ANTHELMINTIC STRATEGIES TO DECREASE GASTROINTESTINAL PARASITE BURDENS IN SOUTHESTERN STOCKER CATTLE OPERATIONS

by

CAITLYN TAYLOR FAGUNDES

(Under the Direction of Robert Lawton Stewart Jr.)

ABSTRACT

Two projects were conducted to evaluate the benefits of anthelmintic strategies and grazing methods aimed at reducing the impact of gastrointestinal nematodes, benefiting beef cattle producers in the southeastern United States. The first project assessed the efficacy of anthelmintic treatments and the performance benefits of a direct-fed fenbendazole pellet compared to a transdermal eprinomectin during a post-weaning backgrounding period and a yearling stocker trial. The direct-fed fenbendazole treatment produced an equal or greater impact on animal performance measures and concurrent reduction in parasite burden compared to the transdermal eprinomectin. The second project evaluated the effects of residual grazing height in rotational versus continuous stocking systems on parasite reinfection in yearling stocker cattle. Stocking method did not influence parasite reinfection in stocker cattle grazing cool-season annual forages. These findings contribute to the understanding of effective anthelmintic strategies and grazing management methods, providing valuable insights for the development of more sustainable and effective cattle management practices.

INDEX WORDS: Anthelmintic, Beef Cattle, Post-weaning, Stocker, Background

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CAITLYN TAYLOR FAGUNDES

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CAITLYN TAYLOR FAGUNDES

Major Professor: R. Lawton Stewart Jr.
Committee: Jennifer Tucker
Angie McDaniel

Electronic Version Approved:

Ron Walcott
Vice Provost for Graduate Education and Dean of the Graduate School
The University of Georgia
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DEDICATION

First and foremost, I dedicate this work to God. I am eternally grateful for the path He laid before me and for walking beside me every step of the way.

To my fiancé, Jordan—thank you for your unwavering support, patience, and love throughout this journey. You stood by me through some of the most transformative moments of my life: relocating across the country to pursue graduate school, parting with my family's generational farm, and leaving behind the home and community that raised me. Amid all the change and uncertainty, you remained my constant—my source of peace, strength, and belonging. Thank you for being not just my encouragement, but my home.

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This work is dedicated to you all. I hope I make you proud.

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CHAPTER 1

INTRODUCTION

The beef cattle industry is an integral part of Georgia’s economy. In 2022, Georgia’s 159 counties collectively produced 1.05 million head of cattle and calves, including 487,000 beef cows and heifers that calved (USDA, 2022). Cattle are not only significant to Georgia’s economy, but to the Unites States economy as well. According to the 2022 USDA Southern Region Cattle Inventory, the United States had an estimated 91.9 million head of cattle and calves. Of this total, 39.5 million head were cows and heifers that had calved, with beef cows accounting for 30.1 million head. The 2022 USDA Cattle Production Census further reported that the U.S. produced 69.1 million head of cattle, while sales of cattle and calves reached $89.4 billion, representing 16.5% of total U.S. agricultural sales. Notably, beef cows made up 33% of the total cattle inventory in 2022, or approximately 29.2 million head.

The majority of Georgia’s beef cattle industry is supported by small-scale cow-calf operations, in which a resident herd of cows produce a calf once a year, and those calves are sold after weaning (Adkins, 2012; Malia, 2018). The weaning phase, marking a significant transition in a calf's life, is often incredibly stressful and is associated with adverse effects. During this phase, calves are abruptly separated from the dam, subjected to vaccinations, dehorning, and castration, while also experiencing a nutritional adjustment to a non-milk diet and additional handling and social reorganization (O’Loughlin et al., 2014; Lynch et al., 2019). The stress response to weaning is characterized by reduced feed intake, increased morbidity, and diminished production (Enríquez et al., 2011; Thrift and Thrift, 2011; Lynch et al., 2019). To mitigate weaning stress, producers are advised to pre-condition, or background, which are intended to boost calves' immunity and enhance their ability to withstand the stress of weaning and transportation as they transition from the birth site through the stocker and feedlot stages of beef cattle production(Thrift and Thrift, 2011). A background phase implements management practices that strengthen the immune system, such as vaccinations and deworming, and train calves to eat from a feed bunk and drink from a trough or fountain. This process is typically conducted over a 30–45-day post-weaning period at the calves' birth location (Thrift and Thrift, 2011).

The stocker cattle production segment is recognized as playing a vital role in linking the cow-calf industry to the feedlot phase of beef production (Galyean et al., 2011). Similar to the cow-calf segment, stocker operations are predominantly structured as land-based enterprises, with cattle primarily grazed on standing forage (Peel, 2003; Cummings et al., 2023). Additionally, as in the feedlot phase, the stocker segment is influenced by the seasonal and spatial distribution of weaned calves, with 70% of the annual calf crop born before July and the remaining 30% born in the latter half of the year (Peel, 2003; Cummings et al., 2023). Unlike the feedlot phase, animal health, along with the development and growth of frame and muscle, is prioritized in stocker production rather than fattening (Peel, 2003).

Unfortunately, weaning stress is not the only factor that can impact animal health and production. Gastrointestinal parasites are also recognized as a significant challenge for producers in the Southeast. Young cattle, particularly grazing calves, are more prone to parasitic infections and typically exhibit higher fecal egg counts than adult animals due to underdeveloped immune systems (Nieman, 2017; Williams et al., 2024). Larval migration in pastures is greatly influenced by climate, with temperature and humidity playing crucial roles in larval survival (Heckler and Borges, 2016; Molento et al., 2016). The favorable environmental conditions in the Southeast further exacerbate these parasite challenges (Williams et al., 2024).

Kumar et al. (2012) found that approximately 80% of parasites are concentrated in the first 5 cm of vegetation. Profitable beef cattle production is undermined by annual losses totaling billions of dollars, driven by declines in feed efficiency, immune function, reproductive performance, liveweight, calf yield, and carcass weight, among other factors (Strydom et al., 2023). According to Craig (2018), the most economically significant cattle nematode is *Ostertagia ostertagi,* due to its potential to cause severe clinical disease. Even in relatively minimal numbers, this parasite can lead to anorexia and impair the animal's ability to efficiently convert forage into meat. Young cattle exhibit the highest egg counts of *Cooperia,* making it the most prevalent parasitic nematode; however, in comparison to *Ostertagia* or *Haemonchus*, *Cooperia* is of lesser clinical significance (Craig, 2018). Parasitic infections are associated with visible clinical signs such as anemia, diarrhea, and a rough hair coat. Subclinical effects may not be visibly apparent but are known to impact nutrient absorption and energy metabolism, ultimately leading to reduced weight gain in calves (Gibbs, 1982).

The introduction of new classes of broad-spectrum anthelmintics in the 1960's and 1980's was quickly adopted by producers due to their efficiency in eliminating worm burdens and preventing the establishment of ingested infective larvae (Sutherland and

Leathwick, 2011; Gilleard et al., 2021). Although various anthelmintic drugs are available, benzimidazoles and macrocyclic lactones have been predominately used for parasite control over the past half-century because of their ability to eliminate a wide range of parasite species while remaining safe for animals. Deworming programs are highly variable, and poor management practices—such as improper dosing, frequent treatments, and the repeated use of the same class of anthelmintic drugs each year—have been shown to contribute to the development of anthelmintic-resistant parasite species (De Graef et al., 2013; Dyary, 2016). Anthelmintic resistance occurs when parasites that would typically be terminated by a given dose, unexpectedly survive the treatment. These surviving worms pass their resistant alleles to their progeny, and resistance is inherited in subsequent generations (Sangster and Gill, 1999). Anthelmintic-resistant parasite populations have placed the need on evaluating strategies to improve anthelmintic efficacy.

The research presented in this thesis is organized into two projects. The first project evaluated anthelmintic efficacy and performance benefits of a direct-fed fenbendazole pellet and a pour-on eprinomectin in yearling stocker cattle and weaned, backgrounding cattle. This project was divided into two, 2-year experiments conducted at two locations. In the first experiment, 81 spring-born stocker calves were used each year. Following weaning, calves underwent a 60-day backgrounding phase at the Eatonton Beef Research Unit in Eatonton, GA. Calves were then transported to the Georgia Mountain Research and Education Center in Blairsville, GA, where they were enrolled in an 84-d yearling stocker trial, and fed a corn silage-based diet, supplemented daily with dried distillers' grains and ground-corn. Body weight was recorded on d 0 and every 28 days thereafter until the conclusion of the experiment. Fecal samples were collected from every animal on d 0, d 14, and all subsequent weigh days to monitor eggs per gram (EPG) and determine fecal egg count reduction (FECR). Body weight and fecal EPG were utilized to evaluate differences between treatments.

In the second experiment, 54 calves (YR 1) and 60 (YR 2), aged 8- to 9-months and recently weaned, were enrolled in a 42-d post-weaning, background period at the J. Phil Campbell Sr. Research and Education Center in Watkinsville, GA. Calves were provided free-choice hay and supplemented daily with dried distillers' grains and ground-corn throughout the experimental period. Body weight was recorded on d 0 and every 14 days thereafter until the conclusion of the experiment. Fecal samples were obtained from each animal on d 0, d 14, and all subsequent weigh days to monitor EPG and determine FECR. Body weight and fecal EPG were used to evaluate differences between treatments. The findings from this project will provide valuable insights into the efficacy of direct-fed fenbendazole method compared to a pour-on eprinomectin treatment, along with their associated effects on gastrointestinal nematode burdens and their potential added value in backgrounding and stocker cattle operations.

The second project evaluated the effects of rotational versus continuous stocking, on parasite reinfection in yearling stocker cattle by controlling residual grazing height in an annual ryegrass-based stockering system. This project occurred at two locations: the Alapaha Range Grazing unit in Alapaha, GA (YR 1), and Tifton Campus Beef Cattle Center in Tifton, GA (YR 2). To accomplish this, body weights were recorded for each animal on d 0, and every 28 days throughout the 56-day experimental period. Fecal samples were collected on each weigh day, with an additional sample collected on d14 to monitor EPG in “tester” cattle. Body weight and fecal EPG were used to evaluate differences between rotational versus continuous stocking. The findings from this project aimed to assess the influence of residual grazing height, controlled by rotational versus continuous stocking on parasite reinfection, in yearling stocker cattle. These data will facilitate comparisons between residual grazing height and stocking method, to determine impact on gastrointestinal nematode reinfection in yearling stocker cattle.

The research conducted in this thesis demonstrates the benefits of effective anthelmintic strategies on animal health and performance, as well as their contribution to more efficient cattle management during the background and stocker phase. By evaluating the impact of stocking method on parasite reinfection, this research enhances the understanding of reinfection dynamics in grazing stocker cattle. These findings provide valuable insights for producers, supporting the refinement of parasite management practices and improve overall animal performance, thereby promoting more sustainable and profitable cattle operations.

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CHAPTER 2

THE REVIEW OF THE LITERATURE

Economic Benefit of Cattle in the Southeast

The beef cattle industry is a key sector of the United States agricultural economy, making a substantial contribution to overall agricultural revenue. In 2022, the U.S. cattle inventory totaled 91.9 million head, including 30.1 million beef cows (USDA, 2022). That same year, cattle and calf sales accounted for the largest share of total animal and animal product receipts, with 69.1 million sold, generating $89.4 billion and representing 16.5% of all U.S. agriculture sales. Of those sold, 29.2 million head were beef cows (USDA, 2024).

Cattle production in the Southeast is a cornerstone of the region's economy, driving agriculture revenue, supporting local jobs, and fostering growth in related industries such as feed production and meat processing. This region is home to approximately 44% of the nation's beef cow herd (Scaglia et al., 2017). The region's cattle production industry is primarily characterized by small-scale cow-calf operations, with 53% of commercial cow owners managing fewer than 50 head (Adkins, 2012).

In Georgia, majority of the industry comprises small-scale cow-calf producers raising beef cattle in each of the state's 159 counties (USDA, 2023). In 2022, Georgia cattle inventory records reported 1.05 million head of cattle and calves in the state, including approximately 478,000 beef cows or heifers that calved (USDA, 2022).

Growing Programs

Weaning stress is a critical challenge in cattle management and can severely impact calf health and growth. At weaning, calves are abruptly separated from their dams, undergo a nutritional adjustment to a non-milk diet (Lynch et al., 2010), and are often immediately transported to a new environment (Beenken-Bobb et al., 2023). The negative effects of weaning are observed in displays of behavioral and psychological distress (Lay et al., 1998; Weary et al., 2008). In a study that determined weaning distress between calves who were weaned by abrupt separation versus those who were weaned in two phases, Haley et al. (2005) reported that calves weaned in two-phases spent 78.9 % less time walking ($P = 0.001$) , 96.6% less bawling ($P = 0.001$), 23.0% more time eating ($P = 0.001$), and 24.1% more time resting ($P = 0.001$), compared to calves who were abruptly weaned.

This high-stress period also leads to impaired immunological function (Lynch et al., 2010; O'Loughlin et al., 2014) and increased exposure to infectious agents when calves are commingled from various sources. Step et al. (2008) evaluated the impact of commingling of beef calves from different sources and weaning protocols on bovine respiratory disease and associated costs. A study was conducted using 509 crossbred beef steers that were sourced either from multiple livestock auctions (MARKET) without known health histories or from a single ranch (RANCH) with a documented weaning protocol. Calves from the ranch were assigned to one of three groups: weaned and immediately shipped (WEAN), weaned and held for 45 days before shipping (WEAN45), or weaned, vaccinated with a modified live viral vaccine, and held for 45 days before shipping (WEANVAC45). It was found that calves sourced from the ranch were significantly less likely ($P < 0.001$) to require treatment for bovine respiratory disease (BRD) than those sourced from auctions. In addition, fewer treatments ($P = 0.001$) and lower health costs ($P < 0.001$) were observed in the WEAN45 and WEANVAC45 groups compared to the MARKET and WEAN groups. These results suggest that better health outcomes and reduced costs can be achieved when calves are sourced from a single, well-managed ranch and preconditioning practices, such as a 45-day weaning and vaccination which are implemented prior to shipment. These studies show the importance of mitigating weaning stress and the benefits of preconditioning on calf health and overall performance.

Preconditioning or background phase

The preconditioning or background phase prioritizes the health of weaned calves by implementing practices such as castration, deworming, and dehorning, before the calves are sold to feedlots as value-added products (Rhinehart and Poore, 2013). A survey by Dhuyvetter et al. (2005) measured the economic viability of preconditioning calves during a 45-day period, summarizing the following findings. King et al. (2006) reported findings from data collected over 10-years on sale price of preconditioned calves from a videotape auction service. Calves who were enrolled in the preconditioning programs received a sale premium ranging from $5.45 in 1995 to $17.44 per 100 kg in 2004. Furthermore, Avent et al. (2007) reported that feedlot managers associate perceived preconditioned cattle bringing a premium of $11.57/100 kg due to reduced morbidity and mortality, increased average daily gain and feed efficiency, and carcass traits over non-preconditioned cattle. Overall, Dhuyvetter et al. (2005) concluded that preconditioned calves can generate additional returns of approximately $14 per head for the cow-calf producer and $40 to $60 per head in the feedlot.

Lalman and Mourer (2017) analyzed sale prices of calves that met Oklahoma Quality Beef Network (OQBN) requirements compared to those with limited health records at the time of sale in the fall of 2010. Cattle enrolled in OQBN program were required to be weaned for a minimum of 45-days, vaccinated at weaning, castrated, dehorned, dewormed, and treated for external parasites. Cattle of a known health status who meet the OQBN but were not enrolled in the program, received a certification and included in the sale. Cattle were categorized and sorted based on their health background, and higher sale premiums were observed for OQBN-enrolled cattle across all weight classes. At 159 kg, average sale prices were recorded at $28.88 per 100 kg for OQBN cattle, $25.04 for certified cattle, $4.52 for cattle with various weaning status, and $3.17 for cattle with limited or no vaccinations. This pricing trend continued at 204, 249, and 295 kg, with OQBN cattle maintaining a premium. At 340 kg, OQBN cattle sold at $22.49 per 100 kg, certified cattle at $18.65, various weaning at $4.52, and those grouped with limited to no vaccinations at $3.17/ 100 kg. The observed price premiums of cattle sold after a minimum of 45-days and a known health background, encourage cow-calf producers to background their calves' before sale. Thereby, providing feedlots with a consistent and uniform group of cattle (Galyean et al., 2011).

Gastrointestinal Parasites

Gastrointestinal parasites, including nematodes and protozoa, infect the digestive tract of cattle and other livestock, feeding on blood, tissue or available nutrients, ultimately damaging the health and efficiency of their host (Herath et al., 2021). Parasitic infections negatively impacts the beef industry by reducing feed efficiency, immune function, reproductive performance, liveweight, milk yield, calf yield, and carcass weight (Strydom et al., 2023). A study was conducted from 1996 to 2002 in the central region of Brazil where, Bianchin et al. (2007) found that cattle treated for gastrointestinal parasites gained an average of 33 kg more than the control group, while cattle treated for ectoparasites gained an average of 13 kg more than control cattle.

Young cattle, especially calves, are most susceptible to parasitic infections, with higher fecal egg counts compared to mature animals due to their naive immune systems (Miller, 1993). Williams et al. (2024) evaluated internal parasite burden in 1,154 Angus cattle ranging from 6 months to 13 years of age in North Carolina. Parasite load was evaluated through fecal egg counts (FEC) and their impact on body weight (BW) and body condition score (BCS). Cattle were categorized into five age groups: 1) calves (*n* = 446), 2) yearling heifers (*n* = 205), 3) 2-year-old (*n* = 260), 4) 3- to 5-year-old (*n* = 501), and 5) 6+-year-old (*n* = 206). Except for calves, which received a single anthelmintic treatment at weaning, no cattle were treated for parasites during the study, regardless of parasite load. The study began in September with FEC, BW, and BCS recorded every 90 days at key production stages, including calving, breeding, weaning, and 90-days post-weaning. Cattle age did significantly impact overall FEC ($P < 0.05$), but FEC did not differ in mature cattle of 3 years of age or older (4.29 ± 4.9 eggs/gram). Calves exhibited the greatest FEC (121 ± 4.2 eggs/gram) of the age groups, whereas cattle aged 6 years or older had the least (4 ± 4.5 eggs/gram). Additionally, cattle age at each research location significantly affected BCS and BW ($P < 0.05$). Differences in FEC, BW, and BCS were also observed between age groups across locations and time ($P < 0.05$). These findings highlight the influence of age on parasite burden, body weight, and body condition, emphasizing the importance of age-specific management strategies in cattle production.

Climate conditions

The favorable environmental conditions in the Southeast exacerbate parasite challenges (Williams et al., 2024). Climate plays a pivotal role in parasite populations, with temperature and humidity crucial elements affecting larval survival and migration in pastures (Heckler and Borges, 2016; Molento et al., 2016). Callinan and Westcott (1986) evaluated vertical migration of trichostrongylid larvae (L3) in soil and herbage under controlled temperatures and humidity conditions to assess the relationship between weather and L3 movement within the pasture. Perennial ryegrass (*Lolium perenne*) and Mt Barker subterranean clover (*Trifolium subterraneum*) were grown for 6 to 20 weeks in sterilized sandy clay loam soil (pH = 5.7) pots. Each pot was seeded with approximately 1,000 L3 of *Teladorsagia* and *Trichostrongylus spp.* sheep nematodes and placed in a 'SHERER' model environment chamber, with temperatures ranging from 10 to 30°C and relative humidity between 40 and 90%. At 24, 48, 72, and 96 h, one pot was removed, sectioned into 2 cm horizontal sections, and analyzed for L3 distribution. On average, eight times the amount of L3 was collected in the soil rather than the herbage, with no significant positive migration ($P = 0.44$) from soil to herbage within the four-day study period. Of the recovered larvae, 71% were found within 2 cm of the soil-herbage interface, 1.3% below 2 cm, and 2.0% on the herbage. The presence of L3 on herbage was significantly influenced by temperature and humidity ($P = 0.01$), with the greatest mean recovery (10.4%) occurring at 15°C and 90% relative humidity after 96 h. Migration was greatest at 72 hours, and the interaction between temperature and humidity significantly impacted L3 movement, with recovery decreasing as humidity decreased. Additionally, migration onto clover was greater than onto grass at lower temperatures and higher humidity levels ($P > 0.01$).

Understanding parasite dynamics, including parasite species, number of adult parasites, egg production rates, and environmental factors, is crucial for effective parasite control in cattle production systems (Gordon et al., 1970; Thomas, 1982). The adult parasite population within the host and the subsequent egg production are primarily influenced by immunological factors, whereas environmental factors like temperature and moisture significantly affect the development and transmission of external larval populations (Thomas, 1982).

Life cycle of internal parasites

The life cycle of internal parasites in gazing beef cattle is a complex process that involves multiple stages of development, transmission, and reinfection, impacting both animal health and productivity. Parasite life cycles generally consist of two phases: the development of larvae to maturity within the host, and the maturation of eggs on the pasture after being excreted in the feces (Gordon et al., 1970). The development of larvae to maturity begins when the host ingests the larvae in the infective third larval stage (L3). Once ingested, the larvae penetrate the intestinal wall and molt into the fourth larval stage, L4 (Craig, 2018). During the L4 stage, the parasite matures, and the female laying eggs, which will eventually be expelled in the feces (Gordon et al., 1970). This marks the beginning of the second phase of a parasite's life cycle: the maturation of eggs on a pasture after being excreted in the feces. The eggs excreted in the feces will hatch on the pasture into L1 larvae. The L1 and L2 larvae remain in the feces, feeding on bacteria until they reach the infective L3 stage. Once they reach the L3 stage, the larvae migrate to areas with moisture, including damp forage, where they are subsequently ingested by grazing animals (Craig, 2018). Larval development on pasture is highly dependent on temperature and moisture conditions. Increased activity is exhibited by larvae at higher temperatures, with optimal development achieved at nearly 100% relative humidity (Craig, 2018). These environmental factors contribute to a heightened susceptibility of grazing cattle in the Southeast to parasitic infections and heavy parasite burdens.

Common Nematodes

In 2007 to 2008, the United States Department of Agriculture (USDA) National Health Monitoring System (NAHMS) conducted a beef study that included 99 producers from 24 states with the largest beef cow populations (Stromberg et al., 2015). Cattle eligible for inclusion in the study were between 6 and 18 months of age, and had not received anthelmintic treatment in 45 days. Each producer submitted up to 20 fecal samples, which were then shipped to a laboratory for analysis of strongyle eggs per gram. Among the collected samples, 85.6% had strongyle-type, *Nematodirus,* and *Trichuris* eggs. Additionally, 91% contained *Cooperia*, 79% *Ostertagia*, 53% *Haemonchus*, 38% *Oesphagostomum*, 18% *Nematodirus*, 7% *Trichuris*, and 3% *Trichostrongylus*.

Stromberg et al. (2012) evaluated the direct effects of *Cooperia* spp. on feedlot cattle after NAHMS identified it as the most prevalent parasite in the U.S. in 2008. At study initiation, 200 calves were sorted into feedlot pens and randomly assigned to receive either a *Cooperia punctata* inoculation via oral syringe or a control treatment consisting of a water-filled syringe. Necropsies performed on days 35 and 60 confirmed that *C. punctata* was recovered in the small intestine, accounting for more than 99% of the recovered worms. Control cattle had greater (*P* = 0.02) total weight gain compared to infected cattle, who had consumed 0.68 kg less (*P* = 0.02) feed each day. Additionally, the study assessed the sensitivity of *Cooperia punctata* to macrocyclic lactone and benzimidazole. Within each pen, cattle were assigned to receive one of the two anthelmintics and FECRT was conducted to determine drug efficacy. Resistance to the macrocyclic lactone was detected, with only 8.8% reduction in parasite load; however, the benzimidazole was highly effective, achieving a 98.1% reduction. These results indicate that *C. punctata* negatively impacts appetite and nutrient uptake in infected animals.

Furthermore, the impact of gastrointestinal parasites has been associated with decreased voluntary feed intake and is one of the largest factors related to production losses (Hawkins, 1993). A study was conducted by Högberg et al. (2019) to determine the effects of nematode parasitism on activity patterns in first-season grazing cattle. This study utilized two groups that were exposed to two different levels of gastrointestinal nematodes during the grazing period. The high-exposure group received 5,000 infective-stage larvae of *O. ostertagi* and *C. oncophora* at turn-out, while the low-exposure group received monthly deworming with a pour-on ivermectin. The heaviest animals in each group were equipped with cattle activity monitors, while body weights and fecal egg counts were collected at turn-out, and every two to four weeks until the end of the study. It was found that cattle in the high-group had a reduced body weight gain (*P* = 0.037) than those in the low-exposure group. Similarly, fecal egg counts remained greater (*P*<0.038) in the high-exposure group compared to the low-exposure group during the duration of the study. Högberg et al. (2019) concluded that cattle with clinical or subclinical parasite burdens exhibit behavioral changes such as, walking times, lying down, and feeding which suggest discomfort.

Anthelmintic

Diagnosing internal parasites in cattle involves various methods, including assessing clinical signs, determining fecal egg counts and culturing the eggs to the infective larval stage (Stromberg and Corwin, 1993). Culturing eggs enables the identification of specific parasite species, which is crucial for determining the most effective treatment and management strategies (Stromberg and Corwin, 1993; Craig, 2018).

Anthelmintics are drugs that are designed to treat and control infections in animals that are caused by parasitic nematodes (Holden-Dye and Walker, 2014; Nixon et al., 2020). There are various anthelmintic drugs available, but optimal animal performance depends on the administration of broad-spectrum anthelmintics. Benzimidazoles and macrocyclic lactones are the most widely used broad-spectrum dewormers, acting by eliminating the existing nematode burdens and preventing the establishment of ingested infective larvae (L3) for a period following treatment (Sutherland and Leathwick, 2011). Broad-spectrum dewormers have been widely adopted by livestock producers for their efficiency in controlling numerous species of nematode parasites, which have a substantial effect on animal productivity (Gilleard et al., 2021).

Benzimidazoles have been widely used as anthelmintics since their discovery and introduction in the 1960s (Gilleard et al., 2021). Benzimidazoles operate through a distinct mode of action by binding to the parasite's microtubules, disrupting its cytoskeletal structure. This interference impairs vital physiological functions, including locomotion and reproduction, ultimately leading to the parasites' inability to survive or reproduce (Holden-Dye and Walker, 2014). Benzimidazoles are highly selective in their action, targeting specific biological processes in parasitic worms while exhibiting low toxicity to mammals. The selective toxicity allows for effective parasite control in livestock with minimal risk to the animals when used at the recommended doses (Jaeger and Carvalho-Costa, 2017). In ruminants, oral administration of benzimidazoles leads to their deposition in the rumen, where they associate with digesta, influencing their availability and effectiveness (Hennessy, 1993). The route of administration affects drug uptake by parasites, with ruminal administration potentially acting as a reservoir for prolonged anthelmintic concentration (Prichard et al., 1977).

Macrocyclic lactones, introduced in 1981, demonstrated significantly greater potency than earlier anthelmintics, with their primary action directed at glutamate-gated chloride channels in nematodes (Wolstenholme et al., 2016; Gilleard et al., 2021). They demonstrated a broad spectrum of activity, effectively targeting both immature and mature stages of numerous gastrointestinal parasites (Gilleard et al., 2021). These drugs act as allosteric modulators, binding to glutamate-gated chloride channels and causing slow-opening, long-lasting channel activation, leading to neuronal and muscle cell hyperpolarization or depolarization (Wolstenholme et al., 2016). This results in paralysis and inhibition of pharyngeal pumping in parasites, and substantial evidence suggests that this disruption of feeding, caused by paralysis of the pharyngeal muscle, is the key mechanism of action at this stage (Wolstenholme et al., 2016).

Anthelmintic Resistance

In the early 1970s, farmers managing grazing animals gained access to new anthelmintics that provided significant advantages over earlier chemicals, including a broader spectrum of activity and increased potency (Gilleard et al., 2021). Over the years, anthelmintic-resistant parasite populations have emerged, challenging the efficacy of these drugs and limiting treatment options for controlling infections. Anthelmintic resistance is largely attributed to the widespread use of effective chemical nematode control methods, which have enhanced cattle productivity in the United States, but have now become one of the primary drivers for anthelmintic resistance (Wray et al., 2022). Anthelmintic resistance occurs when parasite populations that are usually susceptible to a drug, suddenly survive, and a decline of anthelmintic efficacy is observed (Sangster & Gill, 1999; Sutherland and Leathwick, 2011). The surviving nematode population will pass their resistant alleles to their offspring, thereby encouraging selective pressure exerted on the parasite's genome (Sangster and Gill, 1999).

Pour-on macrocyclic lactones have been the preferred method for producers due to their ease of administration, eliminating the need for chutes and minimizing both the time required to apply the product and the stress on the animal (Gasbarre, 2014). Pivoto et al. (2020) assessed the impact of macrocyclic lactones in cattle, focusing on its effects on anthelmintic resistance, animal performance, and the production losses mitigated by effective anthelmintic treatment in Brazil. The results demonstrated that levamisole and albendazole sulphoxide, from the benzimidazole and imidazothiazole drug classes, were highly effective at parasite control compared to the macrocyclic lactones, which were less effective. These findings indicate the presence of nematode resistance to all macrocyclic lactones tested. Furthurmore, heifers treated with levamisole gained an average of 12.1

kg and $18.03 in revenue per heifer than heifers treated with doramectin. This study concluded that the history of indiscriminate use of a single drug class in this herd ultimately lead to the development of nematode resistant populations and associated production losses.

Similar results were observed in the United States (Gasbarre et al., 2009; Gasbarre et al., 2009). Gasbarre et al. (2009) evaluated efficacy and potential resistance in a stocker cattle operation in the upper Midwest after decreased animal productivity and diarrhea were observed. Historically, all cattle in this operation were grazed on the same pasture using an intensive grazing management strategy, with strategically timed deworming program administering fenbendazole and an avermectin from 1980 to 2002. Efficacy test results confirmed resistance to all treatments, including avermectins and benzimidazoles, indicating that the pasture harbored resistant nematode populations. A second year of the study further investigated the relationship between anthelmintics, and resistant nematodes maintained on pasture (Gasbarre et al., 2009), and confirmed that the pasture hosted nematode populations were resistant to avermectins, milbemycin, and a benzimidazole.

Developing mew anthelmintics requires between 50 to 100 million dollars and several years of field trials before a new drug can be introduced (Nixon et al., 2020). Therefore, a thorough understanding of the pharmacology of anthelmintics is crucial for preventing anthelmintic resistance and preserving the efficacy of classes currently available (Sangster and Gill, 1999).

Economics and animal response to parasite control

Managing the parasitism load in beef cattle has many advantageous effects on animal performance. Wohlgemuth et al. (1989) found that increased weight gain in nursing beef calves has been demonstrated following anthelmintic treatment of the cows or calves, with calves showing improved weight gain soon after they were treated. Similarly, Smith et al. (1999) demonstrated that both feedlot steers and calves on pasture dewormed with fenbendazole experienced significant economic benefits. Strategic deworming with fenbendazole resulted in a net benefit of $33.75 per steer if sold at the end of the grazing phase. In the grazing-finishing system, deworming non-dewormed steers at the feedlot with fenbendazole produced a net benefit of $20.41 per head on a live basis, or $30.61 on a carcass adjusted bases. For steers that had been strategically dewormed prior to entering the feedlot, the net benefit was $2.67 per head on a live basis, or $11.07 on a carcass adjusted basis. When accounting for the cost of dead animals, feedlot deworming of pasture control steers or those strategically dewormed on pasture resulted in net benefits of $35.46 or $6.43 per head, respectively. These findings highlight the potential profitability of strategically using anthelmintics in beef cattle production.

Grazing Method

Georgia’s mild winter climate provides optimal conditions for growing cool-season forages (Mullenix and Rouquette, 2018). The state falls within USDA Plant Hardiness zones 8a to 9a, where vegetation is influenced by rainfall and temperature gradients (USDA/ARS, 2023). Annual ryegrass *(Lolium multiflorum)* is a popular cool-season forage grown on approximately 1.1 million hectares in the Southeastern United States (Venuto et al., 2003). Research has shown that annual ryegrass is successful when grown in monocultures, small grain mixtures, or sod-seeded into dormant bermudagrass (Fribourg and Overton, 1973; Beck et al., 2005; Beck et al., 2007).

Beck et al. (2016) found that incorporating cool-season annuals, combined with effective grazing management, extends the grazing season and enhances net returns for grazing calves. This study evaluated three grazing strategies: continuous grazing at a moderate SR (CG) on stockpiled bermudagrass, rotational grazing at a moderate SR (MR) on stockpiled bermudagrass and complementary cool season annuals, and rotational grazing at a high SR (HR) on stockpiled bermudagrass and complementary cool season annuals. For the MR and HR groups, a mixture of wheat (*Triticum aestivum*) and annual ryegrass (*Lolium perenne multiflorum*) were interseeded in the fall into the bermudagrass sod. Results showed a reduction ($P < 0.01$) in hay feeding days with CG requiring 107 ± 10.9 days of hay supplementation, HR reducing to 37 ± 10.9 d, and MR further decreasing ($P = 0.01$) to 15 ± 10.9 d. Calf body weight at weaning in the CG group tended to be greater ($P = 0.09$) compared to the MR group and greater than the HR group ($P < 0.01$). Total calf weaning weight per hectare was greatest ($P < 0.01$) in the HR group and did not differ ($P = 0.31$) between CG and MR. Net returns per hectare were greater in HR, increasing by 107% ($P < 0.01$), while no differences were observed between CG and MR ($P = 0.30$). These findings demonstrate that integrating cool-season annuals with rotational grazing and stockpiled bermudagrass can extend the grazing season, reduce winter feed requirements, and increase net returns.

Stocker cattle production

Stocker cattle operations grow weaned calves on forage or pasture-based diets before transitioning to a feedlot (Greenwood, 2021). Similar to the cow-calf sector, stocker operations are predominantly land-based enterprises. Serving as the intermediary between the cow-calf and feedlot segments, the stocker sector faces constraints related to the seasonal and spatial distribution of supply, as well as the quality of weaned calves throughout the year (Cummings et al., 2023).

Research comparing rotational and continuous grazing has yielded mixed results regarding their impacts on forage production and animal performance. McCollum et al. (1999) evaluated the effects of stocking rate and grazing methods on stocker cattle performance over a six-year period from April to September. The study compared short duration rotational and continuous stocking methods at stocking rates ranging from 52 to 90 animal unit-days per ha. Results indicated that total live weight gain per head was consistently greater ($P<0.05$) each year for continuous stocking compared to rotational stocking. At stocking rates of 52 and 90 animal unit days per ha, total gains for rotational stocking were 12.8 kg and 22 kg per head lower, respectively, than those observed under continuous stocking. Additionally, gain per ha was greater ($P < 0.05$) for continuous stocking at all stocking rates. While net returns increased with stocking rate for both systems, continuous stocking yielded higher net returns across all stocking rates.

In contrast, M. J. Williams and Hammond (1999) assessed the impact of rotational versus continuous intensive stocking on herbage mass, forage crude protein content, and animal performance of cows and calves over a three-year study in Brooksville, Florida. Cow performance was evaluated based on body condition score, weight, and pregnancy rate, while calf performance was measured by average daily gain, weaning weight, and body condition score. Cattle were assigned to either continuous intensive stocking (CIS) or rotational stocking. No differences in herbage mass were observed between treatments after cattle density in the CIS treatment was increased by 75%. Additionally, cattle did not exhibit selectivity between treatments, even as herbage mass of the CIS group increased. Therefore, there were no differences observed between CIS and rotational grazing management on animal performance measures.

Similarly, Rouquette et al. (2023) conducted a more recent evaluation of average daily gain, gain per ha, and forage mass and allowance of rye and annual ryegrass sod-seeded into bermudagrass pastures at varying stocking rates for stocker cattle. The study spanned seven years, with stockers grazed continuously (CONT) at up to three different stocking rates with up to three replicates or rotationally (ROTN) across eight paddocks, with six stockers per replicate pasture, from December to May. Stocking rate affected average daily gain ($P < 0.0001$) and gain/ha ($P = 0.0150$) in both rotational and continuous stocking systems; however, stocking method did not affect the same measures. The optimal balance between maximum gain and forage mass was observed at 1850 kg/ha and a forage height of 16 cm. This study concluded that the decision to implement rotational stocking should be based on forage production considerations rather than animal performance or per land unit area, as rotational stocking was not found to differ from continuous stocking in terms of performance outcomes.

Mckown et al. (1991) observed that cattle on continuous grazing had higher nutrient intake than those on rotational grazing systems, attributing this to variations in stocking rates rather than the grazing systems themselves. Similarly, Bransby (1993) summarized that stocking rate is likely the most important grazing management practice affecting the production of grazing animals. Even without the presence of internal parasites, increasing the stocking rate results in lower forage availability and consumption, leading to reduced intake.

Grazing height and internal parasites

Understanding the distribution of parasite larvae within different portions of forage is essential for assessing the risk of reinfection in grazing livestock. Previous research has examined how forage height influences parasite concentration, providing insight into the potential impact of grazing management strategies on parasite exposure.

Research suggests that grazing management strategies can greatly influence the level of parasite exposure in livestock. While the overall contact with fecal-contaminated patches may be similar across different grazing systems, the timing and intensity of exposure can differ significantly (Smith et al., 2009). Cattle typically avoid grazing near fecal pads unless pasture availability is restricted; however, the tendency of the infectious L3 larval stage to remain in close proximity to fecal pads can significantly influence parasite transmission (Smith et al., 2009). Grazing management strategies can affect cattle exposure to parasite distribution in pastures. Understanding these dynamics is essential for developing efficient parasite control strategies in grazing systems, thereby reducing their impact on livestock health and productivity.

Gazda et al. (2009) evaluated the distribution of sheep nematode larvae in Pensacola bahiagrass (*Paspalum notatum* cv. Saurae) and Aruana Guinea grass (*Panicum maximum* cv. Aruana). In both forages with lower dry matter yield, greater ($P < 0.05$) concentrations of helminth larvae were found in the lower portion of the plant compared to the higher portion. Additionally, animals grazing lower-yield pastures exhibited greater ($P < 0.05$) average fecal egg counts than those in pastures with higher forage yield.

Similar findings were reported by Pegoraro et al. (2008) in a study evaluating the effect of Italian ryegrass management on parasite reinfection risk. Sheep parasite burden and parasite infestation was analyzed across different forage heights (0-2.5, 2.5-5, 5-10, 10-15, and 15 cm). The results indicated that approximately 80% of the parasites recovered were concentrated within the lower 5 cm of vegetation. These finding emphasize the importance of maintaining a residual grazing height of 10 cm to minimize the ingestion of L3 infective larvae (Kumar et al., 2012).

Conclusion

In reviewing the literature, it is evident that gastrointestinal parasites have a major impact on the health and performance of weaned cattle. Post-weaning growing programs play a crucial role in supporting calf development by providing necessary vaccinations, implementing deworming strategies, and optimizing nutrition. Additionally, research has shown that the lower portion of forage contains the greatest concentration of L3 larvae, highlighting the importance of grazing management in parasite control. The growing concern of anthelmintic resistance has challenged the effectiveness of current drugs, and the need to evaluate current anthelmintics strategies is imperative. To mitigate these challenges, management strategies can be implemented to potentially reduce reliance on anthelmintics and effectively control parasite burdens in grazing beef cattle. The research that follows builds on these findings by analyzing the impact of specific management strategies on parasite reinfection, providing valuable insights for improving cattle health and performance.

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CHAPTER 3

POST-WEANING ANTHELMINTIC STRATEGIES: EVALUATION OF EFFICACY AND PERFORMANCE BENEFIT PROVIDED TO STOCKER CALVES BY DIFFERENT DEWORMING STRATEGIES

To be submitted to a peer-reviewed journal (Translational Animal Science)

Abstract

A study was conducted to evaluate the effect of different anthelmintic strategies on growth performance and eggs per gram (EPG) count during a 42-d post-weaning, backgrounding phase and an 84-d yearling stocker trial on two University of Georgia research farms: Georgia Mountain Research and Education Center in Blairsville, GA and J. Phil Campbell Sr. Research and Education Center in Watkinsville, GA. On each farm, 9- to 10-month-old stocker cattle and 8- to 9-month-old newly weaned calves were stratified by weight and EPG collected prior to d 0, and assigned to one of three treatments: 1) direct-fed Fenbendazole pellets (SAFE; Safe-guard®, Merck Animal Health, Deerfield, IL), 2) transdermal Eprinomectin pour-on (POUR; Eprinex®, Boeheinger Ingelheim, Duluth, GA), and 3) and a control group (CONT) whom received no treatment. There were no treatment differences in body weight in either experiment ($P > 0.16$). In Experiment 1, SAFE cattle had greater average daily gain (ADG) overall compared to CONT ($P < 0.02$), with POUR intermediate. In Experiment 2, SAFE and POUR cattle exhibited greater overall ADG compared to CONT ($P < 0.01$), with no difference between SAFE and POUR ($P = 0.45$). In both experiments, EPG was fewest for SAFE ($P < 0.04$) and resistance to macrocyclic lactones is confirmed due to failing to reach ≥95% reduction in EPG after treatment. The results of this study indicate that the direct-fed fenbendazole provided effective parasite reduction, improved growth performance, and represents a practical anthelmintic delivery option for producers lacking animal restraint facilities.

Key words: anthelmintic, stocker, parasites

Introduction

Gastrointestinal parasites are considered a major beef cattle production burden, impacting health, growth rates, and overall productivity, resulting in substantial economic losses, costing the U.S. beef industry $3 billion annually (Andresen et al., 2018; Strydom et al., 2023). Clinical signs such as anorexia, diarrhea, and a general body condition decline are often exhibited by infected cattle (Andresen et al., 2018; Clark et al., 2015). Parasitic infections are more commonly observed in young cattle, particularly calves, who tend to have greater fecal egg counts than adult cattle due to their naïve immune systems (Nieman, 2017; Williams et al., 2024). Following weaning, calves can enter stocker or backgrounding programs, where proper nutrition, vaccinations, and deworming practices enhance their health and appearance before they are sold to feedlots as value-added products (Rhinehart and Poore, 2013). Wohlgemuth et al. (1989) found nursing beef calves experienced increased weight gain after cows or calves received anthelmintic treatment. Given the substantial impact of gastrointestinal parasites on health and productivity, effective parasite control measures, such as anthelmintics, are crucial in post-weaning programs.

Benzimidazoles and macrocyclic lactones are broad-spectrum anthelmintics that were introduced in the 1960’s. These products remained the predominate anthelmintics used to control internal parasites due to efficiently eliminating multiple parasite species, reducing worm burdens, and preventing larvae establishment (Gilleard et al., 2021; Sutherland and Leathwick, 2011). Given the success of this drug class in mitigating negative effects of parasite burdens over the years, the emergence of anthelmintic-resistant nematodes is attributed to frequent and indiscriminate treatment, improper dosing, and repeated annual use of the same drug (De Graef et al., 2013; Gilleard et al., 2021). As a result, surviving worms pass their resistance alleles to their progeny (Sangster and Gill, 1999), contributing to growing prevalence of anthelmintic resistance in the U.S. (Bliss et al., 2008; Gasbarre et al., 2009; Edmonds et al., 2010). Specifically, Bliss et al. (2008) found that overall pour-on macrocyclic lactone efficacy was 66.1%, compared to 99.4% for an oral benzimidazole drench. Additionally in 2017, USDA conducted a survey across 24 states, representing 78.9% of U.S. cow-calf operations. Among operations surveyed, 90.4% sold weaned calves specifically intended for feedlots, stocker programs, or backgrounding operations. In contrast, only 53.9% of operations dewormed calves at weaning (USDA and APHIS, 2021). These findings highlight growing concern over macrocyclic lactone resistance and the shortage of operations deworming calves at weaning, further emphasizing challenges in implementing effective parasite control measures. These challenges may be attributed to the absence of physical restraint facilities; however, further research is needed to identify potential solutions for improving effective parasite control.

Effective anthelmintic strategies are essential for improving cattle productivity and overall health, particularly in post-weaned calves. By reducing elevated parasite burdens, these programs have potential to increase average weight gain compared to untreated calves, thereby improving their value as they transition to feedlots. Despite challenges posed by anthelmintic resistance and limited adoption of deworming practices, direct-fed anthelmintics provide a convenient solution for producers lacking facilities to administer oral anthelmintics; however, research is limited in implementing this practice in weaned beef cattle. Addressing these issues through improved management practices and implementation of more effective parasite control strategies is vital. Therefore, the objective of this study was to evaluate anthelmintic efficacy and performance benefits of a pour-on macrocyclic lactone versus a direct-fed benzimidazole pellet in post-weaning cattle systems.

Materials and Methods

All practices and procedures used in these experiments were examined and approved by the University of Georgia Animal Care and Use Committee prior to the start of the experiments (IACUC A2023 09-013-Y2-A0, and A2022 09-008-Y3-A0). The research was divided into two feeding trials, over two consecutive year experiments. Experiment 1 was a yearling stocker trial conducted at the Georgia Mountain Research and Education Center in Blairsville, GA from November to February during two consecutive years: 2022 to 2023 (YR1) and 2023 to 2024 (YR2). Experiment 2 was a post-weaning, background period conducted at the University of Georgia J. Phil Campbell Sr. Research and Education Center in Watkinsville, GA from October to December of two consecutive years: 2023 (YR1) and 2024 (YR2).

Experiment 1: Yearling Stocker Trial

Each year, 81 nine-to-ten-month-old stocker steers (251 ± 21 kg in YR1; 297 ± 27 kg in YR2) were sourced from the University of Georgia, Eatonton Beef Research Unit (Eatonton, GA). Pre-weaning vaccinations (Pyramid® 5 and Caliber® 7; Boehringer Ingelheim Animal Health USA Inc., Duluth, GA) were administered, and boostered at weaning in early September. Weaning occurred at seven to eight months of age, and all calves received one round of pour-on moxidectin (Cydectin®; Elanco Animal Health, Greenfield, IN) for parasite control.

Following weaning each year, calves remained at their birth location in Eatonton, GA, for approximately 60-d and were provided a diet of stockpiled bermudagrass *(Cynodon dactylon)* and crabgrass *(Digitaria sanguinalis)* pastures and supplemented daily with approximately 2.3 $kg \cdot hd^{-1} \cdot d^{-1}$ of dried distillers' grains, ground ear-corn, and a vitamin and mineral pre-mix. On 1 November 2022 and 2023, stockers were weighed, fecal samples collected, and the 81 stockers were transported to the Georgia Mountain Research and Education Center (Blairsville, GA).

Upon arrival in Blairsville, stockers were provided *ad libitum* access to hay and water for 24 hours. Stockers were given a 14-d acclimation period and fed 4.54 $kg \cdot hd^{-1} \cdot d^{-1}$ of corn silage and 0.91 $kg \cdot hd^{-1} \cdot d^{-1}$ of dried distillers' grains to acclimate to the diet. Prior to experiment initiation, all stockers were stratified by body weight and quantity of fecal EPG collected at transportation and sorted into nine groups. Each group was randomly assigned to one of three treatments: 1) direct-fed Fenbendazole pellets (SAFE; Safe-guard®, Merck Animal Health, Deerfield, IL), 2) transdermal Eprinomectin pour-on (POUR; Eprinex®, Boeheinger Ingelheim, Duluth, GA), and 3) and a control group (CONT) whom received no treatment.

On d -1, silage was restricted by 75% of the previous day's offering and no supplemental dried distillers' grains to ensure treatment intake on d 0. On d 0, no feed was offered prior to cattle processing, and all bunks were cleaned to ensure the absence of residual feed. All stockers were shrunk weighed, fecal samples collected, and treatments were administered. For the POUR groups, transdermal eprinomectin was administered at a dosage of 1 $mL \cdot$ 10 kg body $weight^{-1}$ while each stocker was restrained in the chute. Once all stockers were weighed and fecal samples collected, they were returned to their respective paddocks. All groups received a diet of dried distillers' grains (1.81 kg·hd^{-1}) ground ear-corn (0.45 kg·hd^{-1}). Treatment for the SAFE groups was calculated based on the weight of the heaviest stocker in the group, ensuring a dosage of 5 mg· kg of body weight^{-1}, which was then multiplied by nine and distributed accordingly. The treatment was delivered as pellets, hand-mixed with the dried distillers' grains and ground ear-corn. Feed bunks were inspected to verify that SAFE pellets were consumed, after which all treatment groups received their daily amount of corn silage.

Throughout the remainder of the experiment, normal feeding protocols were resumed. Stockers were provided a corn silage-based diet, with amount adjusted daily based on the previous day's intake and supplemented daily with 1.81 kg·hd^{-1} of a dried distillers' grains mix (90% dried distillers' grains, 5% mineral mix, and 5% limestone) and 0.45 kg·hd^{-1} of ground ear-corn, with these supplements remaining consistent throughout the experiment. Composited feed samples across both years were submitted to Cumberland Valley Analytical Services (Waynesboro, PA) for chemical analysis of each ingredient (Table 3.1).

Experiment 2: Post-weaning, Backgrounding Period

Calves were sourced from the University of Georgia J. Phil Campbell Sr. Research and Education Center in Watkinsville, GA, where this experiment occurred. In YR1, 54 eight-to-nine-month-old calves (242 ± 50 kg) were enrolled in the experiment, and 60 eight-to-nine-month-old calves (225 ± 25 kg) were enrolled in YR2. In both years of the experiment, calves were born from January to February and vaccinated intranasally at birth (Inforce™ 3; Zoetis Animal Health Inc., in Parsippany, NJ). In YR1, at four to five months of age (15 June 2023), all calves were dewormed with pour-on eprinomectin

(Eprinex®; Boehringer Ingelheim Animal Health USA Inc.). Pre-weaning vaccinations (Caliber® 7 and Pyramid® 5; Boehringer Ingelheim Animal Health USA Inc.) were administered and boostered at weaning on 11 October, when calves were eight to nine months old. In YR2, at three to four months of age (1 May 2024), all calves received an oxfendazole oral suspension (Synanthic®; Boehringer Ingelheim Animal Health). Pre-weaning vaccinations (Covexin® 8, Merck Animal Health; Pyramid® 5, Boehringer Ingelheim Animal Health) were administered and boostered at weaning on 7 October, when calves were eight to nine months old.

On d-7 each year, fecal samples and body weights were collected and used to stratify calves by weight and EPG into three groups. The groups were then randomly assigned to one of three treatments as described in Experiment 1. At this time, recently weaned calves underwent a 7-d acclimation period to adjust to the experimental diet, during which calves were provided 0.91 kg of dried distillers' grains and 0.45 $\text{kg}\cdot\text{hd}\cdot\text{d}^{-1}$ of ground-corn. The allocation of dried distillers' grains was increased daily until reaching 1.36 kg on d -1, while corn supplementation remained consistent at 0.45 $\text{kg}\cdot\text{hd}\cdot\text{d}^{-1}$ throughout the acclimation period.

On d-1, feed was restricted for all calves to ensure proper treatment intake on d 0. On d 0, no feed was offered prior to cattle processing, and shrunk body weights and fecal samples were collected, followed by treatment administration. The POUR treatment was administered to calves while restrained in the chute at a dose of $1\text{ml}\cdot 10$ kg body weight^{-1}. For the SAFE treatment, after weights and fecal samples were collected in the chute, calves were penned individually, and treatment was administered, allowing for calf to serve as the experimental unit. Treatment was administered at a dose of $5\text{mg}\cdot\text{kg}$ body weight^{-1}, with pellets hand-mixed into 1.36 kg dried distillers' grains and 0.45 kg of corn. Calves in the SAFE group were monitored in the holding pen and released once all feed and treatment was consumed.

Following d 0, all calves were comingled and managed together on dormant bermudagrass (*Cynodon dactylon*) and crabgrass (*Digitaria sanguinalis*) pastures during a 42-d backgrounding period from October to December in Watkinsville, GA. Calves were rotated weekly between paddocks, ensuring that paddocks were not revisited during the experiment. During the background period, calves were offered *ad libitum* hay (*Lolium multiflorum*, YR1; *Pennisetum glaucum*; YR2), and supplemented daily with 1.81 kg·hd^{-1}·d^{-1} of dried distillers' grains (90% dried distillers' grains, 5% mineral mix, and 5% limestone) and 0.68 kg·hd^{-1}·d^{-1} ground-corn. Feed samples were submitted to Cumberland Valley Analytical Services (Waynesboro, PA), while forage analysis was conducted by the University of Georgia Ag & Environmental Services Labs to assess chemical composition (Table 3.2).

Animal Performance

To evaluate animal performance, calves from Experiment 1 were weighed on d 0, 28, 56, and 84 to determine average daily gain (ADG), while calves from Experiment 2 were weighed on d 0, 14, 28, and 42 for the same assessment.

Anthelmintic Efficacy

Fecal samples were collected at each location prior to treatment on d 0 and post-treatment on d 14 to evaluate differences in EPG. Fecal samples were collected on weigh days, into resealable plastic bags, stored on ice for a minimum of two hours, and shipped overnight to the Merck GI Parasite Diagnostic Lab (Lawrence, KS) for analysis using the

Modified Wisconsin Sugar Floatation method (Smith, 1997). Fecal egg count reduction (FECR) was calculated as:

$$Efficacy\,\% = 100\ \times \frac{(pretreatment\ count) - (posttreatment\ count)}{pretreatment\ count}$$

Statistical Analysis

Animal Performance and Eggs Per Gram

Experiment 1 analyses were performed using group as the experimental unit (n = 9), and stocker as the observational unit. Experiment 2 analyses were performed using calf as the experimental unit. Both experiments were organized in a completely randomized design with treatment (direct-fed Fenbendazole pellet, SAFE; transdermal Eprinomectin pour-on, POUR; control group, CONT) as the fixed effect and year as the random effect. Models were analyzed by restricted maximum likelihood using PROC MIXED in SAS v 9.4 (SAS Institute Inc., 2013, Littel et al., 2006) with an autoregressive (1) covariance structure, selected based on the lowest Bayesian Information Criterion. A Kenwood-Rogers adjustment was applied to correct the denominator degrees of freedom and ensure appropriate standard errors and F-statistics. Means were compared using the LSMEANS procedure with Tukey-Kramer adjustment. Differences were considered significant at $P \leq 0.05$.

Anthelmintic Efficacy

Analyses for both experiments were performed using the "lme4" mixed model CRAN package "eggCounts" (Wang and Furrer, 2018), which utilizes a Bayesian hierarchical model to analyze FECR. Data were analyzed in R statistical programming v4.0.2 (Vienna, Austria) within the integrated development environment (IDE) RStudio v1.3.1073 (Boston, MA). The model incorporated a paired design to account for individual effectiveness for each calf. Anthelmintic effectiveness was determined using the criteria outlined in Geurden et al. (2015) and the World Association for the Advancement of Veterinary Parasitology (Coles et al., 1992). Treatments were classified as Effective, Confirmed Resistance, or Inconclusive according to the percent reduction (%R), Upper 95% confidence interval (U95%), and Lower 95% confidence interval (L95%).

Results and Discussion

Animal Performance

In experiment 1, no treatment by year interaction was observed for any of the animal performance responses ($P > 0.63$), therefore, all data are presented by main effects. There were no treatment differences observed in body weight throughout the experiment ($P > 0.16$; Table 3.3). Similarly, no treatment differences were observed in ADG from d 0 to 56 ($P > 0.09$); however, SAFE had greater ($P < 0.02$) ADG overall (d 0 to 84) than CONT, with POUR not different than both. Additionally, a treatment by year interaction was observed for all DMI data ($P < 0.01$); however, data is presented as main effects (Table 3.4). From d 0 to 56, CONT cattle had less DMI compared to SAFE and POUR cattle ($P < 0.01$), with SAFE and POUR not differing ($P > 0.13$). From d 57 to 84, SAFE had greater ($P < 0.01$) DMI compared to CONT, with POUR intermediate ($P < 0.04$). When adjusted for body weight, overall, CONT cattle consumed less compared to SAFE and POUR cattle ($P < 0.01$), with SAFE and POUR not differing ($P > 0.13$).

In experiment 2, there were no treatment by year interactions observed for any of the animal performance measures ($P > 0.05$), therefore, all data is presented as main effects. There were no treatment differences observed in body weight throughout the experiment ($P > 0.37$; Table 3.5). Similarly, no treatment differences were observed ($P = 0.15$) in ADG from d 0 to 14. Overall, SAFE and POUR exhibited greater ($P < 0.05$) ADG than CONT, but did not differ from each other ($P = 0.45$).

Cattle in the SAFE and POUR groups of both experiments exhibited greater total weight gain and average daily gain than cattle in the CONT group. Similarly, CONT cattle in experiment 1 had less DMI than cattle in SAFE and POUR. These results support the findings of Stromberg et al. (2012) who reported decreased feed intake and average daily gain observed in cattle with greater gastrointestinal parasite burden. At study conclusion, cattle in experiment 1 SAFE had greater overall average weight than POUR cattle. These results agree with Pivoto et al. (2020) who reported greater weight gains in cattle resistant to macrocyclic lactones when treated with benzimidazoles. These results suggest that effective parasite control improves weight gain and average daily gain in yearling stocker cattle and weaned, backgrounding cattle. Also, it improves feed intake in yearling stocker cattle. Cattle treated with SAFE and POUR exhibited better performance than untreated cattle, supporting previous findings that parasite burden negatively impacts growth. Additionally, greater final weights in SAFE cattle compared to POUR cattle highlight the potential benefit of using alternative anthelmintics in animals resistant to macrocyclic lactones.

Anthelmintic Efficacy

In experiment 1, there were no treatment effects observed in EPG on d 0 ($P = 0.46$), as expected; however, treatment differences were observed on d 14, 28, 56, 84 ($P < 0.05$; Table 3.6). On d 14, EPG for SAFE was the least ($P < 0.01$), and POUR had fewer than CONT. For the remainder of the experiment, EPG was fewest for SAFE and similar between CONT and POUR. Day 28 was omitted from the subsequent reduction model, due to the increase of EPG from d 14 to 28. Additionally, all treatments showed some reduction in simulated fecal egg counts on d 14 (Table 3.7). Cattle who received the SAFE treatment eliminated fecal shedding of internal parasite eggs on d 14 and treatment remained effective by meeting 95% reduction on d 56 and 84. Cattle who received the POUR treatment exhibited a reduction in fecal egg counts on d 14; however, POUR failed to meet percent reduction requirements (Coles et al., 1992; Kaplan et al., 2023) on all presented days and resistance is detected.

In experiment 2, there was a treatment by day interaction ($P < 0.05$) observed in EPG (Figure 3.1). There were no treatment differences observed in EPG on d 0 ($P > 0.33$), as expected. Throughout the remainder of the experiment, EPG was greatest for CONT compared to POUR and SAFE ($P < 0.01$), and POUR was greater ($P < 0.04$) than SAFE. Similar to experiment 1, all treatment groups showed a reduction in simulated fecal egg counts on d 14 (Table 3.8). Cattle that received the SAFE treatment eliminated fecal shedding and met the percent reduction threshold and treatment is considered effective (Coles et al., 1992; Kaplan et al., 2023). Cattle who received POUR treatment did not meet the percent reduction threshold, and resistance is detected. Since all cattle were commingled after d 0 and were housed on pastures previously grazed by the herd, reinfection was expected on all treatments. Therefore, d 28 and 42 were excluded from this model.

Cattle from both experiments exhibited resistance to macrocyclic lactones due to failing to reach a minimum of 95% reduction in EPG after treatment as defined by the

World Association for the Advancement of Veterinary Parasitology (Coles et al., 1992; Kaplan et al., 2023). Cattle utilized in this project were sourced from farms who have historically treated their herds with macrocyclic lactones. The results from this study agree with Ramos et al. (2016) who measured resistance to different classes of commercially available anthelmintics. Eggs per gram collected 14-d after treatment, confirmed that fenbendazole was the most effective drug with macrocyclic lactones not effective in parasite reduction (Ramos et al., 2016). Stromberg et al. (2012) reported similar findings with the efficacy of a macrocyclic lactone at 8.8% and benzimidazole at 98.1%. These results indicate that resistance to macrocyclic lactones is present in cattle sourced from farms with a history of macrocyclic lactone use. Fenbendazole was the most effective anthelmintic for reducing parasite burden, consistent with previous reports of declining macrocyclic lactone efficacy. These findings highlight the need for regular monitoring of anthelmintic effectiveness and suggest that alternative parasite control strategies may be necessary to maintain cattle health and performance.

Additionally, cattle in experiment 1 were transported from their birth farm, and managed in a drylot setting with access to dormant pastures that are not grazed by cattle outside of the experimental period. In contrast, cattle in experiment 2 were commingled on contaminated pastures. Average fecal egg counts observed were higher in Experiment 2 than in Experiment 1, suggesting that parasite populations can be sustained in contaminated pastures. These findings align with those of Gasbarre et al. (2009), who reported that the repeated use of the same anthelmintic drug each year leads to the development of resistant parasite populations within pastures.

As anthelmintic resistance continues to threaten the efficacy of parasite control in cattle, the implementation of management strategies that reduce reliance on anthelmintics as the sole method of parasite control is essential for sustaining herd health and productivity. Additionally, assessing anthelmintic efficacy within a herd ensures the implementation of effective parasite control measures. Since 2000, few new drugs have been introduced, as the development of a new chemical class with novel mechanisms of action requires years of clinical studies and an investment of $50 to 100 million (Nixon et al., 2020). To address these challenges, more sustainable parasite control strategies are essential to reducing reliance on anthelmintics as the primary method for managing parasite burdens in cattle.

Conclusion and Implications

The findings of this project highlight the enhanced anthelmintic efficacy and associated performance benefits of a direct-fed fenbendazole pellet relative to a pour-on macrocyclic lactone within post-weaning cattle production systems. The consistent improvements observed in both stocker and weaned calves underscore the biological and economic value of this formulation. Furthermore, the availability of a direct-fed method offers a practical alternative to traditional oral administration, facilitating the strategic use of benzimidazoles without the need for animal restraint. These results suggest that effective parasite control improves feed intake, weight gain, and average daily gain in grazing cattle, and that utilizing alternative anthelmintics can enhance cattle performance, particularly in herds with existing drug resistance. Additionally, the detection of macrocyclic lactone resistance among cattle sourced from farms with historical use highlights the need for regular monitoring of anthelmintic effectiveness and suggests that alternative parasite control strategies may be necessary to maintain cattle health and productivity. This advancement represents a meaningful contribution to parasite control programs, supporting more effective and accessible management strategies for producers. Future research is needed to evaluate the long-term impacts of direct-fed benzimidazole use on parasite resistance, as well as assessing its efficacy across diverse management systems and stages of production.

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Table 3.1. Chemical analysis[1] of feed in an 84-d yearling stocker trial (Experiment 1)

Item	Silage	Dried distillers' grains	Corn
Chemistry analysis[2]			
DM, % DM	34.5	89.1	84.4
CP, % DM	7.3	29.9	8.6
ADF, % DM	23.7	11.5	5.2
NDF, % DM	40.1	27.8	14.4
Crude fat, % DM	-	7.09	4.45
TDN, % DM	72.5	67.3	83.7
Minerals			
Ash, %	3.67	16.79	3.06
Ca, %	0.21	3.44	0.07
P, %	0.22	1.48	0.30
Mg, %	0.13	0.47	0.10
K, %	0.80	1.23	0.40
Na, %	0.01	1.80	0.03
Fe, mg/kg	84	653	57
Mn, mg/kg	26	202	10
Zn, mg/kg	20	367	28
Cu, mg/kg	6	124	6

[1] Feed analysis was performed by Cumberland Valley Analytical Services (CVAS; Waynesboro, PA).

[2] Chemistry Analysis include: Dry Matter (DM), Crude Protein (CP), Acid Detergent Fiber (ADF), Neutral Detergent Fiber (NDF), Total Digestible Nutrients (TDN).

Table 3.2. Chemical analysis[1] of feed in 42-d post-weaning backgrounding trial (Experiment 2)

	Hay[2]		Dried Distillers' Grains		Corn	
Item	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Chemistry analysis[3]						
DM, % DM	100	100	90.5	90.3	87.3	86.6
CP, % DM	8.3	11.1	31.1	27.8	8.3	9.0
ADF, % DM	40.13	44.5	14.5	9.6	4.1	3.1
NDF, % DM	61.8	62.2	32.6	26.7	13.2	11.0
Crude fat, % DM	-	-	7.81	7.05	4.06	3.36
TDN, % DM	57.3	53.5	62.7	71.5	82.9	84.4
Minerals						
Ash, %	-	-	16.27	13.90	4.63	1.77
Ca, %	0.60	0.52	1.86	2.61	0.11	0.01
P, %	0.33	0.42	1.22	1.31	0.38	0.24
Mg, %	0.21	0.27	0.40	0.39	0.12	0.08
K, %	2.95	3.33	1.28	1.22	0.49	0.35
Fe, mg/kg	474	1430	250	582	97	230
Mn, mg/kg	57	113	59	168	9	9
Zn, mg/kg	12	43	130	264	35	33
Cu, mg/kg	0	5	35	88	6	7

[1] Feed analysis was performed by Cumberland Valley Analytical Services (CVAS; Waynesboro, PA). Hay analysis was performed by the University of Georgia Ag & Environmental Services Labs.

[2] Annual Ryegrass (*Lolium multiflorum*; 2023 YR1) and Pearl Millet (*Pennisetum glaucum*; 2024 YR2).

[3] Chemistry Analysis include: Dry Matter (DM), Crude Protein (CP), Acid Detergent Fiber (ADF), Neutral Detergent Fiber (NDF), Total Digestible Nutrients (TDN).

Table 3.3. Animal performance of calves treated with one of three anthelmintic strategies[1] during an 84-d yearling stocker trial (Experiment 1)

	Treatment[1]				
Item[2]	CONT	SAFE	POUR	SEM	*P*-value
Weight, kg					
d 0	272	274	272	4.767	0.91
d 28	308	314	310	5.032	0.53
d 56	339	348	344	5.909	0.31
d 84	372	385	377	6.499	0.16
ADG, $kg \cdot day^{-1}$					
d 0 to 28	1.29	1.43	1.37	0.040	0.17
d 0 to 56	1.20	1.33	1.28	0.024	0.09
d 0 to 84	1.19^{b}	1.32^{a}	1.26^{ab}	0.019	0.01

[1] Treatments included: direct-fed fenbendazole (SAFE; Safeguard®, Merck Animal Health; 5 $mg \cdot kg$ of body $weight^{-1}$); transdermal eprinomectin (POUR; Eprinex®, Boehringer Ingelheim; 1 $ml \cdot 10$ kg of body $weight^{-1}$); and a control (CONT; no anthelmintic treatment).

[2] Items include: Weight (average body weight, kg); ADG (Average Daily Gain, kg/day).

^{ab}Means within a row without a common superscript differ ($P < 0.05$).

Table 3.4. Estimated dry matter intake (DMI)[1] of calves treated with one of three anthelmintic strategies[2] during an 84-d yearling stocker trial (Experiment 1)

Item[3]	Treatment[2]			SEM	*P*-value
	CONT	SAFE	POUR		
DMI, kg					
d 0 to 28	6.75^b	6.96^a	6.90^a	0.023	< 0.01
d 29 to 56	7.94^b	8.44^a	8.38^a	0.037	< 0.01
d 57 to 84	8.89^c	9.46^a	9.41^b	0.014	< 0.01
DMI, % of BW					
d 0 to 28	2.30^b	2.34^a	2.35^a	0.013	0.03
d 29 to 56	2.43^b	2.58^a	2.55^a	0.014	< 0.01
d 57 to 84	2.50^b	2.62^a	2.63^a	0.014	<0.01

[1] Dry matter intake was estimated as the amount of feed offered daily.

[2] Treatments included: direct-fed fenbendazole (SAFE; Safeguard®, Merck Animal Health; 5 mg· kg of body weight^{-1}); transdermal eprinomectin (POUR; Eprinex®, Boehringer Ingelheim; 1 ml·10 kg of body weight^{-1}); and a control (CONT; no anthelmintic treatment).

[3] Items include: DMI (Average Daily Dry Matter Intake, kg); DMI, % of BW (Average Daily Dry Matter Intake, % of body weight).

[ab] Means within a row without a common superscript differ ($P < 0.05$).

Table 3.5. Animal performance of calves treated with one of three anthelmintic strategies[1] during a 42-d post-weaning backgrounding trial (Experiment 2)

	Treatment[1]				
Item[2]	CONT	SAFE	POUR	SEM	*P*-value
Weight, kg					
d 0	239	243	244	5.7	0.79
d 14	245	252	251	5.7	0.66
d 28	250	259	258	5.7	0.53
d 42	259	270	269	5.9	0.37
ADG, $kg \cdot day^{-1}$					
d 0 to 14	0.43	0.58	0.49	0.054	0.15
d 0 to 28	0.40^{a}	0.54^{b}	0.49^{ab}	0.034	0.03
d 0 to 42	0.49^{a}	0.63^{b}	0.60^{b}	0.028	< 0.01

[1] Treatments included: direct-fed fenbendazole (SAFE; Safeguard®, Merck Animal Health; 5 mg· kg of body weight^{-1}); transdermal eprinomectin (POUR; Eprinex®, Boehringer Ingelheim; 1 ml·10 kg of body weight^{-1}); and a control (CONT; no anthelmintic treatment).

[2] Items include: Weight (average body weight, kg); ADG (Average Daily Gain, kg/day).

[ab] Means within a row without a common superscript differ ($P < 0.05$).

Table 3.6. Average eggs per gram (EPG) count by treatment collected on d 0, 14, 28, 56, and 84 from calves treated with one of three anthelmintic strategies[1] during an 84-d yearling stocker trial (Experiment 1)

	Treatment[1]				
Eggs per gram	CONT	SAFE	POUR	SEM	*P*-value
d 0	192	236	175	20.1	0.46
d 14	312^a	1^c	155^b	35.4	< 0.01
d 28	278^a	2^b	266^a	33.2	< 0.01
d 56	131^a	33^b	145^a	16.7	< 0.01
d 84	68^a	8^b	71^a	10.04	< 0.01

[1] Treatments included: direct-fed fenbendazole (SAFE; Safeguard®, Merck Animal Health; 5 mg· kg of body weight^{-1}); transdermal eprinomectin (POUR; Eprinex®, Boehringer Ingelheim; 1 ml·10 kg of body weight^{-1}); and a control (CONT; no anthelmintic treatment).

^{ab}Means within a row without a common superscript differ ($P < 0.05$).

Table 3.7. Fecal egg counts on d 0 and simulated reductions for calves treated with one of three anthelmintic strategies[1] during an 84-d yearling stocker trial (Experiment 1)

					FECRs[4]			
Day	Treatment[1]	*n*[2]	Pre[3]	Post	%R	L95%	U95%	Status[5]
14	CONT	50	196	77	60.8	47.1	76.0	—
	SAFE	51	240	0	100	100	100	Effective
	POUR	46	178	74	58.2	42.8	71.6	Resistance
56	CONT	51	193	94	51.3	37.2	65.1	—
	SAFE	51	236	9	96.4	91.6	99.7	Effective
	POUR	46	181	67	63.3	48.2	77.9	Resistance
84	CONT	49	193	62	68.0	52.1	81.7	—
	SAFE	51	235	8	96.5	95.0	97.9	Effective
	POUR	46	182	70	68.0	52.1	81.7	Resistance

[1] Treatments included: direct-fed fenbendazole (SAFE; Safeguard®, Merck Animal Health; 5 mg· kg of body weight^{-1}); transdermal eprinomectin (POUR; Eprinex®, Boehringer Ingelheim; 1 ml·10 kg of body weight^{-1}); and a control (CONT; no anthelmintic treatment).
[2] Differences in *n* are due to missing samples.
[3] Pre (FEC prior to anthelmintic treatment on d 0).
[4] Fecal egg count reduction is presented as a percent reduction (%R), the upper 95% confidence interval (U95%), and the lower 95% confidence interval (L95%).
[5] The criteria used for status include: Effective: %R and U95% confidence limit above 95% and L95% confidence limit above 90%; Resistant: %R and U95% confidence limit below 95% and L95% confidence limit below 90%; Inconclusive: Criteria for either Effective or Confirmed resistance was not achieved.

Table 3.8. Fecal egg counts on d 0 and simulated reductions for calves treated with one of three anthelmintic strategies[1] during a 42-d post-weaning backgrounding trial (Experiment 2)

					FECRs[4]			
Day	Treatment[1]	*n*[2]	Pre[3]	Post	%R	L95%	U95%	Status[5]
14	CONT	50	163	80	49.9	34.4	66.9	—
	SAFE	51	200	0	100	99.9	100	Effective
	POUR	46	169	91	46.2	31.5	62.7	Resistance

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[1] Treatments included: direct-fed fenbendazole (SAFE; Safeguard®, Merck Animal Health; 5 mg· kg of body weight^{-1}); transdermal eprinomectin (POUR; Eprinex®, Boehringer Ingelheim; 1 ml·10 kg of body weight^{-1}); and a control (CONT; no anthelmintic treatment).

[2] Differences in *n* are due to missing samples.

[3] Pre (FEC prior to anthelmintic treatment on d 0).

[4] Fecal egg count reduction is presented as a percent reduction (%R), the upper 95% confidence interval (U95%), and the lower 95% confidence interval (L95%).

[5] The criteria used for status include: Effective: %R and U95% confidence limit above 95% and L95% confidence limit above 90%; Resistant: %R and U95% confidence limit below 95% and L95% confidence limit below 90%; Inconclusive: Criteria for either Effective or Confirmed resistance was not achieved.

Figure 3.1.

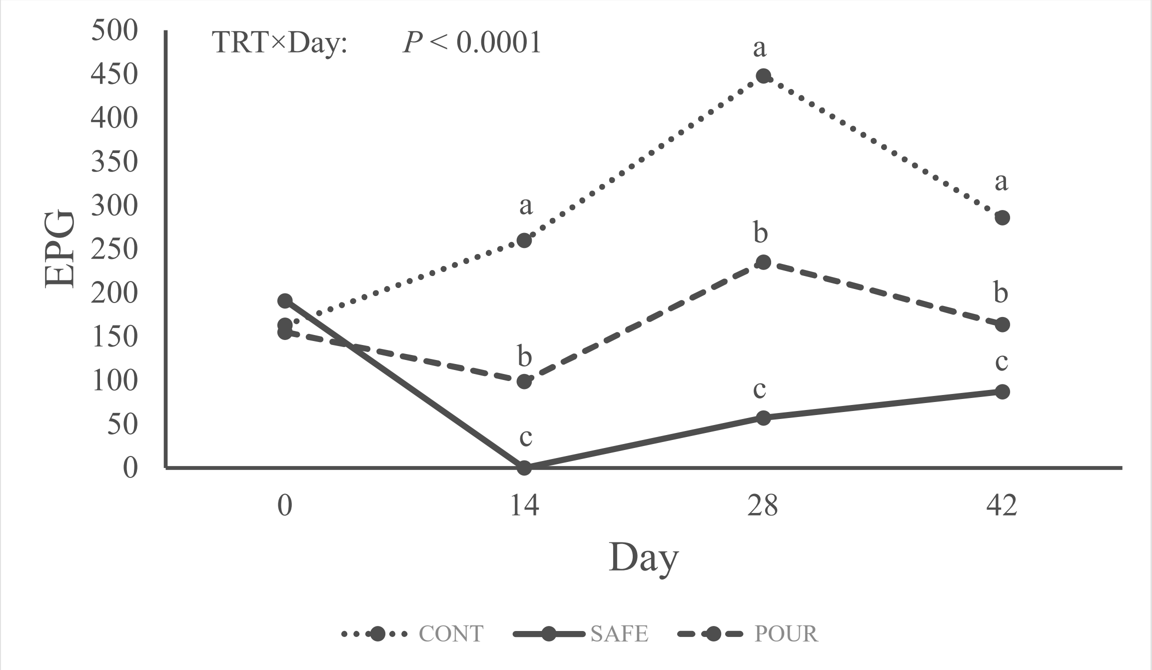

Figure 3.1. Eggs per gram (EPG) by day interaction during a 42-d post-weaning backgrounding trial treated with one of three anthelmintic strategies (Experiment 2). Treatments included: direct-fed fenbendazole (SAFE; Safe-guard®, Merck Animal Health; dosage of 5mg·kg of body weight^{-1}); transdermal eprinomectin (POUR; Eprinex®, Boehringer Ingelheim; 1ml·10kg of body weight^{-1}); and a control (CONT; no anthelmintic treatment). ^{abc}Means within each day without a common superscript differ ($P < 0.05$).

CHAPTER 4

EVALUATION OF ROTATIONAL VERSUS CONTINUOUS STOCKING ON PARASITE REINFECTION IN A RYEGRASS STOCKERING SYSTEM

To be submitted to a peer-reviewed journal (Translational Animal Science)

Abstract

A two-year grazing study was conducted at two University of Georgia research stations: Alapaha Range Grazing Unit in Alapaha, GA (2023) and the Tifton Campus Beef Cattle Center in Tifton, GA (2024) to evaluate the effect of residual grazing height, controlled by rotational versus continuous stocking, on parasite reinfection of yearling stocker calves. At each location, 8 annual ryegrass (*Lolium multiflorum*) paddocks were randomly assigned to rotational (ROTA) or continuous (CONT) stocking. Thirty-two yearling stocker cattle were stratified by weight and eggs per gram (EPG) and randomly assigned to graze one of eight paddocks during a 56-d grazing trial. Within each treatment paddock, stockers were randomly selected to serve as shedders or testers. Testers received an oral benzimidazole drench at study initiation. Body weights and fecal samples were collected and analyzed to determine parasite reinfection and animal performance measures within each treatment. Similarly, forage sample clippings were collected weekly and analyzed for nutritive value. Forage nutritive value did not differ between grazing treatments at either location ($P > 0.13$). Forage mass was greater ($P < 0.01$) in ROTA paddocks at Alapaha and during the second grazing cycle in ROTA paddocks at Tifton ($P < 0.01$). Average daily gain (ADG) did not differ in Alapaha ($P > 0.29$), while at Tifton, ADG was greater in CONT paddocks during grazing cycle 1 ($P < 0.01$). Gain per hectare (GPH) did not differ by treatment in Alapaha but was greater for CONT paddocks during the first grazing cycle ($P < 0.01$). Nematode EPG counts remained low and did not differ between treatments at any sampling date at either location ($P > 0.16$). The results of this study indicate that stocking method did not affect parasite burden or animal performance of yearling stocker cattle grazing cool-season annuals when stocking rates and forage allowance were not limiting.

Key words: stocker, nematode,

Introduction

Annual ryegrass *(Lolium multiflorum)* is a valuable cool-season forage grown on approximately 1.1 million hectares in the southeastern region of the United States, primarily for winter grazing (Venuto et al., 2003). Research has demonstrated that annual ryegrass can be grown in monoculture or mixtures with small grains and clovers to extend the grazing season for stocker cattle in the South (Beck et al., 2005, 2007; Mullenix and Rouquette, 2018). Similarly, Fribourg and Overton (1973) reported that sod-seeding ryegrass onto dormant bermudagrass *(Cynodon dactylon)* resulted in increased yields over a three-year period, thereby prolonging forage production and grazing availability on the land area.

The integration of annual ryegrass into grazing systems not only extends forage availability but also influences various management factors, including grazing strategies and their effects on cattle performance and parasite burden. Williams and Hammond (1999) found that grazing management style had no effect on animal performance of cows and calves. Similarly, Rouquette et al. (2023) conducted a seven-year experiment evaluating stocker cattle average daily gain and gain ha^{-1} on rye-ryegrass pastures, concluding that stocking method did not have an effect on animal performance. In contrast, McCollum et al. (1999) reported lower weight gains and economic returns for stocker cattle under rotational stocking compared to continuous stocking, with greater live weight gains per head per hectare observed in continuously stocked systems.

Additionally, Wyatt et al. (2012) concluded that stocking rate plays a more critical role than stocking method in animal performance and economic outcomes.

Research comparing rotational and continuous grazing systems has yielded mixed results on parasite burden. Callinan and Westcott (1986) reported that more than 70% of larvae were concentrated in the basal 2 cm of pasture with the least found at 6 cm or above, indicating that prevention of overgrazing through rotational stocking could lower the risk of L3 infective larvae ingestion. Sands et al. (2024) reported that cattle managed under rotational grazing exhibited fecal egg count reductions comparable to those receiving anthelmintic treatment, concluding that grazing management plays an important role in limiting larvae transmission. However, Kunkel et al. (1983) reported that fecal egg counts in the pasture of continuous and rotational pastures were not significantly different from each other.

The effects of rotational versus continuous stocking on animal performance and parasite burden have yielded varied results. Therefore, the objective of this study was to evaluate the effect of residual grazing height, controlled by rotational versus continuous stocking, on parasite reinfection of yearling stocker calves. This evaluation aims to provide clearer insights into how grazing management may influence parasite control, which is crucial or improving both cattle health and economic outcomes in beef production systems.

Materials and Methods

All practices and procedures used in these experiments were examined and approved by the University of Georgia Animal Care and Use Committee prior to the start of the project (IACUC AUP A2023 01-009-Y3-A0).

Experimental Location and Establishment

This grazing experiment occurred across two years at two locations. Year 1 (2023) occurred at the University of Georgia Alapaha Range Grazing Unit in Alapaha, GA (31°20'28.1"N 83°13'17.2"W) and year 2 (2024) at the University of Georgia Tifton Campus Beef Cattle Center in Tifton, GA (31°29'39.5"N 83°31'27.4"W). Prior to study establishment, soil samples were collected from each location, shipped to the UGA AESL Lab for analysis, and necessary nutrients were applied following UGA recommendations.

Alapaha

The field selected for this project was an established mixed warm season grass pasture comprised of bermudagrass *(Cynodon dactylon)*, bahiagrass *(Paspalum notatum)*, and crabgrass *(Digitaria sanguinalis)* and was utilized seasonally for grazing and hay harvest. Soils were characterized as Alapaha loamy sand (0-2% slopes), Leefield loamy sand (0-3% slopes), and Stilson loamy sand (0-4% slopes) (USDA Web Soil Survey, 2025). Prior to annual ryegrass planting, the pasture was sprayed at a suppression rate of 2.5 kg a.i. of glyphosate to induce dormancy of the warm season grass base. Annual ryegrass *(Lolium multiflorum;* cvs. Centurion and Ranahan; Mountain View Seeds, Salem, OR) was planted in October 2022 using a no-till drill (Truax company, New Hope, MN) at a rate of 30.3 kg ha^{-1}, following UGA Extension recommendations (Hancock, 2018).

Tifton

In year 2 the experiment was conducted in Tifton, GA in a primarily annually cropped field, most recently cropped with grain Sorghum *(Sorghum bicolor)* prior to annual ryegrass establishment. Soils were characterized as Carnegie sandy loam (3-5%

slope), and Tifton loamy sand (0-5% slope) (USDA Web Soil Survey, 2025). After sorghum harvest in October 2023, paraquat dichloride (Gramoxone® [paraquat dichloride 1,1’-dimethyl-4,4’-bipyridinium dichloride], Syngenta Crop Protection, LLC.) was applied at a rate of 0.6 kg a.i. ha^{-1} to control weeds and terminate any sorghum regrowth. Annual ryegrass *(Lolium multiflorum;* cvs. Centurion and Ranahan; Mountain View Seeds, Salem, OR) was planted in October using a no-till drill (Truax company, New Hope, MN) at a rate of 30.3 kg ha^{-1}, following UGA Extension recommendations (Hancock, 2018). Irrigation at the rate of 2.54 cm was applied in November. Pastures were monitored for weed and insect pests, and 1.6 kg a.i. ha^{-1} of 2,4-D Eter MC (Defy® [2,4-dichlorophenoxyacetic acid, 2-ethylhexyl ester], Syngenta Crop Protection, LLC.) was applied the first week of December to control potentially invasive volunteer broadleaf weeds.

Pasture Management

Four weeks before study initiation in both locations, stocker calves (*n*=32), which had never been de-wormed, pre-grazed the pasture area. For uniform parasite introduction, the pasture was divided into four strips, where each strip was grazed for 1.5 days before moving to the next strip, until the entire study area (8 ha.) had been grazed uniformly (6 days). Three weeks prior to study initiation in Tifton, 56 kg N ha^{-1} was applied; however, N was not applied in Alapaha due to extensive drought conditions. Forage was allowed to grow for two weeks prior to study initiation. One week prior to study initiation, the pastures at both locations were divided into eight 1.0-ha paddocks utilizing temporary electric fencing and each paddock was randomly assigned to one of two treatments: rotational stocking (ROTA) or continuous stocking (CONT). The ROTA paddocks (1.0-ha) were further subdivided into four 0.25-ha to facilitate rotational stocking. Each of these sub-paddocks was grazed for 7-d, after which the stockers were rotated to the next sub-paddock in the sequence, allowing 21-d of rest between rotations. Stockers on the four CONT paddocks had access to the entire 1.0-ha paddock throughout the grazing period. A complete grazing cycle, defined as a 28-d on pasture for both treatments, was achieved twice during the study, totaling 56-d per year. Grazing evaluations occurred from 7 March to 2 May 2023 in Alapaha and 20 March through 15 May 2024 in Tifton.

Forage Response

Prior to study initiation and every 7-d thereafter, forage samples were collected for estimations of forage availability and nutritional value. Forage mass was measured by hand-harvesting forage to 7.5 cm within three randomly placed 0.1 m^2 polyvinyl chloride (PVC) pipe quadrats throughout the paddock. Samples were dried in a forced-air oven at 55°C for four days and weighed to determine forage mass on a dry matter basis. Samples were ground to pass a 1 mm screen with a Wiley Mill (Thomas-Wiley Laboratory Mill: Thomas Scientific). Forage samples were submitted to the UGA Tifton Animal and Dairy Science Nutrition Laboratory and analyzed to determine concentrations of dry matter (DM; AOAC 967.03), acid detergent fiber (ADF; Van Soest et al., 1991), neutral detergent fiber (NDF; Van Soest et al., 1991), and *in vitro* true dry matter digestibility (IVTD48; Ankom IVTD Method 3).

Animal Management

Thirty-two yearling crossbred stocker calves *(Bos taurus* × *Bos indicus)* were sourced from the UGA Alapaha Research Station (Alapaha, GA) each year. Stockers received One Shot Ultra® 7 (Zoetis Animal Health Inc., in Parsippany, New Jersey) at 4 months of age. Weaning occurred in mid-September to early October, and calves were vaccinated with Bovi-Sheild Gold® 5 (Zoetis Animal Health Inc.,). Following weaning, stockers were housed at the UGA Alapaha Grazing Unit on dormant bahiagrass (*Paspalum notatum)* and supplemented daily with 2.3 $kg \cdot hd^{-1}$ of a 33% corn, 33% soybean hulls and 33% corn gluten mix. Two weeks prior to study initiation, stockers were transported to study location, allocated to each grazing paddock and trained to temporary electric fencing as an adjustment period. On d -1, stockers were blocked in groups of four by body weight (Alapaha 323 ± 21 kg; Tifton 345 ± 34 kg) and randomly assigned to treatment. Stockers were provided ad libitum access to water and mineral throughout the experiment. In Alapaha, two stockers per treatment were randomly selected to be excluded from the second grazing cycle due to drought conditions during the experimental months, which limited forage regrowth.

Parasite Reinfection

In Alapaha, one stocker within each of the treatment paddocks was randomly selected to serve as a shedder. These animals were not treated with anthelmintics to simulate natural parasite egg shedding within the grazing system. The remaining three stockers were treated with an oral benzimidazole drench (SAFE; Safe-guard®, Merck Animal Health, Deerfield, Illinois) on d 0 at a dosage of 5 $mg \cdot kg$ of body weight and serve as testers. In Tifton, a similar method was applied; however, two stockers per paddock were randomly selected to serve as shedders. All stockers were processed according to the established and approved UGA Tifton Animal Science standard operating procedures.

Fecal samples from all stockers were collected at each location on d 0 and 14 to evaluate differences in EPG. Additional fecal samples were collected on d 28 and 56 to determine parasite reinfection. Samples were collected into resealable plastic bags, stored on ice for a minimum of two hours, and shipped overnight to the Merck GI Parasite Diagnostic Lab (Lawrence, KS) for analysis using the Modified Wisconsin Sugar Floatation method (Smith, 1997).

Animal Response and Performance

To evaluate animal performance, all stockers were weighed unshrunk at study initiation, midpoint, and termination. To determine average daily gain (ADG), only weights of tester stockers were utilized in the calculation (Eq. 1). Stocking rate (SR) was determined by dividing the total stocker weight by the total paddock area (Eq. 2). Liveweight gain per hectare (Gain ha^{-1}, GPH) was attained by dividing the total LWG (sum of gain by all stockers; testers and shedders) by the total area of each paddock (all 4 subsections combined in ROTA paddocks) (Eq. 3). Forage allowance **(**FA; kg forage DM kg animal LW^{-1}; Eq. 4**)** was calculated as the forage mass (FM) divided by the total average stocker weight for each grazing paddock (Allen et al., 2011).

$Eq.$ 1

$$ADG = \frac{Total\ weight\ of\ testers}{Number\ of\ grazing\ days\ per\ cycle}$$

Eq. 2

$$SR = \frac{Total\ Stocker\ Weight}{Total\ paddock\ area}$$

$Eq. 3$

$$Gain\ ha^{-1} = \frac{Sum\ of\ gain\ by\ testers\ and\ shedders}{Total\ area\ of\ each\ paddock}$$

$Eq. 4$

$$FA = \frac{Forage\ mass, kg}{Total\ animal\ weight\ per\ paddock, kg}$$

Statistical Analysis

All analyses were performed using paddock as the experimental unit. The experiment was organized in a randomized complete block design with four replications and repeated measures. Replications were spatially defined to account for geographic differences (i.e., trees, slope, shade, and soil type). Paddock served as the repeated measure subject. The subject of the random statement was block. All models were ran by location. The fixed effects were treatment (continuous or rotational grazing) and grazing cycle for all models, except eggs per gram (EPG) where the fixed effects were treatment and sampling day. Models were analyzed by restricted maximum likelihood using PROC MIXED in SAS v 9.4 (SAS Institute Inc., 2013, Littel et al., 2006) with an autoregressive (1) covariance structure, selected based on the lowest Bayesian Information Criterion (Littel et al., 2006). A Kenwood-Rogers adjustment was applied to correct the denominator degrees of freedom and ensure appropriate standard errors and F-statistics. Means were compared using the LSMEANS procedure with Tukey-Kramer adjustment. Differences were considered significant at $P \leq 0.05$.

Results and Discussion

Forage Response

There were no differences in nutritive value observed between treatments in either location ($P > 0.13$; Table 4.1). In Alapaha, there were differences in FM between treatments ($P < 0.01$), but not grazing cycles or their interactions ($P > 0.38$; Table 4.3). Rotationally grazed paddocks had increased ($P < 0.01$) FM compared to CONT paddocks. In Tifton, there was a treatment by grazing cycle interaction ($P = 0.01$). During grazing cycle 1, treatment FM was not different ($P = 0.60$); however, in grazing cycle 2, ROTA paddocks had greater FM ($P < 0.01$). In the present study, forage mass was greater in the ROTA treatment compared to the CONT in both locations. These results contradict that of Hafley (1996) who reported greater forage mass in continuous stocking than rotational. Discrepancies between the results of Hafley (1996) and the present study may be attributed to a decreased stocking rate in the previous study, which likely allowed cattle to selectively graze within continuously stocked paddocks.

Animal Responses

Body Weight

There were no differences observed in body weight between treatments at study initiation (d 0), midpoint (d 28), and conclusion (d 56) for either location ($P > 0.35$; Table 4.2). In contrast, Hafley (1996) found that yearling stocker steers grazing Marshall or Surrey ryegrass had greater final body weight on continuously stocked paddocks than those on rotationally stocked paddocks. These results differ from the present study, where no differences in body weight between treatments were observed at either location. This discrepancy could be attributed to differences in grazing pressure, which remained constant in the present study (with the exception of Alapaha, where some stockers were removed due to drought conditions however stocking rate remained equal across treatments), whereas Hafley (1996) implemented an 83% increase in stocking rate.

Stocking Rate and Forage Allowance

In Alapaha, there were differences in SR between grazing cycles because two stockers were removed before the start of grazing cycle 2 ($P < 0.01$; Table 4.3). There were no differences in SR between treatments in either grazing cycle ($P > 0.54$). In Tifton, SR was greater ($P < 0.01$) in cycle 2 as compared to cycle 1, but did not differ between treatments within each grazing cycle ($P > 0.17$). Stocking rates were greater during cycle 2 than cycle 1 because the stockers gained weight during the first 28 day grazing cycle. In Alapaha, FA differed ($P < 0.01$) between cycles but was not different between treatment nor was there a grazing cycle by treatment interaction ($P > 0.08$; Table 4.3). Grazing cycle 2 had greater FA, as compared to grazing cycle 1 ($P < 0.01$). In Tifton, FA differed ($P < 0.01$) between grazing cycles but was not different between treatment or grazing cycle by treatment interaction ($P > 0.08$). Grazing cycle 1 had greater FA, as compared to grazing cycle 2 ($P < 0.01$). In Alapaha, differences were observed between grazing cycles, but not between treatment. The increased forage allowance in grazing cycle 2, could be attributed to removal of stockers at the beginning of the second grazing cycle, and rainfall that occurred during this period after extended drought like conditions (Figure 4.1). Forage allowance in the present study was not limited; however, research has demonstrated that year-to-year climatic variability can result in inconsistent outcomes in forage production and grazing system evaluations. Scaglia (2020) examined the effects of continuous stocking rate on animal performance and gain per unit land area in stocker cattle grazed on annual ryegrass pastures. Findings from this study indicated that weather patterns, particularly fluctuations in annual rainfall, had a significant impact on forage allowance.

Average Daily Gain

There were no differences between treatment, grazing cycle, or their interaction for ADG in Alapaha ($P > 0.29$; Table 4.3). In Tifton, there was an interaction between treatment and grazing cycle for ADG ($P = 0.03$). During grazing cycle 1, CONT paddocks had greater ($P < 0.01$) ADG as compared to ROTA; however, during grazing cycle 2 treatments did not differ ($P = 0.48$). In the present study, there were no consistent differences in average daily gain between treatments across grazing cycles, although differences were detected in Tifton between treatments in grazing cycle 1. Similarly, Marchant et al. (2019) reported that average daily gain for stocker cattle grazing cool-season forage mixtures of wheat, triticale, and annual ryegrass, did not differ across a two-year grazing study. In the present study, yearling stockers grazing annual ryegrass monocultures gained between 0.7 and 1.3 kg per day, which was less than the average daily gain reported by Marchant et al. (2019), ranging from 1.39 to 1.45 kg per day. The greater average daily gain observed by Marchant et al. (2019) may be attributed to the use of ryegrass mixtures; however, nutritive value in both studies was similar. In the present study, no differences in annual ryegrass nutritive value were observed between rotational and continuous treatments at either location. Similarly, Marchant et al. (2019) reported no differences in the chemical composition of wheat and triticale mixtures with annual ryegrass.

Gain per hectare

In Alapaha, GPH differed ($P = 0.01$) between grazing cycles, but did not differ between treatment or treatment by grazing cycle interactions ($P > 0.31$; Table 4.3). Grazing cycle 1 had greater ($P = 0.01$) GPH than grazing cycle 2. In Tifton, there was a treatment by grazing cycle interaction ($P = 0.04$), where GPH was greater ($P < 0.01$) for CONT paddocks during cycle 1, as compared to ROTA, but there were no differences between treatments in grazing cycle 2 ($P = 0.54$). Similar results were reported by Rouquette et al. (2023), who found no differences in gain per hectare among stockers grazing rotational or continuous pastures of annual ryegrass and cereal rye sod-seeded into bermudagrass. Instead, the previous study reported that gain per hectare at a stocking rate of 6 stockers per hectare, achieving 991 kg gain per hectare over a seven-year grazing study. Furthermore, both gain per hectare and average daily gain between rotational and continuous stocking method were not different following the 7-year grazing study. In contrast, the present study shows gain per hectare in Tifton was greater for CONT in both grazing cycles, while no differences in treatment were observed in Alapaha. Interestingly, body weights recorded at study initiation, midpoint, and conclusion were not affected at either location, likely due to the consistent forage quality provided by the annual ryegrass monoculture used in the present study.

Parasite Fecal Egg Per Gram

There were no differences ($P > 0.16$) in EPG between treatments at any sampling date for either location (Table 4.4); however, differences in day between locations were observed. In Alapaha, on d 14 and 28, EPG did not differ ($P = 0.14$), but all other days differed ($P < 0.01$). In Tifton, on both d 14 and 28, EPG did not differ ($P = 0.81$), but both days had fewer ($P < 0.01$) EPG as compared to d 0 and 56, which also did not differ

($P = 0.89$). These findings are similar to those of Hammond et al. (1996), who examined the effects of rotational stocking and CIS grazing on EPG of Angus cows. Hammond et al. (1996) reported that no main effects of grazing method on EPG were observed; however, a grazing method by year interaction was identified, wherein a notable increase in EPG was detected in the CIS group during one study year. This rise was attributed to higher-than-average spring rainfall, while EPG in the rotational group declined during the same period. These results suggest that environmental conditions, particularly seasonal rainfall, may mediate the relationship between grazing strategy and parasite reinfection. Although average rainfall was decreased in Alapaha, there were no treatment by location interactions observed in EPG.

Conclusion and Implications

The results of this study indicate that stocking method did not affect parasite burden or animal performance of yearling stocker cattle grazing cool-season annuals when stocking rates and forage allowance are not limited. For this study a set stocking rate was utilized, future research is warranted to determine if differences in residual grazing height due to increased grazing pressure within varied stocking methods impacts parasite burden and reinfection. Regardless, EPG counts were low and remained low in both locations throughout the evaluation even in shedder animals suggesting that the grazable forage base may be a significant factor in parasite activity in yearling stocker calves. Published data to date are limited in regards to parasite reinfection and stocking method of yearling stocker calves grazing warm-season perennial forage systems.

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Table 4.1. Nutritive value (%) of Annual Ryegrass *(Lolium multiflorum)* in two locations, Alapaha (2023; YR 1) and Tifton (2024; YR 2), grazed by yearling stocker cattle on one of two treatments[1]

	Treatment[1]			
Item[2], %	CONT	ROTA	SEM	*P*-value
Alapaha				
DM	91.4	91.6	0.08	0.13
Ash	9.5	9.7	0.20	0.52
NDF	42.4	42.9	0.54	0.52
ADF	24.2	24.7	0.24	0.18
IVTD	91.4	91.6	0.08	0.13
Tifton				
DM	90.0	90.1	0.10	0.88
Ash	5.0	5.0	0.17	0.92
NDF	45.8	47.4	1.22	0.34
ADF	24.7	26.0	0.75	0.25
IVTD	83.9	82.5	1.06	0.34

[1] Treatments included: Continuous (CONT): stocker cattle had access to the pasture throughout the 56-d grazing period; Rotational (ROTA): 4 sub-paddocks were grazed rotationally for 7 days

[2] Item: Dry Matter (DM), Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF), in-vitro True Digestibility (IVTD)

[3] Standard error of the mean

[ab] Letters denoted differences between rows within location at $P < 0.05$

Table 4.2. Average body weight for yearling stocker cattle continuous or rotationally grazing ryegrass monoculture pasture in Alapaha (YR1) and Tifton (YR2), Georgia during a 56-d grazing period

	Treatment[1]			
Weight, kg	CONT	ROTA	SEM[4]	*P*-value
Alapaha				
Initiation	311	310	9.5	0.87
Midpoint	340	341	10.0	0.89
Conclusion	373	379	12.2	0.64
Tifton				
Initiation	327	340	14.3	0.35
Midpoint	362	358	14.4	0.79
Conclusion	386	385	14.4	0.97

[1] Treatments included: Continuous (CONT): stocker cattle had access to the pasture throughout the 56-d grazing period; Rotational (ROTA): 4 sub-paddocks were grazed rotationally for 7 days

[4] Standard error of the mean.

[ab] Letters denote differences between rows within location at $P < 0.05$.

Table 4.3. Animal performance of yearling stocker cattle continuously (CONT) or rotationally (ROTA) grazing annual ryegrass in two south Georgia locations for two 28 day grazing cycles in spring 2023 (Alapaha) and 2024 (Tifton)

	Grazing Cycle 1		Grazing Cycle 2		SEM[1]	P – value[2]		
Item[3]	CONT	ROTA	CONT	ROTA		GC	TRT	GC x TRT
Alapaha								
FM, kg · ha^{-1}	1960^{bc}	2364^{a}	1683^{c}	2359^{ab}	177.4	0.38	< 0.01	0.39
SR, kg · ha^{-1}	1222^{a}	1249^{a}	665^{b}	691^{b}	35.0	< 0.01	0.54	0.97
FA, kg · kg^{-1}	1.6^{c}	2.0^{bc}	2.3^{ab}	2.9^{a}	0.24	< 0.01	0.08	0.64
ADG, kg · day^{-1}	1.0	1.1	1.1	1.2	0.10	0.23	0.42	0.81
GPH, kg · ha^{-1}	82^{ab}	91^{a}	58^{b}	63^{b}	6.93	0.01	0.31	0.78
Tifton								
FM, kg · ha^{-1}	3432^{b}	3555^{ab}	2880^{c}	3972^{a}	242.2	0.72	< 0.01	0.01
SR, kg · ha^{-1}	1353^{bc}	1327^{c}	1467^{a}	1407^{ab}	27.0	< 0.01	0.30	0.02
FA, kg · kg^{-1}	2.5^{a}	2.7^{a}	1.9^{b}	2.4^{a}	0.17	< 0.01	0.08	0.32
ADG, kg · day^{-1}	1.3^{a}	0.7^{b}	0.9^{ab}	1.0^{ab}	0.12	0.62	< 0.01	0.03
GPH, kg · ha^{-1}	125^{a}	64^{c}	103^{ab}	95^{bc}	9.7	0.65	0.02	0.04

[1] Standard error of the mean.

[2] GC: Grazing Cycle; TRT: Treatments: Continuous (CONT): stocker cattle had access to the pasture throughout the 56-d grazing period; Rotational (ROTA): 4 sub-paddocks were grazed rotationally for 7

[3] Items Include: Average Daily Gain (ADG), Gain Per Hectare (GPH), Stocking Rate (SR), Forage Allowance (FA), Forage Mass (FM).

[ab] Letters denote differences between rows within location at $P < 0.05$.

Table 4.4. Average eggs per gram (EPG) count by treatment collected on d 0, 14, 28, and 56 from yearling stocker cattle on rotational or continuous paddocks during a 56-d stocker trial

	Treatment[1]			
Eggs per gram[3]	CONT	ROTA	SEM[2]	*P* – value
Alapaha				
d 0	44	46	7.7	0.83
d 14	1	1	7.7	0.96
d 28	9	9	7.7	0.97
d 56	33	20	9.5	0.17
Tifton				
d 0	10	18	5.6	0.16
d 14	1	3	5.6	0.64
d 28	1	4	5.6	0.67
d 56	11	17	5.6	0.26

[1] Treatments included: Continuous (CONT): stocker cattle had access to the pasture throughout the 56-d grazing period; Rotational (ROTA): 4 sub-paddocks were grazed rotationally for 7 days

[2] Standard error of the mean.

[ab] Letters denote differences between rows within location at $P < 0.05$.

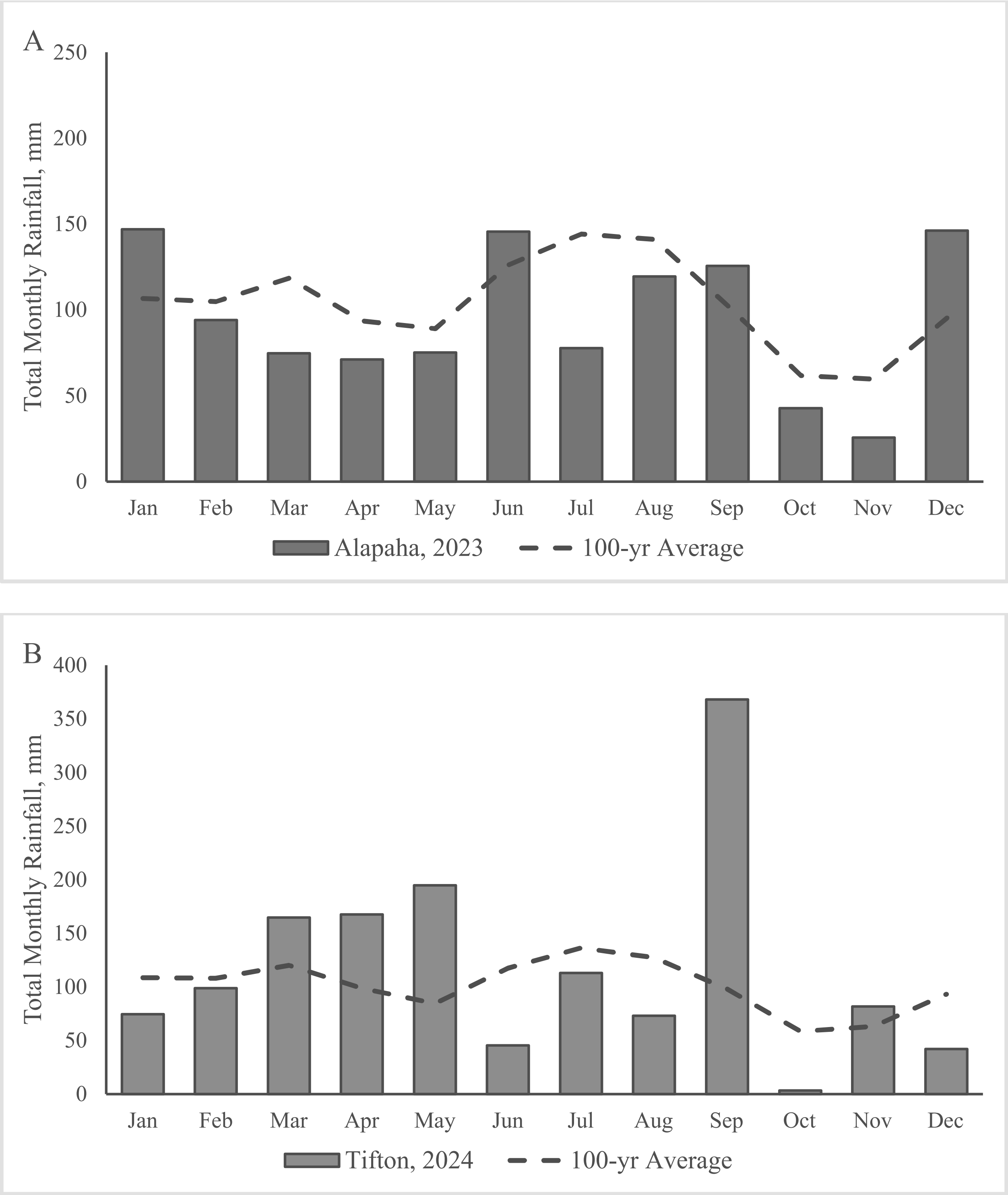

Figure 4.1. Total Monthly Rainfall, mm for (A) Alapaha in 2023, and (B) Tifton in 2024 and the 100-year average at each location. Rainfall data obtained from the University of Georgia Automated Environmental Monitoring Network (UGA-AEMN, 2025).

CHAPTER 5

CONCLUSION AND IMPLICATIONS

The health and performance of weaned beef cattle are challenged by high gastrointestinal nematode burdens. The negative effects of parasitism can be mitigated through targeted interventions during the backgrounding or stocker phase, specifically by optimizing anthelmintic use and implementing management strategies that reduce parasite reinfection. As anthelmintic resistance continues to compromise the efficacy of commonly used macrocyclic lactones, direct-fed benzimidazoles provide producers access to a drug class that was previously difficult to administer without proper facilities.

This thesis investigated the benefits of two anthelmintics with different dosing strategies and grazing methods aimed at reducing the impact of gastrointestinal nematodes, benefiting beef cattle producers in the Southeast. The research conducted was divided into two projects. The first project evaluated animal performance and fecal egg count reduction of a direct-fed fenbendazole product versus a pour-on eprinomectin in yearling stocker cattle and weaned, backgrounding cattle. The second project evaluated the use of stocking method, continuous vs rotational, on parasite reinfection by controlling the residual grazing height in yearling stocker cattle.

The first project was divided into two experiments. The first was conducted over an 84-d yearling stocker trial (Experiment 1; 2022 and 2023), the second experiment occurred during a 42-d post-weaning, backgrounding phase (Experiment 2; 2023 and 2024) at two University of Georgia research units: the Georgia Mountain Research and

Education Center in Blairsville, GA, and the J. Phil Campbell Sr. Research and Education Center in Watkinsville, GA, respectively. Cattle were assigned to one of three treatment groups: transdermal Eprinomectin (POUR; Eprinex®), direct-fed Fenbendazole pellets (SAFE; Safe-guard®), or a control group (CONT) that received no treatment. Fecal samples were collected on d 0 and 14 to evaluate differences in eggs per gram (EPG) and treatment efficacy. Additional samples were collected on d 28, 56, and 84 in Experiment 1, and d 28 and 42 in Experiment 2. Animal performance was assessed through body weight and average daily gain (ADG), which were determined using weights recorded on each fecal collection date. Dry matter intake (DMI) was also measured in Experiment 1.

Cattle in the SAFE treatment group exhibited greater overall ADG, with an average of 1.32 kg/d in Experiment 1 and 0.63 kg/d in Experiment 2. While no significant differences in average body weight were observed among treatment groups throughout both experiments. Additionally, DMI was decreased for CONT (6.75 to 8.89 kg) compared to SAFE (6.96 to 9.46 kg) and POUR (6.90 to 9.41 kg), which did not differ during the experimental period. Resistance to the POUR treatment was observed in cattle from both experiments, as a minimum of 95% reduction in EPG recommended by the World Association for the Advancement of Veterinary Parasitology, was not achieved. In contrast, the SAFE treatment was effective, resulting in a 100% reduction in EPG on d 14 in both Experiment 1 and Experiment 2. The results of this project demonstrate that the direct-fed fenbendazole pellet was effective against gastrointestinal parasite burdens in yearling stocker cattle and post-weaning, backgrounding cattle.

The second project was conducted over a 56-day yearling stocker grazing study at two University of Georgia research farms: the Alapaha Range Grazing Unit in Alapaha, GA (Year 1; 2022), and the Tifton Campus Beef Cattle Center in Tifton, GA (Year 2; 2023). At each location, a total of eight paddocks were assigned to one of two grazing treatments: rotational stocking (ROTA), in which cattle grazed one of four sub-paddocks for seven days before rotating, or continuous stocking (CONT), where cattle had unrestricted access to the entire paddock for the 56-d grazing period. Thirty-two yearling stocker cattle were stratified by weight and EPG and randomly assigned to one of eight treatment paddocks, stockers were chosen at random to serve as shedders or testers, who received an oral benzimidazole drench at study initiation. Forage nutritive value, average body weight, and EPG did not differ between grazing treatments or cycles at either location. Overall, there were no consistent differences in animal performance, parasite reinfection, or forage response throughout the project. The results of this study indicate that stocking method did not affect parasite burden or animal performance of yearling stocker cattle grazing cool-season annuals when stocking rates and forage allowance were not limiting.

Improved animal performance was observed in cattle treated with a direct-fed fenbendazole, while those treated with a pour-on eprinomectin exhibited signs of anthelmintic resistance. These results show that cattle producers can utilize a direct-fed fenbendazole to effectively control anthelmintic without having to restrain cattle and administer an oral dose. This research also aids in the understanding of anthelmintic pharmacology and its role in anthelmintic resistance. Additionally, rotational stocking does not help reduce the reinfection of cattle with gastrointestinal parasites compared to continuous stocking in annual ryegrass.

Further research is warranted for both projects assessing the long-term effects of a direct-fed fenbendazole use on parasite resistance and efficacy across various management systems and stages of beef cattle production. Moreover, continued research is warranted to determine if differences in residual grazing height due to increased grazing pressure within varied stocking methods impacts parasite burden and reinfection.