Ecology/Physiology Workgroup

Nematode Parasites in Small Ruminant Grazing Research: Changing Perspectives

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1.0 Introduction

Grazed forages are an economical feed source and are a critical component to profitable sheep and goat production in the US, particularly in the South, where year-round pasture growth is possible. As with all grazing livestock, the profitability of pasture-based small ruminant production is intimately tied with controlling infection from gastrointestinal nematodes (GIN). These parasites cause economic losses through decreased production, cost of prophylaxis and treatment, and death of infected animals (Miller et al., 2005). For small ruminants world-wide, more money is spent on prevention of diseases from internal parasites than from all other diseases combined (Bath and de Wet, 2000). In the southern US, infection with GIN is the primary constraint to profitable production and could eventually threaten viability of the small ruminant industry in this region. Addressing this problem is important for both parasitologists and forage/pasture researchers. Therefore, this paper will focus primarily on the effects of parasitic infection in small ruminants, novel methods for controlling parasitic nematodes in sheep and goats, interaction of GIN and forages/pastures for small ruminant production, and the need for increased research in this area.

2.0 Effects of gastrointestinal nematode infection in small ruminants

Sheep and goats, and particularly young lambs and kids, are highly susceptible to infection with parasitic nematodes, primarily the bloodworm (*Haemonchus contortus*) and the bankrupt worm (*Trichostrongylus colubriformis*). Haemonchosis, caused by the blood-sucking activity of *H. contortus* in the abomasum, can cause severe anemia, anorexia, condition loss, reduced growth rate and eventual death of infected animals (Miller, 1996). The bankrupt worm resides in the small intestine and causes scours, unthriftiness, and weight loss in small ruminants, but rarely results in death. These two species most often occur in combination, causing devastating consequences unless appropriate control measures are taken.

As described in detail by Miller et al (2005) in a previous paper in this series, the life cycle of GIN consists of a host phase and a free-living phase. During the host phase, a single female of *H. contortus* feeding on blood in the abomasum can produce up to 10,000 eggs per day, which are passed out of the animal in its feces. On pasture, the eggs are susceptible to desiccation and will not survive very hot, dry conditions, but thrive in hot, humid areas with summer rainfall (Smith and Sherman, 1994). Under these conditions, the eggs hatch, develop into infective larvae, and migrate onto surrounding forage, moving laterally and vertically with the available moisture. The grazing animal consumes the plant material, and once inside the host, the larvae travel to the gastrointestinal tract, become imbedded in the abomasal mucosa, and mature to egg-laying adults, allowing the cycle to be repeated. The warm, humid climate of the southern US is ideal for growth and survival of *H. contortus* larvae on pasture, and with a short life cycle of 4-5 weeks from ova to mature, egg-laying adult, the number of infective larvae on pasture can build up very rapidly during warmer months (April-October).

3.0 Conventional methods for controlling parasitic nematodes in small ruminants

Control of nematode parasites has traditionally been based upon anthelmintic treatment and grazing management involving regular movement of animals to 'clean' pastures that are free of parasite larvae. Creating relatively parasite-free pastures can be done by removing all grazing animals from the pasture for long periods of time (9-12 months), or plowing up the pasture and planting annual forages (Miller, 1996). With limited financial and land resources, many small ruminant producers don't have the flexibility to implement such practices and are forced to keep at least part of their herd or flock exposed to contaminated forage. Anthelmintic treatment is easier than pasture management for worm control, and with the development of highly effective drugs beginning in the 1960s, farmers (and researchers) have relied almost exclusively on these dewormers to control GIN in small ruminants, as well as in other livestock species. Veterinarians have generally recommended preventive strategies for controlling internal parasites, either by strategic or suppressive deworming (Heath and Harris, 1991), and in the southern US, producers often deworm all the animals in a herd or flock every 3-4 weeks (Miller, 1996). This continually exposes the GIN population to the drug, greatly increasing selection for anthelmintic resistance. The common practice of 'dose and move', or deworming animals and immediately moving them to clean pasture exacerbates the situation by seeding new pasture with only resistant worms (Van Wyk, 2001).

4.0 Development of anthelmintic resistance in small ruminant GIN

Anthelmintic resistance in small ruminant GIN populations is now recognized as a global threat to the success of drug treatment programs and is threatening production systems in many parts of the world, including the southeastern US (Terrill et al., 2001; Mortensen et al., 2003). Prevalence of multiple drug resistance is reaching alarming proportions. In a test of anthelmintic resistance on goat farms throughout the state of Georgia, Mortensen et al (2003) reported resistance to ivermectin on all 17 of the farms tested, resistance to albendazole on 14 out of 15 farms where this drug was tested, and levamisole resistance on approximately 30% of the farms. Only moxidectin was effective on all of the farms in this study. In a follow-up investigation on some of the same farms 2 years later, Kaplan et al (2005) reported that 50% of the farms had already developed resistance to moxidectin. Similar tests were completed recently on sheep and goat farms throughout the southern US, Puerto Rico, and the US Virgin Islands, with very similar results (Kaplan et al, unpublished data). If this trend continues, total anthelmintic failure is probably inevitable on sheep and goat farms in these regions, and due to high discovery and development costs and a perceived relatively limited market, it is unlikely that new classes of anthelmintics will be developed for small ruminants any time soon (Kaplan, 2004).

5.0 Alternative nematode parasite control strategies

The rapid increase in multiple anthelmintic resistance in small ruminant GIN populations, combined with concerns over environmental effects of excreted anthelmintics, has greatly increased the pressure to develop alternative parasite control methods, and research to address this problem has been initiated at a number of institutions in the US and other parts of the world. A consortium of these institutions, from the southern US, Puerto Rico, Denmark, and South Africa, called the Southern Consortium for Small Ruminant Parasite Control (SCSRPC) was recently formed for the purpose of developing alternative GIN control methods that can be applied on-farm. Research from this group and others has involved development and testing of a number of novel, non-chemical GIN control technologies in addition to strategies to extend the effectiveness and reduce the rate of development of resistance to anthelmintics currently in use. Although this research has developed in response to the crisis of anthelmintic resistance in small ruminant parasites, the concepts may also be used to control GIN in larger animals. Although not nearly as widespread a problem as it is in small ruminants, there have been recent reports of increased incidence of anthelmintic resistance in parasitic nematodes of horses and cattle (Kaplan et al., 2003; Kaplan, 2004). The importance of anthelmintic resistance in cattle grazing research was discussed in a previous paper in this series (Stuedemann et al., 2005).

Targeted use of anthelmintics: Application of 'smart drenching' techniques can be used to enhance and/or preserve the effectiveness of anthelmintics. Information on host physiology, anthelmintic pharmacokinetics, and parasite biology is used to develop strategies that maximize effectiveness of treatments, while reducing rate of development of anthelmintic resistance. For example, increasing the duration of contact time between the parasite and the drug can increase anthelmintic efficacy. This can be done by restricting feed intake for 24 hours prior to treatment to reduce the rate of digesta flow down the gastrointestinal tract (Hennessy, 1994), or by administering 2 doses within a short time frame. Zajac and Gipson (2000) reported an increase in fenbendazole efficacy from 50% for a single dose to 92% when 2 doses were given 12 hours apart.

Knowledge of the dynamics of genetic selection can be used to develop treatment strategies that reduce GIN selection for anthelmintic resistance. Because parasites are over-dispersed within their hosts, meaning that a small percentage (about 30%) of the animals harbor most of the parasites (about 70%), if farmers can identify and treat only those animals that truly need anthelmintic treatment, they will save money by reducing the number of treatments given on a herd basis, greatly lessen selection for resistance, and decrease parasite transmission in the entire herd or flock (Van Wyk, 2001). A method for doing this is now being tested and used on sheep and goat farms in the southern US. The system, called FAMACHA©, was recently developed in South Africa for classifying animals into categories based upon level of anemia. To use FAMACHA©, farmers observe the color of ocular mucus membranes and compare this color to a laminated card with illustrations of eyes from sheep at different levels of anemia. The scale measures anemia from 1 (red mucous membranes) to 5 (white mucous membranes), and it is recommended that sheep in categories 4 & 5 and goats in categories 3, 4, & 5 be treated with anthelmintic (Van Wyk et al., 2001; Vatta et al., 2001). In an evaluation on a sheep farm in South Africa, use of the FAMACHA© system resulted in over 90% less anthelmintic treatments compared with previous years (Bath and Van Wyk, 2001), This system was recently validated on sheep and goat farms in the southern US (Kaplan et al., 2004) and is now being used by a growing number of small ruminant producers throughout the country (Kaplan, pers. comm..).

Novel GIN control strategies: Several promising novel, non-chemical methods of controlling GIN are currently being evaluated throughout the world, and have recently been investigated in the United States. Copper oxide wire particles (COWP) have been reported to effectively reduce *H. contortus* infection in sheep in grazing and confinement feeding trials in Louisiana (Watkins, 2003) and Arkansas (Burke et al., 2004). Doses of 2, 4, and 6 grams of COWP had over 95% efficacy against adult worms in lambs, and reduction in fecal egg count (FEC) of up to 70% has been reported in ewes. In a grazing trial with goats, Kallu et al (2005) reported up to 82% reduction in FEC in goats given 4 g COWP boluses. The COWP are administered to the rumen in a gelatin capsule and eventually pass to the abomasum, where they adhere to the mucosa and begin releasing free copper, creating an environment that allows the animal to expel the nematodes (Chartier et al., 2000).

Research with the nematode-trapping fungus *Duddingtonia flagrans* has demonstrated that this organism serves as a good biological control agent against the free-living stages of GIN in dung pats of grazing livestock. Spores of this fungus are fed as part of a supplement diet and then pass onto the pasture in the animal's feces, germinating and forming hyphae that are able to trap the developing larval stages of parasitic nematodes in the fecal pellet (Larsen et al., 1998). Effectiveness of *D. flagrans* against small ruminant GIN was confirmed in confinement feeding trials with goats in Georgia (Terrill et al., 2004) and sheep in Louisiana (Pena et al., 2001). In the goat trial, concentrations of *D. flagrans* from 100,000 to 500,000 fungal spores per kg live weight were over 90% effective in controlling parasitic larvae in fecal cultures (Terrill et al., 2004). This technology has not been thoroughly tested for sheep and goats under grazing conditions in the US.

Another approach to parasite control that has not been adequately explored in the US is use of medicinal plants with anthelmintic properties. Condensed tannins (CT) in some plants have nematicidal properties against free-living nematodes (Chandel and Mehta, 1990), and grazing forages with CT (Niezen et al., 1995) or feeding purified CT to sheep (Athanasiadou et al., 2000) have shown positive results for controlling GIN or improving nutritional status of GIN-infected animals. Niezen and co-workers (1995) reported that sheep grazing sulla, a CT-containing legume, had higher weight gains and wool growth and lower FEC and worm burdens than animals grazing alfalfa, a non-CT legume. Preliminary research in the United States has confirmed this concept with goats grazing sericea lespedeza (Min and Hart, 2003) or fed lespedeza hay (Shaik et al., 2005). Goats fed the lespedeza hay had 80% lower FEC than control animals fed bermudagrass hay. Similar results were observed in sheep fed sericea lespedeza hay in a trial recently completed in Louisiana (Lange et al., 2005).

Rotational grazing has been shown to be an effective method for reducing nematode larval numbers on pasture in the humid tropics (Barger et al., 1994), but eggs and larvae survive too long on pasture for this to be an effective strategy in more temperate climates. Larval migration, or the lateral or vertical movement of infective larvae on pasture, can be affected by pasture morphology (Miller et al., 2005), suggesting that grazing height may be important in determining exposure of grazing animals to infective larvae. Most of the larvae on pasture are within 2-3 inches of the ground surface. Information is very limited on the use of these methods for controlling GIN infection in grazing animals in the US.

6.0 New paradigms in GIN control

Alternative GIN control technologies can be broken down into strategies that target adult worms in the host (targeted use of anthelmintics, COWP, vaccines, CT-containing forages) or eggs and larvae on pasture (nematode-trapping fungi, rotational grazing, CT-containing forages). Despite successes in many of these strategies in controlled studies, most have been found to be less effective with grazing animals under field conditions. There appears to be no ‘silver bullet’ that will effectively and completely control nematode parasites in small ruminants under field conditions all the time. Because of this, there has been a shift in thinking (if not yet research focus) among many parasitologists in recent years from attempting to eradicate parasitic nematodes to the concept of managing parasites below an economic threshold using a combination of different control strategies that can offer producers a ‘basket of best options’ that can be adapted to various management systems, geographic areas or climatic zones, and different livestock species. Unfortunately, there has been little research to date to confirm these concepts and a general lack of data from which to make assessments of economic feasibility of the technologies. One of the primary reasons for this is the difficulty of designing appropriate field tests due to the complexity of the interactions between parasite status of an animal and forage/pasture factors.

As described in detail by Miller et al (2005) in their paper in this series, grazing animals, parasites, and pasture interact in a number of ways, and these relationships are further influenced by temperature and moisture. The ultimate GIN infection level in grazing animals, and the consequent effects on animal productivity and profitability of livestock farming operations involve a large number of different factors, including effectiveness and frequency of dewormer use, animal age and breed (immunity status), pasture quality and availability (animal nutrition status), plant/pasture height, parasite epidemiology, pasture grazing system and stocking rate, animal species (including single species or mixed grazing), watering systems, and feces moisture content and distribution. A detailed description of these interactions is beyond the scope of this paper, but a point to be emphasized is that parasites must be controlled for grazing animal production to be profitable, and data on forage/pasture-parasite-animal interactions are needed to properly implement any control system.

7.0 Pasture/Animal/Parasite Interaction Research

The nutritional status of grazing animals as determined by pasture quality and availability seems to be a primary determinant of the success or failure of various parasite control strategies under field conditions, but this information is often lacking in papers published in parasitology journals. In addition, information on infection status of animals is usually absent in forage/pasture research journals. In the case of small ruminants, parasite control data that does not include basic information on pasture quality and availability, or forage/pasture research that fails to account for parasite status of both the pasture and the animal both run the risk of being irrelevant to producers, who must constantly contend with the potentially devastating effects of GIN infection on animal productivity and the profitability of pasture production systems. Unfortunately, both parasitologists and forage scientists seem ill-equipped to complete the type of research that can produce data on animal/pasture/parasite interactions independently.

Constraints to animal/pasture/parasite interaction research: The effect of parasites on grazing animals and experimental paddocks has generally been ignored by forage/pasture researchers, with the assumption that pretrial deworming removed the parasite effect, and any exposure to GIN on pasture would be equal across treatment groups (Stuedemann et al., 2005). For parasitologists, the primary interest in pasture has often been in its role as a reservoir for GIN eggs and larvae. Most of the pasture data collected concerned parasite epidemiology to allow optimum strategic use of anthelmintics. There are other constraints to the collection of animal/parasite/pasture interaction data as well, including the general lack of funding for this type of research. Another problem is that the number of classically-trained parasitologists and forage scientists who are qualified to undertake this type of research seems to be dwindling. In both these fields, the emphasis for both funding and job opportunities seems to be oriented toward molecular biology and other types of more basic science rather than applied research. Another constraint to be overcome is the difference in perspective between parasitologists and forage/pasture scientists in the use of animals and pastures as experimental units, or appropriate experimental designs for this type of research. Also, the labor constraints and practicality of collecting parasitological (animal and plant) data, pasture and forage growth and quality information, and animal productivity data simultaneously needs to be considered.

Development of animal/pasture/parasite interaction research protocols: Because of the limitations listed above, designing grazing trials with in-depth focus on both pasture/forage evaluation and parasite infection status of grazing animals and pastures appears to be impractical without access to extensive labor resources well-trained in both parasitology and forage research techniques. This fact does not reduce the need for and the potential value of this type of research, however. Some information is much better than none, and developing research protocols and experimental designs to yield useful parasite/animal/forage-pasture interaction data will require some compromises and cooperation between parasitologists and forage/pasture scientists, as well as cross-training of scientists and laboratory and field research assistants from both camps. Useful information on infection status of grazing animals requires fecal and blood samples for determination of fecal egg count and blood packed cell volume, respectively. Fecal cultures can be readily set up for recovering, counting, and identifying different types of nematode larvae (Miller et al., 2005). Level of pasture infectivity with GIN larvae can be determined by hand plucking or cutting pasture from quadrants in random places in the pasture, and then washing the forage to recover, count, and identify the larvae. These pasture samples can then be dried, weighed, and ground to determine pasture quality parameters, and in the case of quadrant samples, total pasture availability. Pasture height can also be measured easily.

Overcoming some of the other constraints to the design and implementation of this type of research may require input from animal nutritionists, forage and animal extension specialists, forage and animal breeders, and agricultural economists. Bringing the talents and perspectives of individuals from multiple institutions and disciplines to bear on this problem will facilitate funding opportunities as well as encourage fresh perspectives and innovative solutions.

8.0 Summary

The warm, humid climate of the southern US is ideal for growth and survival of *H. contortus* on pasture, and this parasite is particularly pathogenic to small ruminants, causing loss of production and eventual death unless appropriate control measures are taken. Traditionally, this has meant frequent use of anthelmintics, but widespread anthelmintic resistance has rendered this approach unsustainable, threatening viability of the small ruminant industry in the South. A more sustainable approach to parasite control is to manage parasite levels below an economic threshold, and alternative control methods have been developed with a goal of providing producers with a 'basket of best options', but these methods have not been adequately tested or have not performed as well as expected under field conditions. Parasite infection status of sheep and goats is greatly affected by the amount and quality of pasture available to the grazing animal, but there is little data currently available on the forage-pasture/animal/parasite interactions that ultimately control the profitability of pasture-based small ruminant production systems. Designing appropriate experiments to allow this kind of data to be collected is challenging and will require cooperation between forage scientists and parasitologists, with cross-training of personnel in appropriate field and laboratory techniques. This type of cooperative research will hopefully allow development and testing of integrated small ruminant parasite control systems that are simple, adaptable, effective, and economical for producers to implement on-farm.

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