New era of parasite control—BMPs for beef cattle

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Abstract

Control of gastrointestinal nematodes (GIN) may have economic and health impacts in beef cattle operations. In the past several decades, GIN control has relied almost exclusively on the use of anthelmintics. With the increase in anthelmintic resistance (AR) new strategies must be developed. Knowledge of GIN biology and epidemiology in the region based on climate and weather, and specific information from the ranch, such as quantitative fecal egg counts, estimates of AR through fecal egg count reduction tests, ages of the cattle and pasture management are necessary to develop GIN control programs. Control programs should integrate grazing management, management of the immune system so cattle can resist infection, and anthelmintic use.

Key words: beef cattle, gastrointestinal, parasites, nematodes, anthelmintic resistance

Résumé

Le contrôle des nématodes gastro-intestinaux (NGI) peut avoir un impact économique et sanitaire sur les entreprises de bovins de boucherie. Au cours des dernières décennies, le contrôle des NGI se faisait presqu'exclusivement à l'aide d'anthelminthiques. En raison de l'augmentation de la résistance anthelminthique (RA), de nouvelles stratégies doivent être développées. Afin de développer des programmes de contrôle des NGI, il est nécessaire d'avoir une connaissance de la biologie et de l'épidémiologie des NGI dans la région basée sur le climat et la météo et de l'information spécifique au ranch comme le compte d'œufs dans les fèces, l'estimé de la RA à l'aide de tests de réduction de l'excrétion fécal d'œufs, l'âge des bovins et la régie des pâturages. Les programmes de contrôle doivent intégrer la régie des pâturages, la régie du système immunitaire (pour faire en sorte que les bovins résistent à l'infection) et l'utilisation d'anthelminthiques.

Introduction

Control of gastrointestinal nematodes (GIN) may have positive economic and health impacts in beef cattle operations in the United States (US). In the past several decades, GIN control has been based almost exclusively on the use of anthelmintics. The increase in anthelmintic resistance (AR) dictates that new strategies be developed. This paper will focus on the information needed to develop control strategies and give some basic recommendations that can be tailored to individual cow-calf and stocker operations.

Major GIN of Concern

The GIN of cattle that have significant prevalence and veterinary importance in the US are *Cooperia* spp (*oncophora, punctate* and *pectinata*), *Haemonchus placei* and *contortus*, and *Ostertagia ostertagi*.[23,30] National Animal Health Monitoring System (NAHMS) data from 2007-2008 showed that over 80% of operations submitting fecal samples were positive for GIN.[22]

Ostertagia ostertagi is most the most important GIN of cattle because of its high pathogenicity and its impact on a wider age range of cattle.[21] *Haemonchus placei* and *contortus* are also very pathogenic but usually only impact weanlings and yearlings. *Cooperia* spp are less pathogenic than either *Haemonchus* or *Ostertagia*, but in warm wet conditions may be present in very large numbers and become economically and clinically significant.

Anthelmintic resistance is covered in more depth in the previous paper, but warrants mention here. Level of AR is highly variable depending on location, but there is no question that AR is reported across the US for all of the major GIN. Of particular concern is the emergence of AR to *Ostertagia*.[10,31] Deaths due to *Ostertagia* in adult cattle have been reported in Louisiana (C. Navarre, personal communication).

Goals of Control Programs

There are 2 goals in controlling GIN: control economic losses and control clinical disease. The level of infection determines both health and economic impacts of GIN. At low levels, there may be no economic impact and development of immunity can be protective to health. At moderate levels, production losses occur without evident clinical disease. The most studied impact from GIN is on weight gain in young growing animals, but impacts on reproductive efficiency and milk production in adult cows is also reported.[21,29,30] A study from 2013 looking at efficacy and production benefits following use of extended-release injectable eprinomectin showed significant differences in weight gain of 66.9 lb, 42 lb, and 18.9 lb (30.4 kg, 19.1 kg, and 8.6 kg) in calves from Louisiana, Arkansas, and Missouri, respectively.[13] In this study, efficacy was high with fecal egg count reductions > 95% at all sites, and these gains might not be obtained in the face of lower efficacy from AR. Clinical disease from high GIN burdens can occur, even in adults, especially when other stressors occur, particularly nutritional stress.

There is no question that there are economic and sometimes health benefits from controlling GIN in cattle, but predicting the outcomes of deworming on an individual ranch is difficult. Extrapolating research findings to individual farms and expecting similar gains in growing cattle is risky. Levels of AR as well as management factors (weather, nutrition, other diseases, etc.) all impact growth in young cattle. Deworming benefits in older cattle are even less predictable. It's important to remember that AR is not static and that extrapolating gains from studies from even a few years ago can be misleading. On-ranch monitoring and trials are the best way to adapt recommendations to individual ranches.

Background Information Needed to Develop Control Programs

Control programs should integrate grazing management, management of the immune system so cattle can resist infection, and anthelmintic use. The first step is to understand what is happening on an individual ranch. This takes knowledge of GIN biology and epidemiology in the region based on climate and weather, and specific information from the individual ranch, such as quantitative fecal egg counts (FEC), estimates of AR through FECRT, ages of the cattle and pasture management. The reader is encouraged to go to other sources to get more indepth knowledge in these areas. This paper will focus on how to put this information into practice to develop integrated GIN control programs.

Climate and Weather

A basic understanding of how climate and weather impact GIN biology is advantageous when developing pasture management plans. In the northern US, shorter grazing seasons and extended freezing temperatures keep GIN at levels lower than the southern US. The gulf coast states region typically has higher rainfall than the south-central region. The generally low stocking density and low rainfall in the southwestern US greatly lessen GIN transmission compared to the gulf coast states.[22] In the southern US, the climate is too hot most of the summer for the free living stages of GIN to survive, although there are exceptions. The greatest infection risk for *Ostertagia* is from fall through spring.[29] *Ostertagia* does not survive at any time in southernmost parts of Florida and Texas[15] although this may be changing (Tom Craig, personal communication). *Cooperia* and *Haemonchus* are more heat-tolerant than *Ostertagia* and can be problematic in wet summers. Areas with higher rainfall tend towards higher GIN problems. It should be noted that rainfall may be increasing across the US above what is typical,[24] which may change GIN epidemiology from what has been seen in the past.

Climate also impacts seasonal arrestment of development of GIN, the most important of which is the late spring and early summer arrestment of *Ostertagia* in the south and winter arrestment in the north.[30] Resumed development in the fall or spring, respectively, can lead to Type II ostertagiasis, which is not common, but is severe when it occurs. It most commonly occurs in older steers, replacement heifers, and bulls.[29]

On a given ranch, weather plays an important role in GIN transmission by speeding up or slowing down the free-living portion of the life cycle. The ranges vary somewhat depending on the species, but under conditions of moderate temperatures (44.6 to 77°F; 7 to 25°C) and moisture (at least 1 inch [2.54 cm] of precipitation per month), the period from egg hatching to the infective larval stage is 7 to 14 days.[15,27,28] Colder weather can lengthen this period as well as decrease the percent hatch of eggs.[21] Larva must have moisture to migrate from the fecal pat, so drought can delay pasture contamination.[2] If cattle shedding eggs remain on pastures, there can be a buildup of eggs that hatch in a short period of time once rains resume. This can lead to an overwhelming infection, precipitating more severe economic losses and even clinical disease.

Weather also impacts the longevity of the infective stages of larva, which can range from days to several months.[27,28] Infective larva have limited energy stores. In hot weather, their metabolism is faster and these energy stores are used up quickly. The opposite is true in cooler weather. Leaving pastures unoccupied for a few months in the summer (as long as there is rain to make any eggs already there hatch) can greatly reduce the GIN burden.

Pasture and Grazing Management

Pasture management is an important component of GIN control as well as delaying and/or reversing AR. While pasture type, quality, topography and drainage can all influence prevalence of GIN on pasture, these are usually factors that are difficult to change. Grazing management offers the most practical solution.

Pastures with reduced GIN contamination ("safe" or "clean" pastures") can be especially helpful in controlling GIN in stocker cattle.[30] There are several ways of making clean pastures:

- Pasture rest in summer
  - Must have rain at the beginning of the rest period
- Alternating land use as pasture and crop/hay production
- Annual or biannual pasture renovation
- Co-grazing with alternate, less-suitable hosts
  - Alternate calves with adult dry cows
  - Horses (sheep and goats not as suitable as they share GIN species with cattle)

Avoidance of over-stocking is a common recommendation to avoid buildup of GIN on pasture, but "over-stocking" should be defined. It usually refers to too many animals grazing continuously on limited land. Some high intensity "mob" grazing systems have very high stocking rates, but for very short periods of time with long periods of rest. This type of grazing could be detrimental in the short term if pastures are contaminated, since cattle will graze close to the ground. But it may have benefits in the long term by decreasing GIN levels from long rest periods. More research is needed to elucidate benefits and risks.

The combination of safe pastures and suppressive anthelmintic use can hasten the development of AR. Treating an entire group of cattle and turning onto safe pasture will lead to a high population of AR GIN. If that land is not permanent pasture but made safe again following a period of grazing (1 season), then the impact on AR is minimal. If, however, that pasture is used continuously, AR will increase.

Pasture rotation at a set length of time is frequently cited as a way to control GIN. This may be true if the life cycle was not so unpredictable based on weather. Estimates of vertical migration of infective larva are also often used to try to prevent transmission via controlling grazing height. Many factors determine vertical migration (forage type, GIN species, temperature and moisture)[20,28] so predicting where the GIN will lie in wait to try to thwart them with grazing management is difficult and impractical. Grazing management should be based on best management practices for the particular forage being grazed in a particular locale, which maximizes forage sustainability and nutritional benefits to the cattle.

Management that Impacts the Immune System

Understanding how GIN burdens impact the immune system of cattle is beyond the scope of this paper, but readers are encouraged to consider the impact of GIN on vaccine response and disease resistance when developing comprehensive herd health plans. Conversely, understanding how the immune system of cattle impacts GIN burdens is also an important component of developing GIN control programs.

Age, sex, breed, genetics, and overall health all influence susceptibility to GIN. Young cattle, especially stocker calves and replacement heifers, are most susceptible.[29] But older cattle can have severe parasitic disease, including mortality, when GIN burdens are combined with other stressors or are not allowed to develop immunity. This is most evident in brood cows in winter that are either nursing a calf or heavy pregnant, depending on the calving season. A combination of high GIN contamination of pastures and poor nutrition, severe weather and/or other GIN (liver flukes in particular) can lead to serious disease. Males are more susceptible to GIN than females, and bulls should not be overlooked when designing GIN control programs.[1] Cattle don't have as drastic a periparturient drop in GIN resistance as is seen in small ruminants.

There is some evidence that *Bos indicus* breeds of cattle may be more susceptible to *Ostertagia* (Thomas Craig, personal communication). The theory is that these breeds were developed in parts of the world that were too hot for *Ostertagia* to survive, so there was no evolutionary pressure to develop an immune response to *Ostertagia.* Research is needed to clarify this potential species difference in susceptibility.

Some cattle are genetically more susceptible to GIN than others. It's estimated that 20% of cattle harbor 80% of the GIN in a herd. With a moderate heritability index of 0.3, genetic selection for GIN resistance is possible over time.[7,14,16] FECs could theoretically be used as 1 selection tool in cattle, but only in young animals and only with *Cooperia* and *Haemonchus*, not *Ostertagia*. Unfortunately, putting this into practice is more complicated as several other factors may influence FECs. Time of year impacts the FECs and the heritability index, and therefore impacts the power of genetic selection based on FECs.[7] Also, the milking ability of the dam is inversely correlated with GIN burdens in nursing calves[19] and may influence FECs and selection. Selecting for GIN resistance may have positive or negative impacts on other production traits, and much more research is needed to reveal candidate genes that may infer GIN resistance and how these selection tools correlate with other traits of importance.

Diagnostics

Given all of the variables discussed so far, it's easy to see why collecting data on individual ranches is a must. Diagnostic methods are covered in the previous paper. Regardless of the specific techniques chosen and the shortcomings of FECs and FECRT data, this information is still critical to developing control programs on individual ranches. FECs are primarily considered useful for monitoring patterns for grazing management rather than assessing infection levels (ie. treatment threshold).[6] Magnitude of change in weight gains between treated and untreated calves are generally correlated with FECs. In the study by Kunckle cited previously, the greatest change in gains was in Louisiana, where egg counts were higher (140 to 271 FECS) than in Arkansas and Missouri (60 to 68 and 51 to 77 FECS, respectively).[13] But a true universal FEC treatment threshold recommendation is illusive and is best determined with on-ranch trials. In herds where management and nutrition are optimal and FECs remain low, deworming may not be necessary and these herds have the opportunity to put resources elsewhere.

Periodic surveillance of FECs in different groups of cattle at different times of year and under different management schemes and stressors gives insight into the magnitude and timing of GIN burdens. When FEC data over years is combined with production, weather, and grazing data, more targeted treatment decisions can be made. Surveillance of young cattle, particularly at the later part of the nursing period, and 6 to 8 weeks after turnout of stocker cattle are top priority. Monitoring adult cattle under nutritional stress may also be helpful. Changes in management or weather, particularly rainfall, should be taken into consideration when comparing FECs from year to year. FECRT data is a must for guiding refugia-based treatment and management recommendations.

Principles of Control

Refugia-based GIN control strategies offer the best balance of short-term economic benefits of deworming and long-term sustainability of anthelmintic efficacy. "Refugia" are those parasites not exposed to an anthelmintic at the time of treatment and represent a reservoir of genes which impart anthelmintic susceptibility. Refugia provides a source of susceptible worms to mate with resistant worms. When refugia is increased, the rate of resistance development will be reduced.[9,17] GIN in refugia can be on pasture or in animals and we need to preserve one or the other or both populations. Deworming all animals in a group and moving them shortly to a "clean" pasture should be avoided. Also avoid deworming all cattle in times where the climate and/or weather are not conducive to survival of larvae in the environment. For example, "strategic" deworming of cattle in the south–all animals in the early summer–was a common recommendation and is no longer appropriate. Warmer and wetter environments may be more conducive to GIN propagation, but it's harder to eliminate refugia in these areas except under suppressive deworming regimes. This can be an advantage in refugia-based programs.

Two main refugia-based strategies exist: targeted treatment (TT) and targeted selective treatment (TST).[9,12] TT is treatment of the whole herd at the most appropriate times, bearing in mind the need to maintain refugia. Treating a herd for *Ostertagia* in the winter or spring in the southern US and avoiding treatment in the summer when there is no refugia on pasture is one example. TT can be further enhanced by TST, which is selective treatment of only those animals that will most benefit from treatment, leaving the rest of the herd untreated. FAMACHA in sheep and goats is a great example of TST. Unfortunately, there is no chute-side test in cattle like the FAMACHA score in small ruminants to help decide who to treat. TST strategies in cattle that are being researched are based on FECs, weight or weight gain, milk production, age or a combination of these.[3,4,11,12,18] More research is needed to elucidate which strategies are best in different situations, but refugia-based principles can be incorporated in recommendations now.

The following recommendations are meant to be a starting place for developing control programs. These recommendations are made somewhat in a "vacuum" and must be integrated with other herd health and production management decisions.

When it is deemed appropriate to use anthelmintics, they should be used properly. To minimize AR, whenever deworming is necessary, products from 2 or 3 classes of anthelmintic should be used concurrently. Following label directions for storage of products is critical. Don't store products at the processing area unless it is climate-controlled.

There are other non-anthelmintic alternatives (fungi, dung beetles, copper, etc.) that may offer control options in the future. These have been studied more extensively in small ruminants and more research is needed in cattle.

Cow-calf Operations

Increasing overall herd immunity through nutrition, vaccinations, biosecurity, and avoiding stress (weaning, handling, heat, etc.) will allow animals to minimize the impacts and increase immunity to GIN. It is the opinion of the author that lack of proper winter nutrition is the biggest risk to adult cows, and in turn, calves, to develop serious parasitic losses and disease.

GIN control recommendations cannot be made without understanding grazing management on the farm. It's commonly recommended that heifers be managed separately from the older cows for a variety of reasons. Using the same pastures year after year for the heifers should be avoided. Either rotate dry cows through these pastures or have enough pens to be able to rotate and rest pastures. Bulls are the next most susceptible group, and the same recommendations hold for bulls.

Anthelmintic resistance develops on-farm, but it can also be brought in with herd additions. Buying from ranches with active refugia-based control programs would be ideal, but difficult to find at this time. If the status of AR is unknown, then recommendations are to deworm on arrival with at least 2 classes of dewormer, drylot for 48 hours, then put onto pastures with some refugia. Buying heifers that have been in multiple-source stocker operations is a risk for bringing in AR. Bringing naïve cattle to the southern US from northern states or very southern parts of Texas and Florida that may have very little exposure, and therefore immunity, to GIN is also a risk.

FECs are higher in calves, but because of the higher volume of feces put out by cows, total output can be greater in cows.[20] Therefore, cows serve as a good source of refugia. A general recommendation for maintaining refugia in cow-calf operations is leave adult females 4 years of age and older untreated. First-calf heifers are still growing, lactating, and trying to reproduce, so don't need the added stress of GIN, especially *Ostertagia*. There are exceptions, so this is just a starting place. *To make this recommendation work, cattle must be healthy and have appropriate nutrition.* In fall-calving herds, the greatest lactation demands coincide with high risk of *Ostertagia* exposure. Management of purebred Brahman cattle may include second-calf heifers into the group that gets dewormed since they are later-maturing animals and may be more susceptible to *Ostertagia*.

One exception to the above recommendation of not treating older females is when there is a need to treat for liver flukes. Areas with severe liver fluke problems may need to treat all adult cattle. The current products available in the US to treat liver flukes also impact GIN. Careful consideration should be given to the impact of liver fluke treatment on GIN refugia. To minimize the impact on GIN AR, 2 classes of dewormer should be used. Only 1 of these products needs to be effective against flukes. Having pastures with refugia to graze following treatment of all adult brood cows simultaneously would then be appropriate.

Selection of cattle that do well in a particular environment, including level of GIN pressure, can improve herd productivity and lessen use of dewormers and hence AR. One of the advantages of not deworming adult cows is that selection for productive cows is done under the GIN pressure on that ranch. Selecting productive cows does not equate to selecting GIN-resistant cows as many factors influence production. But selecting cows under heavy deworming may lead to selecting cows that are not GIN-resistant. As AR becomes more widespread, this could become a future problem.

Replacement heifers are especially susceptible to *Ostertagia* and usually benefit from deworming. If the entire group is to be dewormed, then maintenance of pasture refugia is important. If that is not possible, consider deworming 90% of the heifers, leaving the heaviest 10% untreated. This ratio of treated vs untreated may need to be shifted based on results of FECRT.

Bulls should generally be managed like replacement heifers. Fencing requirements for bulls makes it more difficult to rotate them to different pastures. But because bulls are more susceptible to GIN, every effort should be made to manage pastures for refugia.

Management of GIN in nursing calves depends on level of exposure. Deworming nursing calves prior to weaning can impact weaning weights and also improve weaning vaccination response. Calving season influences level of exposure. Fall-born calves will be grazing when GIN burdens are potentially high in the winter and spring, and may benefit from deworming prior to weaning. Spring-born calves in general will be exposed at an older age, and waiting to deworm at weaning may be appropriate. Calves from spring-calving herds in high rainfall areas may have high exposure earlier, like fall-calving herds.

Control principles are summarized below:

- Increase overall herd immunity
  - Proper nutrition
  - Decrease stressors
  - Decrease other disease pressures
- Graze cows after calves
- Maintain biosecurity practices to prevent introduction of resistant GIN with herd additions
- Incorporate resistance to GIN in genetic selection programs
- Keep refugia
  - Avoid deworming all animals before turnout onto clean pastures. Especially critical with macrocyclic lactones and other long-acting products.
  - In cow/calf operations consider only deworming cattle < 5 years old and allow older cows to serve as refugia. Be aware of special circumstances that may alter this recommendation such as nutritional stress, treatment for liver flukes.
- Use and store products properly
  - Always use at least 2 classes of dewormer at the same time
  - Dose based on actual weights if possible
  - Don't store products at the processing area unless it is climate-controlled
  - Follow label directions for storage

Stocker Operations

There are basically 2 different scenarios to consider when developing GIN control programs for stocker cattle: calves from a single source where AR levels are known; and calves from multiple sources where the AR levels are not known. Stocker calves with some history are much easier to manage, as their AR and treatment history can be combined with knowledge of the pastures they are grazing to better control GIN and further development of AR.

Stocker calves from multiple sources will likely come in parasitized and stressed. Deworming these calves with an effective dewormer may increase weight gains and may or may not have an impact on morbidity and mortality.[8,26] Grazing on non-permanent pastures (i.e. wheat crop) is ideal as the pasture rest and crop preparation steps help to decrease pasture contamination from year to year and buildup of AR. Even if the entire group of calves is treated, AR risk from year to year is minimal. In contrast, grazing permanent pastures combined with frequent use of dewormers has a high risk for development of AR. This is especially true of the macrocyclic lactones which have a residual effect for weeks to months. Deworming entire groups of calves and using the same pastures continually with no rest is no longer sustainable with the current levels of AR that calves have on arrival (Ray Kaplan, personal communication). The 2 practical options are to leave at least 10% of the calves untreated, or to have enough pasture to allow for rest. Only grazing stockers in the fall-spring allows pastures to rest in the summer, which is the best time to decrease contamination in the south. Resting pastures in the winter may not impact contamination very much. More research is needed on high-intensity ("mob") grazing techniques as this might offer some solutions.

Sample Control Programs for Cow-calf Herds

The following are templates for developing GIN control programs based on calving season. As discussed above, results of FECs and FECRT monitoring, as well as knowledge of grazing and other management factors, should be used to fine tune these recommendations for individual ranches. These recommendations assume use of multiple classes of dewormers and refugia-based grazing management as discussed above, and are not meant as stand-alone recommendations.

Spring-calving Herds

- Summer
  - Monitor FECs in calves mid-summer, especially in warm, wet weather
  - Preweaning
    - Deworm calves at least one month before weaning
    - Earlier if heavy burdens
- Fall
  - Monitor FECs in cows, including flukes if necessary

- Deworm young cows and replacement heifers
    - Deworm adult cows if deemed necessary for liver fluke control
    - Deworm calves depending if and when calves were dewormed preweaning
- Winter
    - Monitor FECs in adult cows and replacement heifers, especially if under nutritional and weather stress
    - Monitor FECs in bulls and consider deworming at time of breeding soundness exams
- Spring
    - Monitor FECs in cows as an indicator of potential pasture contamination for calves

Fall-calving Herds

- Winter
    - Monitor FECs in calves mid-winter
    - Preweaning
        - Deworm calves at least 1 month before weaning
        - Earlier if heavy burdens
    - Monitor FECs in adult cows, replacement heifers and bulls, especially if under nutritional and weather stress
        - Fall-calving cows have the additional stress of lactation during this time
- Spring
    - Deworm calves depending if and when calves were dewormed preweaning
- Fall
    - Monitor FECs in cows, including flukes if necessary
    - Deworm young cows and replacement heifers
    - Deworm adult cows if deemed necessary for liver fluke control
    - Monitor FECs in bulls and consider deworming at time of breeding soundness exams

Economics

The variability of GIN load and level of resistance on individual operations makes determining the return on investment (ROI) from GIN control very difficult. Key performance indicators (KPIs) of successful GIN control that can be easily measured are weight gain, feed conversion and milk production. Other beneficial impacts of GIN control are harder to measure, such as the impact on reproduction, carcass quality and the immune system. On-farm trials may be the best way to evaluate the ROI, using diagnostic tools (ex. pepsinogen, serum antibodies) that correlate better than FEC with level of infection and KPIs. Economic models are beginning to surface that when combined with accurate diagnostics may improve decision making.[5,25]

Conclusions

There is a large body of knowledge about GIN and their control in cattle but there are still many gaps in that knowledge. Much of the recent research has focused on the economic benefits (mostly weight gain) of anthelmintics, while epidemiological data is decades old. More recent epidemiological data as well as documentation of the effectiveness of refugia-based control programs and non-anthelmintic alternatives is needed.

Waiting for all of these knowledge gaps to be filled is not an option. GIN control in cattle can no longer be just about which product to use and when to use them. Changing practices from simple to complex is not easy but is necessary if we are to sustain some anthelmintics for future use. Control programs need to take into account what we do know about GIN epidemiology and combine that knowledge with specific information from diagnostic testing and ranch management. Gathering FEC and FECRT data is necessary and costly in the short term, but in the long term can better equip ranches to make sound management and cattle selection decisions that result in more productive and sustainable ranches.

References

1. Barger IA. Influence of sex and reproductive status on susceptibility of ruminants to nematode parasitism. *Int J Parasitol* 1993;23:463-469. doi:10.1016/0020-7519(93)90034-V
2. Barger IA, Lewis RJ, Brown GF. Survival of infective larvae of nematode parasites of cattle during drought. *Vet Parasitol* 1984;14:143-152. doi:10.1016/0304-4017(84)90120-1
3. Berk Z, Laurenson YCSM, Forbes AB, Kyriazakis I. Modelling the consequences of targeted selective treatment strategies on performance and emergence of anthelmintic resistance amongst grazing calves. *Int J Parasitol Drugs Drug Resist* 2016;6:258-271. doi:10.1016/J.IJPDDR.2016.11.002
4. Berk Z, Laurenson YCSM, Forbes AB, Kyriazakis I. Modelling the impacts of pasture contamination and stocking rate for the development of targeted selective treatment strategies for *Ostertagia ostertagi* infection in calves. *Vet Parasitol* 2017;238:82-86. doi:10.1016/J.VETPAR.2017.03.025
5. Charlier J, van der Voort M, Kenyon F, Skuce P, Vercruysse J. Chasing helminths and their economic impact on farmed ruminants. *Trends Parasitol* 2014;30:361-367. doi:10.1016/J.PT.2014.04.009
6. Eysker M, Ploger HW. Value of present diagnostic methods for gastrointestinal nematode infections in ruminants. *Parasitology* 2000;120:109-119. doi:10.1017/S0031182099005752
7. Gasbarre LC, Leighton EA, Davies CJ. Genetic control of immunity to gastrointestinal nematodes of cattle. *Vet Parasitol* 1990;37:257-272. doi:10.1016/0304-4017(90)90009-Z
8. Griffin CM, Scott JA, Karisch BB, et al. A randomized controlled trial to test the effect of onarrival vaccination and deworming on stocker cattle health and growth performance. *Bov Pract* 2108;52:26-33. http://www.aabp.org/Members/publications/2018/prac_feb/default.asp. Accessed August 29, 2019.
9. Hodgkinson JE, Kaplan RM, Kenyon F, et al. Refugia and anthelmintic resistance: Concepts and challenges. *Int J Parasitol Drugs Drug Resist*. 2019;10:51-57. doi:10.1016/J.IJPDDR.2019.05.001
10. Hunter JS, Yoon S, Yazwinski TA, Williams JC, Rehbein S. The efficacy of eprinomectin extended-release injection against naturally acquired nematode parasites of cattle, with special regard to inhibited fourth-stage *Ostertagia* larvae. *Vet Parasitol* 2013;192:346-352. doi:10.1016/j.vetpar.2012.11.041

11. Jackson A, Ellis KA, McGoldrick J, Jonsson NN, Stear MJ, Forbes AB. Targeted anthelmintic treatment of parasitic gastroenteritis in first grazing season dairy calves using daily live weight gain as an indicator. *Vet Parasitol* 2017;244:85-90. doi:10.1016/J.VETPAR.2017.07.023
12. Kenyon F, Greer AW, Coles GC, et al. The role of targeted selective treatments in the development of refugia-based approaches to the control of gastrointestinal nematodes of small ruminants. *Vet Parasitol* 2009;164:3-11. doi:10.1016/J.VETPAR.2009.04.015
13. Kunkle BN, Williams JC, Johnson EG, et al. Persistent efficacy and production benefits following use of extended-release injectable eprinomectin in grazing beef cattle under field conditions. *Vet Parasitol* 2013;192:332-337. doi:10.1016/J.VETPAR.2012.11.039
14. Leighton EA, Murrell KD, Gasbarre LC. Evidence for genetic control of nematode egg-shedding rates in calves. *J Parasitol* 1989;75:498-504.
15. Levine ND. Weather, climate, and the bionomics of ruminant nematode larvae. *Adv Vet Sci* 1963;8:215-261. https://www.cabdirect.org/cabdirect/abstract/19650802833. Accessed June 28, 2019.
16. Mackinnon M., Meyer K, Hetzel DJ. Genetic variation and covariation for growth, parasite resistance and heat tolerance in tropical cattle. *Livest Prod Sci* 1991;27:105-122. doi:10.1016/0301-6226(91)90090-D
17. McArthur MJ, Reinemeyer CR. Herding the U.S. cattle industry toward a paradigm shift in parasite control. *Vet Parasitol*. 2014;204:34-43. doi:10.1016/j.vetpar.2013.12.021
18. Ravinet N, Lehebel A, Bareille N, et al. Design and evaluation of multi-indicator profiles for targeted-selective treatment against gastrointestinal nematodes at housing in adult dairy cows. *Vet Parasitol* 2017;237:17-29. doi:10.1016/J.VETPAR.2017.03.001
19. Snyder DE. Epidemiology of *Ostertagia ostertagi* in cow-calf herds in the southeastern USA. *Vet Parasitol* 1993;46:277-288.
20. Stromberg BE. Environmental factors influencing transmission. *Vet Parasitol* 1997;72:247-264. doi:10.1016/S0304-4017(97)00100-3
21. Stromberg BE, Gasbarre LC. Gastrointestinal nematode control programs with an emphasis on cattle. *Vet Clin North Am Food Anim Pract* 2006;22:543-565. doi:10.1016/j.cvfa.2006.08.003
22. Stromberg BE, Gasbarre LC, Ballweber LR, et al. Prevalence of internal parasites in beef cows in the United States: Results of the National Animal Health Monitoring System's (NAHMS) beef study, 2007-2008. *Can J Vet Res* 2015;79:290-295. http://www.ncbi.nlm.nih.gov/pubmed/26424909. Accessed June 26, 2019.
23. Stuedemann JA, Kaplan RM, Miller JE, Seman DH. *Importance of Nematode Parasites in Cattle Grazing Research*. Ecology/Physiology Workgroup.
24. USGCRP. Climate Science Special Report. 2017:1-470. https://science2017.globalchange.gov/chapter/front-matter-about/. Accessed June 26, 2019.
25. van der Voort M, Charlier J, Lauwers L, Vercruysse J, Van Huylenbroeck G, Van Meensel J. Conceptual framework for analysing farm-specific economic effects of helminth infections in ruminants and control strategies. *Prev Vet Med*. 2013;109:228-235. doi:10.1016/J.PREVETMED.2012.10.017
26. Wagner RT, Karisch BB, Blanton JR, Woolums A, Smith DR, Kaplan R. Assessment of on-arrival vaccination and deworming on stocker cattle health and growth performance. *J Anim Sci* 2018;96(Supplement S1):55-56. Accessed August 29, 2019.
27. Williams JC, Bilkovich FR. Development and survival of infective larvae of the cattle nematode, *Ostertagia ostertagi*. *J Parasitol* 1971;57:327-338. http://www.ncbi.nlm.nih.gov/pubmed/5102817. Accessed June 26, 2019.
28. Williams JC, Bilkovich FR. Distribution of *Ostertagia ostertagi* infective larvae on pasture herbage. *Am J Vet Res* 1973;34:1337-1344. http://www.ncbi.nlm.nih.gov/pubmed/4748245. Accessed June 26, 2019.
29. Williams JC, Loyacano AF. *Internal parasites of cattle in Louisiana and other southern states*. 2001. https://www.lsuagcenter.com/~/media/system/3/d/3/1/3d31b74693c6eccd47125d34100c80e1/ris104cattleparasites.pdf.
30. Yazwinski TA, Tucker CA. A sampling of factors relative to the epidemiology of gastrointestinal nematode parasites of cattle in the United States. *Vet Clin North Am Food Anim Pract* 2006;22:501-527. doi:10.1016/j.cvfa.2006.07.005
31. Yazwinski TA, Tucker CA, Wray E, et al. Control trial and fecal egg count reduction test determinations of nematocidal efficacies of moxidectin and generic ivermectin in recently weaned, naturally infected calves. *Vet Parasitol* 2013;195:95-101. doi:10.1016/j.vetpar.2012.12.061