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Grass Finishing Systems for Lambs

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Abstract

There is strong interest in sustainably produced meat. Grass-fed lamb could fulfill this market by reducing off-farm inputs. The objective was to examine the effect of grass-finishing or minimal supplementation on performance of lambs in the southeastern US. Katahdin lambs born in October 2013 and 2014 and February 2014 were weaned in January 2014/2015 and May 2014, respectively. Lambs were blocked by gender (fall; winter included only ram lambs) and randomly assigned to receive no (NON) or grain co-product supplement (SUP; 15% CP) at 0.5% of BW/d. Lambs were rotationally grazed on predominantly grass. Body weight, fecal egg counts (FEC), packed cell volume (PCV), and body condition score (2014 fall-born lambs only) were determined every 14 d. Winter lambs were removed from the study after 56 d due to poor performance. Live carcass composition was estimated by ultrasound on d 70 of study and when lambs reached light market weight. Data were analyzed by repeated measures in a mixed model. In the 2013 fall-born lambs, average daily gain (ADG) was greater for SUP than NON rams (184 ± 4.9 > 149 ± 5.5 g/d; $P = 0.007$), but did not differ among ewes (118 vs. 113 ± 5.2 g/d, respectively). The ADG of winter lambs was greater for SUP than NON (44 > 11 ± 9.5 g/d; $P = 0.02$). The ADG did not differ among treatments in 2014 fall lambs. The FEC tended to be lower in SUP than NON ($P < 0.06$) in fall 2013 lambs, but PCV was not different. The FEC of winter-born lambs and 2014 fall lambs was similar between treatments, but PCV was increased in SUP compared with NON lambs (27.0 > 25.5 ± 0.4%; $P = 0.015$; 29.0 > 27.8 ± 0.3%, $P = 0.019$). Modest supplementation can lead to greater gains and improved tolerance to gastrointestinal parasites for fall-born ram lambs when forage quality is limiting, and high quality forage can result in good weight gain without supplementation in these lambs. Winter or

spring-born lambs may not be suitable for a grass-finished system in the southeastern US under these conditions.

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1. Introduction

Ruminant animals are a vital source of protein for the growing world population. There is an urgency to produce protein products in a sustainable manner that do not compete with grains grown for human consumption. Many studies have shown that lambs grow faster on grain-based diets compared to forage-based diets (McClure et al., 1994, 2000; Murphy et al., 1994; Fimbres et al., 2002; Turner et al., 2002; Borton et al., 2005; Demirel et al., 2006; Archimède et al., 2008). However, sheep with access to high-quality pastures and forages can produce a higher quality lamb carcass with similar weight to lambs fed a grain concentrate (McClure et al., 1994; Aurousseau et al., 2007) without grain supplementation that could be used for human consumption. The forage crops used to produce grass-fed protein are more environmentally "friendly" and sustainable compared to grain crops, due to decreased soil erosion and greater potential to store carbon in the soil. Water pollution has the potential to be reduced due to smaller amounts of pesticides and fertilizer used for their production (Jung and Allen, 1995).

Grass-based systems for livestock are growing in popularity in part due to reduced production costs when compared to traditional feed-lot style systems (Notter et al., 1991; Woodward and Fernández, 1999). There is increasing consumer interest in livestock finished on forages without negative effects on tenderness, and many consumers find forage finished meat acceptable (Muir et al., 1998; Lozier et al., 2005; Cox et al., 2006). The USDA Agricultural Marketing Service (2007) defines grass-fed livestock as ruminant animals whose diet, with the exception of milk prior to weaning, is solely derived from forage. However, little public data are available due to this type lamb typically being sold through nontraditional markets. Producing grass-fed lamb is especially popular for small and mid-sized sheep producers. But, little is known on performance of grass fed lamb production in the southeastern U.S. Therefore, the purpose of this project is to examine a grass-finishing system for lambs in the southeastern U.S. and determine the impact of low level supplemental co-product feedstuffs.

2. Review of Literature

2.1. Ruminant animals

Sheep are ruminant animals which have the capability to utilize forages to fulfill their nutrient requirements (Hofmann, 1989). They prefer grass as well as forbs and browse, so they are considered intermediate feeders and have the ability to adapt their feeding behavior depending on the availability and maturity of available forages (Van Soest, 1994). Sheep at different stages of growth require different levels of nutrition, and traditionally grain is often used to meet the greater needs of growing lambs.

The National Agricultural Statistics Service (USDA, NASS, 2015) estimated an inventory of 5.34 million sheep and lambs in the United States. This small sector of meat animal agriculture has the potential to make a big impact on meeting the demand of the rapidly increasing population and need for sustainable livestock products.

2.2. Grazing seasons

Most sheep are seasonal breeders and naturally breed when the days are short in the fall. The gestation period of sheep is approximately 150 days; therefore, ewes that become pregnant in the fall will lamb in the spring. Some breeds of sheep, such as Dorset, Merino, and Katahdins, are out-of-season breeders which are typically able to breed throughout the year. These breeds have an advantage over seasonal breeders due to their ability to lamb in the fall and wean lambs in winter when the available forage is of higher quality than in the summer months in the southeastern U.S. Ewes can take advantage of the higher forage nutrient levels to sustain them in peak lactation and lambs born in the fall will be weaned early in the year and utilize nutritious cool-season grasses that are available. Conversely, lambs that are conventionally born in the spring are weaned in early summer when warm-season grasses dominate their diet. Compared to cool-season grass varieties, warm-season grasses tend to be of lower quality (Galyean and Goetsch, 1993; Barbehenn et al., 2004) and provide less than adequate amounts of energy to fulfill the needs of a growing lamb (NRC, 2007).

In the southeastern United States, the typical cool-season grass used for grazing ruminants is tall fescue [*Schedonorus arundinaceus* (Schreb) Dumort]. This grass has excellent growth in the fall and spring and provides a high protein diet that is excellent for growing lambs and lactating ewes. However, consumption of this grass could negatively affect animal performance (Stuedemann and Hoveland, 1988) as a result of fescue toxicosis. Fescue toxicosis is caused by alkaloids produced by an endophytic fungus that can cause many performance-related issues in livestock such as reduced milk production and pregnancy rates, lameness, and lower weaning weights. Sheep are generally more tolerant to the toxins compared with cattle, and do not always portray typical fescue toxicosis symptoms (Rankins, 1996). Burke et al., (2002) found that pregnancy and lambing rates of mature ewes were not affected by grazing endophyte infected tall fescue, and tropically adapted St. Croix sheep have the potential to excel in this harsh grazing system. Tall fescue can be diluted with a cool-season legume to minimize any adverse health effects.

Warm-season grasses have a shorter growing season, and are more drought tolerant than cool-season species in the mid-southern U.S. However, the nutrient quality of warm-season grasses declines in mid- to late-summer (Ball et al., 1996) because increasing ambient temperatures increases lignifications and decreases digestibility for growing subtropical grasses (Henderson and Robinson, 1982). Lignin is considered a major limiting factor of forage degradation in the ruminant animal (Van Soest, 1994). This leaves growing lambs with few options for nutritious forages in the mid-south region. The most common warm-season grass used in the southeastern United States is bermudagrass (*Cynodon dactylon*). Lema et al. (2000) observed that lambs transferred onto bermudagrass from an endophyte-free tall fescue had a significant decline in average daily gains which remained low throughout the warm-season grazing, and suggests that grazing bermudagrass is a limiting factor in optimal lamb production.

2.3. Forage quality and availability

The availability and quality of forage varies because of season (cool-season or warm-season), and within species (grasses or legumes). Generally cool-season grasses have less lignin and are more highly digestible when compared to warm-season grasses (Galyean and Goetsch, 1993; Barbehenn et al., 2004). This difference in digestibility has been attributed to cool-season grasses having a greater protein content and lower fiber concentration (Wilson et al., 1983; Reid et al., 1988; Barbehenn and Bernays, 1992). Cool-season forages also have a greater concentration of non-structural carbohydrates compared with a warm-season forage with comparable nutritional indices (Bohnert et al., 2011). These forage quality factors have resulted in a significantly greater refusal rate of warm-season grasses compared to cool-season grasses or legumes (Reid et al., 1990), and a greater forage intake by lambs grazing cool-season compared to warm-season forages (Bohnert et al., 2011).

Species of plant that is available to be grazed is a major source of variation in overall pasture quality. Legumes are of greater nutritive value than grasses due to the lower fiber content and have a tendency for increased intake (Amiri and Shariff, 2012). Lambs had significantly greater daily intake and fewer days until finishing when grazing red clover (*Trifolium prantense*) and alfalfa (*Medicago sativa*), compared to lambs grazing ryegrass (Speijers et al., 2004). Lambs grazing alfalfa and chicory in New Zealand also grew faster and had greater intakes than lambs grazing grasses (Scales et al., 1995). The greater intakes observed when animals were consuming legumes is likely due to a faster passage rate and greater potential digestibility, as these factors directly relate to forage intake by the ruminant animal (Minson, 1982).

The most prominent factor affecting forage quality is growth stage or forage maturity. The negative relationship between forage maturity and digestibility is well documented (Jung and Deetz, 1993). Forages are generally more succulent in the early stages of growth which enhances their palatability (Oelberg, 1956). The leaf of a forage is more digestible than the stem.

As a forage matures, the leaf:stem ratio decreases and the fiber and lignin content increase. Greater cell wall content of high forage diets is related to increase in gastrointestinal fill and reduced intake as summarized in many reviews (Campling, 1970; Baile and Forbes, 1974; Mertens, 1994). Sheep that were fed lima-bean and pea vines refused the vines with greater lignin content (Davis et al., 1947) indicating that lignin may be linked to reduced selectivity and intake.

Digestibility and intake of forages vary significantly due to other factors in addition to maturity that include plant variety and management. Grasses can be improved through genetic selection to create a superior variety more conducive to ruminant digestibility. For example, bermudagrass has been bred to produce many hybrid varieties that have an impact on their nutritive value, productivity, and influence on animal production. Breeding bermudagrass to develop a more digestible hybrid resulted in an increased digestibility of over 12% (Burton et al., 1967). In a comparison of three bermudagrass varieties, superior varieties (Tifton-85 and Jiggs) produced a significantly greater amount of beef per hectare ($P < 0.05$) than the less digestible Alicia strain (Scaglia and Boland, 2014). Switchgrass (*Panicum virgatum*) is another warm-season grass in which genetic improvements have been employed to develop strains with greater digestibility for ruminant animals. A developed strain of switchgrass (Trailblazer) produced 24% greater average daily gains in steers compared to other strains observed (Anderson et al., 1988).

Pasture management can affect the digestibility and intake of forages as well. Use of rotational grazing of sheep increased time spent grazing during the day (Penning et al., 1994) and provides a rest period for plants, allowing new plant growth (Gerrish, 2004). Rotational grazing controls forage quality, grazing intake and efficiency, and manure distribution. Nitrogen fertilization of pasture can increase the nitrogen content in forages, and increase herbage mass which has led to increased forage intake by grazing dairy cows (Delagarde et al., 1997).

2.4. Environmental factors on animal growth

Weather also has the possibility to affect lamb production. Cool-season pastures grazed by weaned fall-born lambs typically receive more rain which encourages forage growth, whereas rainfall is typically less than 51mm per month in the summer months in northwest Arkansas (USclimatedata.com) leading to lower forage yield and digestibility for growing lambs. Excessive ambient temperature can cause lamb body temperature to rise. The nutrient requirements for sheep are affected if their body temperature rises above or falls below their thermoneutral zone. This thermoneutral zone is the temperature range at which nutrient expenditure to regulate body heat is at a minimum. The thermoneutral zone is affected by level of nutrition, age, acclimatization and fleece length (Yousef, 1985). When the ambient temperature is outside of the thermoneutral zone, more energy is used to regulate body temperature, therefore less energy is available to be expended on growth (Pluske, et al., 2010). Wind and rain have the potential to cause body temperatures to fall outside of this range and require more energy to regulate body temperature.

2.5. Parasites

The National Animal Health Monitoring System (NAHMS, 2011) reported that internal parasitism is the third greatest cause for non-predator death losses of sheep and lambs in the United States. Pasture parasitic population is highly dependent on climate, particularly temperature and relative humidity (Beveridge, et al., 1989). In particular, internal parasites require a warm, damp environment to thrive. This creates a problem for lamb production in the early summer months because these are the environmental conditions that are typical at the time when traditional spring-born lambs are weaned. An infection of parasitic nematodes has been shown to cause a reduction in voluntary feed intake of up to 50% (Sykes and Greer, 2003). Rapidly growing lambs have a high nutrient demand to maintain growth, and in the event that nutrients are limited, the animal will use the available nutrients to maintain growth and their immunity to parasites will be less of a priority (Coop and Kyriazakis, 1999) causing a higher susceptibility to internal parasites. The problem is further compounded by the fact that most anthelmintics or dewormers fail to control these parasites due to nematode resistance (Kaplan et al., 2005; Howell et al., 2008)

The level of parasite infection on the host can be affected by pasture management and forage grazed. Rotational grazing may reduce the need for deworming compared with continuously stocked pastures (Burke et al., 2009). Some earlier evidence pointed out that plant species may be irrelevant in the control of gastrointestinal parasitism (Anderson et al., 1987), but more recent evidence disagrees with his hypothesis. In the southeastern U.S., high condensed tannin levels in sericea lespedeza (*Lespedeza cuneata*), a warm-season perennial legume, have been used to help small ruminants tolerate gastrointestinal parasite loads (Min et al., 2004; Moore et al., 2008, Burke et al., 2012). Tannins from sericea lespedeza have been shown to aid in the control of *Haemonchus contortus* in sheep and goats (Min et al., 2004; Burke et al., 2007 and 2012). Chicory is another high quality forage grown in the southeast that international researchers have found to have anthelmintic properties (Hoste et al., 2006). In New Zealand and the United Kingdom, sheep grazing chicory (*Cichorium intybus*) had reduced fecal egg counts compared to sheep grazing ryegrass (*Lolium perenne*), tall fescue, and cocksfoot (*Dactylis glomerata*) (Scales et al., 1995). When anthelmintic forages are unavailable, supplementation can offset the negative effects of parasite infection by increasing the availability of protein (Abbott et al., 1986, 1988; Datta et al., 1998). Trials conducted with young sheep (Steel, 2003) achieved enhanced resilience and/or resistance to gastrointestinal nematode infections from supplementation of protein and/or energy after weaning.

2.6. Other animal health issues

Additional animal health issues that have the potential to affect performance include foot rot, and external parasites such as biting flies. Foot rot is a contagious disease in sheep caused by two anaerobic bacteria, *Dichelobacter nodosus* and *Fusobacterium necrophorum* that can cause great flock production and economic losses (Whittier and Umberger, 2009). Parker et al. (1985) reported genetic resistance passed from Targhee sires to their offspring to some extent. In other words, it is possible to select against foot rot in a flock. Animals infected with foot diseases are often lame which can lead to decreased feed intake and overall reduced production. Blood-sucking biting flies (*Simulium* yahense) can be an issue during periods of heavy rainfall and can cause stress and loss of production in livestock. In early spring during constant wet conditions, these flies are abundant and can transmit several disease agents, including protozoa and nematode worms to livestock (Hill et al., 2010). Sheep are vulnerable to these flies due to the acute toxemia and anaphylactic shock caused by toxins introduced by black fly saliva (Cranshaw et al., 1996) that contains an anticoagulant excreted when they cut the skin to feast on the host.

Stressors, such as weaning, can increase parasitic susceptibility in lambs as a result of immunosuppression (Parillo and Fauci, 1979). Demir (1995) concluded that the stress of weaning causes a drop in feed intake and can decrease the growth rate. In cattle, Price et al., (2003) concluded that calves weaned with fenceline contact with their dams showed fewer signs of distress and less of a reduction in weight gain compared to calves abruptly and completely separated from their dams. The absence of the dam's milk after weaning removes a significant source of nutrients and immunological factors (Watson and Gill, 1991) causing great susceptibility to disease and parasite infection for a newly weaned lamb.

2.7. Supplementation

Supplemental feeding with a concentrate provides grazing livestock with added protein and energy when forage quality is inadequate. These supplements typically influence liveweight gain, carcass traits, and meat chemistry (Murphy et al., 1994; Hopkins et al., 2001; Atti and Mahouachi, 2009; Papi et al., 2011). For optimal growth, lambs should be fed a combination of concentrate and forages (Papi et al., 2011). Grazing lambs fed additional supplementation had a larger longissimus muscle area (LMA) compared to lambs without supplementation (Turner et al., 2014), but also had reduced carcass quality due to an increase in the amount of carcass fat (Papi et al., 2011).

The feedstuffs used to supplement rapidly growing lambs differ according to geographic location. For example, if corn is a major crop in the vicinity of the farm, the price will be lower than most feeds, therefore corn is most economical. The starch in corn provides added energy needed if the animal only has access to low quality forages. Forage intake was increased by feeding low levels of corn (Henning et al. 1980; Matejovsky and Sanson, 1995), but was suppressed when greater levels of corn were included in the diet (>23% of DM intake: Henning et al., 1980).

Supplemental co-products are also of great importance in the livestock industry. These products take advantage of feed components that are not otherwise used for human consumption and provide added energy and/or protein to animals consuming forage diets. Substituting a grain with a co-product has shown no significant differences in animal performance or carcass quality (Schauer and Held., 2008; Zelinsky et al., 2009).

2.8. Sheep production systems

The most limiting factors for lamb production in the southeast is adequate nutrition and the unrealized livestock potential due to insufficient nutrition (Ball and Crews, 1993). To obtain optimal livestock production in the southeast U.S., a producer must utilize pastures that contain forages having high nutritive value almost year round. Such forage-based systems potentially make better use of natural resources and produce higher quality meat desired by consumers compared with traditional high-concentrate production systems (Grunert et al., 2004). Cattle and sheep can be raised on relatively low-forage diets or feedlot systems, however, ruminal function and animal health are best when forage-based diets are fed (Jung and Allen, 1995). Also, natural animal behavior favors a pasture system.

The success of a grass-based production system relies heavily on available forage and quality of forage available. In the United Kingdom and New Zealand, the sheep industry relies on perennial ryegrass which has low intake potential and poor nutrient utilization by animals (Holmes, 1989). The addition of legumes to these grass-based pasture can greatly improve grazing animal performance and carcass quality (Holmes, 1989; Fraser and Rowarth, 1996; Frame et al., 1998; Wildeus et al., 2007). Katahdin lambs and meat goat kids were found to produce desirable final body weights and carcass weights for most niche markets in the U. S. on a pasture-based diet, with and without supplementation (Turner et al., 2014).

A popular grazing method with many advantages used in the small ruminant industry is rotational grazing. This type of grazing system helps to control forage growth and tends to provide grazing animals with more vegetative and nutritious forage. In rotational grazing system, a pasture is split into paddocks and animals are generally moved according to height of the forage. This system allows for paddocks to rest and regrow before animals regraze them. Using a 4-cell rotational grazing system increased pregnancy rates and multiple births in Katahdin ewes over continuous grazing on endophyte-infected tall fescue (Backes et al., 2014). However, in some cases this can also lead to decreased rate of gain in lambs when forced to consume forages of low nutrient quality (Burke et al., 2009). If done properly, rotational stocking will help forages stay in the productive and vegetative stage which is the most nutritious stage. During periods of rapid growth, animals may be unable to keep up with growth, and mechanical clipping of pastures may be necessary to keep forage from maturing and becoming undesirable to the animals.

2.9. Carcass composition and meat quality

The carcass composition of a lamb can change under different production systems. Lamb's carcass weight and dressing percentage increased as the level of concentrate fed increased; however, the level of concentrate did not affect LMA (Papi et al., 2011). Ruminants finished on forages have a lower percentage of back fat (BF) compare to high-concentrate diets (McClure et al., 1994; Murphy et al., 1994; Borton et al., 2005, Resconi et al., 2009; Papi et al., 2011); therefore carcass quality was higher in forage-finished ruminants (McClure et al., 1995; Singh et al., 2004; Borton et al., 2005; Karim et al., 2007). Grass-based diets tend to decrease overall fat content and improve the fatty acid composition and antioxidant content in beef (Daley et al., 2010).

A unique tool for estimating these carcass measurements in live animals is the use of real-time ultrasound technology. Ultrasound technology can accurately predict BF and LMA in live lambs when performed by a trained technician and the images traced by experienced interpreters (Notter et al., 2004; Emenheiser et al., 2010). Little has been reported in the literature on estimates of BF and LMA area in lambs fed primarily on forage.

2.10. Objectives

Animal performance in grazing lambs compared to penned lambs fed concentrate has shown an increased length of time to finish (Jacques et al., 2011); however, this comparison is confounded due to different levels of physical activity and internal parasite infection (Priolo et al., 2001). Many studies have been conducted comparing different grass based systems with all-concentrate feedlot systems (McClure et al., 1994; Murphy et al., 1994), but little has been conducted observing minimal or no supplementation to lambs grazing various seasonal forages in the southeastern U.S. Therefore, the objective of this project was to examine a grass-finishing system for lambs in the southeastern U.S. and determine the impact of low level supplemental co-product feedstuffs on performance of lambs reaching a light market weight.

3. Methodology

3.1. Animals and procedures

This experiment was conducted from January 2014 to June 2015 at the USDA, ARS Dale Bumpers Small Farms Research Center in Booneville, AR, USA (35°05' N, 93°59' W, 152 m a.s.l.). All husbandry practices and experimental procedures used in this study were reviewed and approved by the University of Arkansas Institutional Animal Care and Use Committee (Approval #14043; Fayetteville, AR, USA) and the USDA, Agriculture Research Service Institutional Animal Care and Use Committee in Booneville, AR. In addition, the USDA, ARS flock has been Animal Welfare Approved certified since 2012, and must follow the strict regulations outlined (www.animalwelfareapproved.org).

Katahdin lambs born in October 2013 and 2014 (fall) and February 2014 (winter) were weaned in January 2014 (80 ± 1.5 d of age), January 2015 (85 ± 1.8 d of age), and May 2014 (95 ± 1.4 d of age), respectively. At weaning, it was observed that approximately one half of lambs (fall 2013) were lame, with soft lesions between the claw of one or more feet. Thus, these lambs were treated for foot scald by running through a 122 cm footbath of 10% zinc sulfate (Zinc Nacional, S. A., Monterrey, N. L., Mexico) plus surfactant and allowing feet to dry on concrete every 3 d prior to being placed on trial. Lambs were blocked by gender (fall included both genders; winter included only ram lambs to prevent unwanted breeding due to winter-born ewe lambs becoming cyclic by mid- to late-summer), then were randomly assigned to receive no supplement (NON) or co-product grain supplement (SUP) of soyhull pellets, wheat middling pellets, corn gluten pellets, cracked corn, and dried distillers grain (Farmers Cooperative, Van Buren, AR, USA). Grain supplement was sampled weekly throughout the season and a composite sample was analyzed at the end of the season (Table 1). The SUP lambs were supplemented at a rate of 0.5% BW/d throughout the study (adjusted every 14 d). The fall 2013 (n = 20/treatment), winter 2014 (n = 20/treatment), and fall 2014 (n = 16/treatment) lambs each had 2 grazing reps/treatment. Lambs were rotationally grazed on predominantly grass pasture consisting of tall fescue [*Schedonorus arundinaceus* (Schreb) Dumort], hairy vetch (*Vicia villosa)*, bermudagrass (*Cynadon dactylon*), chicory (*Cichorium intybus*), and (or) sericea lespedeza (*Lespedeza cuneata*) depending on seasonal growth (Tables 2 and 3). All paddocks surrounded by temporary polywire fencing were 0.2 ha and lambs were moved to a new paddock every 7 d, and did not return to a paddock for at least 28 d. There were as many as 36 paddocks used per season. Each treatment/replication was randomly assigned to a specific paddock each week; therefore if the paddock was reused after 28 d of rest, the same treatment/replication would be placed back in its assigned paddock. In February 2014, the ground was covered with snow for 2 d and all lambs (2013 fall-born) were given access to bermudagrass hay (9% CP). In February 2015, lambs (2014 fall-born) received access to organic tall fescue hay (14% CP) when snow covered the ground for 1 day. Lambs had access to water and free-choice mineral (Table 4; Nutra Blend, LLC, Neosho, MO, USA) throughout the study period.

In all periods, FAMACHA© scores (scale of 1 to 5; 1 = red or healthy and 5 = white or severely anemic) were recorded every 14 d by examining ocular mucous membranes (Kaplan et al., 2004). Body weight was determined every 14 d to monitor ADG and for supplement adjustment. Body condition scores were recorded every 14 d, for fall 2014 lambs only, on a scale of 1 to 5 (1 = extremely emaciated and 5 = overly fat; Thompson and Meyer, 1994). Fecal samples were collected rectally to determine fecal egg count (FEC) according to Whitlock (1948; sensitivity of 50 eggs/g) and blood was collected from the jugular vein to determine packed cell volume (PCV) using the microhematocrit method every 14 d.

When lambs became anemic according to PCV, lambs received 1 g copper oxide wire particles (COWP; Burke and Miller, 2007) when PCV ≤ 19% or levamisole (8 mg/kg BW; Levasol, Agri. Laboratories, Ltd., St. Joseph, MO, USA) when PCV ≤ 16%; per J. E. Miller personal communication. Due to low PCV, 2 winter-born lambs received COWP (1 NON, 1 SUP) and 3 received levamisole (3 NON) on d 21. Lambs observed to have a soiled dag score or liquid feces received sulfadimethoxine drench (11.3 mg/kg; SulfaMed-G, Bimeda, Inc., Le Sueur, MN, USA) for three consecutive days. Twelve winter 2014 lambs were the only animals to receive sulfa (6 NON, 6 SUP; d 28). All lambs received 1 g COWP to aid in tolerance of gastrointestinal parasites when mean PCV were observed to be falling (2013 fall: d 98 and d 140;

2014 winter: d 35; 2014 fall: d 0 and d 112). Feces were cultured periodically to identify gastrointestinal nematode genera according to Peña et al. (2002), courtesy of Dr. James Miller, Louisiana State University.

Lambs were removed from study and live carcass measurements obtained when light market weight was reached (36 to 41 kg for ewes and 41 to 50 kg for rams, or all lambs at mean 240 d of age if market weight was not reached). Carcass composition was determined by live ultrasonic measurements by capturing images of the LMA and BF on the left side of lambs using an Aloka 500V ultrasound machine (Aloka Co. Ltd., Tokyo, Japan) equipped with 12-cm, 3.5 mHz probe and a standoff guide to ensure proper contact with the animals (Emenheiser et al., 2010). Lambs were closely sheared between the 12^{th} and 13^{th} ribs and a food grade vegetable oil was applied to the area being scanned to obtain adequate acoustic contact. Images were captured and recorded onto a laptop computer for later analysis.

In March 2014 (d 56) 5 "unthrifty" fall lambs were removed from the study (3 NON, 2 SUP), and not included in the statistical analyses. These lambs were in poor condition, were failing to gain weight, and would likely be culled or enter a conventional sheep production system of feeding more grain to meet producer's goals. Their BW was 2 standard deviations (3.1 × 2 kg) below the average (26.4 kg) at that time. Fall ram lambs were observed to be harassing ewe lambs and were sorted into groups by sex (Ram SUP, Ewe SUP; Ram NON, Ewe NON) in May 2014 (d 112). When the 2014 winter-born lambs began losing weight and body condition in June 2014 due to poor forage quality, they were removed from the experiment (d 56). Ultrasonic measurements were taken of BF depth and LMA, and lambs were removed from the study. One of the NON 2014 fall-born lambs was killed by a predator in the first week of the trial.

3.2. Pastures and forage analysis

Forage mass was measured for each paddock when animals were introduced every 7 d and removed from the paddock by random toss of a quadrant (0.093 m^2) 4 times within the paddock and clipping forage to a height of 2.5 cm inside the quadrant. Samples were weighed, then dried in a forced air oven at 55°C for 72 h. Paddocks were mowed when necessary so that forages remained vegetative. Forage samples were collected every 7 d when animals were introduced to a new paddock for determination of forage quality. Forage samples were dried for 72 h at 55°C in a forced air oven and ground to pass through a 1-mm screen using a Model 4 Wiley Mill (Thomas Scientific, Swedesboro, NJ). Samples were then weighed (0.5 g) into ANKOM filter bags and analyzed for acid detergent fiber (ADF) and neutral detergent fiber (NDF) using an ANKOM 2000 Automated Fiber Analyzer (ANKOM Technology, Macedon, NY). All samples were analyzed in duplicate. Nitrogen was analyzed using an Elementar rN^{III} nitrogen analyzer (Elementar Americas, Mount Laurel, NJ, USA) at the Agriculture Diagnostic Laboratory, University of Arkansas, Fayetteville, AR. Percentage of nitrogen was then used to calculate crude protein by multiplying the amount of nitrogen by 6.25. Batch in vitro dry matter digestibility (IVDMD) was performed on the forage samples using the $DAISY^{II}$ apparatus (ANKOM Technology Corp., Fairport, NY; Holden, 1998). Botanical composition was determined by the dry-weight rank method (Mannetje and Haydock, 1963). A 0.28 m^2 quadrant was randomly tossed 20 times in the paddock and the top 3 species of plant were ranked 1, 2, and

3 and which correlates with a percentage (70, 24, and 6, respectively). This was performed at the beginning, middle, end of the study, as well as when animals were placed on a new forage species.

3.3. Statistical analysis

General linear models (SAS; SAS Inst., Inc., Cary, NC) in a completely randomized design were used to determine differences in ADG between the start of experiment and 112 d later, age at finished weight, BF, and LMA. The model included dietary treatment, gender (fall-born lambs), and the interaction. Data for fall-born lambs were also analyzed with year and interactions in the model. The FAMACHA© scores were used to assess anemia in the field, but the more quantitative observation of packed cell volume was used for statistical analysis. Body weight, FEC, PCV, and BCS were analyzed as repeated measures (Littell et al., 1996) using mixed models with an autoregressive covariance structure (SAS). The model included supplement treatment, gender, time and interactions with time specified as a repeated measurement. In addition, BW data from both fall-born lamb seasons was used for homogeneity of regression analysis to plot weight gain over time between dietary treatments and gender. The 2013 and 2014 fall-born lamb data was also analyzed together with year in the model, and all possible interactions tested. The FEC data were log transformed [ln(FEC + 10)] to normalize the data, and means were presented as back transformed data. For all experiments, pen was the experimental unit. For the fall lambs, the days included 0 (day of weaning) to 112 because that was the time period that some animals reached their finished BW. Nutrient analyses were analyzed as repeated measures with treatment, time, and interaction included in the model. Animal was the experimental unit.

Due to unreadable ultrasonic scans, some data was excluded from the set: fall 2013 day 70 scan (1 NON, 2 SUP); finished weight scan (2 SUP), and winter 2014 day 49 (3 SUP).

4. Results

4.1. Animal

4.1.1. Lamb performance

Average daily gain for fall-born lambs was greater the second year (177 ± 3.5 > 141 ± 2.4 g/d; $P = 0.001$) and greater for SUP than NON rams (198 ± 4.1 > 170 ± 4.6 g/d; $P = 0.003$), but did not differ among ewes (NON: 132 ± 3.8; SUP: 134 ± 4.1 g/d). Body weight was greater for ram than ewe lambs throughout the study, and a treatment × sex × day interaction ($P < 0.001$; Figure 1A) was detected. Body weight of lambs was greater the second year and not influenced by treatment; however dietary supplement influenced BW of 2013 fall-born lambs (treatment × year × day, $P < 0.001$; Figure 1B). The ADG of winter-born SUP lambs (males only) was also greater compared with NON (44 > 11 ± 9.5 g/d; $P = 0.02$), but BW was not different (treatment × day, $P = 0.15$; Figure 2). Days to finish of fall lambs did not differ among treatments throughout the study (209 ± 3.3 d; $P = 0.94$), but lambs took longer to reach market weight in the first year (220 ± 2.7 > 199 ± 3.7 d; $P < 0.001$). Ewe lambs took longer to reach market than rams (216 ± 3.5 > 203 ± 3.0; $P = 0.005$). The lambs began to reach market weight in 2013 fall-born season on d 112, and in 2014 fall-born season on d 84. After observing the poor body condition of winter lambs, it was apparent the importance of recording BCS, which occurred only in 2014 fall-born lambs, and was not different among groups.

The differential effect of dietary treatment on body weight between the start and end of the experiment in fall lambs in both years was reflected by the difference ($P < 0.001$) in regressions: $y_{NONRAM} = 21.3 + 0.16x – 1.15 \times 10^{-4}x^2$; $y_{SUPRAM} = 20.5 + 0.16x + 2.6 \times 10^{-4}x^2$; $y_{NONEWE} = 18.5 + 0.098x + 2.5 \times 10^{-4}x^2$; $y_{SUPEWE} = 18.2 + 0.12X + 2.9 \times 10^{-5}x^2$, where y = bodyweight (kg) and x = day of dietary treatment.

The LMA and BF were similar among groups in 2013 fall lambs on d 70 ($P \geq 0.53$), but LMA tended ($P = 0.06$) to be greater in SUP lambs at finished weight ($P = 0.057$; Table 5). The 2014 fall-born males tended to have larger LMA at d 70 than the females (Table 5) and tended to have more BF at finished weight ($P = 0.094$), but otherwise were similar.

4.1.2. Gastrointestinal nematode measures

Fecal egg counts tended to be lower in SUP compared to NON ($P < 0.06$; Figure 3A) in 2013 fall-born lambs. However, FEC was similar in 2014 winter- (Figure 4) and fall-born (Figure 3B) lambs. There were obvious year effects (P < 0.001), but no other year interactions. Unlike BW, there was no treatment × sex × day interaction detected in fall-born lambs ($P = 0.47$; Figure 5A). However, PCV was lower between d 28 and 42 in the 2014 fall-born lambs and SUP improved or increased PCV around this time in both years (treatment × year × day, $P < 0.001$; Figure 5 B). The PCV of fall-born ram lambs was lower than ewes (28.8 < 29.8 ± 0.25%; $P = 0.01$). The PCV was increased in SUP compared to NON in winter-born lambs (27.0 > 25.5

± 0.4%; $P = 0.015$). The PCV of the NON 2014 fall-born ewe lambs was lower than the others, and the SUP ewe lambs highest (treatment × sex; $P = 0.002$).

Haemonchus contortus was the predominant gastrointestinal nematode throughout the 2013 fall-born lamb season with the exception for d 112, for which *Trichostrongylis* spp. was the predominant gastrointestinal nematode (Table 6). *Trichostrongylus* spp. was the sub-dominant genera throughout the experiment. The predominant genera for the winter-born lambs was *Trichostrongylis* spp. (55%) and *Haemonchus contortus* (45%) at d 0 (weaning). On d 42 and d 84 of the 2014 fall-born lamb season (Table 7), *Haemonchus contortus* was predominant, followed by *Trichostrongylis* spp., and on d 112 *Trichostrongylis* spp. was predominant.

4.2. Pastures and forages

4.2.1. Botanical composition

The botanical composition of forages at the beginning of the trial (January) for the 2013 and 2014 fall-born lambs was very similar and primarily consisted of tall fescue (Tables 2 and 3). Composition was determined again at d 84 of each year with tall fescue remaining the predominant forage. The 2013 fall-born lambs remained on the tall fescue until d 140 when lambs were placed on sericea lespedeza at another site on the research station. After 7 d, lambs were returned to tall fescue for the remainder of the trial. However, the 2014 fall-born lambs were removed from tall fescue at day 112 and did not return. Botanical composition is presented for each new forage species grazed (Tables 2 and 3).

4.2.2. Nutrient analyses

The 2013 fall-born lamb pasture analysis for ADF ($P = 0.372$), CP ($P = 0.301$), and IVD ($P = 0.974$) was similar between treatments (Figures 5A and 6A), but the NDF percentage was different ($P = 0.021$). The pasture analysis for the 2014 fall-born lambs for ADF ($P = 0.592$), NDF ($P = 0.999$), CP ($P = 0.184$), and IVD ($P = 0.963$) did not differ (Figures 5B and 6B).

5. Discussion

The literature is nearly void of data on the management of grass-fed lambs in an environment that includes both cool- and warm-season forages. The Katahdin is an easy-care breed that fits well into the challenging environment of the southeastern U.S. because they do not require shearing (few shearers can be found), can be quite tolerant to gastrointestinal nematodes (Burke et al., 2012; Vanimisetti et al., 2004), one of the greatest health challenges of small ruminants in this environment (USDA, NAHMS, 2011), and can take advantage of pastureland that is unsuitable as cropland and forages that are undesirable to cattle. Surprisingly, the fall-born ram lambs in the current study gained well, meeting a moderate BW gain of nearly 200 g/d determined by NRC (2007) with an advantage to the SUP treatment in the 2013 ram lambs. The higher quality of forage available to the 2014 group of lambs likely led to greater ADG in the ewe lambs and the NON group of lambs providing the nutrients required for growth. Energy needs appeared to be met in all groups of lambs born in fall, but protein may have been limiting in early and late spring pastures, especially in early 2014. Thus, the 0.5% BW supplementation to the SUP lambs provided the additional protein needed to meet the moderate weight gain goals.

Because of the greater quality of pasture in spring 2015, for the most part, protein and energy appeared to be met and the SUP did not improve ADG or BW at any time point. Using the NRC (2007) values, a late maturing lamb at 30 kg BW targeted to gain 200 g/d would be expected to consume 1 kg DM and receive 560g/d TDN and 131 g/d CP. Assuming the lamb is consuming only tall fescue forage, when its CP was at a low level of 9% (Figure 7), the lamb would receive only 90 g/d and not meet requirements. But, at a high level of 23% CP, the lamb would receive 230 g/d, exceeding protein requirements. Calculating TDN (TDN = 96.35 - % ADF × 1.15) from published values of ADF (20-37%; Poore et al., 2006) results in TDN values of 54-73% which should meet energy needs of lambs. Therefore, in this example, when forage CP content is low, added supplement will help lambs to meet protein requirements.

The SUP treatment did not reduce the number of days to reach the finishing weight, which was determined to be a light weight suitable for the ethnic market that is widespread in the southeastern U.S. The mature BW of Katahdin rams ranges between 82 and 113 kg and ewes between 57 and 84 kg (www.katahdins.org), but the mature BW of ewes at this location was 59 kg (Burke, 2005) to 62 kg (Burke and Miller, 2002). It is thought that mature size decreases as ambient temperature increases as in the southeastern U.S.

The original intent of this experiment was to indirectly compare growth and gastrointestinal nematode measures between fall and winter born lambs on grass pastures. However, after 56 d post-weaning, the appearance and the body condition of both the NON and SUP winter born lambs was poor. There was greater incidence of coccidiosis and PCV fell to a mean of 22% in the NON group by d 42 (data not shown), meaning lambs were more anemic than the fall-born lambs during their experiment. Warm-season annuals (soybean, *Glycine max*) were planted to meet the grazing needs of these winter born lambs, but establishment failed. Thus, initially, tall fescue was predominant in their pasture, but was of poor quality, and bermudagrass then became available, which at best has 16% CP that quickly declines to 7 or 8% CP and is also a poor energy source (Ball et al., 1996). Thus, it is concluded that forage finishing should not be attempted using winter or spring born lambs on a warm-season grass pasture.

Forage quality analyses for forages grazed by 2013 fall-born lambs showed uncharacteristically high NDF and ADF values. It appears there were unknown analytical errors, although trends appeared to be consistent for ADF, NDF, IVD and CP. On d 31 though d 57 in this experiment, the NDF averaged 87%, and ADF averaged 78%. Reported values for tall fescue are consistently lower: 20-37% ADF and 43-74% NDF including both green and dead plant material (Poore et al., 2006) and at its lowest digestibility, 73% NDF and 42% ADF (NRC, 2007).

The carcass measurements for the 2013 fall-born lambs were similar to previous findings for Katahdin lambs finished on pasture (Turner et al., 2014), but the 2014 fall-born lambs had larger LMA at finish than reported in that study. Carcass measurements appear greatly different in 2013 and 2014. Perhaps, due to d 70 in 2013, lambs averaged 9 kg lighter than at d 70 in 2014, and different ultrasound technicians were used each year which could be a source of variation.

Fecal egg counts tended to be lower in 2013 fall-born SUP compared with NON lambs, and the PCV of the winter-born SUP lambs was greater, which could be the result of the higher protein level of added supplement. A greater dietary protein has been reported to increased tolerance to gastrointestinal nematodes (Coop and Kyriazakis, 1999). Because the FEC were so low in the 2014 fall lambs, differences between groups would not be expected. The higher CP of forages in spring 2015 may have led to the lower FEC of fall-born lambs relative to the previous year.

Even though *H. contortus* was the predominant gastrointestinal nematode present in the 2013 fall lambs, there was a significant proportion of *Trichostrongylus* spp. present, and there were an equal proportion of these genera in the winter-born lambs. This would be expected during cooler months, as *H. contortus* thrives in warm, humid conditions. The reduction of *H. contortus* that occurred after d 98 was in response to the copper oxide wire particles administered, which has been reported to act as an anthelmintic only against these genera of nematode (Bang et al., 1990).

It was not the primary objective in this study to examine gender effects. However, there were obvious differences in performance between ram and ewe lambs. This is to be expected as testosterone in males acts as a growth promotant. Body weights and ADG were greater, and number of days to finishing less in ram than ewe lambs. Similarly, differences existed in gastrointestinal nematode measures, favoring ewe lambs. There may be an evolutionary reason for rams to be more parasitized, in that there is the need to compete with other males and more energy is spent on rutting and fighting, which may affect the immune system, and indirectly increase FEC and reduce PCV. However, physiologically, differences were quite small.

6. Conclusion

The addition of minimal co-product supplementation to a grass diet for fall-born ram lambs is effective to achieve optimal weight gain when forage quality is low. However, when quality of the forage is high the addition of supplementation is unnecessary and lambs can achieve optimal weight gain in a grass-fed system. Improved forage quality appeared to provide an improved tolerance to gastrointestinal parasites and improved weight gain fall-born ram lambs, but not ewe lambs. The 2014 fall-born lamb season was close to an ideal system due to exceeding amounts of high quality forage and the availability of different forage types. Winter- or spring-born lambs do not appear to be suitable for a grass-based system in the southeastern U.S. when high quality summer annuals are not available. For winter- or spring-born lambs to thrive in a grass-based system, high quality warm season annuals must be available to graze when cool season forage quality declines. This will not only address nutrient needs for weight gain, but a system of forages that will allow tolerance or avoidance of the gastrointestinal nematodes that are more prevalent in summer months. Due to uncontrollable environmental factors (inadequate or too much rainfall) it is harder to guarantee the availability of quality warm-season forages compared to cool-season forages.

Production of fall-born ram lambs on quality cool season forages offers sustainable options for southeastern U.S. farmers wishing to minimize off-farm inputs. The niche market for grass-fed lamb may offer premiums, and retention of ewe lambs that thrive in this system for breeding stock offers an additional source of income. More research is needed on effects of various cool season forage varieties on carcass quality, traits, and consumer or taste acceptability.

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Table 1. Co-product supplement analysis. Composite sample (taken from subsamples collected every 7 d throughout the season) analysis on a dry matter basis of supplement fed to 2013 and 2014 SUP fall-born lambs.

Analysis (%)	**Fall 2013**	**Fall 2014**
Dry matter	90.3	90.6
Crude protein	15.1	17.2
ADF	22.9	17.7
NDF	44.8	38.9
TDN	69.9	75.3

Table 2. Botanical composition of paddocks grazed by 2013 fall-born lambs. Forages available in paddocks grazed by all treatments (NON and SUP) in 2013 fall-born lamb season on d 0, 84, and 140.

Forage	% DM		
	Day 0	Day 84	Day 140
Tall fescue	72.4	66.6	5.0
Winter annuals[1]	12.1	13.6	47.2
Hairy vetch	8.8	13.9	-
Broadleaf weeds[2]	6.7	5.9	10.7
Sericea lespedeza	-	-	36.8
Bermudagrass	-	-	0.3

[1] Included (but not limited to) ryegrass, cheat grass (*Bromus tectorum*), and barley (*Hordeum pusillum*).

[2] Included (but not limited to) buttercup (*Ranunculus*) and curly dock (*Rumex crispus*).

Table 3. Botanical composition of paddocks grazed by 2014 fall-born lambs. Forages available in paddocks grazed by all treatments (NON and SUP) in 2014 fall-born lamb season on d 0, 84, 112, 119, and 133.

Forage	% DM				
	Day 0	Day 84	Day 112	Day 119	Day 133
Tall fescue	74.1	72.4	-	-	-
Winter annuals[1]	12.9	6.1	19.2	23.6	2.2
Hairy vetch	6.45	6.9	-	-	7.4
Broadleaf weeds[2]	6.5	14.5	39.6	8.2	4.8
Sericea Lespedeza	-	-	41.2	66.4	-
Bermudagrass	-	-	-	1.8	-
Chicory	-	-	-	-	85.1
White Clover	-	-	-	-	0.5

[1] Included (but not limited to) ryegrass, cheat grass (*Bromus tectorum*), and barley (*Hordeum pusillum*).

[2] Included (but not limited to) buttercup (*Ranunculus*) and curly dock (*Rumex crispus*).

Table 4. Free-choice mineral guaranteed analysis. Manufacturer guaranteed analysis of free-choice mineral offered to all lambs throughout study.

Ingredient	
Calcium (min)	15.0 %
Calcium (max)	18.0 %
Phosphorus (min)	8.0 %
Salt (min)	18.5 %
Salt (max)	22.2 %
Potassium (min)	1.5 %
Magnesium (min)	5.0 %
Copper (min)	275 ppm
Copper (max)	375 ppm
Iodine (min)	320 ppm
Manganese (min)	2,000 ppm
Selenium (min)	25 ppm
Zinc (min)	3,500 ppm
Vitamin A (min)	308,647 IU/kg
Vitamin D3 (min)	77,161 IU/kg
Vitamin E (min)	1,653 IU/kg

Ppm - parts per million
IU/kg – International unit per pound

Table 5. Ultrasonic carcass measurements. Least squares means and standard errors of ultrasound carcass measurements determined on 2013 and 2014 fall-born lambs. Measures include longissimus muscle area (LMA) and back fat depth (BF) on d 70 of study and day of finish.

	NON		SUP				
	Rams	Ewes	Rams	Ewes	*P* (trt)	*P* (sex)	*P* (trt × sex)
2013							
Day 70							
LMA (cm^2)	5.1 ± 0.69	5.8 ± 0.61	5.6 ± 0.61	5.7 ± 0.69	0.763	0.532	0.607
BF (cm)	0.20 ± 0.02	0.17 ± 0.02	0.20 ± 0.02	0.18 ± 0.02	0.660	0.260	0.830
Finish							
LMA (cm^2)	13.6 ± 1.15	13.4 ± 1.09	16.9 ± 1.15	14.6 ± 1.15	0.057	0.269	0.348
BF (cm)	0.40 ± 0.03	0.38 ± 0.03	0.44 ± 0.03	0.37 ± 0.03	0.654	0.164	0.373
2014							
Day 70							
LMA (cm^2)	22.7 ± 1.2	19.7 ± 1.12	21.7 ± 1.05	20.3 ± 1.2	0.863	0.064	0.485
BF (cm)	0.51 ± 0.03	0.45 ± 0.03	0.52 ± 0.03	0.52 ± 0.03	0.285	0.372	0.281
Finish							
LMA (cm^2)	23.9 ± 1.57	22.9 ± 1.24	24.5 ± 1.24	24.2 ± 1.32	0.507	0.654	0.815
BF (cm)	0.42 ± 0.08	0.38 ± 0.06	0.51 ± 0.06	0.32 ± 0.06	0.837	0.094	0.223

Table 6. Parasite genera for 2013 fall-born lambs. Proportion of gastrointestinal nematode genera in pooled fecal culture for grazing fall-born 2013 lambs and either supplemented (SUP) with co-product supplement at 0.5% BW or offered no supplement (NON).

Day of Treatment	Gastrointestinal nematode genera (%)			
	H. contortus	*Trichostrongylus* spp.	*Cooperia* spp.	*Oesophagostomum* spp.
Fall 2013				
D 14				
NON	84	16	0	0
SUP	79	21	0	0
D 28				
NON	100	0	0	0
SUP	79	19	1	1
D 42				
NON	100	0	0	0
SUP	65	31	3	1
D 56				
NON	91	6	2	1
SUP	50	50	0	0
D 70				
NON	69	24	3	4
SUP	58	31	2	9
D 84				
NON	68	25	2	5
SUP	39	54	7	0
D 98*				
NON	62	36	0	2
SUP	65	35	0	0
D 112				
NON	47	53	0	0
SUP	4	94	2	0
D 126				
NON	70	26	3	1
SUP	76	15	6	3
D 154				
NON	36	21	10	23
SUP	15	57	22	6

*All lambs received 1 g copper oxide wire particles.

Table 7. Parasite genera for 2014 fall-born lambs. Proportion of gastrointestinal nematode genera in pooled fecal culture for grazing fall-born 2014 lambs and either supplemented (SUP) with co-product supplement at 0.5% BW or offered no supplement (NON).

Day of Treatment	Gastrointestinal nematode genera (%)			
	H. contortus	*Trichostrongylus* spp.	*Cooperia* spp.	*Oesophagostomum* spp.
Fall 2014				
D 42				
NON	46	48	5	1
SUP	66	27	1	6
D 84				
NON	65	24	8	3
SUP	60	40	0	0
D 112*				
NON	17	63	13	7
SUP	0	67	33	0

*All lambs received 1 g copper oxide wire particles.

Figure 1. Body weight for 2013 and 2014 fall-born lambs. Least squares means and standard errors of body weight (BW) of ram and ewe lambs (Panel A) fed no supplement (NON) or supplemented at 0.5% BW with a co-product feedstuff (SUP), born in both fall 2013 and 2014; treatment × sex × day interaction ($P < 0.001$). Least squares means and standard errors of BW for NON and SUP lambs, including both genders, for fall 2013 (n = 20/treatment) or fall 2014 (n = 16/treatment); treatment × year × day interaction $P < 0.001$. D 0 = d of weaning; d lambs placed on pasture: d 9 (2013) and d 14 (2014).

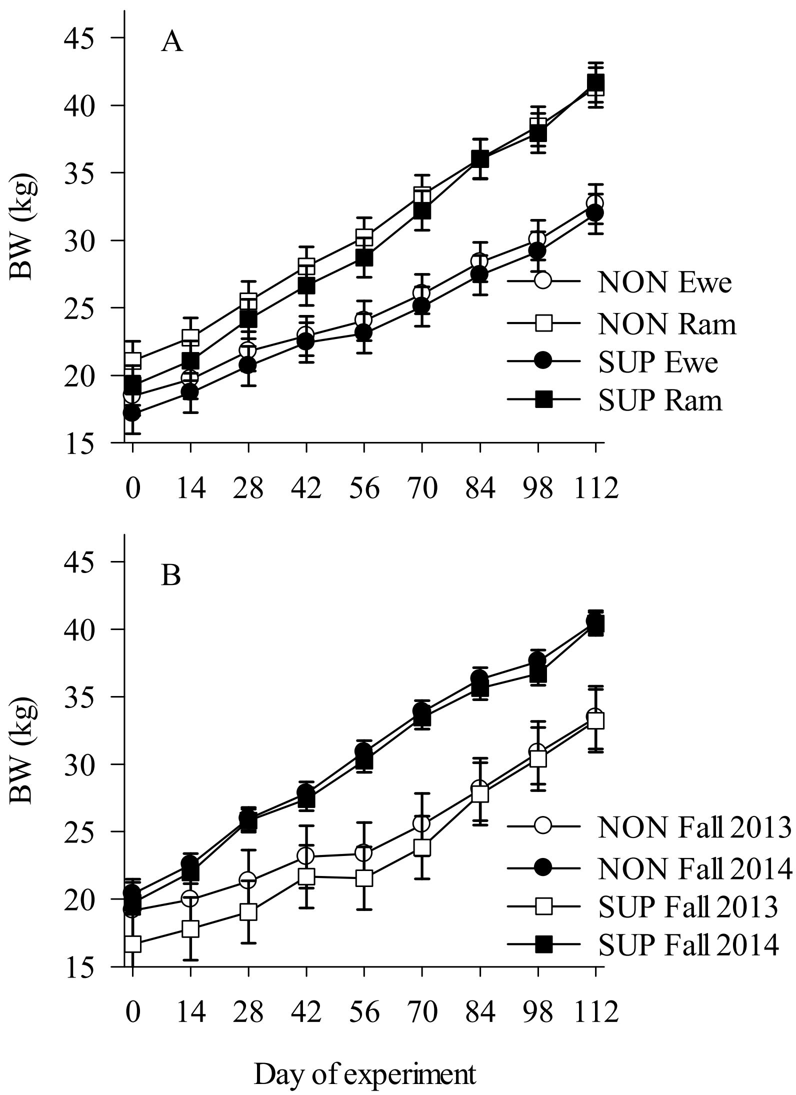


Figure 2. Body weight for 2014 winter-born lambs. Least squares means and standard errors of body weight (BW) of ram lambs born in winter 2014 fed no supplement (NON) or 0.5% BW of a co-product feedstuff (SUP; n = 20/treatment) and grazing predominantly grass pastures. D 0 = d of weaning; d lambs placed on pasture: d 9.

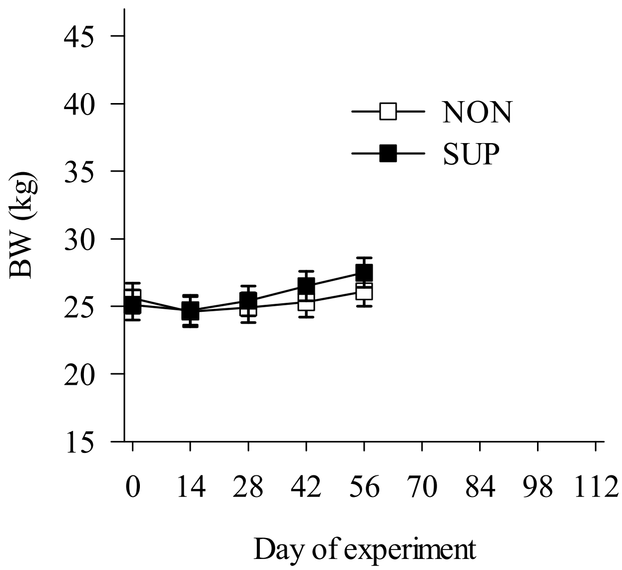


Figure 3. Fecal egg counts for 2013 (A) and 2014 (B) fall-born lambs. Least squares means and standard errors [too small to be observed on these plots; ± 0.14 (Panel A); ± 0.13 (Panel B)] of back-transformed fecal egg counts (FEC) lambs (male and female) fed no supplement (NON) or supplemented at 0.5% BW of a co-product feedstuff (SUP) born in fall 2013 (Panel A; n = 20/treatment) or fall 2014 (Panel B; n = 16/treatment) while grazing predominantly grass pastures. D 0 = d of weaning; d lambs placed on pasture: d 9 (2013) and d 14 (2014).

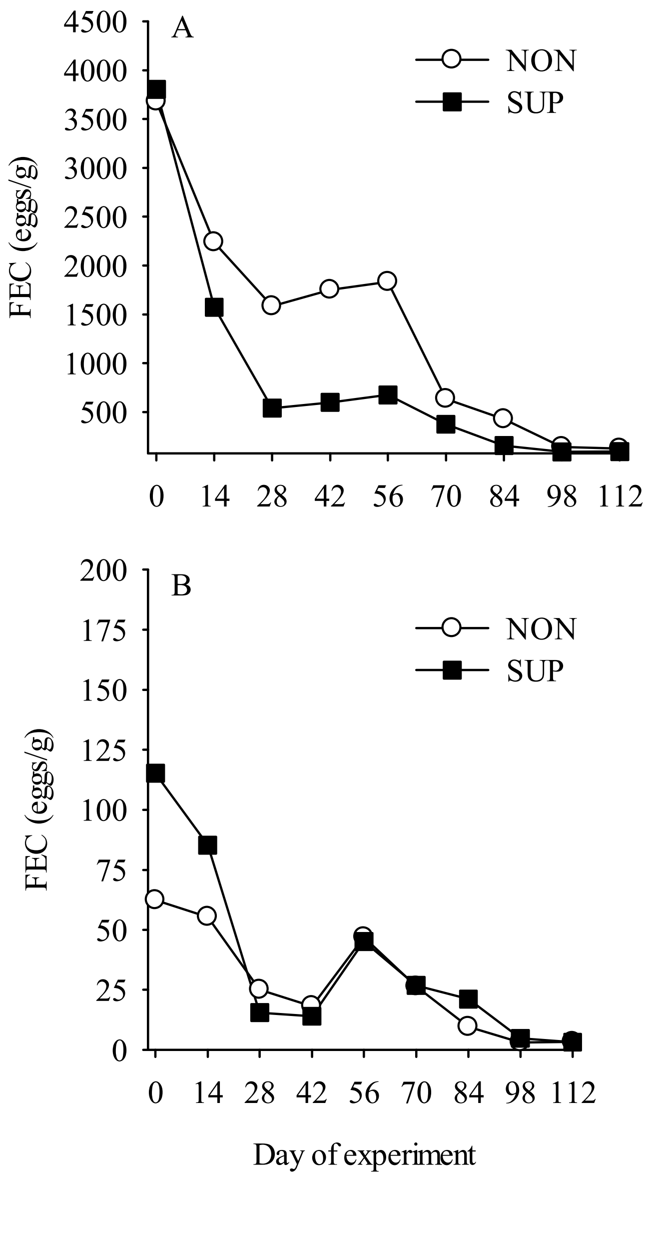


Figure 4. Fecal egg counts for 2014 winter-born lambs. Least squares means and standard errors (too small to be observed on these plots) of back-transformed fecal egg counts (FEC) of lambs fed no supplement (NON) or supplemented at 0.5% BW with a co-product feedstuff (SUP) born in winter 2014 (n = 20/treatment) grazing predominantly grass pastures. D 0 = d of weaning; d lambs placed on pasture: d 9.

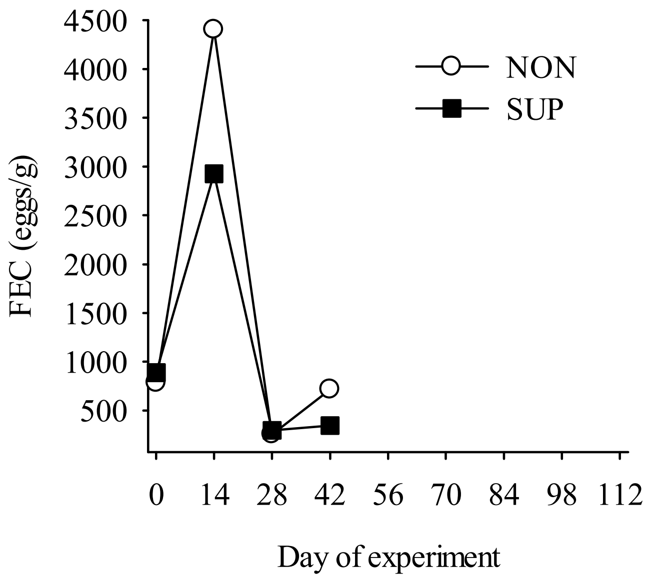


Figure 5. Blood packed cell volume for 2013 and 2014 fall-born lambs. Least squares means and standard errors of packed cell volume (PCV) of ram and ewe lambs (Panel A) fed no supplement (NON) or supplemented at 0.5% BW with a co-product feedstuff (SUP), born in both fall 2013 and fall 2014. Least squares means and standard errors of PCV for NON and SUP lambs, including both genders, for fall 2013 (n = 20/treatment) or fall 2014 (n = 16/treatment). D 0 = d of weaning; d lambs placed on pasture: d 9 (2013) and d 14 (2014).

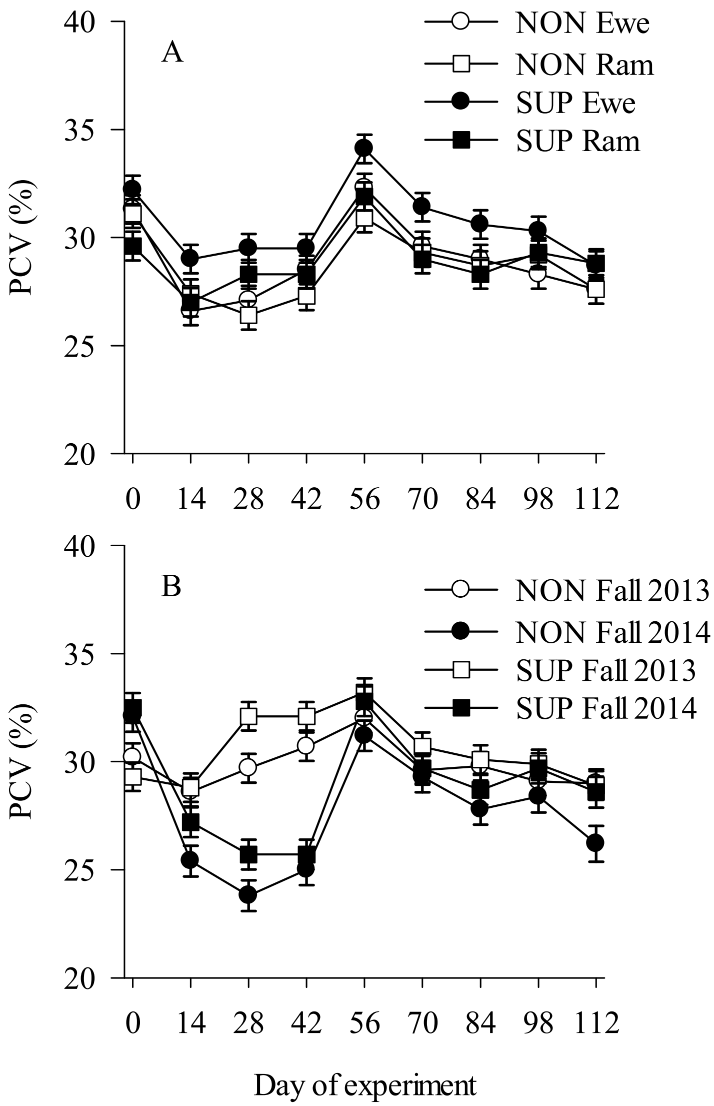


Figure 6. Forage nutrient content available for fall-born 2013 and 2014 lambs. Least squares means and standard errors for nutrient contents of forages grazed by 2013 (Panel A) and 2014 (Panel B) fall-born lambs. Measures included neutral detergent fiber (NDF), acid detergent fiber (ADF), and in vitro digestibility (IVD). There were no treatment effects, therefore day means are presented. D 0 = d of weaning; d lambs placed on pasture: d 9 (2013) and d 14 (2014).

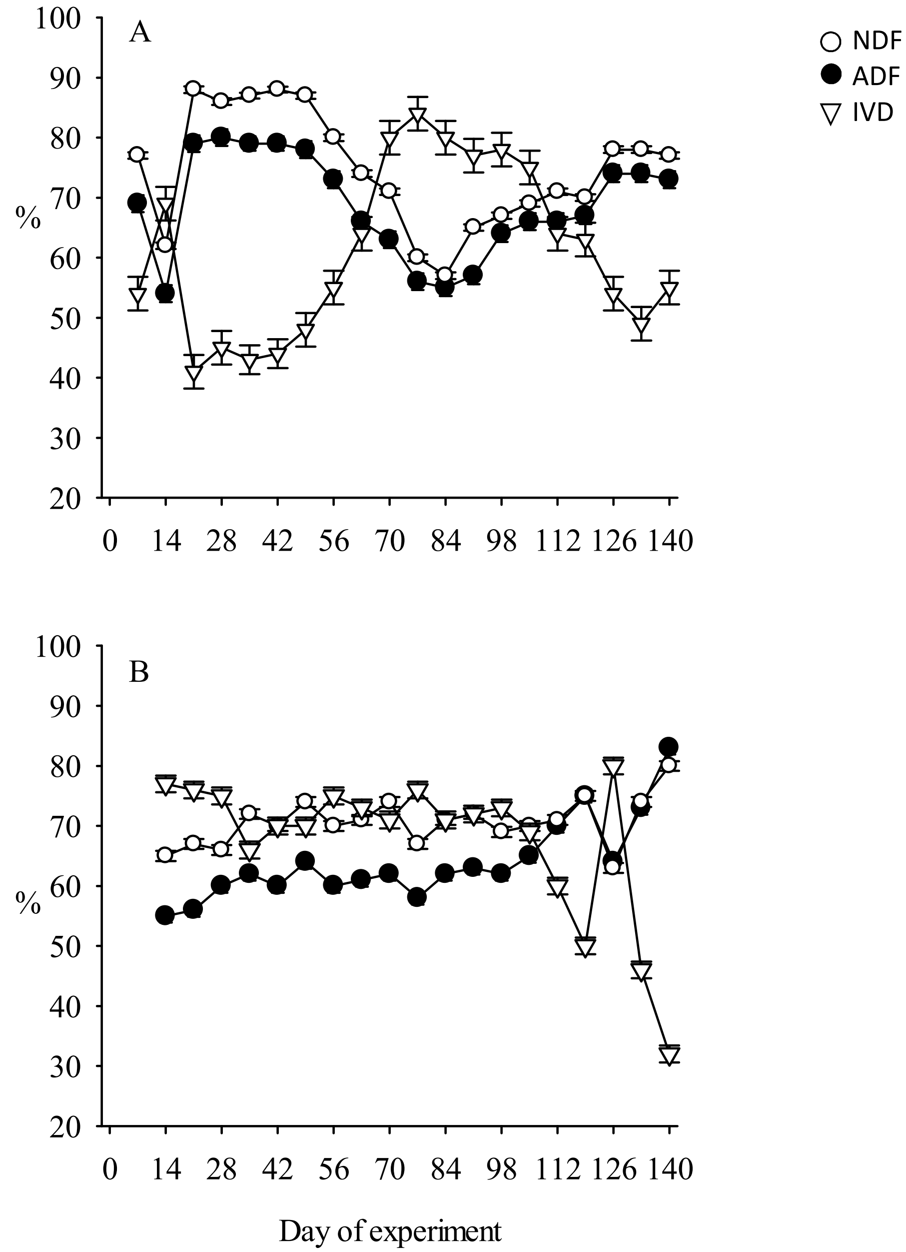
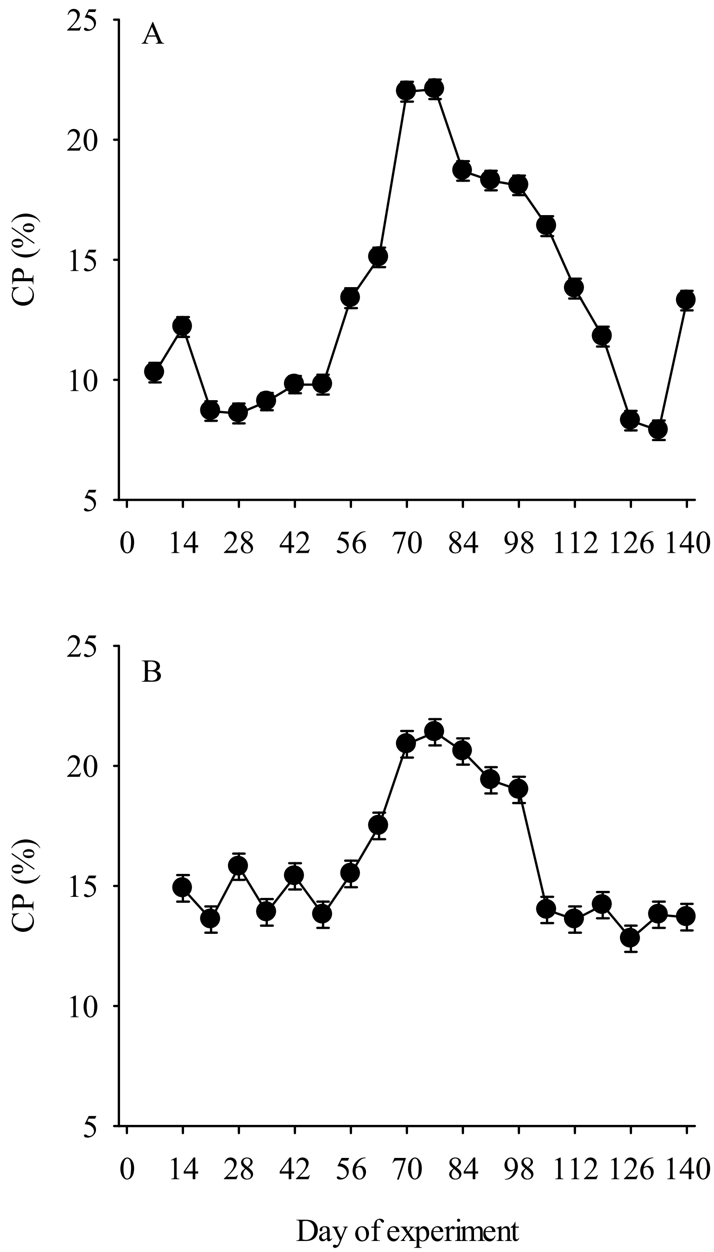


Figure 7. Forage crude protein content available for fall-born 2013 and 2014 lambs. Least squares means and standard errors for crude protein content of forages grazed by 2013 (Panel A) and 2014 (Panel B) fall-born lambs. There were no treatment effects, therefore day means are presented. D 0 = d of weaning; d lambs placed on pasture: d 9 (2013) and d 14 (2014).



UNIVERSITY OF ARKANSAS

Office of Research Compliance

MEMORANDUM

TO: Dr. Joan Burke

FROM: Craig N. Coon, Chairman
Institutional Animal Care and Use Committee

DATE: May 15, 2014

SUBJECT: IACUC APPROVAL
Expiration date: October 14, 2015

The Institutional Animal Care and Use Committee (IACUC) has APPROVED protocol 14043: "Grass finishing systems for lambs born in fall or winter". You may begin work immediately

In granting its approval, the IACUC has approved only the information provided. Should there be any further changes to the protocol during the research, please notify the IACUC in writing(via the Modification form) prior to initiating the changes. If the study period is expected to extend beyond October 14, 2015 you must submit a modification for extension. By policy the IACUC cannot approve a study for more than 3 years at a time.

The IACUC appreciates your cooperation in complying with University and Federal guidelines involving animal subjects.

CNC/aem

cc: Animal Welfare Veterinarian

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