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Research Paper

The effects of alternative weaning strategies on lamb health and performance☆

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ABSTRACT

Two experiments were conducted to determine the effects of weaning age on lamb growth and the severity of parasitic infection in grazing lambs. All lambs were fed in a feedlot until they reached a set marketable weight after their allocated grazing period. In experiment 1, 48 Hampshire × Dorset and Suffolk × Dorset crossbred lambs and 24 Dorset × Suffolk and Dorset × Hampshire crossbred ewes were placed into one of two weaning treatments for 63 days: Pasture control (PC): lambs weaned early at 60 days of age and placed on pasture and Ewe (E): Lambs placed on pasture at 60 days of age with ewe and weaned at approximately 123 days of age. The E lambs had a greater average final body weight, total ADG, and PCV value on day 63 compared to PC lambs during the grazing period ($P < 0.05$). In the feedlot, E lambs spent fewer days in the feedlot to reach market weight and had a greater overall ADG with PC lambs demonstrating a greater G:F and total DMI ($P < 0.05$). In experiment 2, a total of 72 crossbred lambs and 27 crossbred ewes were placed into one of four weaning treatments for 56 days: Pasture control (PC). Ewe (E): lambs weaned at approximately 116 days of age. Social facilitator (SF): lambs weaned at 60 days of age and placed on pasture with non-lactating, non-related ewes. Feedlot control (FC): lambs weaned at 60 days of age and placed in a research feedlot facility. Feedlot control lambs were not re-exposed to parasites after the initiation of the experiment and therefore included as an industry standard control. The E lambs demonstrated greater BW from day 42 to the end of the grazing period and FC lambs had the lowest BW from day 7 to day 28 and a greater ADG on day 56 of the grazing period ($P < 0.05$). The E and FC lambs also demonstrated a smaller difference in change in PCV values from day 28 to the end of the grazing period ($P < 0.05$). In the feedlot, E lambs required less total weight gain and had lower DMI compared to all other treatments to reach market weight ($P < 0.05$). The FC lambs had a greater total weight gain, DMI, and G:F compared to all other treatments ($P < 0.05$). The results from these two experiments demonstrate that extending the weaning age of lambs beyond 60 days of age in pasture-based systems can be beneficial from an animal health standpoint and requires less harvested grain in the feedlot to reach a market appropriate endpoint.

1. Introduction

In the absence of human interference, lambs will naturally wean between 100 and 180 days of age (Arnold et al., 1979). However, natural weaning rarely occurs in a production setting and early weaning (i.e. immediate dissolution of the ewe-lamb bond prior to the natural weaning age) is performed due to several factors including, but not limited to; labor, pasture and feedstuff availability, pasture quality (Orgeur et al., 1998; Napolitano et al., 2008), and lamb weight and age (Karakuş, 2014). It is a common practice in intensive sheep operations such as those found in the Eastern United States for weaning to occur as early as 60 days of age (Ricketts, 1999; Barkley, 2014).

Early weaning can be advantageous from a management standpoint; however, previous research suggests that early weaning results in an acute stress response. Lambs artificially weaned demonstrate both physiological and behavioral deviations associated with the weaning process including elevated cortisol levels (Mears and Brown, 1997; Rhind et al., 1998) and increased locomotion and vocalizations

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(Alexander and Shillito, 1977; Schichowski et al., 2008). In addition, weaning stress can also negatively impact the overall health and production of the lamb as shown in decreased growth rates (Lee et al., 1990) and increased susceptibility to disease and infection (Orgeur et al., 1998).

Furthermore, maintaining the ewe-lamb bond plays a critical role in providing the lamb with milk, which delivers high levels of easily digestible protein during peak lactation at 20–30 days post-partum (Cardellino and Benson, 2002) to sustain the growth and development of a single lamb or set of twin lambs (Snowder and Glimp, 1991). High milk production and continued suckling after peak lactation may result in greater lamb growth. Lambs that are nursing low milk producing ewes may resort to consuming more forage to compensate for the reduced intake of milk (Morgan et al., 2007). However, if these lambs are also provided quality forage, they can have similar growth rates compared to lambs nursing high milk producing ewes (Morgan et al., 2007).

However, geographical location, environmental factors (temperature and rainfall), and forage type can cause forage availability and quality to be highly variable (Buxton, 1996). For instance, in temperate regions, the onset of higher temperatures reduces the growth of cool season grasses and decreases forage availability and quality (Brummer and Casler, 2014). Due to a decrease in forage quality over the latter portion of the grazing season, producers may choose to wean and graze lambs during the spring months to take advantage of optimum forage growth (McCutcheon, 2014). However, a potential negative impact of weaning that is of particular concern for producers raising lambs on permanent pasture-based systems is that lamb health may already be compromised by parasitic infection with *Haemonchus contortus*.

Haemonchus contortus, commonly referred to as the barber's pole worm, is a gastrointestinal parasite that primarily attaches to the mucosa of the abomasal wall (Besier and Love, 2003). Inflammation and injury occur at the site of attachment and results in severe blood loss and generalized malabsorption (Beck et al., 1985). Parasitic infection, like most diseases, will be greatest amongst animals who exhibit a compromised immune response as a result of chronic stress (Etim et al., 2013). In a young lamb's life (prior to 16 weeks of age), weaning is by far one of the greatest multifactorial stressors experienced (Karakuş, 2014).

Recognizing the impact that weaning stress has on the health and productivity of pasture-raised lambs, identifying alternative weaning strategies is critical not only to improve the welfare of the lamb, but to mitigate factors which decrease the function of the immune system and increase susceptibility to parasitic infection. Thus, the objective of these experiments was to evaluate the effects of alternative weaning strategies on lamb growth and health when placed on pastures known to be infected with parasites.

2. Materials and methods

The Ohio State University Institutional Animal Care and Use Committee approved the protocols for these experiments. The animals were cared for in accordance with the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010).

2.1. Experiment 1

2.1.1. Animals and housing

A total of 48 HampshireDorset and Suffolk x Dorset crossbred lambs and 24 Dorset × Suffolk and Dorset × Hampshire crossbred ewes were studied at the Ohio Agricultural Research and Development Center (OARDC) Sheep Unit (Wooster, Ohio, USA) over the summer of 2014. The experiment was initiated in July 2014 and ended in September 2014 for a trial period of 63 days. The conclusion of the trial at 63 days was based upon a decrease in forage growth and dry matter availability. Twin lambs (ewes and wethers), approximately 60 days of age, with an initial average body weight (BW) of 23.8 ± 3.7 kg were allotted by sex, blocked by BW and mineral type (loose mineral vs. block mineral) and randomly assigned to one of two weaning treatments. Each treatment had four replicates with six lambs per replicate.

2.1.1.1. *Weaning treatments*.

1. Pasture Control (PC): Lambs weaned early at 60 days of age and placed on a permanent fescue based pasture in groups of six lambs/paddock for four replicates; n = 24 lambs.
2. Ewe (E): Lambs placed on a permanent fescue based pasture at 60 days of age with their ewe in groups of six lambs/paddock with six ewes/paddock for four replicates; n = 24 lambs, 24 ewes. Lambs were weaned late at approximately 123 days of age.

Pasture-raised lambs (PC and E treatments) were placed on a 3.6-ha grazing plot divided into four replicated pastures. Animals were grazed on an established pasture dominant (90%) in tall fescue (*Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.). Each pasture (152.4 m length × 50.0 m width) was divided into two paddocks (8 paddocks total; one replicate/paddock). The paddock sizes for both treatments had equal stocking density, or equal live animal weight per hectare with an average of 26,000 kg/ha for the duration of the trial. Each paddock consisted of six internal divisions made with electrified temporary fence (VersaNet® Plus, Premier1Supplies, Washington, Iowa, USA). Paddocks were rotationally grazed amongst the six internal divisions, as described by Barger et al. (1994), such that animals were moved every three days to prevent further parasitic infection (Hsu and Levine, 1977; O'Connor et al., 2006) and allowing for approximately 21 days of rest and regrowth for each internal division. *Ad libitum* access to water and one of two mineral sources (described in *Pasture measurements*) were provided and checked daily.

After the completion of the grazing portion of the trial, lambs were placed and housed in a sheep research feedlot facility during the feedlot phase. The length of the feedlot phase ranged from 71 to 103 days based upon a set targeted finishing weight. Each replicate was housed in a pen (4.1 m length × 1.5 m width) on expanded metal flooring with three metal gates and a wooden fence line feed bunk (3.7 m length × 0.3 m width × 0.3 m depth) on the fourth side. Sheep were provided *ad libitum* access to water (0.3 m length × 0.2 m width) via an automatic waterer (Ritchie® Industries Inc., Conrad, Iowa, USA) and fed a diet consisting of 55% dry rolled corn, 25% alfalfa haylage, and 20% supplement pellet to meet or exceed recommended nutrient requirements (Supplementary Table 1; NRC, 2007).

2.1.2. Pasture measurements

Forage quality samples were collected randomly via grab samples (i.e. collecting handfuls of forage as to mimic the grazing motion of a sheep) every two weeks from each paddock (n = 8) over the course of the trial. At the end of the trial, samples from each paddock were combined and analyzed as an average for forage quality per treatment group (Rock River Laboratory, Inc., Wooster, Ohio, USA).

In addition, two mineral sources (Loose mineral: VitaFerm Sheep Mineral, BioZyme® Inc., St. Joseph, Missouri, USA; Block mineral: Morton TM salt block with Selenium, Morton Salt Inc., Chicago, Illinois, USA) were evaluated to determine the impact of form of mineral on animal health and performance. Mineral form was randomly allotted to paddocks to provide equal replication across weaning treatments and was provided throughout the duration of the trial.

2.1.3. Lamb performance and health

2.1.3.1. *Lamb performance*. Body weights were collected on days 0, 29, 42, 57, and 63 of the trial. Lamb weights were collected utilizing a portable balance beam livestock scale (WW Paul Scales, Duncan, Oklahoma, USA). Average Daily Gain (ADG) was calculated by taking the difference in BW between consecutive collection points and dividing by the number of days between each collection point.

2.1.3.2. Lamb health. All lambs were treated with moxidectin at 0.2 mg/kg (Cydectin® Oral Sheep Drench, Boehringer Ingelheim, Ingelheim am Rhein, Germany) on days −14 and 0 of trial to treat any current parasitic infection. Eye scores were utilized to evaluate parasitic infection severity and assessed using the 1–5 FAMACHA© method (Kaplan et al., 2004; Burke et al., 2007; Zajac et al., 2014) on days 29, 42, 49, 57, and 63 of the trial. Eye scores were obtained from either the right or left eye.

Blood samples were collected on days 42 and 63 of the trial to determine packed cell volume (PCV). Blood samples were also collected on days 29, 49, and 57 if a FAMACHA© test resulted in an eye score of 3 or greater. A total of 5.0 mL of blood was collected via jugular venipuncture. All lambs were handled via manual restraint of the head during blood collection. Once blood samples were collected, a subsample was placed into a microhematocrit capillary tube and centrifuged (model no. C-MH30; UNICO®, Dayton, New Jersey, USA) at 2000 rpm for five minutes. Circulating red blood cell percentage was calculated utilizing a microhematocrit capillary tube reader (Damon/IEC Division; American Laboratory Trading, Inc., East Lyme, Connecticut, USA). Throughout the study, sheep were treated when PCV values were less than or equal to 21% based upon consultation with the university veterinarian. Due to experimental design, young lamb's health status were assessed once every 14 days. Frequent monitoring of lamb health was crucial as previous observations at OARDC have shown increased mortality due to parasitic infection when PCV values were less than or equal to 21%. Therefore, to minimize the welfare and production concerns associated with parasitic infection, all lambs with a PCV of 21% or below were treated with moxidectin.

Fecal samples were collected on days 42 and 63 of the trial by obtaining approximately 4 g of feces from the rectum via rectal palpation. Once collected, samples were weighed, placed into plastic cups with 7.0 mL of water per gram of feces, and placed into a refrigerator overnight. Twenty-four hours post collection, fecal samples were mixed with 7.0 mL of Fecasol® solution (Vétoquinol USA Inc., Fort Worth, Texas, USA) per gram of feces. Fecal egg counts were quantified utilizing the McMaster technique (Gordon and Whitlock, 1939; Levecke et al., 2009). Strongyle type eggs, which include the main parasite species of interest *Haemonchus contortus*, were identified and quantified using fecal egg microscopy. Conversely, other species may have been present on pasture, however these species were not identified or quantified.

2.1.4. Statistical analysis

Lamb performance and health data were analyzed using SAS software (version 9.4; SAS Institute Inc., Cary, North Carolina, USA). To determine differences in lamb health and performance for each treatment (PC vs. E), a generalized linear mixed model (PROC MIXED) with a split plot design was used. The model included treatment (PC vs. E) and mineral source (block vs. loose), with treatment and mineral as a fixed effect. Measurements were analyzed based on the day (29, 42, 49, 57, and 63) in which they were collected. Pasture and pen were included as random effects. Treatment means were compared with Fisher's protected LSD using the LSMEANS option in SAS when protected by a significant ($P < 0.05$) F-value and reported with the standard error of the mean. Based upon PCV readings on day 42, a total of 10 lambs needed treatment and therefore data from these individuals were excluded from the analysis for day 63 as these values would compromise the accuracy of the PCV and FEC results (Burke et al., 2009; Turner et al., 2016). The percentages of lambs dewormed per treatment are provided descriptively in the results section.

2.2. Experiment 2

2.2.1. Animals and housing

A total of 72 Hampshire x Dorset and Suffolk x Dorset crossbred lambs and 27 Dorset and Dorset x Suffolk crossbred ewes were studied at the OARDC Sheep Unit over the summer of 2015. The experiment was initiated in July 2015 and ended in September 2015 for a trial period of 56 days. The conclusion of the trial at 56 days was based upon a decrease in forage growth and dry matter availability. Twin lambs (ewes and wethers), approximately 60 days of age, with an initial average BW of 17.9 ± 2.4 kg were allotted by sex, blocked by BW and randomly assigned to one of four weaning treatments. Each treatment had three replicates with six lambs per replicate.

2.2.1.1. Weaning treatments.

1. Pasture control (PC): Lambs weaned early at 60 days of age and placed on a permanent fescue based pasture in groups of six lambs/paddock for three replicates; n = 18 lambs.
2. Ewe (E): Lambs placed on a permanent fescue based pasture at 60 days of age with their ewe in groups of six lambs/paddock with six ewes/paddock for three replicates; n = 18 lambs, 18 ewes. Lambs were weaned late at approximately 116 days of age.
3. Social facilitator (SF): Lambs weaned early at 60 days of age and placed on a permanent fescue based pasture in groups of six lambs/paddock with three mature, non-lactating, non-related ewes/paddock for three replicates; n = 18 lambs, 9 ewes.
4. Feedlot control (FC): Lambs weaned early at 60 days of age and placed in a research feedlot facility in groups of six lambs/pen for three replicates; n = 18 lambs.

Pasture-raised lambs (PC, E, and SF treatments) followed a similar protocol as described in experiment 1, except sheep were housed on a 4.0-ha grazing plot divided into five replicated pastures (9 paddocks total; one replicate/paddock) and provided only loose mineral as previously described. Animals were grazed on an established pasture dominant (90%) in tall fescue (*Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.).

Feedlot raised lambs (FC treatment) and all lambs during the finishing phase of the trial were housed in the same sheep research facility as described in experiment 1. The length of the feedlot phase ranged from 76 to 109 days based upon a set targeted finishing weight. Lambs were fed a diet consisting of 70% whole shelled corn, 15% supplement pellet, 10% alfalfa pellets, and 5% soyhulls to meet or exceed recommended nutrient requirements (Supplementary Table 1; NRC, 2007).

2.2.2. Pasture measurements

Total parasite load was quantified in all nine paddocks utilizing an elutriator to rapidly extract larvae concentrations from herbage samples. This method was used in order to verify that each treatment was subjected to similar parasitic exposure and adapted using techniques as described by Cassida et al. (2012). Larvae samples were collected in the elutriator using 10 μm nylon mesh (ELKO Filtering Co. LLC, Miami, Florida, USA). Elutriator samples were collected three times over the course of the trial on days 8, 33, and 53 and the concentration of larvae populations were calculated as follows (Cassida et al., 2012):

$$\text{Density (Larvae g}^{-1}\text{ DM)} = \frac{\text{(number of larvae counted)}}{\text{count volume (mL)}} \text{x} \frac{\text{(extract volume in mL)}}{\text{dry mass of herbage (g)}}$$

Forage quality samples were collected on days 0, 7, 13, 19, 26, 33, 40, 47, and 54 of the trial. Grab samples were collected randomly amongst each paddock in the 4.0-ha grazing plot and combined into one sample. Quality samples were averaged and analyzed (Rock River

Laboratory, Inc., Wooster, Ohio, USA) by collection point as compared to individual paddocks in experiment 1. Forage dry matter samples were collected on days −1, 12, 22, 37, and 47 using a 0.66 m^2 square quadrat, clipping forage to ground level. Samples were collected from each paddock to determine forage allowance with a total of 18 samples per collection period. Quadrat clippings were dried in a 100 °C oven for 48 h in order to calculate the forage mass available per hectare.

2.2.3. Lamb performance and health

2.2.3.1. Lamb performance. Body weights were collected on days 0, 7, 14, 28, 42, and 56 of the trial. Lamb weights and ADG were collected and calculated utilizing the same equipment and technique as outlined in experiment 1.

2.2.3.2. Lamb health. Similar to experiment 1, all lambs were treated with moxidectin on days −21 and 0 of the trial. Eye scores were assessed on days 7, 14, 28, 42, and 56 of the trial. Blood and fecal samples were collected on days 0, 14, 28, 42, and 56 of the trial. All parameters were calculated using the same methods as described in experiment 1.

2.2.4. Statistical analysis

Lamb performance and health data were analyzed using SAS software (version 9.4; SAS Institute Inc., Cary, North Carolina, USA). To determine differences in lamb performance and health for each treatment (PC, E, FC, SF), a generalized linear mixed model method (PROC MIXED) with a Kenward-Roger approximation for degrees of freedom was used. The model included treatment (PC, E, FC, SF), day (0, 7, 14, 28, 42, and 56) and day by treatment interaction as a fixed effect. Day was utilized as the repeated statement with lamb ID based on a group included as the subject. A *P*-value of ($P < 0.05$) was considered significant when evaluating MIXED model effects. When a fixed effect was a significant source of variation, different levels within the fixed effect were separated using the PDIFF option in SAS and reported with a pooled standard error of the mean. Based upon PCV readings on day 42, a total of 14 lambs needed treatment and therefore data from these individuals were excluded from the analysis for day 56 as these values would compromise the accuracy of the PCV and FEC results (Burke et al., 2009; Turner et al., 2016). The percentages of lambs dewormed per treatment are provided descriptively in the results section.

3. Results

3.1. Experiment 1

3.1.1. Pasture measurements

Forage quality pooled samples for each paddock in experiment 1 are shown in Supplementary Table 2. Over the duration of the trial, the average crude protein of the grazing plot was 19.64%.

3.1.2. Mineral

In the grazing portion of the trial with pasture-raised lambs, no differences in lamb BW or lamb health status (i.e. FAMACHA© eye scores, PCV, and FEC) were noted when comparing mineral type ($P > 0.05$). However, a difference in lamb overall ADG on pasture was observed in which lambs consuming loose mineral had a greater total ADG when compared to lambs consuming block mineral ($P < 0.05$; Table 1).

3.1.3. Lamb performance and health

3.1.3.1. Lamb pasture performance. Lamb pasture performance and health data for experiment 1 are presented in Table 1. There was a treatment effect on lamb performance during the grazing portion of the trial. There were no differences in lamb BW on day 0 at the initiation of the trial ($P > 0.05$). By day 63, lambs in E treatment group demonstrated greater BW compared to PC group ($P < 0.001$) and lambs in E treatment group had greater overall ADG compared to the PC group on day 63 ($P < 0.05$). No other differences were found.

3.1.3.2. Lamb pasture health. There was a treatment effect on lamb health during the grazing portion of the trial when analyzed based upon collection date ($P < 0.05$) as shown in Table 1. On day 42, lambs in PC treatment group exhibited a higher average FAMACHA© eye score compared to lambs in E treatment group ($P < 0.05$). On day 63, lambs in E treatment group, including all lambs on trial and lambs not dewormed during the trial, had a greater average PCV value compared to PC treatment group ($P < 0.05$). On day 42, lambs in E treatment group had a lower average FEC value compared to lambs in PC treatment group ($P < 0.05$). A total of 41.7% of lambs in the PC group received anthelmintic treatment during the trial whereas no lambs in the E treatment group received anthelmintic treatment.

3.1.3.3. Lamb feedlot performance. There was a treatment effect on lamb performance during the feedlot phase of the trial ($P < 0.05$; Table 2). Lambs in E treatment group had greater average BW when entering the feedlot, spent fewer number of days in the feedlot, and a greater overall ADG when compared to lambs in PC treatment group ($P < 0.01$). Lambs in the PC treatment group demonstrated a higher gain to feed ratio (G: F; $P < 0.05$) and greater total DMI when compared to E treatment group ($P < 0.01$).

3.2. Experiment 2

3.2.1. Pasture measurements

Parasite concentrations between each paddock were not different across all collection days ($P > 0.05$; Supplementary Table 3). Forage quality samples from the entire grazing plot based on collection day in experiment 2 are shown in Supplementary Table 4. Over the duration of the grazing portion of the trial, the average crude protein of the grazing plot was 13.49%. Forage dry matter samples for experiment 2 are shown in Supplementary Table 5.

3.2.2. Lamb performance and health

3.2.2.1. Lamb pasture performance. Lamb performance data during the grazing portion of the trial for experiment 2 is presented in Table 3. There was a treatment, day, and treatment by day effect on lamb BW ($P < 0.001$) with no differences in lamb BW noted between treatments on day 0 ($P > 0.05$). On days 7 and 14, lambs in FC treatment group had lower BW compared to all other treatment groups ($P < 0.05$). On day 28, lambs in FC treatment group had lower BW when compared to all other treatment groups ($P < 0.01$), and lambs in E treatment group demonstrated greater BW when compared to all other treatment groups ($P < 0.05$). On day 42, lambs in E treatment group had greater BW when compared to all other treatment groups ($P < 0.0001$). On day 56, lambs in E treatment group demonstrated greater BW when compared to all other treatments ($P < 0.001$), and lambs in FC treatment group had greater BW when compared to PC treatment group ($P < 0.05$).

From BW measurements, ADG was calculated and presented in Table 3. There was a treatment, day, and treatment by day effect on ADG ($P < 0.0001$). On day 7, lambs in FC treatment group had lower ADG when compared to all other treatment groups ($P < 0.0001$). On day 14, lambs in E treatment group had greater ADG when compared to FC and SF treatment groups ($P < 0.01$), and lambs in PC treatment group had greater ADG when compared to FC treatment group ($P < 0.05$). On day 28, lambs in E treatment group demonstrated greater ADG when compared to FC treatment group ($P < 0.05$). On day 42, lambs in E treatment group demonstrated greater ADG when compared to PC and SF treatment groups ($P < 0.001$), and lambs in FC treatment group had greater ADG when compared to PC treatment group ($P < 0.01$). On day 56, lambs in FC treatment group demonstrated greater ADG when compared to all other treatment groups

Table 1
Effects of alternative weaning strategies on lamb performance and health during the grazing portion of the trial in Exp. 1.

	Treatment			Mineral			P − Value	
Item	Ewe	Pasture Control	SEM	Block	Loose	SEM	Lamb	Mineral
No. of lambs	24	24	–	24	24	–	–	–
BW, kg								
d 0	23.6	24.0	0.43	23.9	23.7	0.53	0.3561	0.8132
d 63	39.6	30.3	0.57	33.9	36.0	0.76	0.0001	0.1432
Total ADG, g/day	254	100	6.0	159	195	6.0	0.0004	0.0280
FAMACHA© [a]								
d 29	1.1	1.4	0.1	1.4	1.1	0.1	0.1522	0.2658
d 42	1.3	2.6	0.4	2.0	1.8	0.5	0.0455	0.8065
d 49	1.1	2.3	0.3	1.8	1.6	0.3	0.0720	0.7001
d 57	1.1	2.4	0.3	2.0	1.5	0.3	0.0677	0.3892
d 63	1.2	2.1	0.4	2.0	1.4	0.4	0.1608	0.3829
Packed Cell Volume, %								
d 42	34.3	27.4	2.0	31.3	30.5	2.3	0.0510	0.8200
d 63	33.1	28.7	0.6	31.1	30.7	0.6	0.0127	0.6216
Fecal Egg Count, eggs/g								
Transformed, log (x + 10)								
d 42	4.5	7.9	0.66	5.8	6.6	0.83	0.0103	0.5617
d 63	7.1	7.0	0.51	7.2	6.9	0.68	0.0787	0.7724
Back-transformed								
d 42	80.0	2687.3	–	320.3	725.1	–	–	–
d 63	1202.0	1086.6	–	1329.4	982.3	–	–	–
Lambs not dewormed								
PCV d 63	33.1	29.4	0.6	31.7	30.8	0.6	0.0181	0.3267
FEC d 63								
Transformed, log (x + 10)	7.1	7.5	0.41	7.5	7.1	0.50	0.4462	0.6584
Back-transformed	1212	1808	–	1808	1212	–	–	–

[a] FAMACHA© Eye Score color chart: '1' = red, non-anemic mucous membrane; '2' = red- pink, non-anemic mucous membrane; '3' = pink, mildly anemic mucous membrane; '4' = pink-white, anemic mucous membrane; '5' = white, severely anemic mucous membrane.

Table 2
Effects of alternative weaning strategies on lamb performance during the feedlot phase of the trial in Exp. 1.

	Treatment			Mineral			P − Value	
Item	Ewe	Pasture Control	SEM	Block	Loose	SEM	Lamb	Mineral
Initial Wt, kg	39.6	30.3	0.57	33.9	36.0	0.76	0.0001	0.1432
Final Wt, kg	55.0	54.1	1.11	54.1	55.1	1.51	0.2184	0.6520
Days in feedlot	71.0	102.5	2.5	88.5	85.0	2.5	0.0029	0.3910
Feedlot ADG, g/d	217	234	7.0	227	223	7.0	0.1808	0.7513
Overall ADG, g/d	235	183	5.0	203	214	6.0	0.0016	0.2522
DMI, kg/d	1.3	1.3	0.03	1.3	1.3	0.04	0.0787	0.5996
G:F, kg/kg	0.16	0.19	0.003	0.17	0.18	0.003	0.0106	0.7693
Total DMI, kg	94.4	128.9	4.7	115.0	108.3	6.1	0.0025	0.4928

($P < 0.0001$).

3.2.2.2. Lamb pasture health. Lamb FAMACHA© eye scores, PCV, and FEC values during the grazing portion of the trial are reported as differences from baseline values with the baseline represented as day 7 for FAMACHA© eye scores and day 0 for PCV and FEC values as shown in Table 4. Differences were reported to illustrate the overall change in the lamb's health status as a result of each alternative weaning strategy. A total of 5, 50, and 55% of lambs in FC, PC, and SF treatment groups received anthelmintic treatment during the trial whereas no lambs in the E treatment group received anthelmintic treatment. Lambs were only treated when an individual's PCV value were less than or equal to 21%, thus indicating that those lambs in the E treatment group never demonstrated PCV values that were below this threshold.

There was a day and treatment by day effect on the difference in FAMACHA© lamb eye scores ($P < 0.0001$). On day 42, lambs in E treatment group demonstrated a smaller difference in change between FAMACHA© eye scores at day 42 and baseline day 7 when compared to FC and PC treatment groups ($P < 0.05$). On day 56, lambs in PC treatment group demonstrated a greater difference in change between FAMACHA© eye scores at day 56 and baseline day 7 when compared to all treatment groups ($P < 0.05$). Lambs in SF treatment group demonstrated a greater difference in change between FAMACHA© eye scores at day 56 and baseline day 7 when compared to E treatment group ($P < 0.01$).

For differences in lamb PCV, there was a treatment, day, and treatment by day effect ($P < 0.0001$). On day 14, lambs in FC treatment group demonstrated a smaller difference in change between PCV values at day 14 and baseline day 0 compared to lambs in PC treatment group ($P < 0.05$). On days 28, 42 and 56, lambs in E and FC treatment groups demonstrated a smaller difference in change between PCV values at days 28, 42 and 56 and baseline day 0 compared to PC and SF treatment groups ($P < 0.05$). When evaluating lambs not dewormed during the trial on day 56, lambs in E and FC treatment groups demonstrated a smaller difference in change between PCV values at day 56 and baseline day 0 when compared to PC and SF treatment groups

Table 3
Effects of alternative weaning strategies on lamb performance during the grazing portion of the trial in Exp. 2.

Item	Pasture Control	Ewe	Social Facilitator	Feedlot control	SEM[d]
No. of lambs	18	17	18	18	–
BW, kg					
d 0	17.8	18.3	18.0	17.8	0.85
d 7	20.7[a]	21.6[a]	21.1[a]	18.3[b]	0.85
d 14	21.5[a]	23.2[a]	21.7[a]	18.5[b]	0.85
d 28	22.7[b]	25.3[a]	22.6[b]	19.1[c]	0.85
d 42	24.5[b]	30.3[a]	25.0[b]	22.8[b]	0.85
d 56	24.6[b]	31.5[a]	25.1[bc]	27.3[c]	0.85
ADG, g/d					
d 7	410[a]	480[a]	440[a]	80[b]	36
d 14	120[ab]	220[a]	80[bc]	20[c]	36
d 28	80[ab]	150[a]	70[ab]	40[b]	36
d 42	130[b]	360[a]	170[bc]	270[ac]	36
d 56	10[b]	80[b]	10[b]	320[a]	36

[a,b,c]Means within a row with different superscripts differ ($P < 0.05$).
[d] Pooled standard error of the mean.

Table 4
Differences from the initial measurements on the effects of alternative weaning strategies on lamb health during the grazing portion of the trial in Exp. 2.

Item	Pasture Control	Ewe	Social Facilitator	Feedlot Control	SEM[d]
FAMACHA© [e]					
d 14	−0.2	0.3	0.2	0.3	0.22
d 28	−0.1	0.0	−0.3	−0.3	0.22
d 42	0.5[ac]	-0.3[b]	0.1[bc]	0.4[c]	0.22
d 56	1.1[a]	-0.4[b]	0.5[c]	0.1[bc]	0.22
Packed Cell Volume, %					
d 14	-2.2[a]	-1.8[b]	-1.6[b]	0.6[b]	0.95
d 28	-5.9[a]	-2.1[b]	-4.8[a]	-0.8[b]	0.95
d 42	-7.6[a]	-3.1[b]	-9.9[a]	-0.7[b]	0.95
d 56	-8.8[a]	-3.2[b]	-8.7[a]	-2.6[b]	0.95
Fecal Egg Count, eggs/g					
Transformed, log (x = 10)					
d 14	4.0	4.0	3.7	4.2	0.49
d 28	5.5[a]	5.2[ab]	4.9[ab]	4.2[b]	0.40
d 42	7.0[a]	6.6[a]	7.4[a]	4.9[b]	0.39
d 56	8.3[a]	7.3[a]	7.8[a]	5.2[b]	0.46
Back-transformed					
d 14	44.6	44.6	30.4	56.7	–
d 28	234.7	171.3	124.3	56.7	–
d 42	1086.6	725.1	1626.0	124.3	–
d 56	4013.9	1470.3	2430.6	171.3	–
Lambs not dewormed					
PCV d 56	-10.7[a]	-3.2[b]	-10.9[a]	-2.5[b]	1.06
FEC d 56					
Transformed, log (x = 10)	8.9[a]	7.3[b]	8.7[a]	5.2[c]	0.46
Back-transformed	7322	1470	5993	171	–

[a,b,c]Means within a row with different superscripts differ ($P < 0.05$).
[d] Pooled standard error of the mean.
[e] FAMACHA© Eye Score color chart: '1' = red, non-anemic mucous membrane; '2' = red- pink, non-anemic mucous membrane; '3' = pink, mildly anemic mucous membrane; '4' = pink-white, anemic mucous membrane; '5' = white, severely anemic mucous membrane.

($P < 0.0001$).

There was a treatment, day, and treatment by day effect on difference in total lamb FEC ($P < 0.01$). On day 28, lambs in FC treatment group demonstrated a lower difference in change between FEC values at day 28 and baseline day 0 when compared to PC treatment group ($P < 0.05$). On day 42, lambs in FC treatment group demonstrated a lower difference in change between FEC values at day 42 and baseline day 0 when compared to all other treatment groups ($P < 0.01$). On day 56, lambs in FC treatment group demonstrated a lower difference in change between FEC values at day 56 and baseline day 0 when compared to all other treatment groups ($P < 0.001$). When evaluating lambs not dewormed during the trial on day 56, lambs in E treatment group demonstrated a lower difference in change between FEC values at day 56 and baseline day 0 when compared to PC and SF treatment groups ($P < 0.01$) and a greater difference in change between FEC values at day 56 and baseline day 0 when compared to FC treatment group ($P < 0.001$). Lambs in FC treatment group had a lower difference in change between FEC values at day 56 and baseline day 0 when compared to all other treatment groups ($P < 0.0001$). Although FC lambs were not exposed to parasitic infection during the entirety of both phases, it is still appropriate to compare this group to grazing lambs as the FC treatment group is a negative control and is commonly performed in production practices in the eastern United States.

3.2.2.3. Lamb feedlot performance. Lamb feedlot performance data for experiment 2 can be found in Table 5. Lambs in FC treatment group demonstrated a greater number of days in the feedlot ($P < 0.001$), total weight gain ($P < 0.001$), lower DMI per day ($P < 0.001$) and greater G:F ($P < 0.01$) when compared to all other treatment groups. Lambs in E treatment group demonstrated fewer number of days in the feedlot ($P < 0.001$), lower total weight gain ($P < 0.001$), greater DMI per day ($P < 0.01$), and lower total DMI ($P < 0.05$) when compared to all other treatments.

4. Discussion

For any sheep producer, maximizing production efficiency of pasture-raised lambs requires minimizing clinical signs of disease associated with parasitic infection. This involves evaluating alternative management approaches to improve overall health and well-being of the lamb. Therefore, the objective of these experiments was to evaluate the effects of alternative weaning strategies on lamb performance and health when placed in a permanent pasture-based system known to be infected with *H. contortus* as demonstrated by species identification collected from the elutriator and the use of the FAMACHA© eye scoring system.

4.1. Lamb performance

From a performance standpoint, in both experiment 1 and 2, delayed weaning increased final BW and overall ADG when compared to

Table 5
Effects of alternative weaning strategies on lamb performance during the feedlot phase of the trial in Exp. 2.

Item	Pasture Control	Ewe	Social Facilitator	Feedlot Control	SE
No. of pens	3	3	3	3	–
No. of lambs	17	17	18	17	–
Initial Wt in feedlot, kg	24.6[b]	31.4[a]	25.1[b]	17.8[c]	0.29
Final Wt, kg	52.2	52.6	53.7	53.2	0.80
Total Wt gain, kg	27.6[b]	21.1[c]	28.7[b]	35.5[a]	0.89
Total days in feedlot	108.7[b]	76.0[c]	104.3[b]	132.0[a]	3.9
ADG, g/d	269	280	277	255	12
DMI, kg/d	1.4[b]	1.6[a]	1.4[b]	1.2[c]	0.03
G:F, kg/kg	0.18[b]	0.17[b]	0.19[b]	0.23[a]	0.006
Total DMI, kg	151.1[a]	122.1[b]	150.0[a]	152.4[a]	4.8

[a,b,c]Means within a row with different superscripts differ ($P < 0.05$).

lambs placed on pasture without a lactating ewe (PC, SF). This coincides with work conducted by deNicolo et al. (2006) and Knights et al. (2012) that demonstrated that lambs weaned late (91–159 days of age) had greater BW when compared to their counterparts that were weaned early (69–108 days of age).Therefore, based on the results from our study, deNicolo et al. (2006), and Knights et al. (2012), the major factor contributing to the increase in BW and ADG on delayed weaned lambs is the access to milk.

Milk contains unique characteristics and components that play a key role in the rapid growth and development of offspring (Michaelidou, 2008). Components of milk are readily available, highly digestible, and provide an assortment of high quality essential nutrients, such as protein (Galitsopoulou et al., 2015). Recent research has shown that when compared to other domesticated ruminants, ovine milk contains a greater percentage of total protein (Park et al., 2007; Hernández-Ledesma et al., 2011), which could contribute to increased growth and development of the lamb. Proteins can be further broken down into two categories, casein and whey. Previous research has linked whey protein utilization with muscle protein synthesis, disease resistance, and increase growth and development of body systems (Phillips et al., 2009; Hernández-Ledesma et al., 2011).

From a performance standpoint, Morgan et al. (2007) further examined the effect of milk production on the continued growth of nursing lambs. These authors found that lambs were able to maintain similar weight gain, regardless of the ewe's milk production (high producers vs. low producers) as lambs of the low milk producing ewes learned to compensate for the decrease in milk intake by consuming more forage. In our experiments, lambs placed in the PC and SF treatments had lower BW and ADG as they did not have access to milk compared to those lambs remaining with the ewe. Although milk intake and milk components were not directly tested, the research above indicates that milk provides additional nutrients to the lamb resulting increased BW and ADG. In addition, through behavioral observations in a parallel study conducted by our colleagues on the same group of lambs, results showed that lambs allocated to PC and SF treatments groups displayed an increase in overall time spent grazing (unpublished data). Therefore, due to the lack of access to milk, early weaned lambs consumed more forage when compared to the delayed weaned lambs. Therefore, increased forage intake may subject PC and SF treatment group lambs to more parasites and thus result in lower BW and ADG, as increased parasitic burden reduces effective nutrient absorption.

Differences in BW gain were also noted between experiments, with greater final body weight at the conclusion of the grazing period in experiment 1 compared to experiment 2 when evaluating E and PC treatment groups (Experiment 1: 39.6 kg and 30.3 kg vs Experiment 2: 31.5 kg and 24.6 kg). These differences are likely a result of forage quality in which experiment 1 demonstrated a higher average crude protein compared to experiment 2. In addition, experiment 1 consisted of a greater average percentage of ADF with a lower average percentage of NDF compared to the forage in experiment 2. Forages that contain a lower percentage of NDF may result in a greater DMI and therefore greater ADG (Goering et al., 1991; McClure et al., 1994). Both experiments were conducted on the same grazing plot, thus demonstrating the year to year differences in perennial forage growth. Despite that lambs in experiment 1 demonstrated greater BW due to increased forage quality, delayed weaned lambs in both experiments showed a greater BW regardless of forage quality. Therefore, milk may prove to be an important factor contributing to increased growth of delayed weaned lambs compared to those lambs only consuming forage.

Furthermore, few studies in the literature have explored the use of a social facilitator and its effects on animal performance. The research evaluating the use of a social facilitator or trainer animal has primarily focused on cattle in a feedlot setting. In a series of trials, Loerch and Fluharty (2000) showed that the presence of a trainer animal can improve the initial weight gain of recently placed calves upon entering a feedlot system. Additionally, the authors found that when comparing the presence of a trainer cow with recently received calves placed on pasture (14 days prior to entering the feedlot), those calves that were on pasture with a trainer cow demonstrated increased ADG during the first week after feedlot placement when compared to calves that were not placed with trainer cows while on pasture. Conversely, Gibb et al. (2000) found that recently weaned and transported feedlot steers did not show an improvement in weight gain when placed in the feedlot with a trainer cow. These findings by Gibb et al. (2000) corresponds with our results found in Experiment 2 in which the presence of a social facilitator resulted in the same performance as PC treatment group lambs. In our experiment, this result may be due to a lack of interaction between the lamb and social facilitator on pasture, a result of poor ewe selection with limited mothering experience and/or interest in the lambs, or that the environment in which the lambs were placed was not a novel environment as these lambs were not placed into a feedlot, but rather a pasture that they had been previously housed on.

Moreover, mineral availability may have also influenced the difference in BW and ADG in experiment 1. Mineral type had an effect on lamb total ADG while on pasture as lambs offered loose mineral had a greater ADG gain compared to lambs offered block mineral. Studies have shown that the supplementation of block mineral can result in higher growth rates and improved digestibility of low quality feedstuffs (McDowell, 2003; Mubi et al., 2011). However, loose mineral tends to be easier to consume and thus a greater intake of mineral may result in a greater ADG. As seen in cattle, consumption of the same mineral is significantly greater when the mineral is offered in loose form compared to block form (McDowell, 2003). Additionally, Ragen et al. (2015) noted that when comparing lambs offered supplemental salt in loose or block form, lambs offered loose salt had a greater intake. Although our study did not observe mineral intake, lambs that were offered loose mineral may have had a greater intake and therefore had a greater ADG due to increased intake of mineral allowing the lambs to utilize the forages more efficiently.

4.2. Lamb health

At the end of the grazing portion in both experiment 1 and 2, lambs that were weaned late (E) or weaned directly into the feedlot (FL) demonstrated lower FAMACHA© eye scores and greater PCV values. Stress associated with maternal separation can negatively influence the humoral immune response (Napolitano et al., 1995), thus resulting in an increased susceptibility to disease and infection (Karakuş, 2014). A study by Orgeur et al. (1998) indicated that lambs subjected to reoccurring events of stress (i.e. slowly weaning lambs by separating dam and offspring for a short period of time each day) are more susceptible to infection when compared to lambs that are only subjected to the stressor of weaning once. In agreement with our results, Watson and Gill (1991) found that weaning lambs early at eight weeks of age resulted in greater FEC values and lower PCV values when compared to nursing lambs of 12 and 13 weeks of age, respectively. Lambs that are weaned and immediately subjected to parasitic infection have been shown to have greater FEC and lower PCV values due to a decrease in the immune response as a result of weaning stress (Schichowski et al., 2010).

Additionally, as demonstrated in the current studies, delay weaned (E) lambs had access to milk and displayed lower FEC and greater PCV values when compared to those lambs on pasture (PC and SF) denied access to milk. Research has shown that milk contains immunoglobulins produced by B-lymphocytes which protect the gut mucosa of neonate ruminants from pathogens and disease (Hernández-Ledesma et al., 2011). This effect may improve the immune system and the ability of young ruminants to tolerate gastrointestinal parasitic infection. Furthermore, when growing rats were supplemented with ovine serum immunoglobulins, there was an increase in immune system development considering performance, organ growth, and gut morphology (Balan et al., 2009, 2010). This data suggests that an increase in circulating immunoglobulins may be beneficial in combating disease through increased gut health and immune system development.

Supplemental nutrition is needed in order to support the functioning of immunological tissues to develop an effective immune response against gastrointestinal parasites (Greer, 2008). In the case of the current studies, continued access to milk provided supplemental nutrition to grazing lambs and was found to be effective against parasitic infection as the delayed weaned (E) lambs did not require anthelmintic treatment. Similarly, Kimambo et al. (1988) found that increasing the overall nutritional profile of parasitized lambs generated an immune response against the parasites, which allowed for the previously parasitized lambs to achieve a comparable weight gain to non-parasitized lambs.

Furthermore, additional research suggests that continued suckling of non-weaned lambs may decrease the level of parasitic infection by reducing the establishment of larvae attachment (Watson and Gill, 1991; Iposu et al., 2008). Parasitic establishment may be prevented by components of the milk attaching to the mucosa of the digestive system or the nematodes themselves (Hoang et al., 2010; Hernández-Ledesma et al., 2011). Additional studies have reported that the aid of milk and the use of an alternative forage (i.e. chicory – a natural anthelmintic; Tzamaloukas et al., 2005) have been shown to decrease the FEC of pasture-raised lambs (Kidane et al., 2014). This is in agreement with our results found in experiments 1 and 2, as the late weaned lambs showed a lower level of parasitic infection when compared to early weaned lambs. In both experiments, lambs that were weaned late (E treatment) did not receive anthelmintic treatment. Therefore, extending the age of weaning may aid in reducing the overall production losses associated with parasitic infection of pasture-raised lambs. If early weaning is performed, removing lambs from known parasitized pastures is critical in reducing the risk of production losses associated with parasitic infection.

4.3. Lamb feedlot performance

Upon entering the feedlot in both experiment 1 and 2, late weaned lambs had a greater BW, resulting in greater DMI, fewer number of days in the feedlot, greater overall ADG, and required less harvested grain to reach a common endpoint. Murphy et al. (1994) compared lamb finishing diets of grain concentrates to forage's and demonstrated that lambs receiving concentrate diets had a greater ADG when compared to forage and forage concentrate mixed feeds. Results by McClure et al. (1994) reported that lambs fed grain concentrates resulted in greater ADG, final BW, and total weight gain when compared to forage fed lambs. These results are similar to those found in the FC treatment group as these lambs demonstrated greater G:F when compared to the forage fed lambs in the grazing portion of the trial.

More recent studies focusing on evaluating carcass characteristics show that pasture-raised lambs produce a smaller carcass weight and thus require a greater number of days in the feedlot to reach the same ending marketable weight (Priolo et al., 2002). In our results from experiment 2, lambs weaned to pasture spent a longer amount of time in the feedlot and had a similar total DMI when compared to feedlot raised lambs. However, Díaz et al. (2002) noted that when placed into a feedlot, pasture-raised lambs exhibited increased growth rates due to compensatory growth and thus produced a slightly heavier carcass. This is comparable to our results as FC treatment lambs showed the lowest DMI when compared to all pasture treatments. Therefore, lambs weaned late (E) and weaned early into the feedlot (FL) were marketed at the same age indicating that when the price of grains increase, delaying the weaning of pasture-raised lambs may be economically beneficial.

5. Conclusion

In conclusion, delayed weaning in lambs (116–123 days of age) demonstrated an overall greater final BW and ADG, as well as fewer clinical signs of parasitic infection and thus need for anthelmintic treatment. However, we recognize that further research should be conducted in order to identify and quantify all parasitic nematodes that may affect lamb health and performance. Additionally, upon entering the feedlot, late weaned lambs spent fewer number of days in the feedlot, achieved a greater overall ADG, and were marketed at the same time of lambs that entered the feedlot immediately. Therefore, based on our results, extending the weaning age of lambs may be beneficial from a performance, health, and economic standpoint as it improved overall growth, mitigated the severity of parasitic infection, decreased anthelmintic treatment, and decreased total grain required to reach market weight.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.smallrumres.2017.09.006.

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