

Nutritional and reproductive management strategies to enhance sheep production efficiency

by

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ABSTRACT

Two studies were conducted at the Kansas State University Sheep and Meat Goat Center to evaluate nutritional and reproductive management strategies to increase sheep production efficiency. Experiment 1 assessed the effects of supplementing a liquid direct-fed microbial (DFM; RSG Prime by BIO S.I.) on growth performance, fecal consistency, blood parameters, and fecal microbial populations in feedlot lambs consuming a high-concentrate diet. Seventy-two Dorper × Katahdin lambs (60 d of age; 26.73 ± 0.35 kg BW) were assigned to either a control (CON; no DFM) or DFM treatment (15 mL/head daily) over a 63-day period. Growth performance variables, including average daily gain (ADG), average daily feed intake (ADFI), and gain-to-feed ratio (G:F), were not affected ($P > 0.05$) by DFM supplementation. Fecal scores improved over time ($P < 0.0001$) but were not influenced by treatment. While no treatment × day interactions were observed for blood parameters, serum calcium tended to be lower ($P = 0.06$) in DFM-supplemented lambs, and several metabolites shifted over time ($P \leq 0.03$). Additionally, DFM supplementation altered the relative abundance of specific fecal microbial taxa ($P \leq 0.05$), with notable treatment × day interactions observed in select genera. Overall, DFM supplementation did not impact growth performance but influenced serum chemistry and fecal microbial composition. Experiment 2 evaluated the effects of estrous synchronization protocols using Controlled Internal Drug Release (CIDR) devices of differing durations on reproductive performance in ewes. Fifty-eight Polypay-influenced ewes were assigned to either a 5-day or 14-day CIDR protocol. A subset ($n = 10/\text{treatment}$) of ewes from each treatment were monitored via transrectal ultrasonography to assess follicular dynamics. The 5-day group had larger follicle diameters at CIDR insertion and 7 days post-removal, while the 14-day group had a higher follicle count at the protocol end. Marking by the ram was initiated in the 14-day group

approximately 12 hours earlier than the 5-day group, however there was more variation in time to return to estrus in the group of ewes. Pregnancy outcomes differed, with the 5-day group showing more ewes with single fetuses, and the 14-day group producing more twins via ultrasound on d 75. Total lamb production was similar between treatments (34 vs. 36 lambs). A larger number of ewes remained open in the 14-day group (10 vs. 6 ewes). Limitations of transrectal ultrasonography and ram effect on breeding data make it difficult to establish differences in treatment. These limitations highlight the need for refined imaging technique to establish follicular changes in different CIDR estrous synchronization protocols in future studies. Collectively, these studies demonstrate nutritional and reproductive interventions may not always influence primary performance outcomes. However, these findings may indicate potential changes in sheep health and growth performance that warrants further investigation.

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Chapter 1 - Overview of Sheep Management Principles

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Sheep Nutrition

Nutrition accounts for approximately 60% of the total production costs in a sheep operation. A thorough evaluation of your nutrition program is essential to optimize feed efficiency and control expenses. Under-feeding or failing to meet nutritional requirements can have a significant economic effect on your operation, including reduced fertility and overall productivity.

General Nutrition Practices

Body Condition Scoring

Body condition scoring is a practical tool used by sheep producers to assess the amount of fat and muscle covering the animal's body, providing a valuable indicator of overall health and management effectiveness (Figure 1.1). Since wool can obscure visual assessment, producers are advised to place a hand just behind the last rib to palpate the vertebrae just after the loin (See steps to body condition scoring, Figure 1.2). The body condition scoring system ranges from 0 to 5, based on the prominence of spinal vertebrae and the degree of fat and muscle cover. Maintaining a score of 2 to 3, depending on the stage of production, is ideal for optimal health and performance in sheep.

Nutrition Basics

Diets are balanced to meet the requirements of small ruminants for protein, carbohydrates, fat, water, vitamins, and minerals. Protein requirements change based on the sheep production stage, which are listed in Table 3. Fast-growing lambs require 16% to 18%

protein on average. Protein is found in grains and high-quality forages. Carbohydrates are typically supplied in the diet in the form of forage. Forage positively affects the rumen by adding a scratch factor. The microbes ferment and break down the cell wall, later absorbing the products through the rumen wall. Fat supplies 2.5 times more energy than carbohydrates. Fat should be fed in small quantities (less than 5% of the diet) and is commonly added to minimize grain dust. Feeding small ruminants does not have to be complicated. Many producers can get by feeding corn and alfalfa in different amounts to meet animals' needs at every production stage.

Water

Water is the most important nutrient for all classes of sheep. Having adequate access to water not only affects animal health but also can greatly affect feed intake, efficiency, reproduction, and performance. Sheep will drink 1 to 2 gallons of water for every 4 pounds of dry matter ingested. Lactating or gestational ewes may even double those amounts.

Minerals

Having a high-quality mineral is also vital, as sheep are more sensitive to mineral deficiencies/toxicities than other livestock species. While most manufactured diets are formulated to supply appropriate minerals, supplemental minerals are crucial. Mineral can be provided to sheep in loose (free choice) or most commonly in solid (block) forms most commonly. Be sure to keep minerals in all forms free from the elements. Aspects of a quality mineral include:

- Must be species specific. Sheep cannot consume minerals labeled for other species because of the copper (Cu) levels.
- Help support a proper calcium (Ca) to phosphorous (P) ratio of 2:1 to prevent urinary calculi (kidney stones).

- Keep macro minerals such as sulfur, magnesium, and selenium balanced, as they can negatively affect young lamb growth.
- Include trace minerals such as cobalt, copper, iodine, iron, manganese, molybdenum, zinc, and selenium that are typically provided by forage.

Feeding Lambs

Supplementation

Lambs need 10% to 20% of their body weight in colostrum within the first 24 hours (Table 1.1). Establishing adequate milk intake early in life supports lamb growth and development, and nutritional strategies such as creep feeding can further supplement this foundation as lambs begin transition to solid feed. Creep feeding is a strategy in which a small pen is set up with a gate at the front that only allows lambs to enter. A feeder is placed inside so lambs always have access to feed. Creep feeding trains lambs to eat out of a feeder early. This is helpful during weaning and can keep lambs from getting stressed and going off feed (Table 1.2).

Finishing Lambs

Weaned lambs can be backed off protein from 18% to 16%, then down to 14% at finishing. Replacement females should not be allowed free access to grain after weaning. Extra fat could reduce future milk potential due to deposits in the udder. In addition, lambs on lower-energy diets for a longer period of time finish at heavier weights.

Feeding the Breeding Herd

Feeding Rams

Ram nutrition is often overlooked but is key for a sound breeding season. Libido and fertility are directly correlated to nutrition. Rams can lose up to 12% of their body weight when

turned out with ewes, which is why a body condition score of 3 before the start of breeding is ideal.

Feeding Pre-Breeding Ewes

Nutritional flushing has been found to increase number of lambs born by 10% to 30%. Nutritional flushing is done by increasing energy by 10% six weeks before breeding. This can be as simple as adding $\frac{1}{4}$ to $\frac{1}{2}$ a pound of corn daily to increase the base of nutrition. Ewes with a body condition score of 3.5 or higher do not respond to flushing, so flushing is performed only on scores of 2 to 3. Young ewes should be fed separately from mature ewes. They should be 60% to 70% of their mature weight by breeding, and 80% to 90% by lambing (Figure 1.3).

Feeding Ewes in Gestation

Ewes late in gestation have a smaller capacity in their abdomen to consume large amounts of forage. This is due to the uterus expanding with the growth of the fetus. Increasing the amount of grain fed in the last six weeks also helps prevent pregnancy toxemia, a condition that is caused by ewes not being able to mobilize their fat efficiently to support lambs.

Feeding Ewes in Lactation

Feeding a medicated feed can decrease the risk of toxoplasmosis. Ewe lambs should be fed separately from more mature ewes, as they have their own growth requirements in addition to the requirements of the growing fetus.

Feeding Ewes During Weaning Transition

Lactation peaks about four weeks post-partum. Decreasing feed intake four weeks post-partum helps lambs transition to feed and decreases the risk of mastitis. Feed intake should remain lowered for one-week post-weaning to help the ewe dry up.

Conclusions

Effective sheep feeding strategies requires an approach that adapts to the nutritional requirements of sheep across all stages of production. From ensuring adequate colostrum intake in newborn lambs to supporting the demands of reproduction in older animals, nutrition must be managed intentionally to the production stage and physiological demands of the flock.

Sheep Health

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Maintaining flock health is important because it directly affects animal productivity and farm profitability. Good management reduces disease, positively influencing lamb growth and breeding animal productivity. Proper nutrition leads to higher quality animals or wool products. Well-managed sheep are healthier and more productive, lowering veterinary and feed costs, while also reducing labor in the long run. Facilities are often overlooked in the management of sheep health. Ensuring living conditions are clean, dry, and well-ventilated helps avoid health problems. Routine vaccinations are essential to your animals' health and well-being. Producers should select vaccines based on historical health issues or regional disease risks. Many breeding companies provide vaccine protocols for gestational ewes. A widely used vaccine is CD&T, which provides protection against *Clostridium perfringens* types C and D, as well as tetanus.

General Health Principles

A healthy adult sheep should be alert, healthy-looking, and have an adequate body condition (Body Condition Score 3; See Figure 1.1). Normal vital signs of a healthy adult sheep include:

Normal Range

- Body Temperature: 101 to 104 degrees Fahrenheit
- Heart Rate: 60 to 90 beats per minute
- Respiration Rate: 12 to 35 breaths per minute

Common signs of illness include:

- Head and ears down and droopy
- Thin, sunken appearance.
- Isolation, frequent lying down, and loss of appetite.
- Lethargic, hunched back, pawing on the ground, grinding teeth.

Biosecurity

Biosecurity has three parts: isolating problem animals, directing foot traffic from animals that have not been exposed to diseases or those with underdeveloped immune systems to infected animals, and sanitizing equipment and facilities. Diseases can be spread through direct contact, exposure to wildlife, airborne transmission, contaminated feed or water, foot traffic, and vehicle movement. Common diseases in sheep are listed in Table 1.4. The most effective biosecurity strategy is maintaining a closed flock. Animals new to the flock may introduce infectious diseases or contract diseases to which the established flock has developed resistance. When introducing newly acquired sheep, a two-week quarantine is recommended to prevent disease transmission. Transport stress can reactivate dormant diseases in sheep, making quarantine a crucial step in preventing disease transmission. Testing for ovine progressive pneumonia virus (OPPV) and Johne's disease is recommended before introducing new sheep into the flock.

Things to look for during the quarantine period:

- Changes in appetite, body condition score, and feces.

- Respiratory symptoms, including a runny nose, coughing, or raspy breathing.
- Dull eyes, droopy ears, lying down frequently, and overall poor performance.
- If any of these symptoms appear in newly acquired sheep, consult a veterinarian before introducing them into the flock.

Proactive disease prevention is the most effective way to maintain a healthy flock.

Effective flock management includes checking sheep daily for signs of disease. These signs can include signs of digestive upset, lameness, and respiratory conditions. Know what is normal for the flock to pick out abnormalities.

Many diseases are caused by malnutrition of the gestational ewe. Body condition score of ewes is essential for ewe and lamb health. A ewe's body condition score should be kept between 3 and 4 on a 5-point scale during pregnancy.

Clean living conditions and vigilant observations are essential to keep these infectious agents at bay. To prevent fecal-to-oral reinfection, do not feed sheep on the ground. If an ewe is aborting, remove it from the flock and quarantine to prevent disease spread through infected fetal fluids. Remember to wear gloves and consult a veterinarian.

Work with a veterinarian to create a vaccination program suited to an individual operation. Clostridial vaccines are some of the few recommended for all small ruminants and are given routinely. Clostridial bacteria live in the manure of sheep and are already present in the gut. The bacteria cause ulcerations of the small intestine. Illness can be lethal to lambs but can be prevented with vaccination. CD&T should be administered annually to mature animals. Gestational ewes should receive a CD&T injection 30 days before lambing to provide passive immune protection to their lambs. Lambs should be vaccinated at six to eight weeks and given a booster two to four weeks after.

Common Diseases of the Lambs

Close monitoring of lambs is essential for early disease detection. Lambs that appear unhealthy and are reluctant to stand may be hypothermic or have navel infections. Check the temperatures often of poor-doers. Hypothermia, starvation, navel infections, diarrhea, and pneumonia are the most common causes of lamb mortality. Lambs with a potbelly, that are hunched over, and potentially have a fever, likely have a navel infection. The best way to prevent this is to dip the navel at the base of the abdomen with 7% iodine. Lambs that are overly vocal and sunken-in likely need to be supplemented with a bottle to stay satiated. Triplets may be too much for some ewes. Consider pulling the lamb that drinks best from a bottle off the ewe to help the other two. Diarrhea can cause lamb health to decline quickly. Being proactive and consulting a veterinarian early is important for the lamb's well-being. *E. coli*, *Salmonella spp.*, or *Clostridium perfringens* type C are bacteria that cause diarrhea. Testing is available for these infectious agents. Older lambs may deal with bouts of acidosis or enterotoxemia. Lambs often sort different feedstuffs when being fed a textured feed or when switching feed. Feed consumption can change with the weather and social changes.

Parasite Management

Parasites are a significant concern in sheep production, often leading to reduced performance, anemia, and even mortality, particularly in lambs. Effective parasite control requires an integrated approach that combines pasture management, targeted treatment, and regular health monitoring. Producers whose sheep are struggling with parasites should work with a veterinarian or extension specialist to create a targeted deworming plan tailored to the farm's specific parasite challenges and resistance trends.

External Parasites

External parasites, such as lice and mites, can cause discomfort, wool loss, and skin irritation. These pests are particularly problematic in overstocked or poorly managed pens, where transmission occurs easily. While external parasites are generally less severe than internal parasites, infestations can still affect flock performance and should be addressed promptly.

Prevention and Control

- Routine flock inspections to detect early signs of infestation.
- Proper stocking densities to minimize direct contact transmission.
- Use of approved insecticides or topical treatments when infestations are detected.
- Shearing management to reduce parasite loads in wool-producing breeds.

Internal Parasites

Haemonchus contortus (barber pole worm) is one of the most problematic internal parasites in sheep, particularly in grazing systems. This blood-sucking parasite causes severe anemia, weakness, and can be fatal if left untreated. Clinical signs include pale mucous membranes, bottle jaw (fluid accumulation under the jaw), weight loss, and weakness.

Prevention and Control

- Routine FAMACHA Scoring: Assesses anemia by evaluating the color of the inner eyelid to help identify sheep that need treatment.
- Fecal Egg Counts: Measures parasite load and tracks treatment effectiveness through fecal egg analysis on high-risk individuals.
- Selective Deworming: Only treat sheep with high parasite burdens (FAMACHA score 3 or higher, or a confirmed elevated fecal egg counts) to minimize drug resistance.

- **Culling High Burden Sheep:** Remove chronically infected individuals from the flock to improve genetic resistance to parasitic infections.
- Ensuring nutritional requirements of flock are being met can improve the animal's immune response, enhancing resilience and ability to tolerate parasite burdens

Coccidiosis

Coccidiosis is caused by *Eimeria* spp. and primarily affects young lambs raised in confinement or in heavily stocked environments. Unlike *Haemonchus contortus*, coccidia damage the intestinal lining, leading to diarrhea, weight loss, dehydration, and stunted growth. Early identification and management are essential to prevent production losses associated with coccidiosis outbreaks.

Prevention and Control

- **Minimize Overcrowding:** Reduce stress and exposure by maintaining appropriate stocking densities.
- **Improve Sanitation:** Regularly clean feeding and watering areas to prevent fecal contamination.
- **Use Coccidiostats:** Medicated feeds containing Deccox (decoquinate) or Rumensin (monensin) can help prevent outbreaks.
- **Ensure Adequate Nutrition:** Lambs with poor nutrition are more susceptible to severe infections.
- **Pasture rotation and strategic grazing** play critical roles in reducing parasite burdens.
- Rotate pastures frequently, ensuring sheep do not graze below 5 inches of forage height, as parasite larvae typically reside in lower vegetation (below 4 inches).
- Rest pastures for approximately 60 days to break parasite life cycles.

- Leave freshly dewormed sheep in a dry lot for 24 hours before returning them to pasture to prevent resistant worms from contaminating grazing areas.
- Use selective deworming to maintain refugia (worms not exposed to anthelmintics) within parasite populations, which helps reduce the development of anthelmintic resistance.

Treating animals indiscriminately with dewormers is not recommended due to increasing incidences of resistance. Instead, selective treatment and pasture management are the most effective long-term strategies for sustainable parasite control.

When to Cull Based on Health Issues

A semi-annual review of this checklist is recommended. Giving the flock a physical exam and reviewing records help producers best care for their flock. If an animal in question checks multiple boxes, it is recommended to cull.

For ewes:

- Did the ewe test positive or show symptoms for any diseases such as brucellosis, CL, Johne's, or OPPv?
- Does the ewe show chronic respiratory symptoms?
- Does the ewe struggle with lameness issues?
- Does the ewe need treatment for disease or parasites above average for the flock?
- Does the ewe have poor vision?
- Does the ewe have poor teeth and will they inhibit her from maintaining condition all year round? Are they in worse condition than for the rest of the flock?
- Does the ewe have a low FAMACHA score and a poor worm load in her fecal float?
- Does the ewe have a lower body condition score than the rest of the flock?

- Does this ewe struggle with hoof rot or over-grown hooves more often than the rest of the flock?
- Does the ewe have at least one quadrant of the udder that does not milk? Are there any lumps or hardness in her udder?
- Did the ewe fail to breed multiple times in a row?
- Has the ewe struggled with dystocia problems at lambing?
- Is the ewe in the lower percentage for mothering abilities in the flock?

For rams:

- Did the ram test positive or show symptoms for any diseases such as brucellosis, CL, Johne's, or OPPv?
- Does the ram show chronic respiratory symptoms?
- Does the ram struggle with lameness issues?
- Does the ram need treatment for disease or parasites above average for the flock?
- Does the ram have poor vision?
- Does the ram have teeth appropriate for the diet being fed and will they inhibit him from maintaining condition all year round? Are they in worse condition than the rest of the flock?
- Does the ram have a low FAMACHA score and a poor worm load in his fecal float?
- Does the ram have a lower body condition score than the rest of the flock?
- Does the ram have any swelling or malformed genitals when palpating?
- Does this ram struggle with hoof rot or overgrown hooves more often than the rest of the flock?
- Did the ram have any difficulties passing a breeding soundness exam?

- This is typically conducted by a veterinarian
- A physical exam of the animal is conducted, the tract is palpated, and semen quality is observed
- Has the ram had any difficulties breeding ewes?

Sheep Marketing

This Extension publication has been accepted and published by Kansas State University Research and Extension (3710).

Building brand recognition in the sheep industry is essential for producers entering the market. Whether selling directly to consumers or through sale barns, an effective marketing plan can expand your reach.

Start by identifying your target market and defining the products you intend to sell. Establishing clear business goals and objectives will guide decisions, such as how to form breeding groups for the year. Consider key questions early: What breed of sheep or products will you sell? Where will you market them? What time of year will you sell?

Create a brand that reflects your production philosophy. Establish brand recognition by designing a farm logo and name. Many producers also use social media to expand their customer base and promote their product. Networking — both in-person and online — can significantly boost your marketing efforts, regardless of your operation's size or style.

Consider enrolling in the National Sheep Improvement Program (NSIP) to provide estimated breeding values (EBVs) for your flock. These values help producers turn performance records for economically important traits, such as birth weight, maternal ability, and parasite resistance, into valuable information about an animal's genetic merit. These science-based tools

not only help improve desired traits but also serve as strong selling points that boost buyer confidence in your product.

Developing a clear production and marketing plan early helps manage costs and sets your operation up for long-term success. Using a combination of the strategies outlined in this publication, along with a strong understanding of your market, improves your chances in an ever-changing industry. Stay flexible by regularly reviewing and adjusting your marketing strategies and target markets to maximize returns.

Challenges

Sheep producers face a range of challenges. Being aware of these challenges early on allows for proactive planning. Environmental threats, such as predators, can be mitigated with proper fencing — ideally flush with the ground or buried. Installing traps in common predator pathways and reinforcing weak points in fences can reduce losses. Livestock guardians such as dogs, donkeys, or llamas are effective deterrents when properly trained. However, poorly trained guard animals may harm the flock, so proper training is essential.

Weather and seasonality also affect flock productivity. Harsh winters or hot summers can strain both animals and producers. Develop protocols for lambing during extreme conditions, including ensuring vulnerable lambs have access to shelter. Natural windbreaks, such as trees or man-made structures, offer shade and protection. Shearing should be timed based on the breeding schedule and local climate. For instance, while shearing before lambing can make it easier for lambs to nurse, winter-lambing systems must ensure ewes retain enough wool for insulation.

A major long-term challenge is the decline in the U.S. lamb market. U.S. sheep numbers peaked at 30 million head in 1945 but dropped to around 5 million by 2024. The industry is

currently unable to meet domestic demand, so much of the lamb sold in grocery stores is imported from Australia and New Zealand.

Additionally, lamb is not a dietary staple for many Americans—about 30% have never tried it; however, a consistent year-round lamb supply is important to meet consumer needs. Demand spikes during cultural and religious holidays, leading to seasonal price fluctuations. An increase in demand for American lamb, especially with the modest growth of direct-to-consumer and ethnic markets, could help producers better offset costs and support a positive outlook for growth in the domestic sheep industry.

Product

Most sheep producers aim to sell lamb meat, and there are several routes to market this product. Lambs of any age can be sold at a sale barn on a per-pound basis. Alternatively, producers may choose to retain ownership and send lambs to a feedlot, where they are finished over 30 to 90 days before slaughter. Most U.S. producers follow a spring-lambing model. Sending lambs to feedlots helps maintain a consistent harvest rate, ensuring a year-round supply. Others may raise lambs to finishing weight on-site or sell them post-weaning, either directly to consumers or selling them to a processor by the pound.

Your product strategy depends on your production scale, labor capacity, market access, and local demand. Some sale barns in Kansas publish market reports that can help time the breeding and selling for the highest profitability.

Cost of Lamb

Lamb carcass pricing is influenced by factors such as carcass weight, quality grade, and yield grade. Although slaughter lambs are most commonly sold by live weight, some processors do offer pricing systems that consider carcass characteristics. In a carcass-based pricing system,

the total value is calculated by multiplying the dressed carcass weight by the price per pound. This is the weight of the animal once it has been slaughtered before it is divided into wholesale cuts to be sold. This price per pound can vary depending on carcass weight, yield grade, and quality grade.

To estimate a live animal's price per pound, the total carcass value should be divided by the animal's live weight at harvest. The difference between live value and carcass value is largely due to variations in dressing percentage and carcass traits such as yield and quality grade. Carcasses that meet or exceed industry standards may receive premiums, while subpar carcasses may be discounted. Packers assign quality and yield grades to assess value. Quality grades include Prime, Choice, Good, Utility, and Cull and are based on carcass conformation and fat distribution. Yield grade, scored from 1 to 5, incorporates fat thickness, ribeye area, internal fat estimates, and hot carcass weight. Dressing percentage, the ratio of hot carcass weight to live weight, is also calculated to evaluate carcass efficiency.

Lambs approaching finishing weight, known as feeder lambs, are graded similarly, but while still alive. They are often categorized by frame size:

- Small: less than 100 pounds
- Medium: 100 to 120 pounds
- Large: greater than 120 pounds

Muscle scores range from 1 (most muscular) to 3 (least muscular). These scores help buyers estimate future carcass quality and inform pricing decisions.

How to Read a Market Report

Understanding a market report is vital for pricing decisions. Auction reports typically categorize animals by age, sex, breed, weight, condition, and stage of production. Some auctions

estimate age by examining the animal's teeth, using terms like "broken mouth." Each category in a report includes the number of head sold and the price range. Prices are listed in hundredweight (cwt) — that is, the price per 100 pounds. To convert this to price per pound, divide the cwt value by 100. For example, a 50-pound lamb that sells for \$250 would be listed at \$500/cwt, or \$5 per pound (Table 1.5).

Types of Production

When selling lambs, producers fall into several categories (Table 1.6). This table helps break down products and desired markets. The commercial lamb industry is the biggest of those listed in the following table. Because so many producers choose to sell lambs this way, it's important to plan breeding seasons around what benefits you and your resources.

Traditional Market

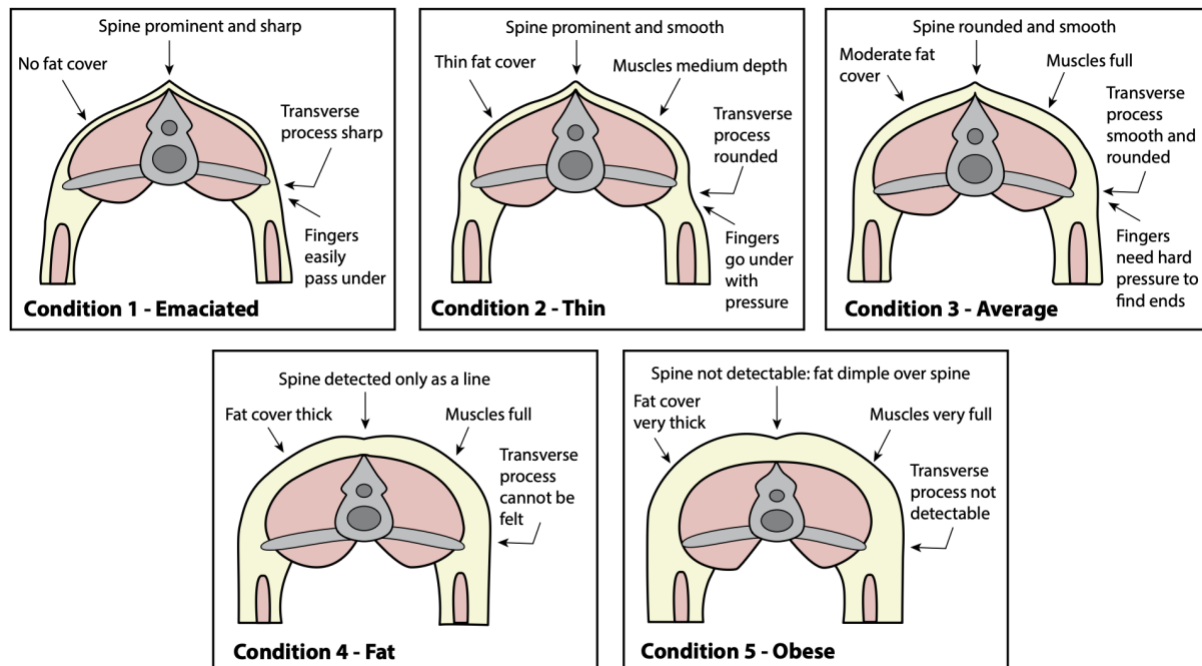
According to the American Lamb Board, the traditional lamb market prefers larger, heavier lambs weighing between 120 and 160 pounds. Prices typically peak between July and October, making fall- or winter-lambing groups advantageous for producers targeting this market. While most U.S. lambs are born between January and May, there is a growing incentive to shift lambing to later in the year. This is due to reduced supply from June through August, creating an opportunity for producers who can time lambing for off-season markets. Breeding for fall lambs can help fill this supply gap and capitalize on peak pricing periods.

Nontraditional Market

The nontraditional market is largely driven by ethnic and religious demand, often differing in timing, weight preferences, and harvesting practices from the traditional market (Table 7). According to the American Sheep Industry Association, approximately 58% of lamb consumed in the U.S. is by minority populations. When marketing to this sector, it is important

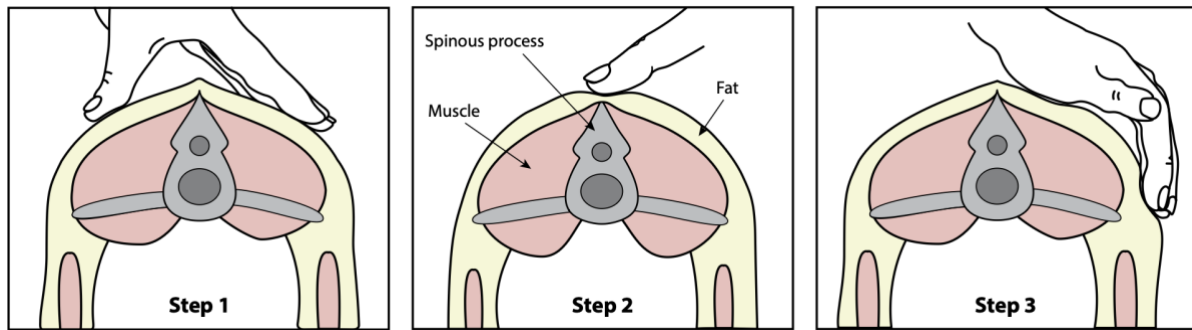
to consider the lamb's weight, sex, and the preferred method of slaughter. Halal and Kosher dietary laws emphasize humane treatment and specific slaughter requirements, which must be respected when marketing to these consumers. As a general guideline, lambs should remain uncastrated and have intact tails when sold for ethnic consumption, as this is often a cultural or religious expectation. Lambs may be sold either at auction or directly to consumers in this market.

Figure 1.1 Body Condition Scoring Chart¹



¹Graphic modified from Oregon State University. Body condition scoring is a practical tool used by sheep producers to assess the amount of fat and muscle covering the animal's body, providing a valuable indicator of overall health and management effectiveness. The body condition scoring system ranges from 0 to 5, based on the prominence of spinal vertebrae and the degree of fat and muscle cover.

Figure 1.2 Steps to Body Condition Scoring¹



¹To properly body condition score sheep, producers are advised to place a hand just behind the last rib to palpate the vertebrae just after the loin to assess prominence of spinal vertebrae and the degree of fat and muscle cover.

Table 1.1 Approximate colostrum needs based on newborn lamb weight¹

Lamb Weight (lb.)	Colostrum needed within the first hour of life (oz)	Colostrum needed within the first 24 hours (oz)*
8	6	13
9	6	15
10	7	16
11	7	18
12	8	20
13	8	22
14	9	24

¹The total amount of colostrum needed during the first hour to 24 hours of life should be split up into feedings of 2 to 4 ounces every 3 to 4 hours. If a lamb needs to be fed bottles regularly, feed a lamb- specific replacer four to six times a day for the first two weeks, then gradually back down to twice daily. (<https://www.merckvetmanual.com/management-and-nutrition/nutrition-sheep/feeding-practices-in-sheep>). Make sure to read the formula's label on how much and how often to feed lambs for proper growth. Lambs raised on milk replacer can be weaned at four to five weeks if they are taking to supplemental feed well.

Table 1.2 Aspects of an adequate creep feed for lambs

Item	Description
Crude Protein	Between 18% to 20% crude protein.
Calcium: Phosphorous Ratio	2:1
Medication	Decoquinat, Lasalocid (prevention of Coccidiosis)
Composition	Can be as simple as 80% cracked corn and 20% soybean meal. Many existing formulations available.
When to use	Introduce at one week of age, continuing to have feed available until post-weaning.

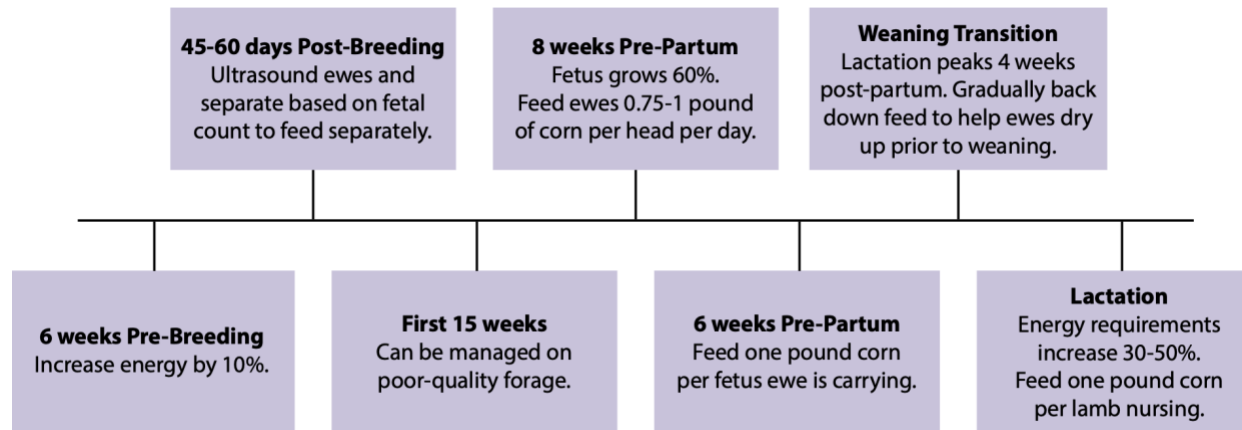
Table 1.3 Nutrient requirements of sheep based on production stage¹

<i>Class/Age</i>	<i>Production Stage</i>	<i>Weight (kg)</i>	<i>Daily DM (kg)</i>	<i>TDN (kg/d)</i>
Mature Ewes	Maintenance	36.36	1.30	0.69
		45.45	1.54	0.82
		54.54	1.76	0.94
		63.63	1.98	1.05
	Breeding	45.45	1.69	0.90
		54.54	1.94	1.03
		63.63	2.18	1.15
Gestational	Early, Twins	45.45	2.15	1.14
		54.54	2.44	1.29
		63.63	2.71	1.44
	Late, Twins	45.45	2.87	1.52
		54.54	3.24	1.72
		63.63	3.57	1.89
Lactational	Early, Twins	45.45	2.48	1.64
		54.54	3.47	1.84
		63.63	3.82	2.03
	Mid, Twins	45.45	2.68	1.42
		54.54	3.02	1.60
		63.63	3.33	1.77
	Late, Twins	45.45	2.53	1.34

		54.54	2.87	1.52
		63.63	3.19	1.69
		45.45	1.77	0.94
Rams	Maintenance	68.18	2.40	1.27
		90.9	2.98	1.58
Late Maturing Lambs	4 months	18.18	1.16	0.77
-Gaining 400g/d		27.27	2.08	1.10
		36.36	2.19	1.16
		18.18	1.36	1.08
	8 months	27.27	2.02	1.34
		36.36	2.19	1.45

¹Table derived from Sheep National Resource Council recommendations

Figure 1.3 Feeding the breeding ewe¹



¹Timeline of nutritional management strategies for ewes throughout the production cycle, including recommended feeding adjustments during pre-breeding, gestation, and lactation to support fetal development and milk production.

Table 1.4 Common diseases of sheep

Name	Cause	Symptoms	Prevention
Brucellosis	- Infection occurs through exposure to bacteria via open wounds or ingestion	- Infertility - Effects male and female reproductive tracts	- Test and cull infected animals - Buy breeding stock from producers who routinely test negative
Caseous Lymphadenitis(CL)	- Highly contagious bacteria - Inhaled or can enter the body through abrasions - Bacteria release toxins and cause abscesses	- Cysts around the lymph nodes or inside the body - Commonly found around neck and jaw - May pop and reveal a yellow, chunky discharge	- Cull animals that have abscesses - Vaccine is available - To prevent spread, do not break open cysts - Lives in soil, eradication difficult
Cryptorchidism	- One or both testicles not descending properly	- Uneven scrotum - Can cause infertility issues	- Culling and is the best prevention due to genetic transmission
Epididymitis	- Physical trauma or bacterial infection	- Inflammation of the epididymis - Reproductive inefficiency	- Breeding soundness exams or routine palpation - Culling based on breeding soundness
Mastitis	- Bacteria coming into the teat. - Can rapidly become ill from absorption of toxins and bacteria	- Udder will become hot to the touch and hard - May lose milking ability on the infected quadrant	- Clean, dry living conditions - High-quality mineral - Routinely check udder of lactating ewes for hardness
Ovine Progressive Pneumonia Virus (OPPV)	- Spreads through respiratory particles and milk	- Lowers lamb crop and milking yield - Lose body condition as soon as two years old	- Test ewes being brought into the flock

		- Accumulates scar tissue in udder - Potential respiratory symptoms	
Ovine Johne's Disease	- Bacteria cause a thickening of the intestinal wall	- Malabsorption of feedstuffs causes extreme weight loss - Can be lethal	- Test and cull infected animals - Buy breeding stock from producers who routinely test negative
Orf (soremouth)	- Highly contagious zoonotic virus - Contact with infected animal	- Scabs around the mouth - Udder and other parts of the body may also become infected	- Vaccine available - Quarantine new animals - Check for scabs before introduction
Pizzle Rot	- Bacteria - Increased urea concentration in the urine can cause irritation - Common in high-protein diets	- Appear similarly to urinary calculi - Urination difficulty and discomfort - Scabs and swelling around prepuce of penis - Common in castrated males	- Keep bedding clean - Flies may cause secondary infection - Feeding high-protein diets may enhance risk for this disease
Pregnancy Toxemia	- Having multiple fetuses - Under or overweight - Difficulty mobilizing fat to support the fetuses	- Hesitant to eat - Tender footed - May lay down and struggle to get back up - Have an off-putting odor and crusty discharge on vulva	- Sort ewes based on number of lambs and body condition score to feed accordingly - Keep ewes at a body condition score 3 to 4 throughout late gestation - High energy and protein in diet - Test for ketone bodies in urine

Polioencephalomalacia (PEM)	- Thiamine deficiency most common - Sulfur overload - Salt toxicity - Toxic plant ingestion - Grain overload - Clostridium bacteria	- Swelling in the brain - Blindness, dilated pupils, elevated head in unnatural position ('star-gazing') - Animals may be down and paddle	- High-quality mineral - Monitor water and feed ingestion closely - Switch feeds gradually
Stillbirth	- Absorption of infectious agents can cross the placental barrier - Campylobacter spp., bacteria; Toxoplasma gondii, protozoan parasite; and Chlamydia abortus, bacteria; are common infectious agents - Come from infected fetal fluids, bird feces, and cat feces	- Fetuses can be reabsorbed, mummified or delivered early	- Campylobacter and Chlamydia can be vaccinated against - Quarantine ewes after abortion - Sanitize to prevent spread - Feeds formulated with decoquinate fight off toxoplasmosis - Aborted fetus and placental tissues should be sent to a local diagnostic lab for full panel results
Urinary Calculi	- Calcium to phosphorus imbalance in diet	- Straining when urinating - Edema in lower abdomen - Common in castrated males	- Add ammonium chloride in diet

Table 1.5 Example of a market report

Category of Animal	Price Cwt	Number of head	Notes
Feeder lambs, 40 to 80 pounds	\$50 to \$110	320	- Lambs weighing 40 to 80 pounds that are ready to be fed out to finishing weight. - Price equals \$0.50 to \$1.10 per pound.
Hair Ewes, Choice 100 to 130 pounds	\$240 to \$275	111	- Ewes displaying hair characteristics weighing 100 to 130 pounds that will likely grade choice based on fat. - Price equals \$2.40 to \$2.75 per pound.
Feeder lambs, medium and large muscle score (1 or 2)	\$230 to \$300	140	- Lambs that are medium and large in frame size and score a 1 or 2 in muscle score - Price equals \$2.30 to \$3.00 per pound.

Table 1.6 Types of sheep production systems

Producer Type	Product	Market
Commercial	- Purebred or crossbred lambs - Fast growing to hit desired market as quickly as possible - Want to affect carcass qualities for meat purposes	- End goal being a quality carcass for slaughter - Feedlots or auctions - Sold by the head or by pound
Seedstock	- Purebred breeding stock, focusing on genetic and phenotypic improvements - Contribute to next generation of the sheep industry - Positively affect traits such as reproductive efficiency, parasite resistance, and growth - May use registration or estimated breeding values for added profit	- Producers looking to heighten genetics in flock - Elite animals sell at a higher rate - Market can be more volatile - Sold in groups or as individuals
Purebred/Club Lambs	- Purebred or crossbred lambs - Focus on phenotypic traits such as anatomy and body balance, structural correctness, and breed characteristics - Primarily wethers who are intended for the show ring	- Many avenues to sell lambs - Online/live sales and private treaty most common - Potentially the most volatile market, having the biggest price range - Sold as individuals

	- Genetics can give buyers an insight into how the animal will grow out and perform	
Stocker	- Buy weaned animals and add value to prepare for finishing weight - Train lambs to eat out of feed bunk, transitioned to a high concentrate diet - Sold to feedlot or for slaughter	- Feedlots or finishing systems looking for lambs who have been converted to grain diets - This phase lowers stress on animal - Helps final goal of high-value carcass for meat purposes

Table 1.7 Marketing lambs for a non-traditional market

Holiday	Time of year	Product Desired
Western Easter	Spring	- Lambs weighing 30 to 45 pounds
Orthodox Easter	Spring	- Lambs weighing 40 to 55 pounds - Should be milk-fed as opposed to grain fed
Pesach (Passover)	Spring	- Lambs weighing 30 to 55 pounds
Cinco De Mayo	May 5th	- Lambs weighing 15 to 30 pounds
Ramadan	Early summer	- Lambs weighing 60 to 80 pounds - Must be younger than a year old - Weights of 45 to 120 pounds are acceptable, and castration is optional - This is a good time to cull older animals
Eid al Fitr	Summer	- Lambs weighing 60 to 80 pounds
Eid ul Adha	Early fall	- Lambs weighing at least 60 to 100 pounds - Must be halal and blemish free - Cannot have been castrated or docked in any way
Muharram	Fall	- Lambs weighing 60 to 80 pounds
Rosh Hashanah	Fall	- Lambs weighing 60 to 110 pounds
Thanksgiving	Late fall	- Lambs weighing 110 pounds
Mawlid al Nabi	Early winter	- Lambs weighing 60 to 80 pounds
Hanukkah	Winter	- Lambs weighing 60 pounds and less - Kosher slaughtering is required
Christmas	December 25	- Lambs weighing 40 to 60 pounds - Milk-fed

Chapter 2 - Effects of direct-fed microbial supplementation on feedlot lamb growth performance, serum biochemical markers, fecal consistency, and fecal microbiota

ABSTRACT

Dietary, environmental, and physiological changes can challenge lamb health and performance during the feedlot transition. This study evaluated supplementation with a liquid direct-fed microbial (DFM; RSG Prime by BIO S.I.) on growth, fecal consistency, blood parameters, and fecal microbial populations in feedlot lambs fed a high-concentrate diet. Seventy-two Dorper × Katahdin lambs (60 d of age, initially 26.73 ± 0.35 kg BW) were fed for 63 d at Kansas State University. Lambs were randomly assigned by initial body weight to pens (3 lambs/pen) and allotted to one of two treatments during the treatment period (d 0–63), with 12 replications per treatment. Treatments were 1) control (CON, no DFM) or 2) DFM supplementation (15 mL/head, orally once daily at 08:00). The DFM contained *Bacillus licheniformis* (10 million CFU/mL), *Bacillus subtilis* (3.5 million CFU/mL), *Lactobacillus acidophilus* (3 million CFU/mL), and *Bacillus pumilus* (2 million CFU/mL). Lambs and feeders were weighed weekly to determine average daily gain (ADG), feed intake (ADFI), and gain-to-feed ratio (G:F). Feces were scored weekly (d 0–42). Blood was collected on d 0 and 21 from one lamb/pen, and fecal

²This work has been accepted for publication in *Translational Animal Science*: Kahler, K.E., K.L. Bentley, and P.L. Dahmer. 2026. Effects of direct-fed microbial supplementation on feedlot lamb growth performance, serum biochemical markers, fecal consistency, and fecal microbiota.

samples were collected for microbial analysis. No differences ($P > 0.05$) were observed for ADG, ADFI, or G:F. Fecal scores were unaffected by treatment ($P > 0.05$) but improved over time ($P < 0.0001$). No treatment $\times$ day interactions were detected for blood variables. Serum calcium tended to be lower ($P = 0.06$) in lambs supplemented with a DFM. Albumin and anion gap decreased significantly from d 0 to 21 ($P \leq 0.01$), while glucose, urea nitrogen, globulin, magnesium, and bicarbonate increased ($P \leq 0.03$). Calcium and potassium tended to be greater in the control group ($P \leq 0.10$). Relative abundance of several genera in the feces showed a significant treatment effect ($P \leq 0.05$). There were statistically significant shifts ($P \leq 0.05$) in fecal microbial populations from d 0 to 21. *Opitutae*, *Bifidobacteriales*, *Treponema*, and *Bifidobacterium* showed treatment $\times$ day interactions ($P \leq 0.05$). In summary, DFM supplementation did not significantly alter growth performance or fecal consistency in feedlot lambs. Lambs supplemented with a DFM had alterations in serum chemistry and changes in fecal microbial populations.

INTRODUCTION

The transition to a feedlot environment presents significant physiological and nutritional challenges for lambs. During this period, lambs often experience stress caused by environmental and dietary changes. Increased exposure to pathogens can weaken the immune system, and when combined with dietary shifts, this can lead to a decline in lamb growth performance. Typically, lambs are moved from a low-concentrate diet alongside their dams to a high-concentrate feedlot ration, a shift that has been associated with an increased risk of ruminal acidosis due to the rapid introduction of dietary starch (Braun et al., 1992). The ruminal microbiome is heavily affected by feed composition and digestion. Microbial shifts occur due to changes in the contents of the rumen, with high forage diets increasing bacterial and fungal populations (Neves et al., 2025).

When high amounts of nonstructural carbohydrates are ingested, the imbalance of microbial populations causes the ruminal pH to drop below 5.4, potentially resulting in epithelial cell damage or death (Brown et al., 2000). The absorption of volatile fatty acids is lowered, causing them to accumulate in the rumen, while the influx of bicarbonate from the bloodstream is reduced. This, in conjunction with damaged ruminal epithelium, allows lipopolysaccharides to translocate into the bloodstream, triggering systemic inflammation and metabolic inefficiency (Minuti et al., 2014). Clinical signs of ruminal acidosis include teeth grinding, anorexia, diarrhea, ruminal stasis, and elevated levels of lactic acid that disrupt metabolic processes (Streitenberger et al., 2025). In severe cases, treatment may require the transfer of rumen fluid to reestablish microbial populations and restore pH balance (Braun et al., 1992). Acidosis has been shown to reduce feed intake and efficiency, causing economic problems for producers. While antimicrobials have traditionally been used to mitigate acidosis (Dirksen and Khamis, 1974; Reis et al., 2018), growing concerns over antibiotic resistance and residues in meat products have spurred interest in alternative strategies (Menkem et al., 2019; Getahun et al., 2023). This consumer and regulatory pressure to limit the use of antibiotics has pushed the industry to explore alternatives.

Common treatment alternatives to antibiotics include buffers such as sodium bicarbonate and magnesium oxide, pre and probiotics, and ionophores (Enemark, 2008). Buffers create efficiency in rumen digestion by maintaining a balanced pH, keeping acidity and alkalinity in check, which allows microbiota to flourish (Kumar et al., 2024). Direct-fed microbials (DFMs) include viable bacteria that can cause a positive shift in the rumen microbiome by increasing lactic acid-utilizing bacteria. DFMs combine lactate-producing and lactate-utilizing bacteria to reduce the severity of acute acidosis in ruminants. Microorganisms can secrete antimicrobial

metabolites, compete with pathogenic microbes, and degrade environmental toxins – collectively enhancing host health and metabolic efficiency (Brashears et al., 2003; Ramirez-Olea et al., 2022). DFMs have also been shown to improve gastrointestinal tract morphology under acidotic stress (Dick et al., 2013).

On the other hand, ionophores improve efficiency and rate of gain by manipulating the transport of ions across membranes, increasing gram-negative bacteria (Spears, 1990). By altering the concentrations of fermentation end products and bacterial populations, ionophores and DFMs have been shown to improve feed conversion efficiency (Seo et al., 2010; Ban and Guan, 2021; Mombach et al., 2021).

Ionophores and DFMs have demonstrated potential in stabilizing ruminal pH and preventing acidosis (Yoon and Stern, 1995). Supplementation with DFMs has been associated with improvements in animal performance (Ban and Guan 2021; Guimaraes et al., 2024), behavior associated with increased feed intake (Lopez et al., 2024), and gut morphology (Dick et al., 2015). The live microbial cultures in DFMs enhance gut microbial balance, reduce disease susceptibility, and support immune function (Guimaraes et al., 2023). This microbial modulation also optimizes fermentation profiles, including reductions in the acetate-to-propionate ratio and improved ruminal ammonia utilization (Dias et al., 2022). These benefits contribute to overall efficiency, increasing G:F.

Notably, spore-forming *Bacillus* species such as *B. licheniformis* and *B. subtilis*, commonly used in DFMs, enhance rumen functionality by promoting the growth of proteolytic bacteria (Green et al., 1999). These organisms produce amylase and cellulase enzymes that aid in the digestion and assimilation of dietary starch, aiding metabolism when a high-starch diet is

being fed (Deng et al., 2018). Their colonization in the rumen positively influences nitrogen metabolism and gut function (Sun et al., 2013).

The present study hypothesized that DFM supplementation could support lambs during the challenging transition to a high-concentrate feedlot diet by enhancing performance and feed efficiency. Specifically, *Bacillus* species in the DFM were expected to secrete lactase, increasing ruminal propionate concentrations through lactate utilization (Ramirez-Olea et al., 2022). Previous findings support that DFM formulations containing *Bacillus* spp. improve both growth metrics and health outcomes in lambs (El-Sayed and Mousa, 2020). Additionally, supplementation with *Lactobacillus acidophilus* has been shown to reduce *Escherichia coli* shedding in feedlot cattle, indicating broader benefits when feeding this product for animal health and productivity (Krehbiel et al., 2003; Younts-Dahl et al., 2005). The objective of this study was to evaluate the effects of a liquid DFM (RSG Prime by BIO S.I.) on the growth performance, fecal consistency, fecal microbiota, and serum metabolites in feedlot lambs.

MATERIALS AND METHODS

All experimental procedures adhered to guidelines for the ethical and humane use of animals for research according to the Guide for the Care and Use of Agricultural Animals in Research and Teaching (FASS, 2010) and were approved by the Institutional Animal Care and Use Committee at Kansas State University (IACUC #4953).

Animals, Housing, and Experimental Design

A total of 72 Dorper X Katahdin wether and ewe lambs were used in a 63-d feeding trial at the Kansas State University Sheep and Meat Goat Center (Manhattan, KS). Lambs were housed in an environmentally controlled facility where temperature, ventilation, and lighting were monitored daily. Lambs were received at approximately 60 d of age and weighed

approximately 26.73 ± 0.03 kg initially. Lambs had access to free-choice hay and water upon arrival. After 24 hours of acclimation, all lambs were weighed, tagged, and vaccinated for *Clostridium perfringens* Types C and D and tetanus (BAR-VAC CD/T; Boehringer-Ingelheim). All lambs were FAMACHA scored, and if mucus membranes scored above a 3 out of 5, lambs were dewormed (Valbazen albendazole oral suspension; Zoetis Inc., Parsippany-Troy Hills, NJ). Lambs were then balanced for sex and allotted to pens in a completely randomized design. Lambs were randomly placed into pens (measuring 1.22 m x 0.91 m) with 3 lambs/pen either 2 ewes and 3 wethers or 3 wethers and 2 ewes). Each pen was lined with barriers to prevent nose-to-nose contact of animals during the experiment to limit the risk of cross-contamination between treatments. Each pen was then randomly assigned to one of two treatment groups to provide 12 replications per treatment: 1) Negative control (CON): no DFM supplementation, 2) Direct-fed microbial (DFM): oral supplementation of 15 mL/day of RSG Prime by Bio S.I. (blend of 10 million CFU/mL *Bacillus licheniformis*, 3.5 million CFU/mL *Bacillus subtilis*, 3 million CFU/mL *Lactobacillus acidophilus*, and 2 million CFU/mL *Bacillus pumilus*).

Diets and Experimental Timeline

Upon allotment on experiment d -7, lambs were limit-fed for 7 days, and the feed allowance was gradually increased until a target DMI of approximately 3.5% BW was reached. During this time, there was no DFM treatment administered. After the 7-d acclimation period, lambs were gradually transitioned to ad libitum access to a 16% crude protein concentrate diet containing roughage (dehydrated alfalfa) to eliminate the need for supplemental forage (Table 2.1). At experiment d 0, lambs assigned to the DFM treatment received 15 mL of the DFM via oral drench. This treatment was administered daily until study conclusion at 08:00 each day. The experimental period included a 63-d feeding length, with lambs and feeders weighed weekly to

determine average daily gain (ADG), average daily feed intake (ADFI) on an as-fed basis, and feed efficiency (G:F).

Fecal Consistency and Microbiota Analysis

Fecal scoring was conducted by two independent, trained scorers weekly from d 0 to d 42 to categorize the consistency of lamb feces per pen. A numerical scale from 1 to 5 was used: 1 being hard pellet-like feces, 2 a firm formed stool, 3 a soft moist stool that retains shape, 4 a soft unformed stool, and 5 a watery liquid stool. On d 0 and 21, fresh fecal samples were collected from one lamb per pen closest to the treatment average BW ($n = 12$ lambs/treatment, 24 lambs total) for fecal microbiota analysis. Fecal samples collected on day 0 were obtained prior to initiation of DFM supplementation and were considered baseline measurements. Consequently, statistical analyses evaluating treatment effects were conducted using post-treatment sampling days. The same lamb was sampled at both time points. Fecal microbiota were evaluated from a single lamb per pen, which may not fully capture within-pen individual variability. However, the selected lamb was intended to be representative of the pen, and this sampling approach allowed evaluation of treatment-associated microbial responses while maintaining consistency across experimental units. Samples were collected into sterile, DNA-free centrifuge tubes and stored at -80°C until shipment to a commercial laboratory (MR DNA, Shallowater, TX) for DNA extraction and taxonomic analysis.

Genomic DNA was isolated from each sample using the PowerSoil DNA Isolation Kit (Qiagen Inc., Valencia, CA). Approximately 250 mg of fecal matter was added to a PowerBead (Qiagen Inc., Valencia, CA) tube and homogenized using the PowerLyzer (Qiagen Inc., Valencia, CA) to induce cell lysis. The purified DNA was then eluted and stored at -20°C until PCR amplification. The 16S universal primers 515F (GTGYCAGCMGCCGCGGTAA) and

806R (GGACTACNVGGGTWTCTAAT) were utilized to amplify the 16S gene of samples on the Illumina NovaSeq (Illumina Inc., San Diego, CA) via the bTEFAPâ DNA analysis service (Dowd et al., 2008). Each sample underwent a single-step 35 cycle PCR using the Qiagen ALLtaq Plus Master Mix Kit (Qiagen, Valencia, CA) under the following conditions: 95°C for 5 minutes, followed by 30 cycles of 95°C for 30 seconds; 53°C for 40 seconds; and 72°C for 1 minute; after which a final elongation step at 72°C for 10 minutes was performed. Following PCR, all amplicon products from different samples were mixed in equal concentrations and purified using calibrated solid phase reversible immobilization (SPRI) beads. Samples were sequenced utilizing the Illumina NovaSeq (Illumina Inc., San Diego, CA) chemistry following the manufacturer's protocols.

Data processing was conducted using a proprietary analysis pipeline (MR DNA, Shallowater, TX). Sequences were depleted of primers, short sequences (< 150 bp) were removed, and sequences with ambiguous base calls were removed. Sequences were quality filtered using a maximum expected error threshold of 1.0 and dereplicated. The dereplicated or unique sequences were denoised; unique sequences identified with sequencing or PCR point errors were removed, followed by chimera removal, thereby providing a denoised sequence or operational taxonomic unit (OTU). Final OTUs were taxonomically classified using BLASTn (Altschul et al., 1990) against a curated database derived from NCBI (www.ncbi.nlm.nih.gov). Alpha and beta diversity analyses were conducted as previously described by (Dowd et al., 2008b; Edgar, 2017) using Qiime v.2 (Boylen et al., 2019). After stringent quality sequence curation, a total of 23,311,504 sequences were identified and utilized for final microbiota analyses. The average reads per sample were 24,336. For alpha and beta diversity analysis, samples were rarefied to 48,000 sequences.

Statistical analysis as well as all alpha and beta diversity analyses were performed using a variety of computer packages including XLstat, NCSS 2007, R, and NCSS 2010. Alpha and beta diversity analysis was conducted using QIIME2 as described previously (Dowd et al., 2008b; Edgar 2010; Cephas et al., 2011; Eren et al., 2011; Bolyen et al. 2018).

Serum Metabolites

On d 0 and 21, whole blood samples were collected from one lamb per pen that was closest to the treatment average BW ($n = 12$ lambs/treatment, 24 lambs total) to analyze serum metabolites. The same lambs were sampled at each time point. Samples were collected from the jugular vein into sterile 10 mL vacuum-sealed tubes (Monoject™ Blood Collection Tube, Mansfield, MA) using a 22 gauge 1" blood collection needle (Fisher Scientific, Hampton, NH). Samples were immediately placed on ice until transport to the Kansas State University Veterinary Diagnostic Laboratory (Kansas State University, Manhattan, KS) for a complete blood panel, serum chemistry, and hepatic profile analysis via spectrophotometry. Briefly, samples were centrifuged for 5 min at 3,000 rpm (Eppendorf North America, Enfield, CT) to separate the serum for analysis. Chemistry assays were then performed utilizing the Cobas c501 (Roche Diagnostics, Indianapolis, IN). Glucose, urea nitrogen, albumin, globulin, total calcium, phosphorus, total magnesium, sodium, potassium, chloride, bicarbonate, anion gap, sodium potassium ratio, aspartate transaminase, plasma pyridoxal 5'-phosphate (P5P), alkaline phosphatase, sorbitol dehydrogenase, and creatine kinase were all analyzed for each sample.

Statistical Analysis

Growth performance and fecal consistency data were analyzed as a completely randomized design with pen as the experimental unit because lambs were group-housed and feed intake was measured at the pen level. Therefore, feed intake and derived performance variables

could not be attributed to individual animals. While this approach does not capture individual variation among lambs within a pen, it reflects the unit at which treatments were applied and feed intake was measured. Fecal consistency scores were analyzed using a linear mixed model treating the score as a continuous response variable. Sampling day was included as a repeated measure to account for multiple observations collected over time. For fecal microbiota and serum metabolite data, individual lamb was the experimental unit. Data were analyzed using the GLIMMIX procedure of SAS (v.9.4, SAS Inst., Cary, NC) with the model including treatment, sampling day, and treatment $\times$ sampling day interaction as fixed effects. Initial body weight was evaluated as a potential covariate for growth performance variables but was not included in the final model because it was not significant ($P > 0.10$).

Fecal microbiota data were analyzed with individual lamb as the experimental unit to represent one sample selected from each pen on each sampling day (d 0 and d 21). Sampling day was included as a repeated measure to account for multiple observations collected from the same lamb over time. The relative abundance was determined as the total proportion of reads for a sample classified into the specific microbial phyla or family. Samples with a low relative abundance ($< 0.01\%$) were excluded from the analysis. Once the relative abundance for each sample was calculated, data were analyzed as a completely randomized design with the model including dietary treatment, sampling day, and their interaction as fixed effects. Data were analyzed as repeated measures given the two sampling time points on d 0 and d 21. Statistical comparisons of observed features and Shannon Diversity indices for each treatment group were conducted using Kruskal-Wallis pairwise comparisons. Beta diversity was analyzed using a weighted UniFrac distance matrix with pairwise analysis of similarities (ANOSIM) used to evaluate differences in microbial communities between groups over time.

Serum metabolite data were log transformed prior to analysis. With individual lamb as the experimental unit, the data were analyzed using the GLIMMIX procedure of SAS (v.9.4, SAS Inst., Cary, NC). The model included the main effects of treatment and sampling day, as well as the treatment $\times$ sampling day interaction. The LS Means were utilized to partition treatment differences, and all comparisons included Tukey-Kramer multiple comparison adjustments. Significance was determined at $P < 0.05$ and tendency at $0.05 \leq P < 0.10$.

RESULTS AND DISCUSSION

Lamb Growth Performance and Fecal Consistency

BW and growth performance variables were not affected by treatment throughout the 63-d experimental period ($P \geq 0.20$; Table 2.2). There was no evidence of a difference in ADG over the experimental period ($P = 0.35$). Likewise, ADFI ($P = 0.79$) and G:F ($P = 0.20$) were statistically similar across treatments. Collectively, this indicates that supplementation with a DFM did not significantly impact feedlot lamb growth performance compared to a control under the conditions of this trial. Treatment had no effect on fecal scores ($P > 0.05$, Figure 1), indicating that fecal consistency was not altered by DFM supplementation. Nevertheless, fecal scores improved over time ($P < 0.0001$) in both groups, with a reduction observed from d 0 to d 42. This trend may reflect the natural stabilization of gastrointestinal function as lambs matured and adapted to their diet.

Despite variable responses to DFM supplementation reported in the literature, several mechanisms have been proposed to explain potential changes in growth performance, including modulation of rumen microbial communities, stabilization of rumen pH, and enhanced fiber digestion (Newbold et al., 1996; McAllister et al., 2011). Certain strains of direct-fed microorganisms are known to promote the activity of lactate-utilizing and cellulolytic bacteria,

which can shift rumen fermentation toward increased volatile fatty acid production, particularly propionate, thereby improving energy availability to the host (Nagaraja and Titgemeyer, 2007; Oba and Allen, 2003). However, these responses are often inconsistent, as they may depend on factors such as diet, animal age, microbial strain, and environmental conditions. Antwi et al. (2019) reported supplementation of DFM products to lambs did not influence growth performance. Additionally, Zulkifli et al. (2000) indicated temperature may cause inconsistent growth results for DFM-supplemented ruminants. The absence of treatment effects on growth parameters in the present study may reflect that lambs were already performing near their genetic capacity. Potential benefits may have occurred at the level of digestive function or microbial balance without translating to measurable improvements in BW gain or feed utilization within the 63-d period. Further research evaluating a longer post-supplementation period is warranted to determine whether this response represents a lasting advantage.

Serum Metabolites

There was no evidence of a significant treatment $\times$ day interaction for any of the measured serum metabolites ($P > 0.05$, Table 2.3), indicating that changes over time were independent of treatment. There was a tendency for blood calcium levels to be lower in lambs receiving the DFM supplementation compared to lambs in the control group ($P = 0.06$), suggesting a possible but inconclusive effect in nutrient metabolism and gut absorption that may warrant further investigation in larger studies.

Several blood chemistry parameters demonstrated significant changes over time, regardless of treatment. Specifically, concentrations of potassium tended to decline ($P = 0.06$), while albumin and anion gap significantly decreased from d 0 to d 21 ($P < 0.05$). potentially reflecting physiological adaptations during the early feedlot transition period. The decline in

serum albumin is consistent with the stress response observed during early feedlot transition (Tóthová et al., 2013). Potassium typically decreases extracellularly due to acidosis or a reduction in feed intake, however since no reduction in feed intake was observed, the decrease could be attributed to a decreasing rumen pH or intracellular shifts supporting tissue growth (Schneider et al., 2016). The reduction in anion gap may indicate stabilization of volatile fatty acid production and utilization as lambs transitioned to a new diet (Salles et al., 2012).

Conversely, levels of glucose, urea nitrogen, globulin, magnesium, and bicarbonate increased significantly from d 0 to d 21 ($P < 0.05$), likely reflecting metabolic adjustments associated with early growth and dietary adaptation. Glucose elevations are expected as lambs transition from forage to a concentrate-based diet, increasing energy availability. Additionally, this high-concentrate diet altered nitrogen metabolism as the lambs utilized different protein sources and levels when changing diets and continued to elevate as the rumen microbes adapted (Jin et al., 2018). Nitrogen cycling patterns change as the microbial populations establish in response to new substrates, resulting in increased urea production initially (Stewart and Smith, 2005). Globulin production is a direct indicator of immune system activity over a stressful period. It has been shown that animals transitioning to feedlot conditions develop higher globulin levels due to exposure to diverse microbial challenges (Chovanová et al., 2021). The immune activation is a normal adaptive response that typically stabilizes once animals fully acclimate to their new environment. Magnesium concentrations similar to calcium are affected by blood pH and can act as an alkalizer in acidic conditions (Russel and Roussel, 2007). Serum electrolytes sodium, potassium, and chloride interact with bicarbonate to maintain acid-base equilibrium, with alterations in these parameters indicating shifts towards acidosis or alkalosis. The observed

changes in magnesium and bicarbonate concentrations as lambs adapted to a new diet likely reflect metabolic adjustments and ruminal adaptation to a high-concentrate diet.

These results did not indicate that DFM supplementation facilitates metabolic efficiency during the critical transition phase following weaning. In addition to this, a significant day effect was noted in several blood biochemical parameters, irrespective of treatment. The observed temporal changes in blood metabolites highlight the complex interplay between dietary supplementation, ruminal health, and systemic physiological responses. Importantly, the lack of significant treatment-by-sampling day interactions suggests that both DFM and control groups experienced similar adaptive trends, possibly driven more by the natural course of post-weaning development than by the DFM intervention alone.

Lamb Fecal Microbiota

Alpha diversity metrics including observed features (Amplicon Sequence Variants) and Faith's Phylogenetic Diversity (Faith PD) were compared among treatment groups using Kruskal-Wallis pairwise tests. Observed features represent raw richness, defined as the number of unique sequences detected in a sample. Shannon diversity incorporates both richness and evenness, reflecting the number of taxa present and the distribution of their relative abundances. Faith PD accounts for phylogenetic relatedness and can distinguish communities with comparable richness but differing evolutionary diversity.

Pairwise Kruskal-Wallis comparisons for observed features identified significance in 4 instances. There was a time significance in both treatment groups with day 0 being significantly higher in observed features of alpha diversity than day 21 ($P < 0.005$; Table 2.4). Additionally, alpha diversity and microbial evenness in the control group on day 0 was significantly higher than the treatment group on day 21 ($P < 0.007$). Similarly, the treatment group on day 0 was

significantly higher than the control group on day 21 ($P \leq 0.001$). No significant differences were detected among groups for Shannon diversity ($P \geq 0.24$). Faith PD demonstrated a pattern of significant differences comparable to those observed for the observed features metric.

Beta diversity was assessed using weighted UniFrac distances to evaluate differences in microbial community structure among treatment and sampling day groups. Principal coordinate analysis (PCoA) was used to visualize patterns in community composition (Figure 2). Pairwise analysis of similarity (ANOSIM) revealed significant differences in microbial community composition between day 0 and day 21 samples within both treatment groups ($R \geq 0.71$, $P \leq 0.001$; Table 2.5). In contrast, microbial communities did not differ between treatment groups within the same sampling day, as no significant differences were observed between control and DFM-treated lambs on day 0 ($R = -0.05$, $P = 0.728$) or day 21 ($R = 0.10$, $P = 0.058$). These results indicate that temporal changes in microbial community composition were more pronounced than treatment effects over the course of the study.

Since lambs were allotted to treatments on d 0 and fecal samples collected for microbial analysis on d 0 were obtained prior to the initiation of DFM supplementation, the d 0 samples represent baseline microbial community composition before animals received the experimental treatment. While several taxa showed statistically significant differences on d 0 between treatment groups, these differences reflect natural inter-animal variability in the fecal microbiome rather than true treatment effects; thus, were not considered in the statistical model. Baseline variation in microbial community composition is to be expected as the microbiome develops differently amongst individual animals (Huang et al., 2022). Our primary objective was to investigate changes in the fecal microbiota over time, therefore the statistical model focused on post-treatment sampling days to determine whether DFM supplementation influenced

microbial populations after treatment initiation. Fecal microbiota composition shifted over time, consistent with previous studies (Alawneh et al., 2024; Badman et al., 2019). It is difficult to conclude whether these differences directly reflect the influence of DFM supplementation on microbial community structure and function in conjunction with normal gastrointestinal development. At the Phyla level, the relative abundance of *Candidatus saccharibacteria* and *Verrucomicrobiota*, decreased from day 0 to 21 ($P < 0.05$, Table 2.6). *Verrucomicrobiota* exhibited a trend ($P = 0.06$) toward higher abundance in the DFM-treated group compared to control though, this was not statistically significant. At the class level, although *Opitutae* showed a statistically significant treatment x sampling day interaction ($P = 0.03$), the biological relevance of these differences is miniscule. Specifically, the relative abundance of *Opitutae* on d 0 was statistically different between treatments ($P = 0.03$); however, it is important to note that the numeric difference was not biologically relevant and the extremely low relative abundance across both treatments at both sampling days suggests that the d 0 differences likely are not attributed to treatment.

Additionally, four specific orders; *Anaerolineales*, *Bifidobacteriales*, *Pirellulales*, and *Kordiimonadales*, showed significant decreases in relative abundance from day 0 to day 21 across both treatments ($P < 0.02$). This likely reflects a general adaptation to the environmental and dietary conditions of the study, as microbial communities stabilize over time. At the family level, *Francisellaceae* and *Butyricicoccaceae* also showed significant reductions over time ($P < 0.05$), reinforcing changes in microbial composition over time.

At the genus level, *Treponema* had a significant treatment x sampling day interaction ($P = 0.03$), whereas *Bifidobacterium* had a significant treatment × day interaction ($P = 0.05$). This

interaction in *Bifidobacterium*, a genus often associated with gut health, may reflect competitive shifts in the microbial environment or dietary transitions.

Overall, these findings highlight that both time (acclimation) and treatment (DFM supplementation) contributed to shaping the fecal microbiota similar to previous studies (Campbell et al., 2024; Fomenky et al., 2018). Several taxa demonstrated treatment x sampling day interactions, suggesting that DFM supplementation may influence temporal shifts in the microbial community during transition periods. However, these interactions do not clearly indicate whether DFMs consistently promote stabilization of specific microbial groups. While some taxa exhibited patterns that could reflect responses to environmental or physiological stressors, the biological significance of these changes remains uncertain (Magalhães et al., 2024). Additionally, many genera from the Phyla, Order, and Genus level showed a significant change from day 0 to day 21, and *Opitutae*, *Bifidobacteriales*, and *Treponema* importantly showed a treatment x sampling day interaction. These patterns may reflect physiological adaptations associated with dietary and environmental transitions rather than a direct effect of a DFM supplementation (Cull et al., 2022). Despite these findings, several limitations should be acknowledged. Baseline microbial composition was not incorporated as a covariate in the statistical model, which may limit the ability to fully account for inherent inter-animal variability in the fecal microbiome. Additionally, the evaluation of microbial communities at only two time points restricts interpretation of the full temporal dynamics of microbial succession. Future work incorporating baseline-adjusted models and more frequent sampling would provide a more comprehensive understanding of how DFM supplementation influences microbial community development.

CONCLUSIONS

In summary, supplementation with a DFM did not impact growth performance over a 63-d treatment period. All lambs, regardless of treatment, demonstrated changes in fecal consistency and blood biochemistry over time, which may provide insight into underlying physiological responses to diet and development. Fecal microbial populations differed between treatment groups and changed over time during the study period. While these patterns suggest that DFM supplementation may influence microbial community shifts during dietary and environmental transitions, the results do not clearly demonstrate that DFMs improved microbial adaptation during this period. Future studies should consider longer trial durations, alternative DFM strains or dosages, and more detailed assessments of rumen microbial dynamics to fully capture the potential benefits of DFM interventions in ruminant production systems.

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Table 2.1 Formulation of standard diet and calculated nutrient composition¹

Ingredient	% of Diet
Corn	39.71
Soybean meal, 48% CP	15.00
Soybean hulls	35.70
Dehydrated alfalfa	3.00
Ammonium chloride	1.00
Limestone	1.60
Sodium chloride	0.50
Selenium selenite	0.001
Vitamin A 30,000 IU	0.015
Vitamin D 30,000 IU	0.004
Vitamin E 20,000 IU	0.001
Zinc oxide	0.008
Dicalcium phosphate	0.96
Molasses	2.50
Total	100.00
Calculated analysis (as-fed basis)	
Crude protein, %	16.0
Crude fat, %	2.0
Crude fiber, %	17.0
Calcium, minimum, %	0.9
Calcium, maximum, %	1.3
Phosphorus Minimum, %	0.5

¹A standard diet was formulated to meet nutrient requirements for lambs and contained roughage to eliminate feeding of additional forage. The same diet was fed to all animals and nutrient values were calculated from formulated values.

Table 2.2 Effect of a direct-fed microbial (DFM) on feedlot lamb growth performance¹

Item	Treatment ²		SEM	<i>P</i> -value
	Control	DFM		
BW, kg				
d 0	26.48	26.98	0.346	0.33
d 63	43.31	43.05	0.589	0.77
Experimental period (d 0 to 63)				
ADG, kg/d	0.27	0.26	0.009	0.35
ADFI, kg/d	1.39	1.38	0.030	0.79
G:F	0.19	0.19	0.004	0.20

¹A total of 72 lambs (Dorper x Katahdin; initially 26.73 ± 0.35 kg BW) were used in a 63-d growth trial with 3 lambs per pen and 12 replicate pens per treatment.

²Lambs were randomly assigned to either a control (no DFM supplementation) or a DFM (supplementation with 15 mL per day of RSG Prime by BIO S.I.).

Table 2.3 Effect of a liquid direct-microbial (DFM) on feedlot lamb blood chemistry¹

Item	Treatment		SEM	P-values		
	Control	DFM		Treatment	Day	Treatment x Day
Albumin, g/dL			0.027	0.78	< 0.01	0.30
d 0	1.22	1.23				
d 21	1.14	1.11				
Glucose, mg/dL			3.086	0.52	0.03	0.15
d 0	76.50	79.50				
d 21	88.83	82.08				
Urea nitrogen, mg/dL			1.294	0.95	0.02	0.63
d 0	16.17	16.67				
d 21	19.75	19.08				
Calcium, mg/dL			0.139	0.06	0.87	0.15
d 0	10.46	10.43				
d 21	10.71	10.23				
Globulin, g/dL			0.132	0.29	< 0.01	0.96
d 0	2.74	2.93				
d 21	2.96	3.15				
Magnesium, mg/dL			0.034	0.56	< 0.01	0.95
d 0	0.84	0.87				
d 21	0.95	0.97				
Potassium, mmol/L			0.025	0.10	0.06	0.44
d 0	1.81	1.78				
d 21	1.78	1.72				
Bicarbonate, mmol/L			0.065	0.91	< 0.01	0.69
d 0	2.91	2.92				
d 21	3.21	3.18				
Anion gap, mmol/L			0.047	0.84	< 0.01	0.94

d 0	3.39	3.38
d 21	3.11	3.10

¹A whole blood sample was taken from one lamb per pen closest to the treatment average BW on d 0 and d 21. The same animal was sampled at both time points.

Table 2.4 Pairwise Kruskal-Wallis comparisons of observed features alpha diversity among treatment and sampling day groups¹

Comparison Group		Statistical Values ²		
		H-value	<i>P</i> -value	q-value
Control d 0	Control d 21	8.0033	0.0047	0.0093
Control d 0	DFM d 0	1.3333	0.2485	0.2979
Control d 0	DFM d 21	7.3633	0.0067	0.0100
Control d 21	DFM d 0	10.2720	0.0014	0.0041
Control d 21	DFM d 21	0.0033	0.9540	0.9540
DFM d 0	DFM d 21	11.0256	0.0009	0.0041

¹ On d 0 and 21, fresh fecal samples were collected from one lamb per pen closest to the treatment average BW ($n = 12$ lambs/treatment, 24 lambs total) for fecal microbiota analysis. Statistical comparisons of observed features were conducted using Kruskal-Wallis pairwise comparisons.

²H= Kruskal-Wallis test statistic; q = Benjamini-Hochberg false discovery rate-adjusted *P*-value.

Table 2.5 Pairwise ANOSIM comparisons of microbial community composition among treatment and sampling day groups¹

Comparison Group		Statistical Values ²		
		R	<i>P</i> -value	q-value
Control d 0	Control d 21	0.7645	0.001	0.0015
Control d 0	DFM d 0	-0.0452	0.728	0.728
Control d 0	DFM d 21	0.7480	0.001	0.0015
Control d 21	DFM d 0	0.7442	0.001	0.0015
Control d 21	DFM d 21	0.0990	0.058	0.0696
DFM d 0	DFM d 21	0.7097	0.001	0.0015

¹On d 0 and d 21, fresh fecal samples were collected from one lamb per pen closest to the treatment average BW ($n = 12$ lambs/treatment, 24 lambs total) for fecal microbiota analysis. Statistical comparisons of treatment and sampling day groups were conducted using the ANOSIM test.

²R = ANOSIM test statistic indicating the degree of separation between groups. A value closer to 1 indicates a greater dissimilarity; q = Benjamini-Hochberg false discovery rate-adjusted *P*-value.

Table 2.6 Effect of a liquid direct-fed microbial (DFM) on the relative abundance of the most abundant taxa in feedlot lamb fecal samples¹

	Treatment ²			P-values		
Item	Control	DFM	SEM	Treatment	Day	Treatment x Day
<i>Phyla</i>						
<i>Verrucomicrobiota</i>			0.296	0.06	0.02	0.31
d 0	0.055	0.104				
d 21	0.004	0.038				
<i>Candidatus saccharibacteria</i>			0.124	0.34	<.0001	0.34
d 0	0.005	0.002				
d 21	0.000	0.000				
<i>Class</i>						
<i>Opitutae</i>				0.03	<0.001	0.03
d 0	0.004	0.001	0.112			
d 21	0.000	0.000				
<i>Order</i>						
<i>Anaerolineales</i>			0.241	0.91	<.0001	0.91
d 0	0.013	0.011				
d 21	0.000	0.000				
<i>Bifidobacteriales</i>			0.343	0.81	<.0001	0.04
d 0	4.390	20.090				
d 21	0.343	0.050				
<i>Pirellulales</i>			0.168	0.64	<.0001	0.64
d 0	0.015	0.022				
d 21	0.000	0.000				
<i>Kordiimonadales</i>			0.267	0.77	0.02	0.77
d 0	0.003	0.005				
d 21	0.000	0.000				
<i>Family</i>						
<i>Francisellaceae</i>			0.211	0.71	0.01	0.64
d 0	0.004	0.004				

d 21	0.001	0.000				
<i>Butyricicoccaceae</i>			0.247	0.90	<.0001	0.45
d 0	0.214	0.129				
d 21	0.008	0.012				
Genus						
<i>Treponema</i>			0.314	0.54	0.02	0.03
d 0	0.285	2.310				
d 21	9.206	2.803				
<i>Bifidobacterium</i>			0.348	0.87	<.0001	0.05
d 0	4.323	20.090				
d 21	0.302	0.049				

¹A fresh fecal sample was collected from one lamb per pen closest to the treatment average BW on d 0 and d 21 ($n = 24$) for analysis of fecal microbial populations using 16s DNA sequencing. The same lamb was sampled at both time points.

²Lambs were randomly assigned to either a control (no DFM supplementation) or a DFM (supplementation with 15 mL per day of RSG Prime by BIO S.I.).

Chapter 3 - Comparison of 5-day Versus 14-day CIDR Estrous Synchronization Protocol on Reproductive Characteristics in Ewes

ABSTRACT

Controlled Internal Drug Release (CIDR) devices are widely used in sheep for estrous synchronization with protocols ranging from 5 to 14 days of vaginal exposure. Previous research has shown that longer CIDR protocols may increase the incidence of persistent follicles or reduce follicular quality (Viñoles et al., 2001; Menchaca & Rubianes, 2004) but may also improve synchronization of estrous expression (Martinez-Ros et al., 2018). The objective of this study was to evaluate the use of transrectal ultrasonography to assess the effects of a 5- versus 14-day CIDR estrous synchronization protocol on follicular dynamics, time to return to estrus, conception rate, and lamb production following natural breeding. Fifty-eight Polypay-influenced ewes (2 years of age; average body weight = 90 kg) were used in a 62-day study conducted at the Kansas State University Sheep and Meat Goat Center (Manhattan, KS). Ewes were blocked by age and randomly assigned to one of two CIDR treatments: 5 days or 14 days of CIDR exposure ($n = 29$ per treatment). A subset of ewes ($n = 10$ per treatment) was randomly selected for transrectal ultrasonography to evaluate follicular dynamics. Ewes underwent ultrasonography to monitor follicular development based on the length of protocol. A single ram was introduced following CIDR removal, and marking activity was recorded at standardized morning and evening time points. Conception and fetal number per ewe were determined via transabdominal ultrasonography on day 75. Follicle counts increased over time in both treatments. The 5-day group had an average follicle diameter of 0.41 cm on day 0, whereas the 14-day group had an average follicle diameter of 0.28 cm. The 5-day group maintained larger follicles 7 days after CIDR removal (0.54 cm vs. 0.44 cm). The 14-day group started showing estrous expression 12

hours earlier following CIDR removal, however three ewes were not marked until 17-19 days after CIDR removal. The 5-day group started marking at h 24 and were marked within 84 hours. Ultrasound results indicated that the 5-day group carried more single fetuses than twins (13 singles vs. 9 sets of twins). The 14-day group had a higher number of twins (17 sets of twins vs. 2 singles). Six ewes in the 5-day group and ten ewes in the 14-day group remained open. Total lamb production was similar between groups with 34 lambs for the 5-day group, and 36 lambs for the 14-day group. These findings suggest that shorter CIDR exposure may support favorable follicular development without compromising overall lamb output. Adjusting for ram fertility and libido in future studies could be better managed by using the same ram opposed to one per treatment. Additionally, this study demonstrates limitations of transrectal ultrasonography for characterizing ovarian responses in synchronized ewes, as successful ultrasound localization of both ovaries was not consistently achieved. Further research is warranted to refine ultrasonographic assessment of corpora lutea and to more precisely define how CIDR duration influences ovarian dynamics and reproductive efficiency.

INTRODUCTION

Controlled Internal Drug Release (CIDR) devices containing progesterone are widely used in estrous synchronization protocols to improve reproductive efficiency in ewes. By initiating and synchronizing estrous cycles during seasonal anestrus, year-round breeding and consistent lamb production is more attainable. These devices have been used in protocols varying in length of CIDR application. The CIDR in sheep synchronizes estrus by mimicking the luteal phase, suppressing endogenous gonadotropin release, and allowing for follicular turnover (Evans & Robinson, 1980; Menchaca et al., 2004). However, prolonged exposure to exogenous progesterone may promote the development of persistent follicles, which are associated with

reduced oocyte quality and compromised fertility (Viñoles et al., 2001; Menchaca & Rubianes, 2004).

Sheep are seasonally polyestrous, meaning they undergo anestrus in periods of long daylight. This is due to melatonin which affects luteinizing hormone in the ewe, causing seasonal anestrus (Malpaux et al., 2001). It is believed that seasonal anestrus prevents sheep from lambing in inadequate environmental conditions to promote overall lamb survival (Rosa and Bryant, 2003). Naturally ovulating in short photoperiods results in spring born lambs when the grass is rich, temperature is mild, and energy reserves in the ewe can be replenished quickly. However, being able to breed ewes outside of their natural breeding season can have positive economic effects.

Exogenous hormone injections have been shown to adjust natural estrous cycles and are commonly used in addition to the CIDR device to synchronize reproduction. The corpus luteum (CL) develops and is maintained by episodic pulses of Luteinizing Hormone (LH) and is lysed by prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$). Following ovulation, the CL becomes the primary source of progesterone that establishes the environment conducive for embryo development and implantation. If fertilization occurs, progesterone secretion from the CL establishes pregnancy, suppressing estrus behavior and inhibiting further ovulation. Administration of exogenous $PGF_{2\alpha}$ in ewes reduces ovarian blood flow and induces CL lysis (Vonnahme et al., 2006), causing serum progesterone concentrations to decrease as the CL regresses. The decline in progesterone permits follicular development and return to estrus. A surge in LH then triggers ovulation, leading to formation of a new CL from the ovulated follicle (Przygodzka et al., 2021).

The Progesterone from the CIDR device prevents dominant follicles from ovulating. This causes follicles to regress at the time of insertion and promotes the emergence of a new follicular

wave, a process that typically requires 5–7 days (Martinez-Ros and Gonzalez-Bulnes, 2019a). The device continuously releases exogenous progesterone, mimicking the function of the corpus luteum and maintaining circulating progesterone concentrations similar to those observed during the luteal phase. Elevated progesterone suppresses gonadotropin secretion, preventing the preovulatory LH surge, inhibiting ovulation while the CIDR remains in place (Año-Perello et al., 2020). Removal of the device results in a rapid decline in progesterone, allowing increased gonadotropin secretion, continued follicular maturation, and subsequent ovulation. When CIDR devices are administered across a flock, these coordinated hormonal and follicular responses result in synchronization of estrus and ovulation, enabling timed breeding or artificial insemination.

In recent years, shorter-duration CIDR protocols, particularly the 5-day regimen, have gained popularity. These protocols are often coupled with injections of PGF_{2α} (e.g., Estrumate) and equine chorionic gonadotropin (eCG) or human chorionic gonadotropin (hCG)-based treatments (e.g., PG600) at CIDR withdrawal to ensure luteolysis and stimulate follicular development (Menchaca et al., 2007). Studies comparing 5- vs. 14-day protocols have shown that shorter durations may result in improved pregnancy rates likely due to reduced follicular aging and improved synchronization of hormones (Swelum et al., 2018; Viñoles et al., 2011). However, extending CIDR duration has been shown to improve synchronization and decrease variation in the interval to estrus onset among ewes (Martinez-Ros et al., 2018).

Rectal ultrasonography was used to evaluate follicular dynamics in ewes throughout synchronization protocols. Literature has emphasized downstream reproductive outcomes such as estrus response, timing of ovulation, or lambing rate without directly examining the underlying ovarian dynamics, such as follicular wave patterns, that are influenced by CIDR

duration (Mellieon et al., 2012; Menchaca et al., 2007; Viñoles et al., 2011). It's hypothesized that CIDR duration may alter follicular wave emergence, dominant follicle persistence, and luteal regression patterns in ways that are not fully captured by pregnancy outcomes alone. Therefore, the objective of this study was to compare reproductive performance between a 5-day versus 14-day CIDR protocol. Additionally, results from transrectal ultrasonography were used to generate hypotheses regarding how protocol length may influence follicular dynamics and underlying ovarian physiology.

MATERIALS AND METHODS

All experimental procedures adhered to guidelines for the ethical and humane use of animals for research according to the Guide for the Care and Use of Agricultural Animals in Research and Teaching (FASS, 2010) and were approved by the Institutional Animal Care and Use Committee at Kansas State University (IACUC #5479).

Animals, Experimental Design, and Estrous Synchronization Protocols

A total of 58 Polypay-influenced ewes with an average age of 2 yr. and approximate weight of 90 kg were used in a 62-day estrous synchronization study at the Kansas State University Sheep and Meat Goat Center (Manhattan, KS). On d -1, ewes were balanced for age and randomly allocated to one of two CIDR protocol treatments: 5-day or 14-day. Insertion of the CIDR was considered d 0 for each group (Figure 3.1). At d 0, a clean, unused CIDR device (EAZI-BREED CIDR; Zoetis, Kalamazoo, MI) was vaginally inserted into each ewe according to the manufacturer's label. A subset of ewes ($n = 10$ per treatment/20 total) were randomly selected for transrectal ultrasound to assess follicular dynamics. The ovaries of ewes on the 5-day CIDR protocol were scanned via ultrasound on d 0, 3, and 13. The ovaries of ewes on the 14-day CIDR protocol were scanned on d 0, 3, 5, 9, 12, and 22. These time points were selected

to evaluate ovarian follicular dynamics in the cycle while avoiding excessive manipulation near CIDR withdrawal, which could disrupt or prematurely regress pre-ovulatory follicles.

Additionally, both groups were scanned 7 days after CIDR removal (d 13 for 5-day protocol and d 22 for 14-d protocol) to evaluate ovulation outcomes and assess potential fertilization during this timeframe. Briefly, ewes were restrained in a holding chute or manually by trained personnel. Feces were removed and a lubricant gel was introduced into the rectum. Ultrasound was conducted using a Sonosite ultrasound machine (Sonosite; FUJIFILM Sonosite, Inc., Bothell, WA) and a 7.5 MHz transducer probe adapted for transrectal examinations (Figure 3.2). To facilitate adequate reach and stability, a custom probe extension was constructed from a 16-inch segment of 1-inch diameter polyvinyl chloride (PVC) pipe. This pipe segment was cut in half longitudinally to provide space for the cord of the probe to fit. The distal 3.5 inches of one end of the PVC pipe were trimmed to approximately 1 inch in width and then bent to create an approximately 30° angle. This modification formed a cradle that allowed secure placement of the linear probe within the PVC adapter. The probe was firmly secured to the adapter using adhesive tape. Lubricant gel was applied to the probe surface to improve the visual of the scan, and a disposable probe cover was secured over the adapter prior to insertion. This modified assembly functioned similarly to a rectal ultrasound wand, providing sufficient length, rigidity, and directional control to allow consistent visualization of the ovaries via the rectum. Once the ovaries were located, individual follicles were identified and frozen images were captured. Follicular diameter was measured using on-screen calipers, and the total number of visible follicles per ovary was recorded.

As a part of the estrous synchronization protocol, a single injection of 1 mL PGF_{2α} (Estrumate; Merck Animal Health Rahway, NJ) was administered intramuscularly to each ewe

($n = 29$ per treatment/58 total) 48 h prior to CIDR removal (protocol d 3 for ewes in the 5-day group; protocol d 12 for ewes in the 14-day group). At the conclusion of each synchronization protocol (d 5 or d 14), CIDR devices were removed, and at this time a single injection of 3 mL eCG and hCG (PG600; Merck Animal Health) was administered intramuscularly to each ewe ($n = 29$ per treatment/58 total).

Breeding of Ewes and Pregnancy Determination

Following CIDR removal, ewes were kept in their respective groups and allowed 24 h until they were exposed to one Polypay ram per treatment for natural breeding. Each ram (weighing 105 kg at 1-3 yrs) passed a breeding soundness exam within 30 days of trial start date. Mating activity was tracked at a standardized time each AM and PM utilizing a standard breeding harness and marking crayon that was placed on the ram. At these timepoints, ewes who were estimated to have over 6 inches of color on the rump from marking crayon were recorded as “marked” to estimate time to return to estrus after CIDR withdrawal. Twelve hours after the recorded marking, ewes were sorted out of pen with ram. After the 17-day breeding window had concluded, rams were removed, and ewes were kept in their respective groups.

On d 75 ewes from both groups were abdominally scanned via ultrasound to determine lamb counts by veterinarians from Kansas State University College of Veterinary Medicine (Manhattan, KS). After pregnancy determination, the study was concluded, and ewes returned to normal management conditions of the Kansas State University Sheep and Meat Goat Center.

Data Analysis

A subset of ewes in the 5-day CIDR group ($n=10$) were scanned rectally via ultrasonography on d 0, 3, and 13. A subset of ewes in the 14-day CIDR group ($n=10$) were selected to undergo ovarian ultrasound on d 0, 3, 5, 9, 12, and 22. Total follicle count per ewe

was recorded at each examination and summarized as the mean follicle count per ewe for each collection day. Individual follicle diameters (cm) were measured, and the mean follicle diameter per ewe was calculated for each scanning day.

During the breeding period, the number of ewes marked by rams during each 12 h interval was recorded until all ewes were marked. Following pregnancy diagnosis, marking data for ewes determined to be open were retrospectively evaluated to determine the timing of estrus expression relative to ram exposure. On trial d 75, fetal counts were determined for each ewe via abdominal ultrasonography. Total lamb numbers were summarized by treatment group. Pregnancy rate in a 34-day breeding period was calculated as the proportion of ewes diagnosed pregnant within each treatment group. Pregnancy rates were also summarized separately for the subset of ewes that underwent ultrasound to allow comparison with the overall treatment groups. Descriptive statistics (means, counts, and proportions) were used to summarize all data.

RESULTS

Follicular Dynamics

Results from the 5-day CIDR treatment are presented in Table 3.1. The results presented are numerical differences, as statistical significance was not feasible due to low number of data points. Follicle count increased over time, peaking on d 3 at a mean of 2.8 follicles, having the lowest number of follicles on d 13 (7 days post-CIDR withdrawal) at a mean 1.3 follicles. Mean follicular diameter was 0.41 cm on d 0, and showed a numerical increase to a maximum of 0.54 cm on d 13. Results from the 14-day CIDR treatment are presented in Table 3.2. Follicle count peaked on d 12 with a mean of 3.3 follicles. Mean follicular diameter was 0.28 cm on d 0 and measured 0.44 cm on d 22.

Return to Estrus Time

Return to estrus time for both treatment groups is presented in Table 3.3. In the 5-day protocol, ewes were first marked 24 h after CIDR withdrawal and marking continued through 84 h post-withdrawal. The ram began to mark ewes in the 14-day protocol at 12 h and marking continued until 468 h (19.5 days) post-withdrawal. After pregnancy was determined, marking data for ewes diagnosed as open were retrospectively evaluated. These results are presented in Table 3.4. Open ewes in the 14-day group were marked between 24 and 84 h post-CIDR withdrawal, with the highest marking frequency occurring at 12 and 24 h. Open ewes in the 5-day group were marked between 12 and 96 h post-withdrawal, with the majority of markings occurring at 60 h.

Pregnancy and Prolificacy

Ultrasound results for both treatment groups are presented in Table 3.5. These results indicated that there were greater instances of ewes carrying single fetuses than twins in the 5-day group (13 ewes carrying singles vs. 9 ewes with twins). The 14-day group had a higher amount of twin pregnancies than single fetuses, with 17 ewes who underwent ultrasound with twins versus 2 ewes who were carrying singles. Six ewes in the 5-day group and ten ewes in the 14-day group were diagnosed open. There were 34 lambs in the 5-day group and 36 lambs in the 14-day group that were identified on d 75 via abdominal ultrasound.

The subset of ewes that were randomly selected to have their ovaries be rectally scanned by ultrasound from each treatment ($n=10$ per treatment) were compared to the total from each treatment ($n=19$ per treatment) in Table 6. Within the 5-day treatment group, ewes that were included in the ultrasound subset had a pregnancy rate of 70%, whereas ewes in the same treatment group that were not examined via ultrasound had a pregnancy rate of 84.21%. In the

14-day treatment group, the subset that underwent ultrasound had a pregnancy rate of 60%, compared with 68.42% in ewes that were not examined by ultrasonography.

DISCUSSION

Follicular Dynamics

Although there are limitations to the data, there were observed follicular changes between the two treatment groups. Follicle count showed an increase over time for both CIDR protocols, with the 14-day group having the most follicles at the end of the treatment protocol. This is consistent with a typical follicular cycle in ewes where multiple waves of follicles can be shown due to follicles growing and regressing (Bartlewski et al., 2011). Numerically, there were larger follicles 7 days after CIDRs were withdrawn from both groups, which is similar to Martinez-Ros et al. (2019b) who demonstrated follicle size was shown to peak 5-7 days after CIDR insertion.

The 14-day group had a higher follicle count post-CIDR withdrawal. On the respective post-withdrawal scanning days (d 13 for the 5-day group and d 22 for the 14-day group), ovaries in the 14-day group appeared larger and were easier to identify by ultrasonography. However, the accuracy of the d 13 ultrasound evaluation in the 5-day group is limited as it was difficult to consistently identify both ovaries and distinguish between the right and left ovaries throughout the trial. Ovaries were particularly difficult to visualize at this timepoint.

Differences in structure of the two CIDR protocols limited the ability to make direct comparisons between treatment groups, as data collection occurred on different days depending on the assigned CIDR protocol. Additionally, visualization of both ovaries by transrectal ultrasonography was inconsistent throughout the study. The rectal probe handle was developed as a proof-of-concept to assess the feasibility and functionality of the prototype design. In several ewes from both treatment groups, only one ovary was able to be reliably visualized, especially at

the beginning of the study. This raises some concern, as it was also difficult to decide which ovary was being scanned. As ewes got closer to ovulation, ovarian size increased, making it easier to identify and measure follicles. Additionally, corpus lutea were not recorded accurately. Due to limitations in data completeness and reliability, statistical analyses were not performed, and the authors elected to report results descriptively.

Future studies should use a rectal wand to capture images more completely and allow the user more flexibility when scanning. A better case definition of what an image of a CL would be recorded as and how it would be measured on ultrasound is needed. In addition, standardized protocols should be established for situations in which both ovaries cannot be easily identified, such as scanning the ewe again in the following hour or evacuating the urinary bladder to improve visualization. This is particularly important in small ruminants, as the reproductive tract cannot be manipulated rectally to improve visualization during ultrasonography, unlike in larger ruminants such as cattle.

Return to Estrus Time

The time ewes took to return to estrus appeared to be less variable in the 5-day group. In both the 5-day and 14-day groups, most ewes were marked by 36 hours. The 14-day group started to be marked 12 hours earlier than the 5-day group. This is supported by previous literature that shows sheep who were exposed to a CIDR device for 14 days displayed an earlier onset of estrus than in shorter CIDR treatments (Martinez-Ros et al., 2018). However, the 5-day group had a shorter window of time to return to estrus post-CIDR withdrawal. This is supported by a study conducted by Whittier et al., (2013) which showed cows on a 5-day treatment had increased estrus expression before they were artificially inseminated compared to a 7-day treatment.

The time to return to estrus in the 14-day group was influenced by three ewes who did not mark in the first 17 days. Two rams were used to ensure the two large groups of synchronized ewes could be covered in a short amount of time. Although both rams in each group passed a breeding soundness exam within 30 days of the trial, there was an age and experience difference between them. The ram that was used in the 5-day group was 3 years old and had been used at the Kansas State University Sheep and Meat Goat Center for 2 years previously. The ram that was used in the 14-day group was eight months old and had never bred ewes before. Because three ewes had not been marked by the end of the first 17 days, the young ram was allowed an additional estrous cycle to breed these ewes. When the three previously unmarked ewes expressed estrus within the first 48 hours of the following cycle, it suggested the inexperienced ram may have been unable to successfully breed all 29 ewes of the 14-day group during the initial, condensed breeding window. Consequently, differences in ram age and experience likely confounded measurements of return to estrus, preventing clear establishment of causation when comparing CIDR protocol effects on estrus timing.

Pregnancy and Prolificacy

In addition to exhibiting a longer estrus expression window, the 14-day group had a greater proportion of open ewes compared to the 5-day group. These findings are consistent with previous research demonstrating improved pregnancy outcomes with shorter CIDR protocols (Thomas et al., 2016; Whittier et al., 2013). However, interpretation of these results is complicated by potential ram effects, as observational breeding data were not recorded to confirm successful insemination. Despite the lower overall pregnancy rate, the 14-day group had a greater number of ewes carrying twins at ultrasonographic examination on d 75 (Table 5). This

outcome may be associated with the increased follicle number and larger follicle size observed in the 14-day group relative to the 5-day treatment.

Ewes who underwent ultrasonography were descriptively evaluated separately for comparison to determine whether differences in pregnancy rate were attributable to the CIDR protocol or to the transrectal ultrasonography procedure itself (Table 3.6). The 5-day group exhibited a higher pregnancy rate than the 14-day group, which may reflect differences in CIDR exposure duration. However, this conclusion remains tentative due to the potential confounding effect of ram fertility and breeding behavior. Additionally, ewes not undergoing ultrasonography demonstrated a higher pregnancy rate. This reduction may be attributable to reproductive tract manipulation near the breeding period. Although ewes were intentionally not scanned 2 days prior to CIDR withdrawal or 7 days post-withdrawal to minimize disruption of preovulatory follicles, the group who underwent ultrasonography still exhibited lower pregnancy rates. Future studies should control for ram effects and incorporate detailed breeding observations to better determine whether extended CIDR protocols contribute to increased prolificacy despite reduced conception rates.

CONCLUSIONS

In summary, transrectal ultrasonography of ewes undergoing estrous synchronization with a CIDR device for either 5 or 14 days demonstrated numerical differences in follicular dynamics, interval to estrus, conception rate, and lambs born per ewe. The 5-day CIDR protocol resulted in higher conception rates and a more synchronized return to estrus, whereas the 14-day protocol was associated with a greater incidence of twin pregnancies but also a higher proportion of open ewes. Interpretation of estrus return data was limited by differences in ram age and breeding experience, which likely influenced breeding efficiency and confounded treatment

effects. Further research is warranted to address technical challenges associated with identifying ovaries and corpora lutea via transrectal ultrasonography and to better isolate treatment effects by controlling for sire influence. Such refinements will help clarify and lay groundwork for future studies on how CIDR protocol duration affects both conception success and overall lamb crop outcomes.

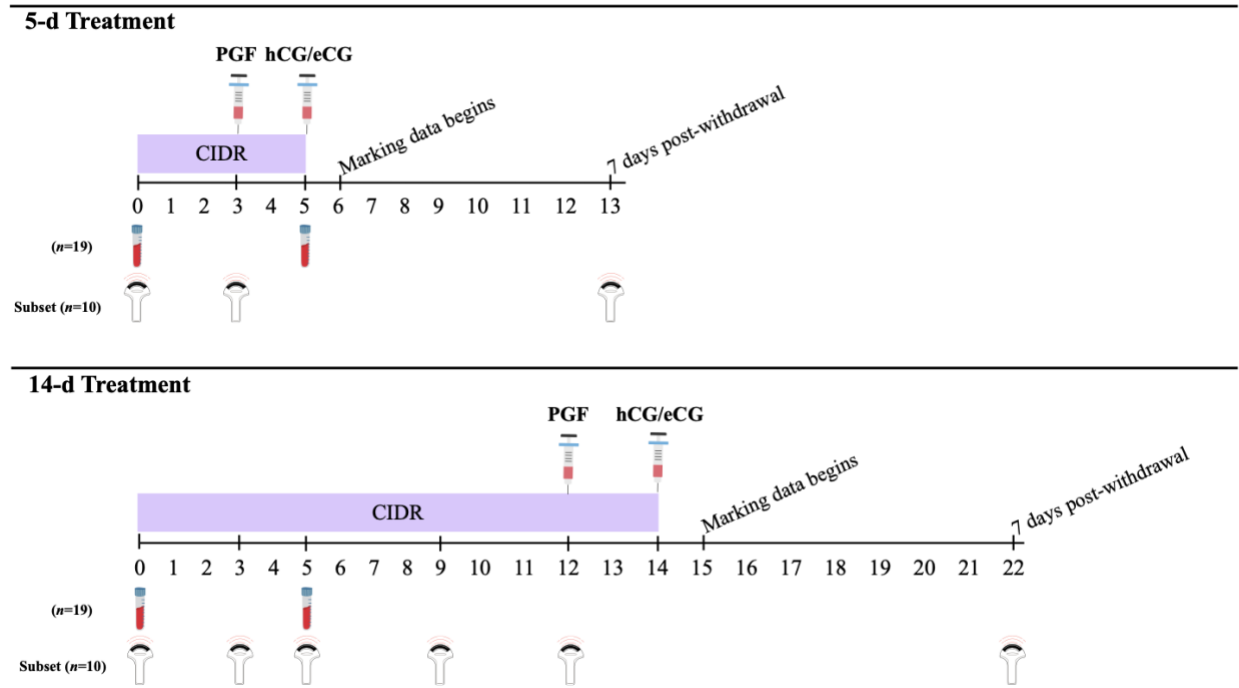
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Figure 3.1 CIDR protocol treatment timeline¹



¹Experimental timeline of 5-day and 14-day treatment groups

Figure 3.2 Transducer probe handle adapted for transrectal examinations¹



¹To facilitate adequate reach and stability, a custom probe extension was constructed from a 16-inch segment of 1-inch diameter polyvinyl chloride (PVC) pipe. This pipe segment was cut in half longitudinally to provide space for the cord of the probe to fit. The distal 3.5 inches of one end of the PVC pipe were trimmed to approximately 1 inch in width and then bent to create an approximately 30° angle. This modification formed a cradle that allowed secure placement of the linear probe within the PVC adapter.

Table 3.1 Effect of a 5-day CIDR protocol on follicular dynamics in Polypay ewes¹

Item	5-d
Average Follicle Count	
d 0	
d 3	2.8
d 13	1.3
Average Follicle Size, cm	
d 0	0.41
d 3	0.38
d 13	0.54

¹A subset of ewes ($n = 10$ per treatment/20 total) were randomly selected and rectally scanned via ultrasound for follicular dynamics. For each ewe, all visible follicles were counted and measured at each timepoint. Mean follicle count represents the average number of follicles per ewe. Mean follicle size represents the average diameter of all measured follicles across ewes within each timepoint.

Table 3.2 Effect of 14-day CIDR protocol on follicular dynamics in Polypay ewes¹

Item	14-d
Average Follicle Count	
d 0	1.9
d 3	2.3
d 5	2.7
d 9	2.4
d 12	3.3
d 22	3.0
Average Follicle Size, cm	
d 0	0.28
d 3	0.35
d 5	0.35
d 9	0.42
d 12	0.48
d 22	0.44

¹A subset of ewes ($n = 10$ per treatment/20 total) were randomly selected and rectally scanned via ultrasound for follicular dynamics. For each ewe, all visible follicles were counted and measured at each timepoint. Mean follicle count represents the average number of follicles per ewe. Mean follicle size represents the average diameter of all measured follicles across ewes within each timepoint.

Table 3.3 Effect of CIDR protocol on time to return to estrus post-cidr withdrawal¹

	Time Ewes Were Marked After CIDR Withdrawal									
	12 h	24 h	36 h	48 h	60 h	84 h	96 h	17 d	18.5 d	19 d
5-day		8	12	4	5	1				
14-day	7	9	6	2	1		1	1	1	1

¹Exposure to rams occurred for 17 days for each group and during this time, mating activity was tracked at a standardized time each AM and PM utilizing a standard breeding harness and marking crayon. At these timepoints, ewes who had over 6 inches of color on rump from marking crayon were recorded as “marked” to estimate time to return to estrus after CIDR withdrawal. 12 hours after the initial marking, ewes were sorted out of pen with ram.

Table 3.4 Effect of CIDR protocol on time to return to estrus post-CIDR withdrawal of ewes that remained open¹

	Time Open Ewes Were Marked After CIDR Withdrawal							
	12 h	24 h	36 h	48 h	60 h	72 h	84 h	96 h
5-day		1	1	1	2		1	
14-day	3	3	1	1	1			1

¹Exposure to rams occurred for 17 days for each group, and during this time, mating activity was tracked at a standardized time each AM and PM utilizing a standard breeding harness and marking crayon. At these timepoints, ewes who had over 6 inches of color on rump from marking crayon were recorded as “marked” to estimate time to return to estrus after CIDR withdrawal. 12 hours after the initial marking, ewes were sorted out of pen with ram. Pregnancy status was determined on d 75 via ultrasound. Marking records were reviewed to determine timing of estrus expression in ewes who were classified as open.

Table 3.5 Effect of CIDR protocol on subsequent lamb counts in utero on d 75¹

Item	Treatment	
	5-d	14-d
Number of Lambs		
No-lamb	6	10
Single	13	2
Twins	9	17
Triplets	1	0
Total Lamb Count	34	36

¹Ewes were scanned abdominally via ultrasound on trial d 75 to assess the number of lambs each ewe had in utero

Table 3.6 Effect of CIDR protocol and transrectal ultrasonography on pregnancy rate¹

Item	Non-Ultrasounded Ewes <i>n</i> =19 ewes/treatment		Ultrasounded Ewes <i>n</i> =10 ewes/treatment	
	5-d	14-d	5-d	14-d
Number of Lambs				
No-lamb	3	6	3	4
Single	7	2	6	0
Twins	8	11	1	6
Triplets	1	0	0	0
Pregnancy Rate ²	84.21%	68.42%	70%	60%

¹A subset (*n*=10 per treatment, *n*=20 total) of ewes were scanned rectally (d 0, 3, and 13 for 5-day group and d 0, 3, 5, 9, 12, and 22 for 14-day group) to determine follicular dynamics during CIDR protocol. Ewes were scanned abdominally via ultrasound on trial day 75 to assess the number of lambs each ewe had in utero

²Pregnancy rate determined by percentage of pregnant ewes bred within 34 days