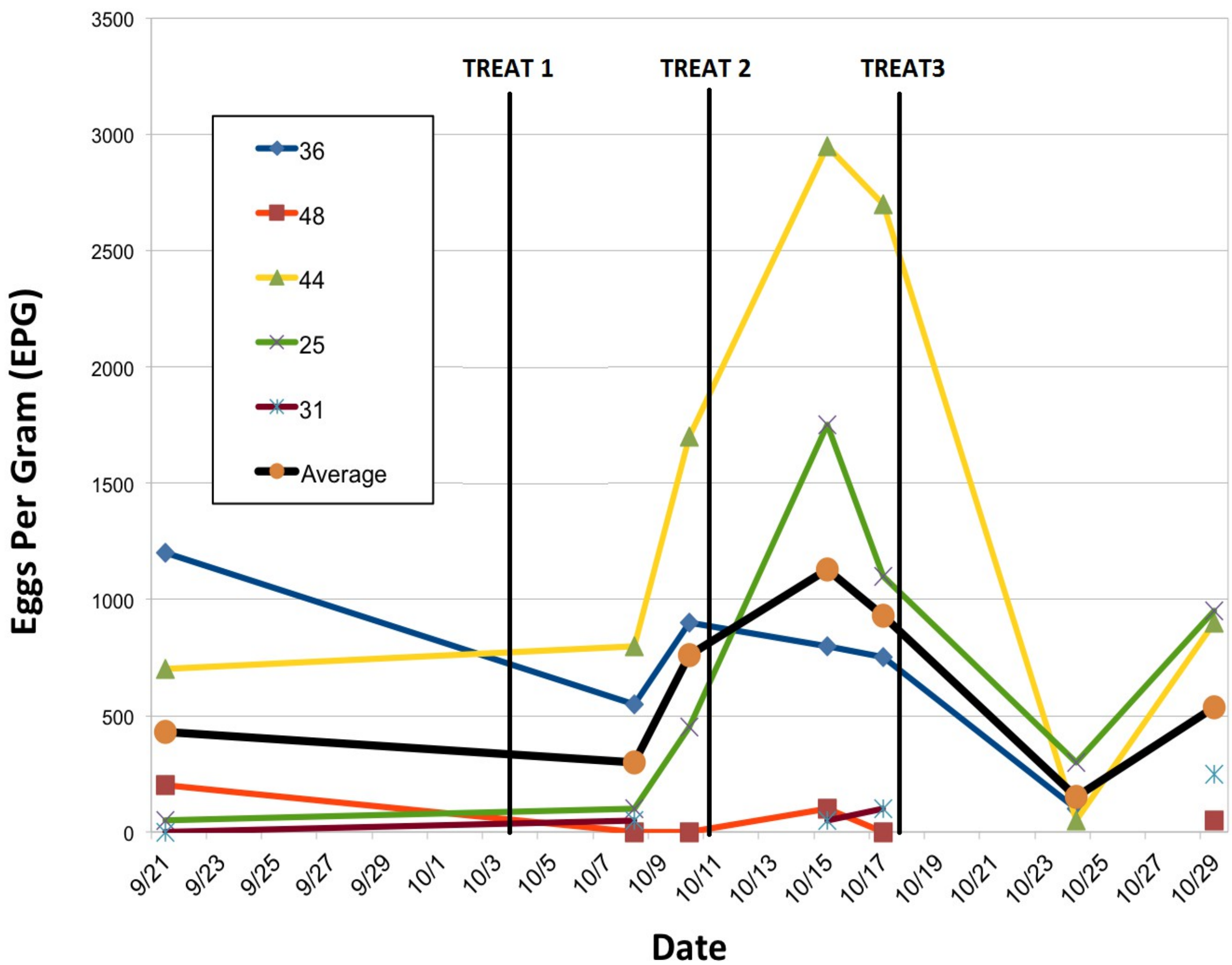

Figure 5. Fecal eggs per gram (EPG) for adult sheep over three-week treatment period.

Despite low counts on 10/24, however, by 10/29 every sheep had experienced sharp increases in EPG. It is difficult to ascertain whether this spike was due to a data anomaly on 10/24, or to the failure of the medication to be effective over time. It is unclear if the medication only works during active treatment. The FAMACHA scores did not show this increase, but this is likely due to the lag time seen between the two factors. Once worms are established and laying eggs it may take several days for signs of anemia to be seen. If the worms had reestablished by 10/29 effects of this may have shown up in later data had that data been collected.

The mechanisms of HSP are unknown. Made from cayenne powder, garlic, and diatomaceous earth the product could have worked similarly to other garlic products tested by Noon (2003) and Jackson-O'Brien (2012) - by improving the health of each sheep's digestive system and preventing the worm from attaching to the intestines to breed, or by killing the worm itself, through toxicity or other methods. More research is necessary to determine the mechanisms of the product and results could illuminate the usefulness of the product at a treatment.

The testing of HSP by Fertrell suggests that the medication is effective, especially in young lambs. In order to confirm this, however, more trials are needed. Other trials of the product have been and are currently being conducted but the data to these studies was not available or considered in this study.

FUTURE RESEARCH:

Further testing of the Fertrell product should focus on EPG patterns and medication *persistence. More counts should be taken on treatment days, throughout the process, and for several weeks after to determine medication persistence. A suggestion for product design is to provide a better applicator for administering the medication. This applicator should allow the medication to be applied at the back of the sheep's throat in a way that prevents the medication from escaping and the sheep from biting the medic.*

Table 1. Before, during, and after FAMACHA and EPG counts during treatment. Data from the lowest day, 10/24/13, were used to determine ultimate EPG decreases. *NOTE: Values missing in egg per gram columns were a result of insufficient fecal sample amounts from individuals on that date.*

SHEEP		**BEFORE (9/21/13)**		**Highest Count**		**AFTER (10/29/13)**		**10/24/13**	
Name	Adult or Lamb (A/L)	FAMACHA	EPG	Date	EPG	FAMACHA	EPG	EPG	% of Highest Count
6	L	3	3550	10/08/13	5950	3	1300	350	5.88%
8	L	3	3000	10/08/13	7250	2	2650	400	5.52%
9	L	3	3650	09/21/13	3650	1	1850	200	5.48%
16	L	2	2650	10/17/13	4400	1	3500	750	17.05%
25	A	4	50	10/15/13	1750	2	950	300	17.14%
31	A	4	0	10/29/13	250	2	250	-	-
36	A	3	1200	09/21/13	1200	2	-	100	8.33%
44	A	4	700	10/15/13	2950	3	900	50	1.69%
48	A	4	200	09/21/13	200	2	50	-	-
52	L	2	1050	10/29/13	4800	2	4800	900	18.75%
Average	-	3.2	1605	10/08/13	2283	2	3250	381.5	16.69%

PART 2: Literature Review – Alternative Management

There are a variety of other methods for parasite control that farmers can use in addition to, or in place of, dewormers. Regardless of whether anthelmintics are chemical or natural, resistance can still build over time. Using one or more alternative method in addition to using anthelmintics can decrease exposure and increase resistance to *H. contortus*. The following literature review investigates the effectiveness of the three following alternative methods: (1) selective treatment, (2) pasture rotation, and (3) nutrition supplementation, and identifies areas for potential research into them. The three practices were chosen from an expansive pool of alternative parasite management methods, identified for their popularity amongst scientific studies and their perceived effectiveness. They were also chosen based on their economic and implementation feasibility for the Dickinson College Farm.

FUTURE RESEARCH:

Many other methods for managing H. contortus *exist but will not be extensively reviewed in this paper due to time restraints and limitations for practicability at the Dickinson College Farm. There is the valuable opportunity for further research into these methods, such as biological control, vaccination (Stear* et al.*, 2007), increasing host resistance through breeding (Piedrafita* et al.*, 2010), using copper oxide particles (Bang* et al., *1990), and managing for soil organisms (Wells, 2005),*

Selective Treatment

Anthelmintic treatment is most problematic, and resistance most prevalent, when farmers treat all sheep in a herd at once. Wiping out all responsive parasites and leaving only resistant ones to breed quickly increases parasite resistance to the drug. Research indicates that, on average, 20% of a herd is consistently more susceptible to infection with *H. contortus*. As a result, these individuals can carry 80% of a herd's worm burden (Burke, 2005). Recent studies focused on the benefit of maintaining populations of parasites in herds that are unexposed to anthelmintics, called *refugia* (Gaba *et al*., 2010). A study by Gaba *et al.* in 2010 found that identifying and treating only highly infected individuals decreased parasite resistance to benzimidazoles and greatly lowered levels of haemonchosis. Populations of resistant nematodes that result from testing are diluted over time by mating with the unselected, susceptible refugia. The most effective way to maintain refugia is through Targeted Selective Treatments (TST), where some sheep in a flock are left untreated (Gaba *et al*., 2010; van Wyk and Bath, 2002).

The FAMACHA system was created to identify those animals unable to cope with current *H. contortus* challenges on pasture. FAMACHA uses a color-coded chart to determine levels of anemia in sheep through the color of their eyelids (Morgan, 2005). When infected with fatal haemonchosis a sheep's conjuctivae changes from a deep, healthy red through shades of pink to white. The color change is a result of progressively worsening anemia (van Wyk and Bath, 2002). Following a variety of trials and studies, a FAMACHA “chart” was created, with five color blocks ranging from red (1) to white (5). When the sheep's eye color is matched against this card, only those sheep with eye color matching with 4 and 5 need immediate attention; all others are considered healthy enough to avoid treatment (van Wyk and Bath, 2002). The

FAMACHA method is useful for determining which individuals are showing signs of infection. It does not, however, identify those individuals with high resilience to the parasite – those with high egg loads and low anemia levels. These individuals can infect others in the field, therefore, another method for selective treatment is the McMaster's method – a veterinary practice for determining parasite loads by counting eggs in sheep feces suspended in a flotation solution using a special slide and a light microscope.

With these practices only sheep showing high levels of infection (those scoring 1-2 or with high EPGs) are treated and drug responsive refugia populations are maintained. During the experimental study outlined in Part 1, discrepancies were identified between individual sheeps' FAMACHA scores and their corresponding EPGs. Some sheep, those more resilient to the parasite, had high EPG counts yet showed little infection. Alternatively, some who were highly anemic possessed low EPG counts.

FUTURE RESEARCH:

There is the opportunity to further investigate the discrepancy between apparent anemia and egg levels – particularly between adults and young lambs – their causes and the external factors that may lead to increased resilience to haemonchosis.

Selective treatment is a highly effective method for lowering parasite resistance to chemical anthelmintics. Using FAMACHA or the McMaster's method decreases costs for farmers, as they buy fewer chemical anthelmintics, and keeps their herds responsive to those drugs. However, selective treatment is time intensive. Farmers should ensure FAMACHA checks often, once a month if possible. The McMaster's method should be conducted as often as time allows, especially on those sheep scoring 3 in FAMACHA – these sheep do not need to be treated based on FAMACHA but if they have high egg loads they should because they are infecting others.

Pasture Rotation

Simply reducing the number of animals on pasture reduces concentrations of larval contaminants by limiting the number of egg-producing individuals and providing more area for grazing (Morley and Donald, 1980). Given enough space, livestock will avoid manure piles and the grass surrounding them. This decreases the reingestion of larvae (Wells, 2005; Bukhari and Sanyal, 2011). Just lowering densities of livestock, however, may not be profitable overall. Rotational grazing plans remedy this by allowing for high densities of animals but moving them before deposition becomes too concentrated (Stear *et al.,* 2007).

Pasture rotation involves partitioning pasture and rotating livestock sequentially through the partitions over time, leaving most of the pasture uninhabited at all times and providing the cleanest, and highest forage, fields at each move. This can include rotation with fallow fields, other livestock, or crop production (Stear *et al*., 2007). Integrating pasture rotation into grazing management plans has been proven to reduce *H. contortus* infestations by reducing the number of infective third stage larvae on the fields available to grazing animals (Barger, 1999; Eysker, 2005; Larsson *et al.*, 2006). *H. contortus* larvae often only crawl an inch or so from the ground onto the grasses. Ensuring that animals do not graze below that point decreases chances of infection (Wells, 2005). Profitability increases if partitions are inhabited by multiple species. *H. contortus* only infects sheep and goats, so sheep can be grazed on the same pasture as cattle and poultry (Stear *et al.,* 2007).

Rotational grazing ensures that fecal deposition is spread out in low concentrations and also interrupts the lifecycle of the parasite. When animals are rotated and grazed fields left to rest, the larvae cannot survive long enough to reinfect their hosts upon return (Bukhari and Sanyal, 2011; Stear *et al.,* 2007; Wells, 2005). Without a host infective larvae eventually die from environmental exposure and soil organisms that consume or destroy them (Wells, 2005). Any rotational setups that prevent the sheep from returning to the same areas of pasture until most of the larvae have died will suffice for reducing reinfection (Eysker, 2005). The amount of time this takes, however, is climate and environment dependent and farmers will have to judge their fields' fallow time accordingly (Barger, 1999; Stear *et al.,* 2007). Despite this variability, thirty days is a time period mentioned in literature for the tropics. This number is often derived from the time period necessary for the grasses to grow well above the 1.5 inch climb the larvae are able to climb, decreasing the sheep's chance of infection and increasing the nematode's chances of dying on pasture (Wells, 2005; Chandrawathani *et al.*, 2004).

Pasture rotation significantly decreases exposure to the worm, however, an entire year of rest is necessary to *ensure* none of the parasite larvae survived and the field is truly clean Wells,

2005. For most farmers this is impossible economically, for many even a 30 day rest is unreasonable. For this reason other methods should be used to manage for *H. contortus* – including selective treatment, nutrition supplementation and actual treatment – whether chemical or natural.

FUTURE RESEARCH

Perhaps the most useful research to be conducted at the Dickinson College Farm is determining the number of days the pasture should remain fallow before re-grazing. This would require measuring the lifetime of larvae in the L3 stage on the pasture in various environmental conditions.

Other best management practices for pasture management including providing clean pasture after deworming and maintaining cleanliness in pasture settings. Providing pasture that has not been grazed for 12 months is the only way to ensure a 100% *H. contortus* free pasture. This clean pasture should be used immediately after deworming to best minimize re-infection. This can be new pasture, pasture grazed by other livestock, or pasture that has been hayed, renovated, or rotated with crops (Wells, 2005). Additionally, because feces are the number one carrier of the larvae, feed troughs and water sources should be located where they cannot be contaminated with feces (Wells, 2005).

Nutritional Supplementation

Studies show that healthy adult animals rarely need to be dewormed (Wells, 2005). Most animals develop immunity against internal parasites, which keeps the parasites from reproducing but doesn't kill them. It is young animals that have not developed immunity and those animals whose immunities are compromised that are the most affected by *H. contortus* (Wells, 2005; Strain and Stear, 2001; Abbott *et al.*, 1988). This was observed in Part 1 of this report as, during the baseline EPG assessment, all four young lambs had EPG counts over three times as high as their adult mothers (See Figures 4 and 5). Once a sheep is infected, *H. contortus* impairs the animal's functions by reducing its voluntary food intake and the efficiency with which its food is used (Houtert and Sykes, 1996; Parkins and Holmes, 1989). At both of these stages, before and during infection, heightened immunity is crucial to controlling parasitic stages within the host and thereby increasing resilience *and* resistance (Stear *et al.,* 2007).

Ingested larvae start to exsheath in the rumen, then develop into fourth stage larvae in the gastric glands. After leaving the gastric glands, the adults live, mate and develop within the protective mucus layer on the surface of the abomasal mucosa. This environment is affected by the host's protective immune response. Since the nematode has evolved to thrive in unhealthy digestive tracts, anything that makes the environment healthier will affect the speed of their development and be detrimental to their survival (Stear *et al*., 2007). Nematodes in resistant hosts lay fewer eggs which may be less viable and take longer to develop (Stear and Bishop, 1999; Stear *et al*., 2007). Therefore, the better the host's immune system, the less likely they are to show signs of infection.

In a study in 1943, researchers observed that sheep placed on a high plane of nutrition were able to reduce their worm burden significantly, and many of the sheep were even able to cure themselves (Whitlock *et al*., 1943). Sheep with healthy immune systems tend to have healthier digestive tracts that the worms are less adapted to colonizing (Wells, 2005). Most research on nutrition for managing the impact of *H. contortus* focuses on the protein losses that result from decreased food intake (Coop and Kyriazakis, 2001; Strain and Stear, 2001; Abbot *et al.*, 1988). Infection causes protein deficiency by increasing the demand for amino acids by the gastrointenstinal tissue in the ailmentary tract while reducing supply through depression of appetite. The mechanisms for this depression of appetite are not well understood (Houtert and Sykes, 1996). The result, however, is direct competition between the immune system and other body tissues for scarce amino acids. Peripheral tissues end up being denied the nutrients they require for optimal growth (Sykes and Coop, 2001). Protein supplements as a part of a herd's diet or before and during infection can prevent or reduce clinical signs of infection by *H. contortus* (Sykes and Coop, 2001; st *et al.* 1988; Strain and Stear, 2001). Additional dietary protein enhances the ability of the infected host to repair mucosal damage (Stear *et al.,* 2007; Coop and Holmes, 1996).

Other recent evidence suggests that it may be possible to fight off *H. contortus* infection through the grazing of certain leguminous forages and herbs (Niezen *et al* 1998, Marley *et al.,* 2003, Paolini *et al.* 2005, Shaik *et al* 2004). Chicory (*Cichorium intybus* L.) is promising because it grows well and has been proven effective in reducing parasite loads in lambs (Marley *et al,* 2003). Possible mechanisms for doing so include increased protein or trace element supply that help enhance tissue repair in the intestines, decreasing the survival of free-living worm stages, reducing ingestion of larvae, or providing direct toxicity to the nematodes (Stear *et al.,* 2007). Other types of forage that contain compounds with anthelmintic properties – such as condensed tannins or sesquiterpenes – are sericea (*Lespedeza cuneata* (Dum.-Cours) G. Don.) and birdsfoot trefoil (*Lotus corniculatus* L.). These plants can be planted in hedgerows or as medicinal gardens, places where they can be set aside so as not to be overgrazed (Wells, 2005; Marley *et al.,* 2003).

As seen previously, sheep with healthy immune systems, and therefore digestive tracts, are more likely to fend off infection by *H. contortus*. Literature concerning the use of plant foods for managing *H. contortus* focused only on protein forage sources. The literature was expanded to include general sheep health many other herbs were found to have benefits for sheep immunity (Mirzaei-Aghsaghali, 2012; de Bairacli Levy, 1952). Most of these herbs were sourced from traditional testimonies of herbs farmers used to treat their sheep in past, many from Juliette de Bairacli Levy's 1952 *The Complete Herbal Handbook for Farm and Stable*. Few the herbs have been scientifically tested. Recognizing the value of traditional knowledge of the subject, a pilot project was designed at the Dickinson College Farm to test the effectiveness of these herbs in maintaining healthy digestive tracts in the sheep and thereby preventing nematode infection. The mechanisms of most of these herbs in managing for sheep stomach parasites are largely unknown but would be worth testing based on the amount of anecdotal testimonies to them. These herbs were planted as an experimental “medicinal” garden, expanding on the idea introduced above by Ann Wells (2005). See Table 2 for the plants being researched and installed.

FUTURE RESEARCH

Due to time constraints, this research project will end with the seeding of the pasture garden. Opportunities exist for research into the installation design of, management plan for, and research into the results of maintaining an in pasture medicinal garden for the management of H. contortus.

Table 2. Herbaceous plants with anthelmintic and digestive tract improvement properties for medicinal garden.

Herb	**Scientific Name**	**Purpose**	**Sources**
Yarrow	*Achillea millefolium* L.	Fights infection; pain reliever; effective against gastrointestinal hemorrhages	de Bairacli Levy, 1952 Brunetti, 2006
Fennel	*Foeniculum vulgare* Mill.	Digestive aid; tonic	de Bairacli Levy, 1952 Duval, 1994
Chickweed	*Stellaria media* (L.) Vill.	Digestive aid; anti-inflammatory; protein source	de Bairacli Levy, 1952
Nettle	*Urtica urens* L.	Tonic; expectorant; restorative for liver, gallbladder, and kidneys	de Bairacli Levy, 1952 Brunetti, 2006
Parsley	*Petroselinum crispum* (Mill.) Nyman ex A. W. Hilland	Aids digestion; aperitive; diuretic; stimulant; and diaphoretic	de Bairacli Levy, 1952
Burdock	*Arctium lappa* L.	Blood purifier; diuretic	Brunetti, 2006
Dandelion	*Taraxacum officinale* L.	Blood cleanser; tonic; strengthens teeth; protein source;	de Bairacli Levy, 1952 Brunetti, 2006
Thyme	*Thymus serpyllum* L.	Stimulent and diuretic; milk tonic; dewormer	de Bairacli Levy, 1952
Echinaecea	*Echinaecea purpurea* L.	Enhances non-specific type immune system; blood purifier	Brunetti, 2006
Chicory	*Cichorium intybus* L.	Dewormer; tonic; contains insulin	Brunetti, 2006 Marley *et al.,* 2003
Chamomile	*Matricaria chamomilla* L.	Aids digestion	de Bairacli Levy, 1952

CONCLUSIONS

Part 1 found the Herbal Supplement Powder (HSP) developed by Fertrell as a promising alternative to chemical anthelmintics, the use of which is not sustainable for managing *H. contortus.* The product was especially effective in young lambs . As seen with past studies, natural ingredients, like garlic, have a better chance of maintaining respondent parasite communities due to their use of non-specific pathways to manage the worm (Mali and Mehta, 2008; Londhe *et al.*, 2011; Noon, 2003). It is unknown whether the ingredients in this product work as anthelmintics that kill the worms or whether they increased the sheeps' abilities to expel the immature adult worms before they could establish in the intestines. More research is necessary to determine the mechanisms of the products ingredients. The Dickinson College Farm should try, and it possible test, this product again. More trials are needed to determine the longevity of the product and ensure the effectiveness of HSP. A greater number of egg per gram (EPG) counts before, during, and for several weeks after, treatment are crucial.

Part 2, the literature review, investigated the viability of alternative *H. contortus* management methods in literature and found several that are feasible for the Dickinson College Farm:

- **Selective treatment,** as shown by van Wyk and Bath (2002) is a very effective way to reduce parasite resistance by maintaining a refugia parasite community responsive to anthelmintics. This method is the first defense against parasite resistance – at least FAMACHA should be used by all small ruminant farmers, every month if possible. Those able to conduct McMaster's as well should do so to target highly resilient sheep.

- **Pasture rotation** breaks up the life cycle of the worm, ensuring the lowest concentrations of infective larvae on available pasture at all times. It also ensures that the grass is too high for larvae to travel and re-consumption is decreased. As most farmers do not have the land available to rotationally graze all year without revisiting a field this method cannot be used as the only approach to managing for *H. contortus.* Rotationally grazing in whatever capacity available, however, is a key way to decrease herd exposure to the worm.
- **Nutrition supplementation**, although not very scientifically researched outside protein supplements, has potential as a management method. Sheep on high planes of nutrition, with healthy immune systems and healthy digestive tracts, tend to be far more resistant and resilient to *H. contortus.* A **medicinal garden** was planted to test the viability of herbs as dietary supplements for improving the immune system and resilience to the parasite. Future research should implement this project and investigate the results.

This research is the first step towards designing a better management plan for the Dickinson College Farm and the greater livestock farming community. At this point in time, based on the results of this research, the Dickinson College Farm, and other farms like it, should combine the practices listed. FAMACHA assessments should be done every month, with at least those sheep scoring as 3's analyzed using the McMaster's method. Then, those sheep showing signs of anemia and those with egg counts above 1,000 should be treated using the Herbal Supplement Powder, another natural dewormer, or a chemical anthelmintic like Ivermectin. In addition to these treatment methods, the farm should manage pasture rotation in a way that maximizes the height of the pasture available for the sheep at all times. Furthermore, the medicinal garden should be established, and protein supplements given to the herd periodically to improve immune systems. These best management practices should be sufficient to at least significantly decrease parasite resistance to anthelmintics on any small farm. Further research is necessary to understand the specific mechanisms of the dewormers and supplements as well as the life cycle of the worm on pasture in the Pennsylvania climate. Further research into these topics should closely examine the references cited in this report.

Anyone interested in continuing the research covered in this report can contact emilyannbowie@gmail.com or farm@dickinson.edu with questions or inquiries.

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