Sheep & Goat Research Journal
Volume 33, 2018 - November

Gastrointestinal Nematode Infection and Growth of Grass Based Katahdin Lambs

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Summary

Grass-finishing lambs presents a challenge in the southeastern United States due to poor quality perennial grasses much of the year and presence of gastrointestinal nematodes (GIN). The objective of this study was to examine the effect of forage-based production, either grass-fed or grass-based with modest supplementation, on GIN infection and growth of fall-born lambs. Katahdin lambs born in October 2013 and 2014 were weaned in January of the respective following yr at 80 d ± 1.5 d or 85 d ± 1.8 d of age, respectively. Lambs were blocked by sex and randomly assigned to receive no (NON) or grain by-product supplement (SUP; 15% CP) at 0.5% of body weight/d. A winter-born group of lambs was used as a contemporary comparison, but observed for a shorter period due to poor performance. Lambs were rotationally grazed on predominantly grass, legumes and forbs as grass quality waned. Body weight and body condition score (2014 fall-born lambs only), fecal-egg counts (FEC), and blood-packed-cell volume (PCV) were determined every 14 d. Data were analyzed by repeated measures in a mixed model or general linear model. Average daily gain between d 0 and d 84 was greater for SUP than NON lambs (137 g/d ± 4.9 g/d > 110 g/d ± 5.0 g/d; $P = 0.003$) in the first year, but similar between treatments the second year (NON, 175 g/d ± 5.3 g/d; SUP, 179 g/d ± 5.2 g/d; treatment × yr, $P = 0.02$). Rams gained faster than ewes (179 g/d ± 3.6 g/d > 121 g/d ± 3.6 g/d; $P < 0.001$). The average daily gain (d 0 to d 35) of winter lambs was greater for SUP than NON (33 g/d ± 8 g/d > -6 g/d ± 8 g/d; $P = 0.001$). The FEC were similar between treatments in fall-born lambs, but PCV was increased in SUP compared with NON lambs, particularly at 28 d post-weaning (treatment × yr × d, $P < 0.001$). Results in this study suggest that modest supplementation should result in greater gains in fall-born-ram lambs and improved tolerance to gastrointestinal parasites when forage quality is limiting. High-quality forage should result in good weight gain without supplementation.

Key Words: Forage, Gastrointestinal Nematodes, Grass-fed, Sheep

Introduction

Ruminant animals are a vital source of protein for the growing world population. There is a growing urgency to produce protein products in a sustainable manner that does not compete with grains grown for human consumption. Access to excellent pastures and forages can produce high-quality, leaner-lamb carcasses without grain supplementation and a healthier fatty-acid profile (McClure et al., 1994; Aurousseau et al., 2007; De Brito et al., 2017). In fact, many consumers prefer the flavor of grass-fed meats (Muir et al., 1998; Lozier et al., 2005; Cox et al., 2006). However, forage-based lambs are susceptible to gastrointestinal nematode (GIN) infection.

Gastrointestinal nematodes are considered to be one of the most significant health problems of small ruminants, which lead to poor weight gains, anemia and death loss. Little is known about grass finishing in warmer climates in transitional zones between cool-season, tall-fescue-dominated pastures and poorer-quality, warm-season grasses, both of which support an ideal GIN habitat to complete its life cycle. Many consumers of grass-fed proteins prefer minimal exposure to synthetic chemicals, therefore it is desirable to reduce the need for anthelmintics. Alternatives include use of copper oxide wire particles (Bang et al., 1990; Burke and Miller, 2006), protein supplementation (Kyriazakis and Houdijk, 2006), intensive grazing (Colvin et al., 2008), and changing the season of exposure of lambs to GIN (Burke and Miller, unpublished data). Fall born compared with winter- or spring-born lambs are exposed to less pathogenic GIN genera.

Little is known about susceptibility to GIN and growth of fall-born, grass-fed lamb production in the southeastern United States. Grass fed is defined as ruminant animals whose diet, with the exception of milk prior to weaning, is solely derived from forage (USDA, 2007; A Greener World, Animal Welfare Approved, *https://animalwelfareapproved.us*). Therefore, the objective was to examine forage-based production, either grass fed or grass-based with modest supplementation on growth and GIN infection of Katahdin lambs.

Materials and Methods

Animal Procedures

The experiment was conducted from January 2014 to June 2015 at the USDA, ARS Dale Bumpers Small Farms Research Center in Booneville, Ark., U.S.A. (35°05' N, 93°59' W, 152 m a.s.l.). All animal procedures were approved by the ARS Institutional Animal Care and Use Committee, and the sheep flock is certified by the Animal Welfare Approved program (*www.animalwelfareapproved.org*).

Katahdin lambs born in October 2013 and October 2014 (n = 40 and 32, respectively) were weaned in January 2014 (80 d ± 1.5 d of age) and January 2015 (85 d ± 1.8 d of age), respectively. At weaning (d 0), as many as one half of the lambs in each season were lame and required soaking with zinc sulfate prior to being placed on trial on d 9 to d 14. Lambs were blocked by sex (2013: n = 22 rams, n = 18 ewes; 2014: n = 17 rams, n = 15 ewes) and randomly assigned to one of four groups (n = 10/group in 2013; n = 8/group in 2014). Two groups of lambs received no supplement (NON) and two groups were fed a commercial by-product grain/corn mix (SUP; 2013, n = 20/treatment; 2014, n = 16/treatment). Ingredients of the supplement were soy hull pellets, wheat-middling pellets, corn-gluten pellets, cracked corn, and dried-distillers grain (Five Way Mix, Farmers Cooperative, Van Buren, Ark., U.S.A.; 15% minimum CP, 3.6% minimum crude fat, 11% maximum crude fiber). This supplement was sampled weekly throughout the season and a composite sample was analyzed for nutrients at the end of the season (Table 1). Each SUP group was supplemented at a rate of 0.5% body weight/d throughout the study (adjusted every 14 d). Lambs had access to free-choice water and mineral (Table 2; Nutra Blend, LLC, Neosho, Mo., U.S.A.) throughout the study period. In February 2014, the ground was covered with snow for 2 d and lambs were given access to bermudagrass hay (*Cyonodon dactylon*; 9% CP). In February 2015, lambs received access to organic tall-fescue hay (*Festuca arundinacea*; 14% CP) when snow covered the ground for 1 day. Pasture and forages are described below.

Lambs grazed from weaning (d 0) until they reached a light-market weight (36 kg to 41 kg for ewes and 41 kg to 50 kg for rams) at which time they were removed from the study. If target weight was not met by 240 d of age, corresponding to approximately 155 d post weaning, lambs were removed from trial. Body weight was determined every 14 d. Body condition

Table 1. Composite sample (taken from subsamples collected every 7 d throughout the season) analysis on a DM basis (%) of supplement fed to 2013 and 2014 SUP lambs.

Nutrient	2013	2014
DM	90.3	90.6
CP	15.1	17.2
ADF	22.9	17.7
NDF	44.8	38.9
TDN	69.9	75.3

Table 2. Composition of mineral salt provided by manufacturer (NutraBlend, Neosho, MO, USA) offered free-choice 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), µg/g	275
Copper (max), µg/g	375
Iodine (min), µg/g	320
Manganese (min), µg/g	2,000
Selenium (min), µg/g	25
Zinc (min), µg/g	3,500
Vitamin A (min), IU/kg	308,647
Vitamin D3 (min), IU/kg	77,161
Vitamin E (min), IU/kg	1,653

scores were recorded every 14 d, for 2014 lambs only, on a scale of 1 to 5 (1 = emaciated; 5 = overly fat).

Pastures and Forages

Each group of lambs was rotationally grazed on pasture initially consisting of predominantly endophyte-infected Kentucky-31 tall fescue (*Festuca arundinacea*), with a lesser proportion of hairy vetch (*Vicia villosa*), and later, as tall-fescue quality declined, a chicory (*Cichorium intybus*), or sericea lespedeza (*Lespedeza cuneata*) pasture depending on seasonal growth (Table 3). Grass-fed certification allows for consumption of non-grass forages. Farmers commonly utilize available forage resources as seasons change. All paddocks were surrounded by temporary polywire fencing and were 0.2 ha. 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 or 9 different paddocks per lamb group used per season. This resulted in a stocking rate of 40 lambs/ha or a range of 161 kg/ha to 323 kg/ha for each 0.2 ha sub-plot for fall 2014 lambs, or 50 lambs/ha or a range of 194 kg/ha to 352 kg/ha for fall 2013 and winter lambs (described below). This is a conservative stocking rate compared to the set stocking rate of 560 kg/ha for continuous grazing commonly used at this research location. Each lamb group was randomly assigned to a specific paddock each week; therefore if the paddock was reused after 28 d of rest, the same lamb group would be placed back in its assigned paddock. Forage was never limiting (never below 20 cm) throughout the study period for each season with the exception of the two days of snow cover in 2014 and one day in 2015, and hay was offered.

Every 7 d, upon introduction and removal of lambs from paddocks up to d 140, forage quality was determined on four randomly selected sites within paddocks clipped to 2.5 cm within a 0.093 m^2 quadrant. Samples were weighed, then dried in a forced air oven at 55°C for 72 h, and ground to pass through a 1-mm screen using a Model 4 Wiley Mill (Thomas Scientific, Swedesboro, N.J., U.S.A.). Samples were then weighed (0.5 g) and placed 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, N.Y. U.S.A.). All samples were analyzed in duplicate. The coefficient of variation for ADF and NDF was 1.3% and 1.8%, respectively. Nitrogen was analyzed using an Elementar rN^{III} nitrogen analyzer (Elementar Americas, Mount Laurel, N.J., U.S.A.) at the Agriculture Diagnostic Laboratory, University of Arkansas (Fayetteville, Ark., U.S.A.). Percentage of nitrogen was then used to calculate CP by multiplying the amount of nitrogen by 6.25. Batch in vitro dry matter digestibility (IVDMD) was determined on the forage samples using the DAISY^{II} apparatus (ANKOM Technology Corp., Fairport, N.Y.; Holden, 1998).

Botanical composition was determined by the dry-weight rank method (Mannetje and Haydock, 1963) on d 0, d 84, d 112 (2015 only), d 119 (2015 only; transferred to new warm

Table 3. Botanical composition of forages in paddocks grazed by fall born lambs in percent dry matter. Forages available in paddocks grazed by all treatments (NON and SUP) on d 0 (mid-January), 84 and 140 post-weaning for 2013 lambs, and d 0, 84, 112, 119, and 140 for 2014 lambs.

	D post-weaning				
Forage	0	84	112	119	140
2013					
Tall fescue [*Schedonorus arundinaceus* (Schreb) Dumort]	72.4	66.6			5.0
Winter annuals[1]	12.1	13.6			47.2
Hairy vetch (*Vicia villosa*)	8.8	13.9			-
Broadleaf weeds[2]	6.7	5.9			10.7
Sericea Lespedeza (*Lespedeza cuneata*)	-	-			36.8
Bermudagrass (*Cynadon dactylon*)	-	-			0.3
2014					
Tall fescue [*Schedonorus arundinaceus* (Schreb) Dumort]	74.1	72.4	-	-	-
Winter annuals[1]	12.9	6.1	19.2	23.6	2.2
Hairy vetch (*Vicia villosa*)	6.45	6.9	-	-	7.4
Broadleaf weeds[2]	6.5	14.5	39.6	8.2	4.8
Sericea Lespedeza (*Lespedeza cuneata*)	-	-	41.2	66.4	-
Bermudagrass (*Cynadon dactylon*)	-	-	-	1.8	-
Chicory (*Cichorium intybus*)	-	-	-	-	85.1
White Clover (*Trifolium repens*)	-	-	-	-	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*).

season paddocks), and d 140. A 0.28 m^2 quadrant was randomly tossed 20 times in the paddock, and the top three species of plant were ranked 1, 2, and 3 (which correlates with a percentage of 70, 24, and 6, respectively). Paddocks were mowed when necessary so that forages remained vegetative.

Winter Born Contemporary Lambs

The original objective included a comparison of fall- and winter-born lambs. However, this group was not included in the final analyses alongside the fall-born lambs. In general, lambs are born between January and May in the southeastern United States. A group of Katahdin lambs of similar genetics and management belonging to the ARS flock were born February 2014 and weaned in May (95 d ± 1.4 d of age; n = 40; n = 20/treatment). Only ram lambs were used in this group to minimize harassment of ewe lambs and unwanted breeding, which occurs more frequently in winter than fall-born lambs, as they begin to mature when day length begins to decrease. The dietary treatments were the same as fall-born lambs, and groups grazed available forages. Grazing on d 35 coincided with d 140 of 2014 fall-born lambs (Table 3), which was predominantly chicory. Lambs began to lose weight and body condition by June, or d 35 due to poor forage quality and possibly heat stress (peak temperature in June 2014 was 34°C with greatest humidity measured at 90%) and were removed from the experiment. Animal Welfare Approved regulations require sheep to maintain a body condition score of 2 or higher and several lambs had fallen to 2 or lower. Body weight and condition data and GIN measures (see next Section) were collected. The low-body condition of these lambs prompted determining condition in 2014 fall lambs, which had not been conducted in 2013.

Gastrointestinal Nematode Measures and Management

Fecal samples were collected rectally to determine FEC according to Whitlock (1948; sensitivity of 50 eggs/g) and blood was collected from the jugular vein to determine blood-packed-cell volume (PCV) using the microhematocrit method every 14 d.

Lambs were treated for anemia with either 1 g copper oxide wire particles (COWP; Burke and Miller, 2006; PCV ≤ 19%) or levamisole (8 mg/kg body weight; Levasol, Agri. Laboratories, Ltd., St. Joseph, Mo., U.S.A.; PCV ≤ 16%). All lambs received 1 g COWP when PCV of several lambs was observed to be decreasing (2013: d 98 and d 140; 2014: d 14 and d 112). Feces were cultured on all 2013 born samples, on d 42, d 84, and d 112 of fall 2014 lambs, and on d 0 of winter-born lambs to identify GIN genera according to Peña et al. (2002).

Two winter-born lambs received COWP (1 NON, 1 SUP) and 3 received levamisole (3 NON) on d 21, and all received COWP on d 14. Lambs observed to have soiled rear quarters or liquid feces indicative of coccidiosis received sulfadimethoxine drench (11.3 mg/kg; SulfaMed-G, Bimeda, Inc., Le Sueur, Minn., U.S.A.) for three consecutive days. Twelve winter 2014 lambs were the only animals to receive sulfadimethoxine (6 NON, 6 SUP; d 28).

Statistical Analyses

One of the NON 2014 fall-born lambs was killed by a predator in the first week of the trial. In March 2014 (day 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 (below 2.5), were failing to gain weight [2 standard deviations (3.1 kg × 2 kg) below the mean (26.4 kg)], and would likely be culled or enter a conventional sheep-production system of feeding more grain to meet producer's goals. Fall-ram lambs became sexually active and were sorted into groups by sex (Ram SUP, Ewe SUP; Ram NON, Ewe NON) in May 2014 (d 112).

In the 2013 fall-lamb group, 3 lambs met target body weight by 98 d and 7 by 112 d and were removed from experiment; in the 2014 fall-lamb group, 1 lamb met target body weight by 70 d, 2 by 84 d, 3 by 98 d and 7 by 112 d. Thus, average daily gain was determined between d 0 (weaning) and d 84. Age at finishing was considered as the first date in which lamb met body weight target (ewes, 36 kg; rams 41 kg) minus the birth date. Two means were determined. A mean was determined for only lambs that finished, and a mean for all lambs, assigning the final date (154 d post-weaning) as day to finish for lighter lambs.

General linear models (SAS; SAS Inst., Inc., Cary, N.C., U.S.A.) in a completely randomized design were used to determine differences in average daily gain and age at finished weight. The model included supplement treatment, sex, year, and the 2- and 3-way interactions. If an interaction was determined non-significant ($P > 0.10$), it was removed from the model.

Body weight, BCS, FEC, and PCV were analyzed as repeated measures (Littell et al., 1996) using mixed models with an autoregressive covariance structure (SAS). The model included supplement treatment, sex, year, day and 2-, 3- and 4-way interactions with day specified as a repeated measure. In addition, body weight data in both years were used for homogeneity of regression analysis to determine the equation of weight gain over time between supplement treatments and sex. The FEC data were log transformed [ln(FEC + 10)] to normalize the data and means were presented as back-transformed data. Standard errors of back-transformed means were derived by assuming that the standard error of the mean transformed FEC were approximately equal to the coefficient of variation of back-transformed means. For the fall lambs, the days included 0 (d of weaning) to 112 (a majority of lambs remained on study).

Forage nutrients were analyzed as a repeated measures each year with supplement group, days post-weaning and the interaction included in the model. An autoregressive covariance structure was used.

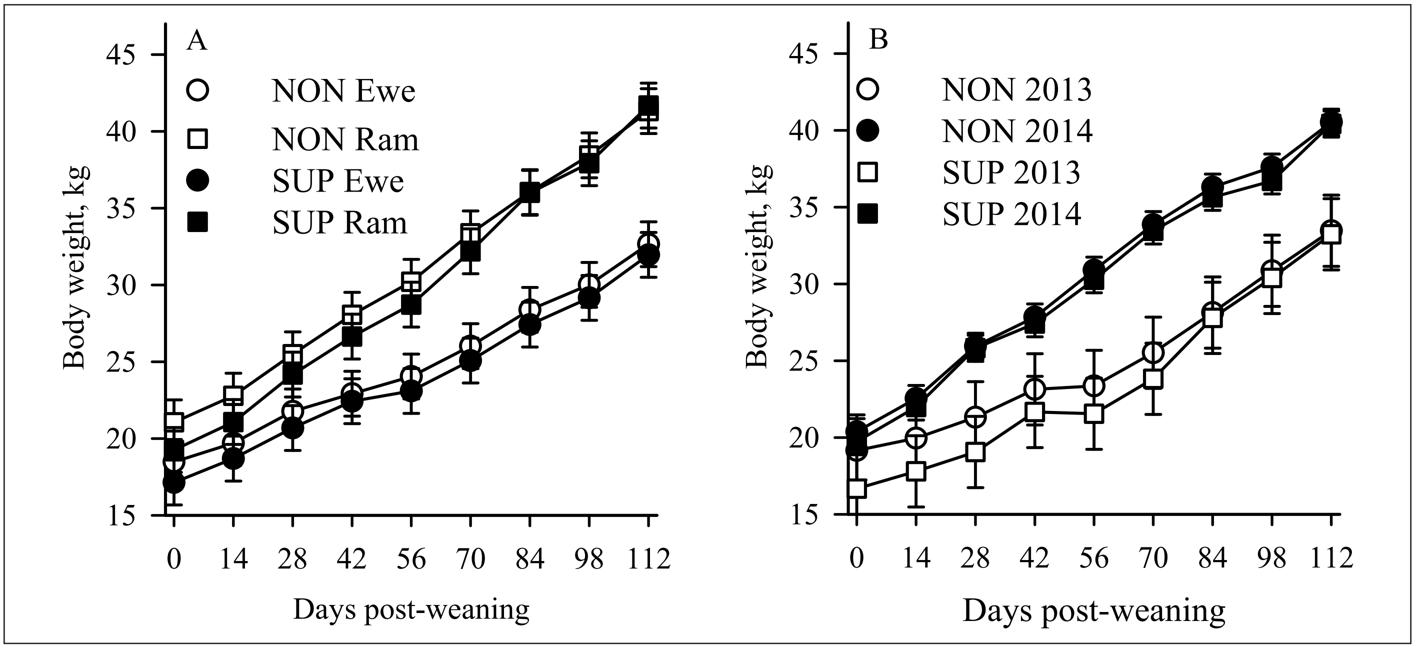
Winter Born Lambs. The average daily gain was determined between d 0 and d 35. The GLM model included supplement treatment only. Mixed models with repeated measures for day to determine differences in body weight, FEC, and PCV included supplement treatment and the day × supplement interaction.

Results

Lamb Growth

Average daily gain was greater for SUP than NON in the first year (137 g/d ± 5.2 g/d > 110 g/d ± 5.0 g/d), but similar in

Fig. 1. Least squares means ± standard error of body weight of ram and ewe lambs (Panel A) fed no supplement (NON) or supplemented at 0.5% body weight with a by-product grain supplement (SUP), born in both fall 2013 and 2014 between weaning (d 0) and 112 d post-weaning (treatment × sex × day interaction, $P < 0.001$). Least squares means ± standard error of body weight for NON and SUP lambs, including both sexes, for fall 2013 (n = 20/treatment) or fall 2014 (n = 16/treatment; treatment × yr × d, $P < 0.001$; Panel B). Lambs were placed on pasture on d 9 (2013) or d 14 (2014).



the second year (NON, 175 g/d ± 5.3 g/d; SUP, 179 g/d ± 5.2 g/d; treatment × yr, $P = 0.02$). There was no treatment × sex interaction and rams gained faster than ewes (179 g/d ± 3.6 g/d > 121 g/d ± 3.6 g/d; $P < 0.001$). Body weight was greater for ram than ewe lambs throughout the study, and a treatment × sex × day interaction was detected ($P < 0.001$; Fig. 1A). Body weight of lambs was greater the second than the first year and not influenced by supplement treatment; however supplement influenced body weight of 2013 lambs (treatment × yr × d, $P < 0.001$; Fig. 1B). When considering only lambs that reached target body weight, days to finish did not differ among treatments throughout the study (207 d ± 4.6 d; $P = 0.87$), and was similar between years ($P = 0.14$) and sexes ($P = 0.11$). When assigning d 154 as day to finish in lambs that did not meet target body weight, it tended to take longer for NON compared with SUP lambs in the first year, but reversed in the second year (2013: NON, 224 d ± 5 d; SUP 215 d ± 5 d; 2014: NON, 205 d ± 5 d; SUP, 214 d ± 5 d; $P = 0.08$), and rams finished before ewe lambs (ram, 206 d ± 4 d; ewe, 224 d ± 4 d; $P < 0.001$). There were 14 lambs (2 rams, 12 ewes) in the first year and 8 lambs (3 rams, 5 ewes) in the second year that did not meet the target weight by 140 d post-weaning. Lambs began to reach target weight in 2013 on d 98, and in 2014 on d 70. After observing the poor body condition of winter-born lambs, it was apparent the importance of recording body condition score, which occurred only in 2014 fall-born lambs, and was not different among groups (3.1 ± 0.03, $P = 0.76$).

The differential effect of dietary treatment on body weight between the start and end of the experiment in both years was reflected by the difference ($P < 0.001$) in regression equations: $y_{NON\text{-}RAM} = 21.3 + 0.16x - 1.15 \times 10^{-4}x^2$; $y_{SUP\text{-}RAM} = 20.5 + 0.16x + 2.6 \times 10^{-4}x^2$; $y_{NON\text{-}EWE} = 18.5 + 0.098x + 2.5 \times 10^{-4}x^2$; $y_{SUP\text{-}EWE} = 18.2 + 0.12X + 2.9 \times 10^{-5}x^2$, where y = body weight (kg) and x = d of dietary treatment.

The average daily gain of winter born SUP lambs (males only) was also greater compared with NON (33 g/d ± 8 g/d > -6 g/d ± 8 g/d; P = 0.001), and body weight was lower in NON than SUP by 35 d post-weaning (25.3 kg ± 1.1 kg < 26.5 kg ± 1.1 kg; treatment × d, $P = 0.02$).

Gastrointestinal Nematodes

Fecal egg counts were similar between dietary treatments ($P = 0.282$) and declined with time (day, $P < 0.001$; Fig. 2). The FEC were greater in 2013 than 2014 lambs ($P < 0.001$) and greater in rams than ewes (651 eggs/g ± 96 eggs/g > 187 eggs/g ± 27 eggs/g; $P < 0.001$). The PCV was lower between d 28 and d 42 in the 2014 lambs and SUP improved or increased PCV around this time in both years (treatment × yr × d, $P < 0.001$; Fig. 3). The PCV of ram lambs was lower than ewes (28.8% < 29.8% ± 0.26%; P = 0.01). The PCV of the NON 2014 ewe lambs was lower than the others at several time points, and the SUP ewe lambs highest (treatment × sex; $P = 0.002$; data not shown).

The FEC of winter-born lambs were similar ($P = 0.526$) between treatments and were 834 eggs/g ± 325 eggs/g, 3589 eggs/g ± 1399 eggs/g, 275 eggs/g ± 107 eggs/g on d 0, d 14, and d 28 (d, $P < 0.001$). The PCV was increased in SUP compared to NON in winter-born lambs (27.0% > 25.5% ± 0.4%; $P = 0.015$).

Haemonchus contortus was the predominant GIN in 2013 lambs with the exception of d 112, for which *Trichostrongylis* spp. was the predominant GIN (Fig. 4). Otherwise, *Trichostrongylus* spp. was the sub-dominant genera throughout the experiment. On d 42 and d 84, *Haemonchus contortus* was

Fig. 2. Least squares means ± standard error of back-transformed fecal egg counts (FEC) from 2013 and 2014 fall born lambs fed no supplement (NON; n = 17 in 2013; n = 15 in 2014) or supplemented at 0.5% body weight with a by-product grain supplement (SUP; n = 18 in 2013; n = 16 in 2014) while grazing predominantly grass pastures between weaning (d 0) and d 112 post-weaning. Lambs were placed on pasture on d 9 (2013) or d 14 (2014).

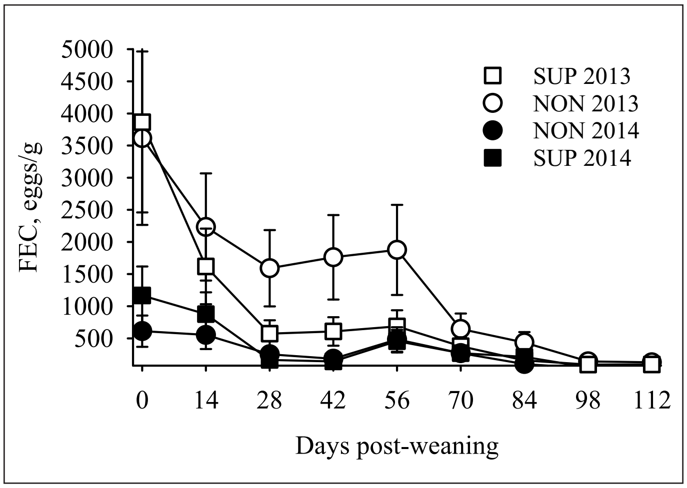


Fig. 3. Least squares means ± standard error of packed cell volume (PCV) from 2013 and 2014 fall born lambs fed no supplement (NON; n = 17 in 2013; n = 15 in 2014) or supplemented at 0.5% body weight with a by-product grain supplement (SUP; n = 18 in 2013; n = 16 in 2014) while grazing predominantly grass pastures between weaning (d 0) and 112 d post-weaning. Lambs were placed on pasture on d 9 (2013) or d 14 (2014).

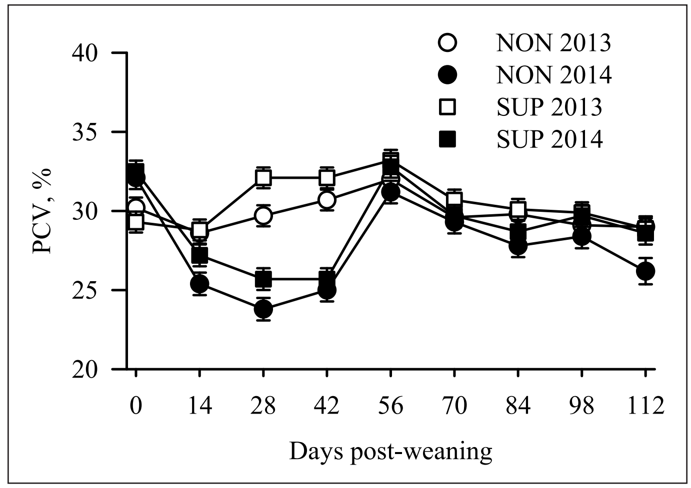
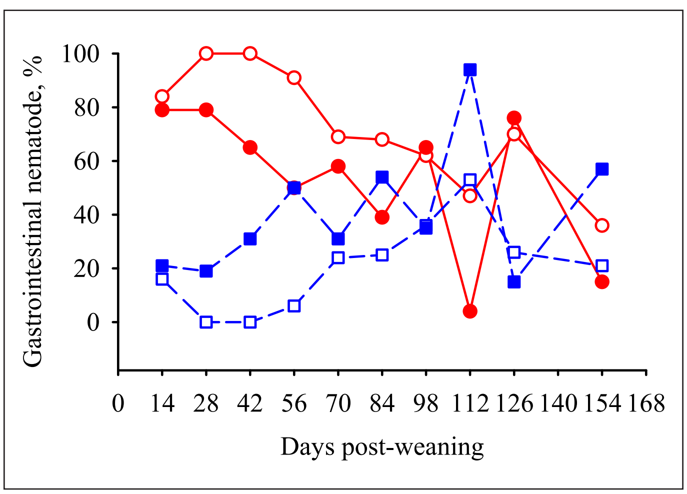


Fig. 4. Proportion of *Haemonchus contortus* (red solid lines) or *Trichostrongylus* spp. (blue dashed lines) larvae in pooled cultured feces from unsupplemented (NON; open symbols) lambs, or 0.5% body weight supplementation (SUP; closed symbols) 2013 fall born lambs 14 to 154 d post-weaning (d 0 = weaning) while grazing predominantly grass pastures. Remaining proportion of larvae were *Cooperia* spp. (0 to 22%) and *Oesophagostomum* spp. (0 to 23%). All lambs received 1 g copper oxide wire particles as a dewormer on d 98.



predominant, followed by *Trichostrongylis* spp., and on d 112 *Trichostrongylis* spp. was predominant in 2014 lambs (Table 4).

Winter Born Lambs

The average daily gain of winter--born SUP lambs (males only) was also greater compared with NON (33 g/day ± 8 g/day > -6 g/day ± 8 g/day; *P* = 0.001), and body weight was lower in NON than SUP by 35 days post-weaning (25.3 kg ± 1.1 kg < 26.5 kg ± 1.1 kg; treatment × day, *P* = 0.02).

The FEC of winter-born lambs were similar (*P* = 0.526) between treatments and were 834 eggs/g ± 325 eggs/g, 3589 eggs/g ± 1399 eggs/g, 275 eggs/g ± 107 eggs/g on days 0, d 14, and d 28 (day, *P* < 0.001). The PCV was increased in SUP compared to NON in winter-born lambs (27.0% > 25.5% ± 0.4%; *P* = 0.015). The predominant genera for the winter-born lambs was *Trichostrongylis* spp. (55%) and *Haemonchus contortus* (45%) on d 0 (weaning).

Pastures Composition and Quality

The botanical composition of forages at the beginning of the trial (January) for the 2013 and 2014 lambs was very similar and primarily consisted of tall fescue (Table 3). Composition was determined again on d 84 of each year with tall fescue remaining the predominant forage. The 2013 fall-born lambs remained on 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 (d 154). However, the 2014 fall-born lambs were removed from tall fescue at d 112 and did not return. Botanical composition is presented for each new forage species grazed (Table 3).

The forage quality analyses for ADF (*P* = 0.686), NDF (*P* = 0.742), CP (*P* = 0.301), and IVDMD (*P* = 0.974) were similar between treatments in 2014 (Fig. 5A and 6A). Forage quality in 2015, ADF (P = 0.507), NDF (*P* = 0.733), CP (*P* = 0.184), and IVDMD (*P* = 0.963), were also similar (Fig. 5B and 6B).

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 with high prevalence of GIN. The

Table 4. Parasite genera for 2014 fall born lambs. Proportion of gastrointestinal nematode genera in pooled fecal culture for grazing lambs and either supplemented (SUP) with grain by-product supplement at 0.5% body weight or offered no supplement (NON).

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

Katahdin is an easy-care breed that fits well into the challenging environment of the southeastern United States because they do not require shearing, can be quite tolerant to GIN (Burke and Miller, 2002; Vanimisetti et al., 2004), and can take advantage of pastureland that is unsuitable as cropland. The fall-born-ram lambs in the current study gained well, meeting a moderate average-daily gain of nearly 200 g/d (NRC, 2007). The higher quality of forage available to the 2014 group of lambs led to greater average-daily-gain providing the nutrients required for growth. Energy needs appeared to be met in lambs born in fall, but protein was limiting in early and late-spring pastures in 2014. Thus, the 0.5% body weight supplementation to the SUP lambs in the first year approached nutrient demands of moderate weight gains. 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 growth at any time point. Using the NRC (2007) values and that lambs consumed forages representative of the sample collection, a late-maturing lamb at 30 kg body weight targeted to gain 200 g/d would be expected to consume 1 kg DM and receive 560 g/d energy as total digestible nutrients (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% in 2014 (Fig. 6), the lamb would receive only 90 g/d and not meet requirements. But, at a moderate (16% CP) or high (23% CP) level of protein, the lamb would receive 160 g/d or 230 g/d, respectively, exceeding pro-

Fig. 5. Least squares means ± standard error of nutrient contents of forages grazed by 2013 (Panel A) and 2014 (Panel B) fall born lambs between weaning (d 0; mid-January) and d 140 post-weaning (early May). Winter born lambs grazed with 2013 fall born lambs between d 114, coinciding with their d 9 entry, and d 140 (no further forage data for winter born). Measures included neutral detergent fiber (NDF; open circles), acid detergent fiber (ADF; closed circles), and in vitro dry matter digestibility (IVDMD; triangles). There were no treatment effects, therefore data was plotted over days.

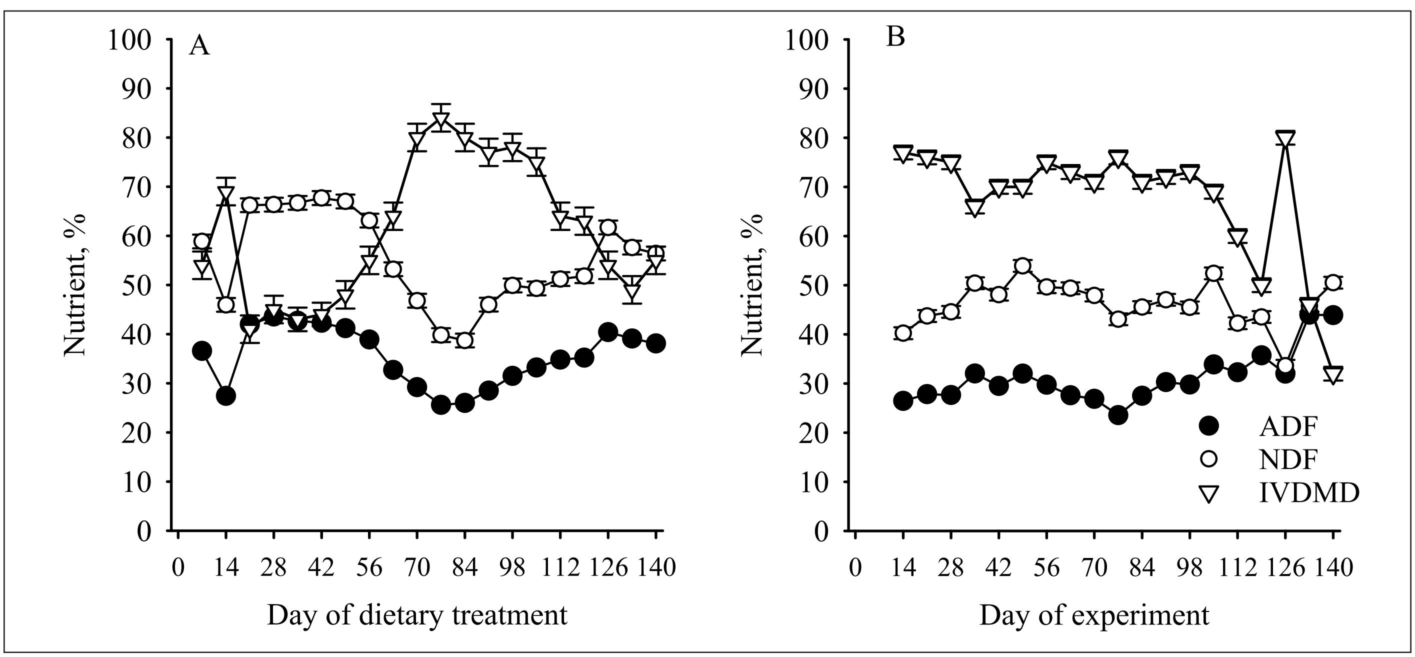
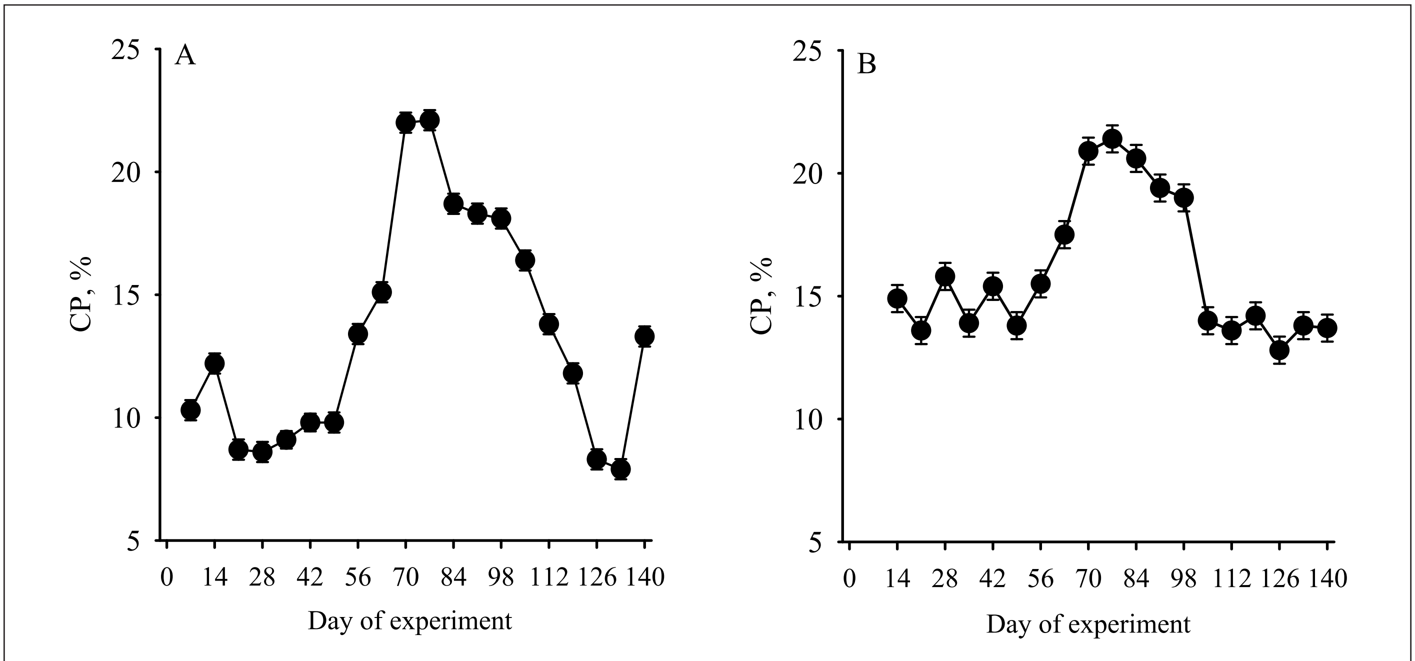


Fig. 6. **Least squares means ± standard error of crude protein (CP) content of forages grazed by 2013 (Panel A) and 2014 (Panel B) fall born lambs between weaning (d 0) and d 112 post-weaning. Winter born lambs grazed with 2013 fall born lambs between d 114, coinciding with their d 9 entry, and d 140 (no further forage data for winter born). There were no treatment effects, therefore day means are presented.**



tein requirements. Calculating TDN [TDN = 96.35 – (% ADF × 1.15)] from published values of ADF (20% to 37%; Poore et al., 2006) results in TDN values of 54% to 73%, which should meet (or nearly meet at lower levels in 2014) energy needs of lambs. Therefore, in this example, when forage CP content is low, added supplement will help lambs to meet protein requirements, although still fall short.

Winter-born lambs were initially placed on predominantly tall-fescue paddocks. Tall fescue is known to have adverse effects on growth of lambs (Hemken et al., 1979; Parish et al., 2003) due to an association of the fungus *Epichloë coenophilia* and the plant that produces ergot alkaloids (Schmidt et al., 1982). Ergot alkaloid concentrations usually increase as temperatures warm (Rottinghaus et al., 1991). Thus, in addition to lower-forage quality when lambs first entered paddocks, lambs were likely affected by the tall-fescue toxins, leading to body weight loss in NON lambs and nominal gains in SUP. Heat stress often influences weight gains in livestock, especially before adaptation, which may have occurred in the winter-born lambs and fall-born lambs that had not met finished body weight, contributing to poor gains and these lambs not meeting target body weight. Further, IVDMD was determined to decline with increasing environmental temperature (Allinson, 1971; Henderson and Robinson, 1982), contributing to poor gains in these lambs.

The SUP treatment did not reduce the number of days to reach finishing body weight, which was determined to be a light-body weight suitable for the ethnic market that is widespread in the southeastern United States. The mature body weight of Katahdin rams ranges between 82 kg and 113 kg and ewes between 57 kg and 84 kg (*http://www.katahdins.org* [accessed on 15 September 2017]), but the mature-body weight 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 United States.

We were interested in determining an appropriate finishing system for grass based lamb production in the southeastern United States. By 35 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; lambs had been removed from paddocks), indicating that lambs were more anemic than fall-born lambs in this experiment. Warm-season annuals (soybean, *Glycine max*) were planted to meet the grazing needs of these winter-born lambs, but establishment failed due to inadequate soil moisture. Thus, initially, tall fescue was predominant in their pasture, but was of poor quality, and late-growth-winter annuals became available on another pasture with some sericea lespedeza. The increase in IVDMD on d 126 in the second year likely reflects a large proportion of this warm-season legume. Lambs likely would not have consumed much sericea lespedeza without dams demonstrating grazing (Burke et al., 2012). Thus, without forages with adequate protein and energy, forage finishing should not be attempted using winter-born lambs on a grass pasture. Whether lambs are born in fall or winter, it is apparent that having quality forages on pasture with at least 15% CP is critical.

The low FEC of the 2014 fall-born lambs may have been associated with the increased CP before and after weaning. Increased dietary protein has been reported to increase tolerance to gastrointestinal nematodes (Abbott et al., 1986; Datta et al., 1999; Coop and Kyriazakis, 1999; Steel, 2003). Under a greater challenge in 2013 fall-born lambs, FEC tended to be lower in SUP compared with NON lambs between 28 d to 56 d when forage CP was low. However, the drop in PCV just after weaning was likely associated with stress of weaning, which may lower tolerance to GIN. Similarly, PCV of the winter born SUP lambs was greater than NON lambs.

Even though *H. contortus* was the predominant GIN 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 lower pathogenicity of non-*H. contortus* genera and lower FEC subsequent to weaning led to overall greater tolerance to GIN in fall-born lambs than we have observed in winter-born lambs (Burke and Miller, 2006; Burke et al., 2012). The greater stress of GIN in a fall-lambing system lies with dams exposed to poor-quality grasses before cool-season grasses emerge.

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). Although not measured statistically, the lower proportion of *H. contortus* in the SUP 2013 fall-born lambs could have been associated with more protein in the diet which did not occur the subsequent year when protein was not limiting. However, it is not clear why *H. contortus* would respond differentially than *Trichostrongylus* spp. or other genera present in the gastrointestinal tract.

It was not the primary objective in this study to examine sex 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 average-daily gain were greater, and number of days to finishing less in ram than ewe lambs. Differences existed in GIN measures, favoring ewe lambs likely because more energy was diverted to growth than immune responses in rams compared with ewes (Kyriazakis and Houdijk, 2006). However, physiologically, differences were quite small. The average-daily gain of ram lambs, particularly when protein was not limiting in the forage system, was acceptable to meet requirements of a grass-fed certification.

Conclusion

The addition of minimal by-product grain supplementation to a forage 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 improved tolerance to GIN and improved weight gain in ram but not ewe lambs, although deworming was not necessary for any fall-born lamb. Winter-born lambs were not suitable for a grass-fed system without any supplementation or moderate supplementation in the southeastern United States because of poor growth potential and a greater GIN challenge on pasture. 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.

Acknowledgments

Supported by USDA NIFA Organic Research and Education Initiative (Project No. 2010-51300-21641).

The authors would like to thank Jackie Cherry, Connie Cox, Charles Lee, Sam Tabler, Karen Chapman, Cody Tabler, Hannah Toland, Caleb Crelia, and Ciarra Lubke at the ARS station in Booneville for their assistance with data and sample collection and analyses.

Mention of trade names or commercial products in this manuscript is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. USDA is an equal opportunity provider and employer.

Literature Cited

Abbott, E. M., J. J. Parkins, and P. H. Holmes. 1986. The effect of dietary protein on the pathophysiology of acute ovine haemonchosis. Vet. Parasitol. 20:291–306.

Allinson, D. W. 1971. Influence of photoperiod and thermoperiod on the IVDMD and cell wall components of tall fescue. Crop Sci. 11:456-458.

Animal Welfare Approved. Certified Grassfed by AGW Standards. *http://animalwelfareapproved.us/standards/grassfed/* (Accessed 15 September 2017).

Aurousseau, B., D. Bauchart, X. Faure, A. L. Galot, S. Prache, D. Micol, and A. Priolo. 2007. Indoor fattening of lambs raised on pasture Part 1: influence of stall finishing duration on lipid classes and fatty acids in the longissimus thoracic muscle. Meat Sci. 76:241-252.

Bang, K. S., A. S. Familton, and A. R. Sykes. 1990. Effect of copper oxide wire particle treatment on establishment of major gastrointestinal nematodes in lambs. Res. Vet. Sci. 39:132-137.

Burke, J. M., 2005. Lamb production of Dorper, Katahdin, and St. Croix bred in summer, winter, or spring in the southeastern United States. Sheep and Goat Res. J. 20:51-59.

Burke, J. M., and J. E. Miller. 2002. Relative resistance of Dorper crossbred ewes to gastrointestinal nematode infection compared with St. Croix and Katahdin ewes in the southeastern United States. Vet. Parasitol. 109:265-275.

Burke, J. M., and J. E. Miller. 2006. Evaluation of multiple low dose copper oxide wire particles compared with levamisole for control of Haemonchus contortus in lambs. Vet. Parasitol. 139:145-149.

Burke, J. M., J. E. Miller, J. A. Mosjidis, and T. H. Terrill. 2012. Use of a mixed sericea lespedeza and grass pasture system for control of gastrointestinal nematodes in lambs and kids. Vet. Parasitol. 186:328-336.

Colvin, A.F., S. W. Walkden-Brown, M. R. Knox, and J. M. Scott. 2008. Intensive rotational grazing assists control of gastrointestinal nematodosis of sheep in a cool temperature environment with summer-dominant rainfall. Vet. Parasitol. 153:108-120.

Coop, R. L., and I. Kyriazakis I. 1999. Nutrition-parasite interaction. Vet. Parasitol. 26:951-962.

Cox, R. B., C. R. Kerth, J. G. Gentry, J. W. Prevatt, K. W. Braden, and W. R. Jones. 2006. Determining acceptance of domestic forage- or grain-finished beef by consumers from three southeastern U.S. states. J. Food Sci. 71:542-546.

Datta, F. U., J. V. Nolan, J. B. Rowe, G. D. Gray, and B. J. Crook. 1999. Long-term effects of short-term provision of protein-enriched diets on resistance to nematode infection, and live-weight gain and wool growth in sheep. Int. J. Parasitol. 29:479-488.

De Brito, G. F., E. N. Ponnampalam, and D. L. Hopkins. 2017. The effect of extensive feeding systems on growth rate, carcass traits, and meat quality of finishing lambs. Comp. Rev. Food Sci. Food Safe. 16:23-38.

Hemken, R. W., L. S. Bull, J. A. Boling, E. Kane, L. P. Bush, and R. C. Buckner. 1979. Summer fescue toxicosis in lactating dairy cows and sheep fed experimental strains of ryegrass-tall fescue hybrids. J. Anim. Sci. 49:641-646.

Henderson, M. S., and D. L. Robinson. 1982. Environmental influences on yield and in vitro true digestibility of warm-season perennial grasses and the relationships to fiber components. Agron. J. 74:943–946.

Holden, L. A., 1998. Comparison of methods of in vitro dry matter digestibility for ten feeds. J. Dairy Sci. 82: 1791-1794.

Katahdin Hair Sheep International. Breed Standard. *http://www. katahdins.org/about-the-breed/breed-standard/* (Accessed 15 September 2017).

Kyriazakis, I., and J. Houdijk. 2006. Immunonutrition: Nutritional control of parasites. Sm. Rumin. Res. 62:79-82.

Littell, R. C., G. A. Milliken, W. W. Stroup, and R. D. Wolfinger. 1996. SAS system for mixed models. Cary, NC. SAS Institute, Inc.

Lozier, J., E. Rayburn, and J. Shaw. 2005. Growing and selling pasture-finished beef: Results of a nationwide survey. J. Sustain. Agric., 25:93-112.

Mannetje, L. T., and K. P. Haydock. 1963. The dry-weight-rank method for the botanical analysis of pasture. J. Brit. Grassl. Soc. 18:268-275.

McClure, K. E., R. W. Van Keuren, and P. G. Althouse. 1994. Performance and carcass characteristics of weaned lambs either grazed on orchardgrass, ryegrass or alfalfa or fed all-concentrate diets in drylot. J. Anim. Sci. 72:3230-3237.

Muir, P. D., J. M. Deaker, and M. D. Bown. 1998. Effects of forage and grain-based feeding systems on beef quality: A review. N. Zeal. J. Agric. Res. 41:623-635.

NRC, 2007. Nutrient Requirements of Small Ruminants: Sheep, Goats, Cervids, and New World Camelids. The National Academies Press. Washington, DC.

Parish, J. A., M. A. McCann, R. H. Watson, C. S. Hoveland, L. L. Hawkins, N. S. Hill, and J. H. Bouton. 2003. Use of nonergot alkaloid-producing endophytes for alleviating tall fescue toxicosis in sheep. J. Anim. Sci. 81:1316-1322.

Peña, M. T., J. E. Miller, M. E. Fontenot, A. Gillespie, and M. Larsen. 2002. Evaluation of Duddingtonia flagrans in reducing infective larvae of Haemonchus contortus in feces of sheep. Vet. Parasitol. 103:259-265.

Penning, P. D., Parsons, A. J., Orr, R. J., and Hooper, G. E., 1994. Intake and behavior responses by sheep to changes in sward characteristics under rotational grazing. Grass and For. Sci. 49: 476-486.

Poore, M. H., M. E. Scott, and J. T. Green, Jr. 2006. Performance of beef heifers grazing stockpiled fescue as influenced by supplemental whole cottonseed. J. Anim. Sci. 84:1613-1625.

Rottinghaus, G. E., B. B. Garner, C. N. Cornell, and J. L. Ellis. 1991. HPLC method for quantitating ergovaline in endophyte-infested tall fescue: seasonal variation of ergovaline levels in stems with leaf sheaths, leaf blades, and seed heads. J. Agric. Food Chem. 39:112-115.

Schmidt, S. P., C. S. Hoveland, E. M. Clark, N. D. Davis, L. A. Smith, H. W. Grimes, and J. L. Holliman. 1982. Association of an endophytic fungus with fescue toxicity in steers fed Kentucky 31 tall fescue seed or hay. J. Anim. Sci. 55:1259-1263.

Steel, J. W. 2003. Effects of protein supplementation of young sheep on resistance development and resilience to parasitic nematodes. Aust. J. Agric. Res. 27:277-286.

USDA AMS, 2007. United States standards for livestock and meat marketing claims, grass (forage) fed claim for ruminant livestock and the meat products derived from such livestock. AMS-LS-07-0113.

Vanimisetti, H. B., S. L. Andrew, A. M. Zajac, and D. R. Notter. 2004. Inheritance of fecal egg count and packed cell volume and their relationship with production traits in sheep infected with Haemonchus contortus. J. Anim. Sci. 82:1602-1611.

Whitlock, H. V. 1948. Some modifications of the McMaster Helminth egg-counting technique apparatus. J. Counc. Sci. Ind. Res. 21:177-180.