The effects of alternative treatment strategies to increase production and reduce the severity of parasitic infection in sheep

THESIS

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By

Braden Joseph Campbell

Graduate Program in Animal Sciences

The Ohio State University

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Master's Examination Committee:

Monique D. Pairis-Garcia, Advisor

Francis F. Fluharty, Advisor

Michael S. Lilburn
Abstract

Internal parasitic infection is one of the greatest challenges that the small ruminant industry faces today. As a result, the efficacy of anthelmintic drugs has decreased due to over and improper drug use, thus the implementation of alternative methods to mitigate the development of parasitic resistance is critical. To address this concern, two sets of experiments were performed: 1) investigate moxidectin carryover concentrations in the plasma and milk of lactating ewes and quantify the carryover of drug to the nursing lamb; and 2) investigate the effects of alternative weaning strategies on lamb health and performance when grazed on parasitized pastures.

In the first experiment, four lactating ewes were administered a single oral dose of moxidectin (0.2 mg/kg) after a 157 d wash out period. Plasma and milk samples from the ewe and plasma from their nursing lamb were collected post drug administration. At 60 d post oral administration, moxidectin residues were present in the milk and plasma of the lactating ewes. Moxidectin residues were also present in the plasma of the nursing lambs 4 d post administration. In addition, orally administrated moxidectin was detected in milk up to at least 157 d post treatment. Therefore, alternative methods to anthelmintic treatment are needed as drug residues remain in the body for an extended period of time and may contribute to the development of resistant parasite populations in young lambs.
In the second set of experiments, alternative weaning strategies were assessed over a two year period. In experiment 1, 48 lambs and 24 ewes were placed into one of two weaning treatments for 63 d: Pasture control (PC): lambs weaned at 60 d of age and placed on pasture. Ewe (E): Lambs placed on pasture at 60 d of age with ewe and weaned at approximately 123 d of age. The E lambs had a greater average final Body Weight (BW), total Average Daily Gain (ADG), and Packed Cell Volume (PCV) value on d 63 during the grazing period and spent fewer days in the feedlot when compared to PC lambs. In experiment 2, 72 lambs and 27 ewes were placed into one of four weaning treatments for 56 d: Pasture control (PC). Ewe (E): lambs weaned at approximately 116 d of age. Social facilitator (SF): lambs weaned at 60 d of age and placed on pasture with non-lactating ewes. Feedlot control (FC): lambs weaned at 60 d of age and placed in a feedlot. At the end of the grazing period, E lambs demonstrated the greatest BW and FC lambs had the greatest ADG when compared to all treatment groups. The E and FC lambs also demonstrated a smaller difference in change in PCV values at the end of the grazing period compared to PC and SF lambs. During the finishing phase, E lambs required less feed compared to all other groups. The results from these two experiments demonstrated that weaning lambs at an older age in pasture-based systems can be beneficial from an animal health and production standpoint.
Dedication

To my parents:

Joseph F. Campbell and Bridget L. Campbell
Acknowledgments

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Vita

May 2011 .................................................. Waterford High School, Ohio

May 2015 .................................................. B.S. Animal Sciences - Bioscience Specialization, The Ohio State University

May 2015 to Present .................................. Graduate Research Associate, Department of Animal Sciences, The Ohio State University

Field of Study

Major Field: Animal Sciences
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Chapter 1

Literature Review

Introduction

In the Eastern United States, lambs are commonly weaned at 60 days of age. Weaning, defined as the abrupt separation of dam and offspring, is conducted in most production systems in order to increase the production efficiency of the lamb and decrease the time period required to return the ewe to a reproductive state. However, this early weaning practice is stressful and can result in deviations to physiological and behavioral parameters of the lamb, and can ultimately negatively impact growth and production. Factors influencing the ewe-lamb bond development will first be discussed followed by the dissolution of the ewe-lamb bond.

The objectives of this literature review are to provide an overview of the literature regarding the development and dissolution of the ewe-lamb bond and the impact this bond has on the health and productivity of the lamb. In addition, the literature review will provide a background on parasitic infection of pasture raised lambs and discuss the limitations and challenges for treatment.
**Ewe-lamb bond development**

The ewe-lamb bond is a connection that occurs immediately after parturition and if left unaffected, remains until the lamb is 100 to 180 days of age (Arnold et al., 1979). This relationship provides the lamb with nourishment, protection, and physical support (Newberry and Swanson, 2001), and is critical for the success of the newborn lamb. The development and sustainability of this bond is dependent upon several factors including hormonal regulation, nutritional state of the ewe, and sensory cues (Newberry and Swanson, 2008).

**Hormonal regulation**

The initial foundation of the maternal ewe-lamb bond is attributed to the composition and regulation of ovarian hormones during parturition (Dwyer et al., 2004). The rapid onset of maternal behavior immediately after parturition is associated with oxytocin, a neuropeptide secreted by the paraventricular nucleus in the brain (Lévy et al., 1992). A surge in progesterone and estradiol results in increased mRNA expression leading to oxytocin production (Keverne, 1988; Broad et al., 1993). The increase in released oxytocin has shown to induce maternal behavior by attracting ewes to amniotic fluid, which in turn is the first and most important olfactory recognition mechanism in the ewe-lamb bond (Kendrick et al., 1987; Lévy and Poindron, 1987; Kendrick et al., 1991). In comparative studies conducted in mice, results show that a decrease in progesterone concentrations during late gestation depressed the development of maternal care (Wang et al., 1995).
In conjunction with hormonal concentrations, Dwyer et al. (2004) noted that previous experiences of multiparous ewes influence the onset and development of maternal care. Ewes which have had previous exposure to these hormonal changes tend to develop a greater balance of maternal behaviors and cues earlier on than ewes with no experience. The effects of previous exposure and experience are attributed to the continued evolution of the mature ewe’s neuroendocrine system response (Kendrick et al., 1991). Therefore, the combination of hormonal concentrations and previous maternal experiences of the ewe contribute to the strength and development of the ewe-lamb bond.

**Nutritional state**

The natural separation of the lamb and ewe (i.e. weaning) will primarily depend upon the nutritional state of the ewe with milk yield as the major component contributing to the stability of this relationship (Arnold et al., 1979). The most critical factor in the ewe-lamb bond relationship is the overall health and nutritional status of the ewe (Dwyer et al., 2003). Weaning will naturally occur when the total milk production of the ewe decreases below 550 ml (Penning and Gibb, 1979) as the cost of suckling (energy required to nurse off the ewe) is greater than the benefit of the milk (low or no milk supply; Penning and Gibb, 1979; Jensen and Recén, 1989). Malnutrition can indirectly affect the ewe-lamb bond as the ewe will yield less milk as a source of nutritional sustenance due to a reduction in milk production and create a delay or reduction in the hormonal pathways (oxytocin) that regulate maternal behavior (Charismiadou et. al., 2000; Dwyer et al., 2003). Preliminary observational and descriptive studies by Thomson and Thomson (1949) demonstrated that under or limit-fed ewes required additional time
to nurse and groom their lambs when compared to properly or adequately fed ewes. Under fed ewes demonstrated weaker ewe-lamb bonds by exhibiting low instances of grooming, infrequent vocalizations towards offspring, and a low acceptability for offspring to nurse (Dwyer, 2008). Furthermore, malnutrition can also have an effect on the emotional and behavioral development of the lamb. In a comparative study with rats by Almeida et al. (1996), individuals reared by malnourished dams displayed less socially interactive behaviors. Dwyer et al. (2003) also found that lambs born from malnourished ewes not only displayed lower birth weights, but suckling behaviors were underdeveloped and overall nursing time was greater in these lambs compared to the control group.

**Sensory cues**

Development of the ewe-lamb bond occurs directly after birth and remains an important relationship throughout the young life of the lamb. Physical or tactile contact including rubbing, licking, nudging, and pawing occurs immediately at birth and plays a significant role in the development of the ewe-lamb bond. Not only do these behaviors assist in stimulating the lamb post-parturition, but these events allow the ewe to utilize sensory cues to further identify and associate herself with her offspring.

**Auditory cues**

Almost immediately after birth, the ewe will clean off its offspring and vocalize low frequency soft pitched tones towards its lamb for the first three hours post-partum (Alexander and Shillito, 1977; Sèbe et al., 2007; Sèbe et al., 2008). Sheep vocalizations can be identified as one of two distinct categories referred to as “bleats.” The first
category of bleats, which are low-pitched in tone, typically occur with a closed mouth. The other category of bleats are high-pitched tones that are associated with an open mouth. Low-pitched softer tones are used when the ewe and lamb are in close proximity and during the time of nursing (Sèbe et al., 2007), while high-pitched tones and increases in vocalization frequency occur when the lamb and ewe are physically separated (Torres-Hernandez and Hohenboken, 1979).

According to Sèbe et al. (2008), although auditory cues play a critical role in ewe-lamb recognition, visual cues are most likely the dominant cue utilized to identify offspring. Additional results from observational studies regarding the development of the ewe-lamb bond indicate that auditory cues (used in the formation of the ewe-lamb bond, not associated with stress) peak at three hours post-partum (Sèbe et al., 2007) and are categorized as low-pitched soft tones. Furthermore, Orgeur et al. (1998) indicated an increase in high-pitched tones when the ewe and her offspring became separated, thus supporting a stress response from the ewe.

**Visual cues**

Furthermore, ewes also utilize visual cues in order to locate and differentiate between her offspring and unfamiliar lambs. Sheep have a 290° visual field with very poor peripheral vision, but quickly adjust towards movement when it is detected in the peripheral view (Dwyer, 2008). In a study conducted by Kendrick et al. (1995), sheep were able to differentiate between sheep and human faces and familiar and unfamiliar sheep faces when subjected to two pictures placed side by side. These test sheep were not only able to accurately differentiate between familiar and unfamiliar sheep, but continued
to correctly identify familiar conspecifics two years after the initiation of the study. This study supports that a ewe can recognize her offspring’s face when compared to an unfamiliar lamb and that facial features play an integral role in this identification. For example, Alexander and Shillito (1978) demonstrated that when a white lamb’s face was colored or darkened, the dam avoided her offspring regardless of olfactory recognition. This would indicate that once the bond between the ewe and lamb is formed, small alterations in appearance may influence the ewe-lamb bond. However, it should be noted that ewes are not capable of recognizing their lamb’s face until three weeks post-partum (Kendrick et. al., 1996) and lambs are incapable of visually recognizing their dams for up to four weeks after birth (Kendrick, 1994). These findings suggest that although the visual cues are important for the development and sustainability of the ewe-lamb bond, sensory and tactile cues remain the most important factors in earlier bond development.

**Olfactory cues**

During the process in which the ewes cleans off her lamb, the ewe will develop olfactory memories to identify the specific and unique scent of her lamb. These olfactory memories will continue to be used by the ewe to associate herself with her offspring and to allow for exclusive nursing of her lamb (Keller et al., 2003). It has been suggested that volatile organic compounds found in wool fibers could potentially be involved in this unique ewe-lamb recognition as seen in Döhne Merino lambs (Burger et al., 2011). In addition, amniotic fluid provides individual chemosensory properties, specific to each lamb and ewe, which also plays an important role in the development of the ewe-lamb bond by triggering hormonal responses as described previously (Lévy and Poindron,
1987; Dwyer et al., 1999; Keller et. al., 2003). As the lamb continues to develop and grow, stronger odors persist from the glands around the tail and rump regions. These emitted odors will then be utilized by the ewe to quickly identify and locate her offspring via direct contact with these regions (Alexander, 1978).

**Deviations to natural weaning**

Natural weaning, defined as the gradual separation and dissolution of the bond between dam and offspring (Arnold et al., 1977) without human interference, rarely occurs in commercial production settings. In intensive sheep operations such as those found in the Eastern United States, lambs are separated from the ewe on an average of 60 days of age. In less intensive operations such as those found in the Western United States, separation varies dependent upon nutritional sustenance availability, but can occur as late as 130 days of age (Kirschten et al., 2015). The following sections will define early separation of the ewe-lamb bond (i.e. early weaning) and discuss the negative consequences of early separation on lamb health and productivity.

**Early weaning**

Early weaning is defined as the elimination of the unique bond between dam and offspring, occurring primarily via elimination of direct contact (Newberry and Swanson, 2001). The practice of weaning is a common technique in the sheep industry due to practicality, economical value, ease in management for the producer, and reduction of potential negative reproductive implications associated with natural weaning (Orgeur et al., 1998; Napolitano et al., 2008). In the Eastern United States, it is standard to wean lambs at 60 days of age (Ricketts, 1999; Barkley, 2014), however there is little scientific
data to explain why this age has been chosen. Information provided by sheep producers conclude that weaning at 60 days of age is based on ewe lactation. Natural peak milk production of the ewe occurs around 21-30 days post parturition and then begins to steadily decline over a 63 day lactation curve (Cardellino and Benson, 2002). Producers have chosen to wean at 60 days of age recognizing that nutritional milk supply may no longer be adequate for the lamb and weaning the lamb off of milk may promote an increase in solid concentrate feed intake. However, from a welfare perspective, weaning lambs at this age results in a stress response exhibited by both lamb and ewe (Newberry and Swanson, 2001). Schichowski et al. (2008) found that lambs weaned at 56 days of age demonstrated higher incidences of agitation, restlessness, and vocalizations when compared to lambs weaned at 112 days of age (Sèbe et al., 2008). Orgeur et al. (1998) hypothesized that gradual separation, beginning at 25 days of age whereas the time of separation increased with age, of the ewe and lamb at 90 days of age will result in a less stressful weaning process when compared to abrupt weaning at 90 days of age. Although, concerns with this approach would be the potential onset of mastitis, research has not shown that decreased suckling bouts at this age solely result in the onset of clinical signs of mastitis. However, in this study, neither weaning strategy was identified as more or less stressful than the other, noting that the abrupt separation method is ultimately less labor intensive for the producer with no additional negative impact associated with the ewe and lamb welfare.
Weaning stress

Early weaning is considered the most stressful if this occurs within the first two weeks of life (Newberry and Swanson, 2001). Stress associated with this process is demonstrated by an increase in locomotion and vocalization, specifically characterized by high pitched tones by the lamb and ewe (Alexander and Shillito, 1977; Schichowski et al., 2008). Decreased growth rates are also associated with early weaning due to the extended amount of time that is required for lambs to adapt to a solid concentrate feedstuff (Napolitano et al., 2008).

Following weaning, lambs demonstrate a strong motivation to nurse. Without the presence of the ewe, newly weaned lambs may often demonstrate elevations in redirected behaviors, including increased oral manipulation (i.e. bar biting and wool chewing) directed towards inanimate objects or other lambs (Napolitano et al., 2008). For example, lambs weaned at birth (i.e. lambs removed from their dams in a sheep dairy production setting) exhibit increased abnormal oral behaviors including suckling of the navel and scrotum of pen mates (Stephens and Baldwin, 1971). This redirected oral behavior is not limited to the time of weaning, but can have long-term negative consequences on the lamb’s behavioral repertoire.

In addition to the inability to suckle, other factors associated with weaning and change to the environment can have negative impacts on lamb welfare and behavior. Vasseur et al. (2006) demonstrated that lambs supplied low levels of forage (i.e. low fiber diets) in feedlot or dry lot systems seek out fiber supplementation in the form of wool from other pen mates. This behavior, coined “wool biting,” is characterized as the act of
picking and eating the wool of a targeted pen mate. The combination of low fiber diets in addition to a lack of environmental stimulation may cause severe wool biting behavior among a pen of sheep that increases in severity and frequency over time (Lynch et al., 1992). Therefore, early weaning not only elicits an acute stress response associated with the removal of the lamb from the ewe, but can have long term effects on the behavior and development of the lamb as well.

**Weaning impact on lamb health and production**

One of the greatest challenges associated with early weaning is the negative impacts attributed to stress on animal health and production. During stressful periods, lambs are more susceptible to infection as a result of an increase in circulating cortisol. This will result in deviations of the lymphocyte neutrophil ratio and an overall decreased immune system response (Orgeur et al., 1998; Dickerson and Kemeny, 2004). Yvoré et al. (1980) found that recently weaned lambs exhibit clinical signs of coccidiosis (characterized by diarrhea and decreased growth rates associated with a lack of appetite) due to a drastic increase in the stress levels as compared to control lambs that were not weaned. Furthermore, in a review by Marai et al. (2007), stress associated with increased levels in ambient temperature demonstrated a decrease in growth rate, average daily gain, and total body weight of finishing lambs. Consequently, these findings would indicate that stress is affecting more than the behavioral and emotional state of the animal and can have detrimental consequences to overall lamb health.

From a production standpoint, abrupt or early weaning results in weight loss, poor body condition, and slower growth rates when compared to non-weaned mammals.
Further research by Tadich et al (2009) suggested that a combination of weaning lambs at 70 days of age and long distance transportation (i.e. multifactorial stressors), resulted in body energy reserve depletion as a consequence of poor appetite post transport. Further studies have identified several negative production consequences associated with early weaning. According to Lee et al. (1990), lambs weaned at an average of 14 weeks of age exhibited a decrease in growth rate when compared to lambs weaned at 23 weeks of age. In addition, lambs weaned at 14 weeks of age required an extended period of time on feed in order to reach the same slaughter weight as those lambs weaned at 23 weeks of age.

Although the literature demonstrates the detrimental effects of production and health of lambs due to the acute stress response due to weaning, long term impacts to lamb productivity is limited. Sañudo et al. (1998) demonstrated no difference in average daily gain at the time of slaughter and Geenty (1980) also demonstrated no impact on growth rate when comparing lambs weaned at four weeks of age compared to nursing lambs of the same age. More recent work conducted by Abdel-Fattah et al. (2013) demonstrated that weaning lambs at 60 days of age resulted in increased final body weight and average daily gain. Therefore, although weaning results in an acute stress response to both the lamb and ewe, long term consequences to this practice are limited.

In addition, weaning age can also influence lamb carcass quality. Lambs weaned early between the ages of four to six weeks, demonstrate decreased carcass fat cover, thus resulting in a higher quality product (Geenty, 1980). It should be noted that although overall quality of the product increased when lambs were weaned at four to six weeks,
this study did not take into account the economic breakdown of profit to loss associated with alternative weaning ages. Furthermore, extended weaning programs can negatively influence meat quality as prolonged weaning results in increased overall carcass fat (Sañudo et al., 1998) contributed by increased milk intake. Therefore, meat quality and market profitability should be taken into account when evaluating weaning strategies on-farm (Ekiz et al., 2016).

**Parasitic infection in the sheep industry**

Nutrition is the greatest cost for a livestock operating system, whereas the second greatest cost is maintaining healthy animals. Specific to the small ruminant industry, one of the greatest medical costs that producers encounter is the use of anthelmintic products to control and treat internal parasitic infection (Waller et al., 1995; Besier and Love, 2003). Parasitic infection in lambs results in decreased body weight, skeletal growth, and wool quality (Coop and Holmes, 1996) and clinical signs of disease including anemia, lethargy, infertility, and if left untreated ultimately death (Perry and Randolph, 1999; Besier and Love, 2003). Each of the aforementioned production parameters will contribute to the economic value of the lamb, thus the presence of one or more of these factors will result in a decrease in profit losses.

**Haemonchus contortus (Barber pole worm)**

*Haemonchus contortus*, commonly referred to as the barber’s pole worm, is a gastrointestinal parasite that attaches to the mucosa of the abomasal wall and small intestine (Besier and Love, 2003). This attachment results in inflammation and injury to the mucosal membrane and results in severe blood loss and generalized malabsorption.
(Beck et al., 1985). In order to avoid production losses, clinical signs of infection must be identified and recognized by utilizing methods that are both specific to parasitic infection and the parasite of interest.

**Parasitic infection identification**

Laboratory diagnostic techniques to determine the level of parasitic infection include assessing packed cell volumes (PCV) and fecal egg counts (FEC). The PCV value is used to evaluate the percentage of circulating red blood cell platelets as an indicator of anemia. The platelet level reading is received from a micro-capillary tube that has been centrifuged and placed on a micro-capillary tube reader (Kaplan et al., 2004). Average PCV values for sheep range from 24% to 45% (Research Animal Resources, 2009). A low value indicates a decreased volume of circulating red blood cells for sheep parasitized with nematodes that consume blood. A PCV value at or below 21% often represents that anthelmintic treatment should be considered (Amarante et al., 2004).

The FEC values are determined by collecting fecal samples and viewing the samples under a microscope with a McMaster slide (McKenna, 1981). The McMaster slide is a piece of glass with a fine etched grid used for calculating the number of eggs in a fecal sample to determine the average number of eggs per gram of feces (Cringoli et al., 2004). The greater the number of eggs per gram of feces is an indicator of an elevated level of parasitic burden or infection. Both techniques can be utilized in order to quantify the degree and severity of parasite infection. Additional visual cues that serve as indicators of parasitic infection is the development of low body condition scores, the
presence of bottle jaw (subcutaneous submandibular edema; pooling of fluid under the mandible), diarrhea, and a dulling of color in the wool or hair coat of an animal (Zajac et al., 2014).

Parasitic infection in lambs can be evaluated by examining both clinical and physiological signs associated with the health and growth of the animal. In an experiment looking at the direct effects of parasitic infection, 64, two-year-old Merino ewes were taken off of pasture, placed into a feedlot system, and orally administered 750 infective

*H. contortus* larvae in order to determine the effects of stress on the rate of parasitic infection (Fell et al., 1991). Results from this study indicated that there was no difference in feed intake of the infected ewes when compared to a control group of non-infected ewes in the feedlot. Furthermore, fecal egg counts (FEC) of both groups remained low (less than 2000 eggs) prior to the 21 day incubation period of the parasite, demonstrating that the ewes naturally maintained a low level of infection. Conversely, Vanimisetti et al. (2004) demonstrated an increase in FEC and a decreased packed cell volume (PCV) value in both ewes and lambs when subjected to infection. In this particular study it was noted that lambs exhibited higher FEC and lower PCV when compared to mature ewes. This could be due to the underdevelopment of the lamb’s immune system, thus increasing the vulnerability to infection. Furthermore, when assessing parasite tolerance among sheep breeds, Amarante et al. (2004) found that over a year time period Santa Ines sheep displayed a greater overall mean PCV value when compared to the Suffolk sheep. Similar results were seen when comparing FEC values of the two breeds, with Santa Ines lambs
excreting approximately 11,000 eggs per gram of feces and Suffolk lambs excreting approximately 21,000 eggs per gram of feces.

In addition, Gulland (1992) assessed the mortality rate of an infected flock. Within 11 weeks, 320 of the 455 subjects died due to parasitic infection with post mortem findings indicating extreme emaciation with little or no fat remaining on the carcass. Results from this study also indicated the physiological damage associated with parasitic infection such as erosion of the abomasal mucosa, osteogenesis imperfecta, and discoloration of the liver caused by filtering congestion. Moreover, other physiological indicators of parasitic infection include an increase in immunoglobulin antibody and white blood cell counts with increases in concentrations of IgA in the gut is associated with an increased susceptibility to parasitic infection (Stear et al., 1999). Furthermore, an increase in the concentration of white blood cells, specifically eosinophils, indicates the present of nematode infection (Stear et al., 2002) as these cells are used to attack foreign parasitic cells.

**Treatment options for parasitic infection**

Internal parasitic infection is one of the greatest challenges that the small ruminant production industry faces today (Waller et al., 1995). This challenge is derived from either over or improper anthelmintic drug use, which in turn has resulted in anthelmintic resistance (AR; Kaplan and Vidyashankar, 2012). Anthelmintic resistance is characterized as the heritability of parasitic nematodes to survive an effective dose of anthelmintic products (Echevarria et al., 1996). Resistance is inherited and developed from worms that have survived previous anthelmintic exposure. Worms that persist
beyond anthelmintic treatment contribute to the development of resistance in the next
generation by genetic transfer of resistant genes (Coles, 2005). Through this genetic
transfer, the newly generated nematodes will possess genes that are resistant to the
current active ingredient in the anthelmintic. Thus, an increased exposure to anthelmintic
drugs among resistant and non-resistant populations will continue to increase the
prevalence and severity of AR globally (Papadopoulos et al., 2001).

The type of resistance in which a parasite exhibits is classified by the manner in
which it is developed. If a parasite is resistant to a specific anthelmintic, it will also show
signs of “side resistance” to drugs found within the same family. For example, once a
flock or herd exhibits resistant to albendazole, it will also develop a side resistance to
fenbendazole due to both anthelmintic products originating from the Benzimidazole drug
class (Roeber et al., 2013). This occurs when the same active chemical compounds are
being used to eliminate the parasites (Prichard, 1994). In addition to side resistance,
parasites utilize other resistance strategies such as cross resistance. Cross resistance is the
result of two unrelated chemicals becoming non-effective towards a specific parasite
(Sangster, 1999). As parasites become more resistant to modern day anthelmintics,
alternative treatment strategies must be considered.

Ultimately, AR can only be minimized by maintaining non-resistance parasite
populations. Parasites that have never been exposed to anthelmintics are defined to be in
a state of refugia (Coles, 2005). This unique group of parasites do not possess the newly
developed genes that are resistant to current anthelmintics, thus increasing the prevalence
of these parasites will contribute to the genetic transfer of non-resistant genes.
Implementing new on-farm strategies that specifically focus on minimizing anthelmintic use will now be discussed.

**Pasture management for parasitic infection**

The environment in which a parasite lives and thrives can highly influence its growth, development, and viability. Typically, AR is most prevalent in hot, humid climates, which are ideal growing conditions for most parasitic species (Waller et al., 1995). Parasitic larvae survive well near ground level where there is enough moisture to support their survival. The more moisture amongst the forage, the further up the forage the larvae can travel and increased likelihood for consumption and infection of sheep (Karki, 2010; Waller et al., 1995). Grazing intensity can also influence the parasite load on the pasture and affect the ease of infection (Waller et al., 1995). Therefore, if sheep are forced to overgraze an area and graze the forage down to ground level in a pasture that has a heavy parasite load, infection is inevitable. Management programs utilizing rotational grazing (rotation between grazing’s in specific areas that allow for the pasture to rest and regrow) in combination with anthelmintic treatment on an “as needed basis” could be a potential solution to reducing production losses and reducing the risk and chances of AR.

**Treatment protocols based on clinical signs**

Anthelmintic products are available for medical treatment in order to treat and reduce the level of parasitic infection. However, the continued use of anthelmintic products have led to the development of resistance of internal parasites, specifically *H. contortus*. A method commonly used in managing and reducing the use of anthelmintics
is only treating sheep demonstrating clinical signs of disease. For example, with the development of the FAMACHA© eye scoring system invented by Dr. Francois “Faffa” Malan (FAffa MAlan CHArt) of South Africa, producers can estimate the level and severity of *H. contortus* infection for each individual sheep (Van Wyk and Bath, 2002; Kaplan et al., 2004; Burke et al., 2007). The FAMACHA© system allows for the identification and treatment of individuals that are incapable of surviving the negative effects associated with parasitic infection (Mahieu et al., 2007), therefore allowing producers to treat animals on an “as needed basis.” This method decreases the amount of individuals treated that are capable of surviving in the presence of parasitic burden, thus decreasing the rate of AR.

The FAMACHA© eye scoring system is one of the most common on-farm approaches utilized to determine anemia severity by evaluating and scoring the mucous membrane color of the eye (Van Wyk and Bath, 2002; Kaplan et al., 2004; Burke et al., 2007 Zajac et al, 2014). The use of this specific scoring system is only valid when *H. contortus* is the primary internal parasite causing clinical signs of infection (Zajac et al., 2014). The FAMACHA© eye scoring system ranges in values from 1-5, with a value of 1 indicated by a deep cherry red eye mucous membrane representing a healthy individual with no infection as compared to a value of 5 indicated by a pale or pearly white eye mucous membrane representing a compromised individual with severe parasitic infection.

When utilizing the FAMACHA© eye scoring system, one option to control AR is treating only those individuals exhibiting a FAMACHA© score 3 or greater (Lewandowski, 2010; Zajac et al., 2014). According to Burke et al. (2007), the treatment
of individual exhibiting an eye score of 3 and greater will result in a lower amount of anemic animals and anthelmintics used. The important aspect of this type of diagnostic is the correct assignment of each FAMACHA® score. In a comparative review presented by Van Wky and Bath (2002), results indicate that the estimate inaccuracy of the FAMACHA® eye scoring system can be as high as 44%, with over half of the incorrectly scored animals adjacent to the correct eye score category. This proves that the slightest change in eye color and appearance within a small valued scale can be easily misinterpreted, resulting in an incorrect diagnostic. An increase in diagnostic error will contribute to the increased probability of mistreatment of animals, thus contributing to the advancement of AR (Van Wky and Bath 2002).

However, the implementation and appropriate practice of the FAMACHA® eye scoring system has proven to reduce the number of treatments administered. As demonstrated in a study conducted by Malan et al. (2001), only 30% of the test sheep flock was found unable to withstand parasitic burden without one treatment. In addition, this study demonstrated that only 10% of the individuals treated required an additional treatment. In a similar goat study, researchers found that continued use of FAMACHA® eye scoring over a two year period resulted in an average of 0.57 doses per goat per kidding period when compared to the control group averaging three doses per goat per kidding (Mahieu et al., 2007). Therefore, the use of the FAMACHA® eye scoring system can be effectively utilized as a tool to manage and identify animals in need of anthelmintic treatment, reduce the amount of anthelmintic used, and ultimately contribute to the increase in parasite populations found in refugia (Burke et. al., 2007).
Conclusion

As producers continue to wean lambs at an early age, the negative effects associated with stress must be considered. Disruption of the ewe-lamb bond immediately alters the lamb’s social environment and initial source of nutrition via milk. Emotional and physiological stress during the time of weaning can result in production losses attributed to a decrease in energy efficiency and increase in susceptibility of disease and infection. Parasitic infection specifically that caused by *H. contortus*, is of great concern in the sheep industry as it decreases the overall health and production of the lamb. Detection of parasitic infection and severity are important in determining treatment options, thus reducing the number of excessive treatments which contribute to AR. Furthermore, alternative non-anthelmintic practices and minimizing stress in lambs to improve immune response are critical management decisions that must be evaluated to improve the health, production, and welfare of forage fed lambs.
References


Lewandowski, R., 2010. Use FAMACHA© correctly. The Ohio State University Extension OARDC.


Chapter 2

An investigation of oral moxidectin carryover to nursing lambs via milk

Abstract

The purpose of this study was to investigate the concentrations of moxidectin in the plasma and milk of lactating ewes and in the plasma of their nursing lamb. Four, single lamb bearing Border Leister x Dorset ewes were administered a single oral dose of moxidectin (0.2 mg/kg). Plasma and milk samples were collected nine times within the first 72 h and at 30 and 60 d post drug administration and measured using high-performance liquid chromatography. A pharmacokinetic analysis of moxidectin was conducted on ewe plasma and resulted in a $C_{\text{MAX}}$ 13.05 ng/mL at 8.24 h ($T_{\text{MAX}}$). Lamb plasma samples were reported descriptively and moxidectin reached peak concentration at 12-72 h post administration with an average concentration of 3.00 ng/mL. Three of the four ewes on trial demonstrated quantifiable levels of moxidectin in milk at baseline sampling. Ewe milk samples reached a peak concentration at 8-24 h post administration with an average concentration observed measuring 176.64 ng/mL. Moxidectin levels were detected up to 60 d in all milk samples. The results from this study demonstrate that orally administrated moxidectin is carried over into the milk and evident in the plasma of nursing lambs. Further research is needed in order to understand how moxidectin drug
concentrations and drug exposure time influences the fetus and nursing lamb in regards to the development of resistant parasitic populations.

**Highlights**

- Moxidectin was detected in sheep milk 157 days post treatment
- Moxidectin residues were measureable in the blood plasma of nursing lambs
- Lambs exposed to anthelmintics may increase risk to develop anthelmintic resistance

**Keywords**

moxidectin, anthelmintic resistance, plasma, milk, sheep

**Introduction**

Gastrointestinal parasitic infection is one of the greatest challenges that the small ruminant industry faces today (Waller et al., 1995; Goolsby et al., 2017). This challenge is derived from either over or improper anthelmintic drug use, resulting in the global development of anthelmintic resistance (AR; Kaplan and Vidyashankar, 2012). Anthelmintic resistance is described as the heritable capability of parasitic nematodes to survive effective anthelmintic doses. The development of resistant heritable genes within current parasite populations can result in limited anthelmintic drug efficacy (Coles, 2005).
Moxidectin, the active drug ingredient in Cydectin® Oral Drench for Sheep, is a broad-spectrum endectocide categorized within the Macrocyclic Lactone (ML) family (Durden, 2007). Moxidectin’s mode of action results in disruption of the parasite’s cell membrane via the inhibition of glutamate gated chloride channels (Molento et al., 2004; Godoy et al., 2015). Moxidectin is most effective on the Trichostrongylidae family of parasites including *Haemonchus contortus*, *Ostertagia circumcincta*, and *Trichostrongylus colubriformis* (Roeber et al., 2013; Zarrin et al., 2015).

Moxidectin is a unique treatment option for sheep producers as it is labeled to be administered to non-pregnant, gestating, or lactating ewes. Moxidectin is also unique as it is highly lipid soluble and remains in the body for a longer period of time, thus minimizing dosing frequency for the producer (McKellar and Jackson, 2004). Ultimately, decreasing AR within the sheep industry requires judicious use of anthelmintics and long term development and maintenance of non-resistant nematode populations (e.g. refugia populations). To accomplish this, the industry must not only evaluate treatment protocols for mature sheep, but understand the impact of anthelmintic drug treatments on offspring. To date, no published research has quantified the transfer of oral moxidectin concentration from the ewe to nursing offspring via milk. Therefore, the objectives of the present study were to determine the pharmacokinetic parameters of moxidectin in lactating ewes administered moxidectin orally and quantify moxidectin carryover in the milk to nursing lambs.
Materials and Methods

The Ohio State University Institutional Animal Care and Use Committee approved the protocol for this experiment. 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).

Animals, housing and husbandry

Four, fall lambing Border Leister x Dorset cross ewes (78.2 ± 12.7 kg, mean bodyweight ± standard deviation; 2.9 ± 1.1 years, mean age ± standard deviation), mated to a Dorset x Hampshire cross ram were used in the present study. Each ewe reared a single lamb (ewes, n = 2, wethers, n = 2) born between September 24 and September 27, 2015, with average lamb age of 24.5 ± 1.5 d at the onset of trial.

Sheep were housed in one group pen (7.6 m length x 9.1 m width) composed of concrete flooring, straw bedding, and an outdoor concrete pad (outdoor area: 18.3 m length, 9.1 m width). Sheep were provided water *ad libitum* via an automatic waterer and hand-fed a custom diet consisting of ground corn, soybean meal, and minerals to meet or exceed recommended nutrient requirements (NRC, 2007). A total of 2.2 kg of feed and 4.1 kg of second cutting alfalfa x orchard grass hay was fed communally at 08:00h daily. One hundred and fifty seven days prior to the initiation of the study, all ewes received an oral treatment of moxidectin (0.2 mg/kg; Cydectin® Oral Sheep Drench, Boehringer Ingelheim, Ingelheim am Rhein, Germany) to control for internal parasitic infection. This permitted for a 157 day wash out period prior to the initiation of the study.
Experimental design and sample collection

Baseline samples of milk and blood from the ewe and blood from the lamb was collected five days prior to drug administration. All four ewes were administered moxidectin orally at the beginning of the trial (0.2 mg/kg; Cydectin® Oral Sheep Drench, Boehringer Ingelheim, Ingelheim am Rhein, Germany). For the oral administration of the drug, each dose was calculated based on ewe weight collected on the day of administration. All blood and milk samples were collected at 0, 2, 4, 6, 8, 12, 24, 48, 72 h and at 30 and 60 d post drug administration.

Ewe and lamb blood samples were collected via jugular vein using a 19.1 mm 20 gauge hypodermic needle with a 6 mL luer-lock tip plastic syringe (Covidien™ Monoject™, Mansfield, MA, USA). Once collected, blood samples were instantly transferred into a 7.0 mL K3 EDTA vacutainer blood collection tube (BD Vacutainer, Franklin Lakes, NJ, USA) and remained on ice for no longer than 60 min prior to centrifugation. Samples were centrifuged at 1500 x g for 12 min at 0°C. Collected plasma was placed into 1.8 mL cryovials (Nunc™ CryoTube™ Vials, Thermo Scientific, Suzhou, Jiangsu, China) and frozen at -70°C until analysis.

Milk samples were collected from each ewe one min after each blood collection time point for approximately 30 sec. Milk was collected via manual stripping of the udder and alternating sides between collection points. Lambs were permitted free access to the udder during the entirety of the study except during the milk collection period. Samples were collected directly into 1.8 mL cryovials, immediately placed on ice, and frozen at -70°C until analysis.
**HPLC analysis of moxidectin concentration**

Serum and milk concentrations of moxidectin were determined using high-performance liquid chromatography (HPLC) utilizing previously described methods (Pairis-Garcia et al., 2013; Pairis-Garcia et al., 2015) at CYCADS/Racing Chemistry Laboratory, Iowa State University, College of Veterinary Medicine (Veterinary Diagnostic laboratory, Ames, IA, USA).

**Pharmacokinetic analysis**

Noncompartmental analysis for plasma moxidectin concentrations was performed with the NonCompartment R package (Bae, 2017). The parameters included the area under the curve from time zero to infinity (AUC\text{\textsubscript{INF}}) based on the last observed concentration and determined with the linear trapezoidal rule, the percent of the AUC extrapolated to infinity (AUC\text{\textsubscript{EXTRAP}}), the clearance by fraction dose (Cl/F) determined by dose/AUC\text{\textsubscript{INF}}, the first order rate constant associated with the terminal portion of the curve (λz), the half-life by λz (T\text{\textsubscript{1/2}} λz) determined as ln(2)/λz, the mean residence time extrapolated to infinity (MRT\textsubscript{0-INF}), the maximum plasma concentration (C\text{\textsubscript{MAX}}) and the time to maximum plasma concentration (T\text{\textsubscript{MAX}}). For the calculation of all parameters, plasma moxidectin concentrations below the lower limit of quantification (LOQ) were set to zero.
Results

Following oral administration of 0.2 mg/kg moxidectin, no adverse effects were noted, nor were there any instances of mastitis due to repeated milk collections. Pharmacokinetic parameters of plasma collected from lactating ewes are summarized in Table 2.1.

Moxidectin concentrations were detected in the plasma of lactating ewes following 2 h post oral administration with moxidectin achieving a maximum concentration of 13.05 ng/mL (C_{MAX}) at 8.24 h (T_{MAX}; Figure 2.1). Moxidectin concentrations were not present in lamb plasma until 6-12 h post ewe treatment. Moxidectin in lamb plasma reached its maximum concentration 12-72 h post administration averaging 3.00 ng/mL (Figure 2.1). Drug concentrations in lamb plasma were below the LOQ for the first 4-12 h and 30 and 60 d post administration.

Moxidectin concentrations in the milk of ewes are shown in Figure 3. Three of the four ewes demonstrated detectable levels of moxidectin at the baseline milk sample averaging 1.62 ng/mL. Among the four ewes, moxidectin in the milk reached its greatest average concentration of 176.64 ng/mL 8-24 h post administration. On day 60, all ewe milk samples averaged 1.07 ng/mL (Figure 2.2).

Discussion

Alternative treatment methods for parasitic infection are needed in order to reduce AR and increase refugia populations in pasture systems. Treating pregnant and lactating ewes with anthelmintics may contribute to AR if drug concentrations reaching offspring...
impacts nematode populations within the lamb. More specifically, AR may develop when
the treatment dose ingested by the offspring via milk is below the effective dose
concentration, resulting in parasitic genetic resistance to the administered drug.
Therefore, the objectives of the present study were to determine the pharmacokinetic
parameters of moxidectin in the blood of lactating ewes administered a single oral dose of
moxidectin and quantify moxidectin carryover in the milk of treated ewes to the blood
plasma of nursing lambs.

Previous research evaluating the pharmacokinetic properties of orally
administrated moxidectin coincides with our $C_{\text{MAX}}$ of 13.05 ng/mL (Lespine et al, 2004).
Both Molento et al. (2004) and Alvinerie et al. (1998) demonstrated greater $C_{\text{MAX}}$
concentrations between 17.20 and 28.07 ng/mL, respectively. The results of the current
study also demonstrated a decreased $T_{\text{MAX}}$ when compared to the previous studies. The
decrease in $C_{\text{MAX}}$ and $T_{\text{MAX}}$ in the current study may likely be due to the influence of
parasite load on drug concentration. Lespine et al. (2004) and Pariad et al. (2016)
reported lower drug values in parasitized sheep due to alterations in body fat reserves.
Although total worm burden was not quantified, this may be a reason why the results
from the current study deviate from previous research (Alvinerie et al., 1998; Lespine et
al., 2004; Molento et al., 2004).

Baseline milk samples from three of the four lactating ewes on trial contained
detectable moxidectin concentrations, thus demonstrating a carryover of drug residue
from the previous treatment. Farm records indicate that all ewes received anthelmintic
treatment on May 10, 2015, resulting in a 157 d wash out period prior to the onset of the
present study. This information demonstrates that the 157 d wash out period proved to be insufficient in eliminating moxidectin residues from ewe milk and highlights significant concern regarding the exposure of drug to fetus and offspring.

Additionally, results of the current demonstrate that moxidectin residues were present in all milk samples at 30 and 60 d post administration with an average concentration of 2.87 and 1.07 ng/mL, respectively. These results coincide with a previous study demonstrating moxidectin concentrations averaging 3.77 ng/mL 35 d post-administration (Imperiale et al., 2004). Moxidectin concentrations in milk are even greater when administered subcutaneously, as demonstrated by Leathwick et al. (2015) who reported on average 43.80 and 16.70 ng/mL on 27 and 32 d post anthelmintic treatment. These authors also reported that drug residues were measured at low concentrations 80 d post treatment. Anthelmintics administered subcutaneously result in slower release and utilization of the drug and remain in the body for a greater amount of time compared to orally administered drugs (Alvinereie, 1998; Imperiale et al., 2004; Lespine et al., 2004). Therefore, the data from the current study and Leathwick et al. (2015) demonstrate that regardless of subcutaneous or oral administration routes, moxidectin residues can be detected in milk up to 60-80 d post treatment. Future research is needed to evaluate how moxidectin concentrations in the milk change past 80 d post treatment, given no studies have evaluated milk beyond this time point, but results from the present study suggest that drug residues can still be present up to 157 d post-administration.
Moxidectin concentrations in the milk of lactating ewes resulted in detectable levels of moxidectin in the blood plasma of lambs. In contrast to Leathwick et al. (2015) who administered moxidectin subcutaneously to the ewe, concentrations of moxidectin were detected in lower quantities when administered orally. Lambs in the present study demonstrated a drug concentration of 3.00 ng/mL post treatment, which is less when compared to Leathwick et al. (2015), who reported an average concentration of 15.50 ng/mL. Furthermore, Leathwick et al. (2015) assessed nematode populations in lambs and concluded that 15.50 ng/mL resulted in the selectin of AR populations of nematodes. Therefore, further research identifying the consequences of moxidectin administered orally to lactating ewes on AR development in nursing lambs is needed.

**Conclusion**

Overall, there is a lack of scientific information on the impact of moxidectin concentrations on the development of AR resistance in nursing lambs exposed to the drug via milk. As demonstrated in the present study, moxidectin concentrations were detectable up to 157 days post-administration and this drug is transferred to the nursing lamb via milk. Further research is needed in order to understand how moxidectin drug concentrations and drug exposure time influences the fetus and nursing lamb in regards to the development of resistance parasitic populations.
Acknowledgments

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References


Table 2.1. Pharmacokinetic parameters of moxidectin in the plasma of lactating ewes after oral administration (0.2 mg/kg)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Ewe 1</th>
<th>Ewe 2</th>
<th>Ewe 3</th>
<th>Ewe 4</th>
<th>Geometric Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>C&lt;sub&gt;MAX&lt;/sub&gt;</td>
<td>ng/mL</td>
<td>15.12</td>
<td>12.13</td>
<td>11.34</td>
<td>13.94</td>
<td>13.05</td>
</tr>
<tr>
<td>T&lt;sub&gt;MAX&lt;/sub&gt;</td>
<td>h</td>
<td>12</td>
<td>8</td>
<td>12</td>
<td>4</td>
<td>8.24</td>
</tr>
<tr>
<td>AUC&lt;sub&gt;INF&lt;/sub&gt;</td>
<td>h × ng/mL</td>
<td>427.94</td>
<td>3068.06</td>
<td>270.23*</td>
<td>329.12</td>
<td>756.02</td>
</tr>
<tr>
<td>AUC&lt;sub&gt;EXTRAP&lt;/sub&gt;</td>
<td>%</td>
<td>12.94</td>
<td>35.76</td>
<td>--</td>
<td>13.52</td>
<td>18.43</td>
</tr>
<tr>
<td>Cl/F</td>
<td>mL/h/kg</td>
<td>478.56</td>
<td>66.54</td>
<td>--</td>
<td>622.04</td>
<td>270.56</td>
</tr>
<tr>
<td>T&lt;sub&gt;1/2 λz&lt;/sub&gt;</td>
<td>h</td>
<td>27.81</td>
<td>1169.98</td>
<td>--</td>
<td>19.28</td>
<td>85.60</td>
</tr>
<tr>
<td>λz</td>
<td>1/h</td>
<td>0.0249</td>
<td>0.0005</td>
<td>--</td>
<td>0.0360</td>
<td>0.0081</td>
</tr>
<tr>
<td>MRT 0-INF</td>
<td>h</td>
<td>33.18</td>
<td>1443.77</td>
<td>18.43**</td>
<td>30.27</td>
<td>113.19</td>
</tr>
</tbody>
</table>

<sup>1</sup>C<sub>MAX</sub> = maximum concentration, T<sub>MAX</sub> = time of C<sub>MAX</sub>, AUC<sub>INF</sub> = area under the curve extrapolated to infinity, AUC<sub>EXTRAP</sub> = % of AUC extrapolated, Cl/F= clearance by fraction dose, T<sub>1/2 λz</sub> = half-life by λz, λz = negative of best fit terminal slope, MRT<sub>0-INF</sub> = mean residence time extrapolated to infinity.

* AUC from zero to last.

** Using AUC from zero to last.
Figure 2.1. The average concentration (ng/mL) of moxidectin in ewe and lamb plasma post treatment with a single oral dose of moxidectin (0.2 mg/kg).
Figure 2.2. The average concentration (ng/mL) of moxidectin in the milk of lactating ewes post treatment with a single oral dose of moxidectin (0.2 mg/kg).
Chapter 3

The effects of alternative weaning strategies on lamb growth and infection severity of *Haemonchus contortus*

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 x Dorset and Suffolk x Dorset crossbred lambs and 24 Dorset x Suffolk and Dorset x 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) as previously described above. Ewe (E): lambs placed on pasture at 60 days of age with ewe and 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.

**Highlights**

- Delayed weaning improved overall lamb performance on pasture
- Delayed weaning reduced overall parasite load of lambs on pasture
- Addition of non-related, non-lactating ewe did not improve lamb health or growth
- Delayed weaning into the feedlot required less grain to reach a marketable weight
Keywords
lambs, weaning, stress, growth, FAMACHA

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 (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 to 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.

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).

Experiment 1

Animal and housing

A total of 48 Hampshire x Dorset and Suffolk x Dorset crossbred lambs and 24 Dorset x Suffolk and Dorset x 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.

**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-hectare 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 x 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 26000 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 re-growth for each internal division. \textit{Ad libitum} access to water and one of two mineral sources (described in \textit{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 71-103 days based upon a set targeted finishing weight. Each replicate was housed in a pen (4.1 m length x 1.5 m width) on expanded metal flooring with three metal gates and a wooden fence line feed bunk (3.7 m length x 0.3 m width x 0.3 m depth) on the fourth side. Sheep were provided \textit{ad libitum} access to water (0.3 m length x 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 (Table 3.1) to meet or exceed recommended nutrient requirements (NRC, 2007).

\textit{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.

**Lamb performance and health**

**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.

**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 sub-sample 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 grams 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). In addition, the main
parasite species of interest, *Haemonchus contortus*, was identified and quantified using fecal egg microscopy. Conversely, other species may have been present on pasture, however these species were not identified or quantified.

**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. Fecal egg count data were normalized using log (x + 10) transformation. 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.
Experiment 2

**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.

**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-hectare 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 76-109 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 (Table 3.1) to meet or exceed recommended nutrient requirements (NRC, 2007).

*Pasture measurements*

Total parasite load was quantified in all nine paddocks utilizing an elutriator to rapidly extract larvae concentrations from herbage samples. Herbage samples were collected randomly via grab samples (i.e. collecting handfuls of forage as to mimic the grazing motion of a sheep). The method of elutriation 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 10µm 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):

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

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-hectare 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 m² square quadrat, clipping all forage within the quadrat 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 hours in order to calculate the forage mass available per hectare.

**Lamb performance and health**

**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.
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.

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. Fecal egg count data were normalized using log ($x + 10$) transformation. 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.
Results

Experiment 1

Pasture measurements

Forage quality pooled samples for each paddock in experiment 1 are shown in Table 3.2. Over the duration of the trial, the average crude protein of the grazing plot was 19.64%.

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 3.3).

Lamb performance and health

Lamb pasture performance

Lamb pasture performance and health data for experiment 1 are presented in Table 3.3. 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.
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 3.3. 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.

Lamb feedlot performance

There was a treatment effect on lamb performance during the feedlot phase of the trial (P <0.05; Table 3.4). 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).

Experiment 2

Pasture measurements

Parasite concentrations between each paddock were not different across all collection days (P > 0.05; Table 3.5). Forage quality samples from the entire grazing plot
based on collection day in experiment 2 are shown in Table 3.6. 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 Table 3.7.

**Lamb performance and health**

**Lamb pasture performance**

Lamb performance data during the grazing portion of the trial for experiment 2 is
presented in Table 3.8. 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 3.8. 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 (P < 0.0001).

*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 3.9. 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 (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.

*Lamb feedlot performance*

Lamb feedlot performance data for experiment 2 can be found in Table 3.10. 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.

**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.

**Lamb performance**

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

**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.

**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.
Acknowledgments

We would like to thank our colleagues at the OARDC sheep research facility (Douglas Clevenger, Roger Shearer, Nikki Berry, Johel Bielke, and Kirsten Nickles) and the countless undergraduate students at The Ohio State University for assisting in data collection, on-farm work, and technical service during the trials.
References


<table>
<thead>
<tr>
<th>Item</th>
<th>Exp. 1 Diet</th>
<th>Exp. 2 Diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingredient</td>
<td>% on DM basis</td>
<td>% on DM basis</td>
</tr>
<tr>
<td>Dry rolled corn</td>
<td>55.00</td>
<td>----</td>
</tr>
<tr>
<td>Whole shelled corn</td>
<td>----</td>
<td>70.00</td>
</tr>
<tr>
<td>Alfalfa haylage</td>
<td>25.00</td>
<td>----</td>
</tr>
<tr>
<td>Alfalfa pellets</td>
<td>----</td>
<td>10.00</td>
</tr>
<tr>
<td>Soyhulls</td>
<td>----</td>
<td>5.00</td>
</tr>
<tr>
<td>Supplement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground corn</td>
<td>12.80</td>
<td>----</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>5.04</td>
<td>11.02</td>
</tr>
<tr>
<td>Urea</td>
<td>----</td>
<td>1.00</td>
</tr>
<tr>
<td>Limestone</td>
<td>----</td>
<td>1.00</td>
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<tr>
<td>Monosodium phosphate</td>
<td>0.05</td>
<td>----</td>
</tr>
<tr>
<td>Trace mineral salt&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.50</td>
<td>----</td>
</tr>
<tr>
<td>Sheep salt w/selenium&lt;sup&gt;b&lt;/sup&gt;</td>
<td>----</td>
<td>0.50</td>
</tr>
<tr>
<td>Vitamin A</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Vitamin D</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Vitamin E</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Selenium</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Amaferm (64 g/lb. in conc.)</td>
<td>----</td>
<td>0.39</td>
</tr>
<tr>
<td>Ammonium chloride</td>
<td>0.40</td>
<td>0.40</td>
</tr>
<tr>
<td>A-V fat</td>
<td>1.02</td>
<td>0.50</td>
</tr>
<tr>
<td>Analyzed composition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NDF, %</td>
<td>16.03</td>
<td>13.29</td>
</tr>
<tr>
<td>Calculated composition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude protein, %</td>
<td>13.07</td>
<td>17.47</td>
</tr>
<tr>
<td>Calcium, %</td>
<td>0.38</td>
<td>0.57</td>
</tr>
<tr>
<td>Phosphorous, %</td>
<td>0.35</td>
<td>0.36</td>
</tr>
<tr>
<td>NEm, Mcal/kg</td>
<td>1.98</td>
<td>2.03</td>
</tr>
<tr>
<td>NEg, Mcal/kg</td>
<td>1.33</td>
<td>1.38</td>
</tr>
</tbody>
</table>

<sup>a</sup> Contained > 93% NaCl, 0.35% Zn, 0.28% Mn, 0.175% Fe, 0.035% Cu, 0.007% I, and 0.007% Co.

<sup>b</sup> Contained > 90.2% NaCl, 0.1% Zn, 0.8% Mn, 0.125% Fe, 0.01% I, 0.002% Co, and .009% Se.
<table>
<thead>
<tr>
<th>Pasture</th>
<th>% Crude Protein</th>
<th>% ADF&lt;sup&gt;1&lt;/sup&gt;</th>
<th>% aNDF&lt;sup&gt;2&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>DN</td>
<td>22.82</td>
<td>44.24</td>
<td>59.69</td>
</tr>
<tr>
<td>DS</td>
<td>19.01</td>
<td>36.07</td>
<td>55.54</td>
</tr>
<tr>
<td>EN</td>
<td>17.28</td>
<td>36.56</td>
<td>64.19</td>
</tr>
<tr>
<td>ES</td>
<td>20.79</td>
<td>33.46</td>
<td>52.44</td>
</tr>
<tr>
<td>FN</td>
<td>18.16</td>
<td>36.24</td>
<td>56.73</td>
</tr>
<tr>
<td>FS</td>
<td>20.32</td>
<td>31.61</td>
<td>49.39</td>
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<tr>
<td>GN</td>
<td>19.73</td>
<td>33.86</td>
<td>52.49</td>
</tr>
<tr>
<td>GS</td>
<td>19.02</td>
<td>38.07</td>
<td>52.95</td>
</tr>
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</table>

<sup>1</sup>Percent Acid Detergent Fiber  
<sup>2</sup>Percent Neutral Detergent Fiber
Table 3.3. Effects of alternative weaning strategies on lamb performance and health during the grazing portion of the trial in Exp. 1

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Ewe</th>
<th>Pasture Control</th>
<th>SEM</th>
<th>Block</th>
<th>Loose</th>
<th>SEM</th>
<th>Lamb</th>
<th>Mineral</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of lambs</td>
<td>24</td>
<td>24</td>
<td></td>
<td>24</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BW, kg</td>
<td></td>
<td></td>
<td></td>
<td>0.43</td>
<td>23.9</td>
<td>23.7</td>
<td>0.53</td>
<td>0.3561</td>
</tr>
<tr>
<td>d 0</td>
<td>23.6</td>
<td>24.0</td>
<td>0.37</td>
<td>23.9</td>
<td>33.9</td>
<td>36.0</td>
<td>0.76</td>
<td>0.0001</td>
</tr>
<tr>
<td>d 63</td>
<td>39.6</td>
<td>30.3</td>
<td>0.57</td>
<td>33.9</td>
<td>36.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total ADG, g/day</td>
<td>254</td>
<td>100</td>
<td>6.0</td>
<td>159</td>
<td>195</td>
<td>6.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FAMACHA©</td>
<td></td>
<td></td>
<td></td>
<td>1.1</td>
<td>1.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d 29</td>
<td>1.1</td>
<td>1.4</td>
<td>0.1</td>
<td>1.4</td>
<td>1.1</td>
<td>0.1</td>
<td>0.1522</td>
<td>0.2658</td>
</tr>
<tr>
<td>d 42</td>
<td>1.3</td>
<td>2.6</td>
<td>0.4</td>
<td>2.0</td>
<td>1.8</td>
<td>0.5</td>
<td>0.0455</td>
<td>0.8065</td>
</tr>
<tr>
<td>d 49</td>
<td>1.1</td>
<td>2.3</td>
<td>0.3</td>
<td>1.8</td>
<td>1.6</td>
<td>0.3</td>
<td>0.0720</td>
<td>0.7001</td>
</tr>
<tr>
<td>d 57</td>
<td>1.1</td>
<td>2.4</td>
<td>0.3</td>
<td>2.0</td>
<td>1.5</td>
<td>0.3</td>
<td>0.0677</td>
<td>0.3892</td>
</tr>
<tr>
<td>d 63</td>
<td>1.2</td>
<td>2.1</td>
<td>0.4</td>
<td>2.0</td>
<td>1.4</td>
<td>0.4</td>
<td>0.1608</td>
<td>0.3829</td>
</tr>
<tr>
<td>Packed Cell Volume, %</td>
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<td></td>
<td></td>
<td>34.3</td>
<td>27.4</td>
<td>2.0</td>
<td>31.3</td>
<td>30.5</td>
</tr>
<tr>
<td>d 42</td>
<td>34.3</td>
<td>27.4</td>
<td>2.0</td>
<td>31.3</td>
<td>30.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d 63</td>
<td>33.1</td>
<td>28.7</td>
<td>0.6</td>
<td>31.1</td>
<td>30.7</td>
<td>0.6</td>
<td>0.0127</td>
<td>0.6216</td>
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<tr>
<td>Fecal Egg Count, Egg/g</td>
<td></td>
<td></td>
<td></td>
<td>4.5</td>
<td>7.9</td>
<td>0.66</td>
<td>5.8</td>
<td>6.6</td>
</tr>
<tr>
<td>Transformed, log (x+10)</td>
<td></td>
<td></td>
<td></td>
<td>7.1</td>
<td>7.0</td>
<td>0.51</td>
<td>7.2</td>
<td>6.9</td>
</tr>
<tr>
<td>Back-transformed</td>
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<td></td>
<td></td>
<td>80.0</td>
<td>2687.3</td>
<td></td>
<td>320.3</td>
<td>725.1</td>
</tr>
<tr>
<td>d 42</td>
<td>7.1</td>
<td>7.5</td>
<td></td>
<td>31.7</td>
<td>30.8</td>
<td></td>
<td>0.6</td>
<td>0.0181</td>
</tr>
<tr>
<td>d 63</td>
<td>1212</td>
<td>1808</td>
<td></td>
<td>1808</td>
<td>1212</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lambs not dewormed</td>
<td></td>
<td></td>
<td></td>
<td>33.1</td>
<td>29.4</td>
<td>0.6</td>
<td>31.7</td>
<td>30.8</td>
</tr>
<tr>
<td>PCV d 63</td>
<td></td>
<td></td>
<td></td>
<td>7.1</td>
<td>7.5</td>
<td>0.41</td>
<td>7.5</td>
<td>7.1</td>
</tr>
<tr>
<td>FEC d 63</td>
<td></td>
<td></td>
<td></td>
<td>1212</td>
<td>1808</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transformed, log (x+10)</td>
<td></td>
<td></td>
<td></td>
<td>7.1</td>
<td>7.5</td>
<td></td>
<td>7.5</td>
<td>7.1</td>
</tr>
</tbody>
</table>

1 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 3.4. Effects of alternative weaning strategies on lamb performance during the feedlot phase of the trial in Exp. 1

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment</th>
<th>Mineral</th>
<th>P – Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ewe</td>
<td>Pasture</td>
<td>SEM</td>
</tr>
<tr>
<td>Initial Wt, kg</td>
<td>39.6</td>
<td>30.3</td>
<td>0.57</td>
</tr>
<tr>
<td>Final Wt, kg</td>
<td>55.0</td>
<td>54.1</td>
<td>1.11</td>
</tr>
<tr>
<td>Days in feedlot</td>
<td>71.0</td>
<td>102.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Feedlot ADG, g/d</td>
<td>217</td>
<td>234</td>
<td>7.0</td>
</tr>
<tr>
<td>Overall ADG, g/d</td>
<td>235</td>
<td>183</td>
<td>5.0</td>
</tr>
<tr>
<td>DMI, kg/d</td>
<td>1.3</td>
<td>1.3</td>
<td>0.03</td>
</tr>
<tr>
<td>G:F, kg/kg</td>
<td>0.16</td>
<td>0.19</td>
<td>0.003</td>
</tr>
<tr>
<td>Total DMI, kg</td>
<td>94.4</td>
<td>128.9</td>
<td>4.7</td>
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</table>
Table 3.5. Larvae density (Larvae g-1 DM) in Exp. 2

<table>
<thead>
<tr>
<th>Collection Day</th>
<th>Pasture Control</th>
<th>Ewe</th>
<th>Social Facilitator</th>
<th>S.E.</th>
</tr>
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<tbody>
<tr>
<td>8</td>
<td>24.4</td>
<td>15.6</td>
<td>17.6</td>
<td>10.45</td>
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<td>33</td>
<td>8.5</td>
<td>4.3</td>
<td>6.5</td>
<td>3.57</td>
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<tr>
<td>53</td>
<td>8.6</td>
<td>17.8</td>
<td>18.2</td>
<td>11.21</td>
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</table>
Table 3.6. Forage quality samples on a dry matter basis by collection period in Exp. 2

<table>
<thead>
<tr>
<th>Collection Day</th>
<th>% Crude Protein</th>
<th>% ADF&lt;sup&gt;1&lt;/sup&gt;</th>
<th>% aNDF&lt;sup&gt;2&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>14.71</td>
<td>31.35</td>
<td>49.78</td>
</tr>
<tr>
<td>7</td>
<td>14.36</td>
<td>34.20</td>
<td>59.47</td>
</tr>
<tr>
<td>13</td>
<td>13.69</td>
<td>32.41</td>
<td>55.95</td>
</tr>
<tr>
<td>19</td>
<td>10.58</td>
<td>34.98</td>
<td>60.67</td>
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<tr>
<td>26</td>
<td>14.53</td>
<td>34.69</td>
<td>57.13</td>
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<td>33</td>
<td>14.40</td>
<td>38.56</td>
<td>57.29</td>
</tr>
<tr>
<td>40</td>
<td>13.44</td>
<td>34.26</td>
<td>57.84</td>
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<tr>
<td>47</td>
<td>12.03</td>
<td>38.04</td>
<td>59.07</td>
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<td>54</td>
<td>13.63</td>
<td>32.13</td>
<td>56.33</td>
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</table>

<sup>1</sup>Percent Acid Detergent Fiber (ADF)

<sup>2</sup>Percent Neutral Detergent Fiber (NDF)
Table 3.7. Forage dry matter, kg/ha in Exp. 2

<table>
<thead>
<tr>
<th>Collection day</th>
<th>Pasture Control</th>
<th>Ewe</th>
<th>Social Facilitator</th>
<th>SEM(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1</td>
<td>1414.7(^b)</td>
<td>2309.6(^a)</td>
<td>1975.8(^{ab})</td>
<td>275.73</td>
</tr>
<tr>
<td>14</td>
<td>2392.7(^b)</td>
<td>2993.7(^{ab})</td>
<td>3303.7(^a)</td>
<td>275.73</td>
</tr>
<tr>
<td>22</td>
<td>1985.0</td>
<td>1658.7</td>
<td>1904.4</td>
<td>275.73</td>
</tr>
<tr>
<td>37</td>
<td>2154.7(^b)</td>
<td>3224.4(^a)</td>
<td>1346.3(^c)</td>
<td>275.73</td>
</tr>
<tr>
<td>47</td>
<td>1283.4</td>
<td>1702.2</td>
<td>1917.1</td>
<td>275.73</td>
</tr>
</tbody>
</table>

\(^{a,b,c}\) Means within a row with different superscripts differ (P < 0.05)

\(^1\) Pooled standard error of the mean
Table 3.8. Effects of alternative weaning strategies on lamb performance during the grazing portion of the trial in Exp. 2

<table>
<thead>
<tr>
<th>Item</th>
<th>Pasture Control</th>
<th>Ewe</th>
<th>Social Facilitator</th>
<th>Feedlot control</th>
<th>SEM&lt;sup&gt;1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of lambs</td>
<td>18</td>
<td>17</td>
<td>18</td>
<td>18</td>
<td>----</td>
</tr>
<tr>
<td>BW, kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d 0</td>
<td>17.8</td>
<td>18.3</td>
<td>18.0</td>
<td>17.8</td>
<td>0.85</td>
</tr>
<tr>
<td>d 7</td>
<td>20.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>21.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>21.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>18.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.85</td>
</tr>
<tr>
<td>d 14</td>
<td>21.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>23.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>21.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>18.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.85</td>
</tr>
<tr>
<td>d 28</td>
<td>22.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>25.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>22.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>19.1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.85</td>
</tr>
<tr>
<td>d 42</td>
<td>24.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>30.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>25.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>22.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.85</td>
</tr>
<tr>
<td>d 56</td>
<td>24.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>31.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>25.1&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>27.3&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.85</td>
</tr>
<tr>
<td>ADG, g/d</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d 7</td>
<td>410&lt;sup&gt;a&lt;/sup&gt;</td>
<td>480&lt;sup&gt;a&lt;/sup&gt;</td>
<td>440&lt;sup&gt;a&lt;/sup&gt;</td>
<td>80&lt;sup&gt;b&lt;/sup&gt;</td>
<td>36</td>
</tr>
<tr>
<td>d 14</td>
<td>120&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>220&lt;sup&gt;a&lt;/sup&gt;</td>
<td>80&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>20&lt;sup&gt;c&lt;/sup&gt;</td>
<td>36</td>
</tr>
<tr>
<td>d 28</td>
<td>80&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>150&lt;sup&gt;a&lt;/sup&gt;</td>
<td>70&lt;sup&gt;ib&lt;/sup&gt;</td>
<td>40&lt;sup&gt;b&lt;/sup&gt;</td>
<td>36</td>
</tr>
<tr>
<td>d 42</td>
<td>130&lt;sup&gt;b&lt;/sup&gt;</td>
<td>360&lt;sup&gt;a&lt;/sup&gt;</td>
<td>170&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>270&lt;sup&gt;ac&lt;/sup&gt;</td>
<td>36</td>
</tr>
<tr>
<td>d 56</td>
<td>10&lt;sup&gt;b&lt;/sup&gt;</td>
<td>80&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10&lt;sup&gt;b&lt;/sup&gt;</td>
<td>320&lt;sup&gt;a&lt;/sup&gt;</td>
<td>36</td>
</tr>
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</table>

<sup>a, b, c</sup> Means within a row with different superscripts differ (P < 0.05)

<sup>1</sup> Pooled standard error of the mean
Table 3.9. 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

<table>
<thead>
<tr>
<th>Item</th>
<th>Pasture Control</th>
<th>Ewe</th>
<th>Social Facilitator</th>
<th>Feedlot Control</th>
<th>SEM(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FAMACHA(^2)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d 14</td>
<td>-0.2</td>
<td>0.3</td>
<td>0.2</td>
<td>0.3</td>
<td>0.22</td>
</tr>
<tr>
<td>d 28</td>
<td>-0.1</td>
<td>0.0</td>
<td>-0.3</td>
<td>-0.3</td>
<td>0.22</td>
</tr>
<tr>
<td>d 42</td>
<td>0.5(^ac)</td>
<td>-0.3(^b)</td>
<td>0.1(^bc)</td>
<td>0.4(^c)</td>
<td>0.22</td>
</tr>
<tr>
<td>d 56</td>
<td>1.1(^a)</td>
<td>-0.4(^b)</td>
<td>0.5(^c)</td>
<td>0.1(^bc)</td>
<td>0.22</td>
</tr>
<tr>
<td><strong>Packed Cell Volume, %</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d 14</td>
<td>-2.2(^a)</td>
<td>-1.8(^b)</td>
<td>-1.6(^b)</td>
<td>0.6(^b)</td>
<td>0.95</td>
</tr>
<tr>
<td>d 28</td>
<td>-5.9(^a)</td>
<td>-2.1(^b)</td>
<td>-4.8(^a)</td>
<td>-0.8(^b)</td>
<td>0.95</td>
</tr>
<tr>
<td>d 42</td>
<td>-7.6(^a)</td>
<td>-3.1(^b)</td>
<td>-9.9(^a)</td>
<td>-0.7(^b)</td>
<td>0.95</td>
</tr>
<tr>
<td>d 56</td>
<td>-8.8(^a)</td>
<td>-3.2(^b)</td>
<td>-8.7(^a)</td>
<td>-2.6(^b)</td>
<td>0.95</td>
</tr>
<tr>
<td><strong>Fecal Egg Count, eggs/g</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transformed, log (x+10)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d 14</td>
<td>4.0</td>
<td>4.0</td>
<td>3.7</td>
<td>4.2</td>
<td>0.49</td>
</tr>
<tr>
<td>d 28</td>
<td>5.5(^a)</td>
<td>5.2(^ab)</td>
<td>4.9(^ab)</td>
<td>4.2(^b)</td>
<td>0.40</td>
</tr>
<tr>
<td>d 42</td>
<td>7.0(^a)</td>
<td>6.6(^a)</td>
<td>7.4(^a)</td>
<td>4.9(^b)</td>
<td>0.39</td>
</tr>
<tr>
<td>d 56</td>
<td>8.3(^a)</td>
<td>7.3(^a)</td>
<td>7.8(^a)</td>
<td>5.2(^b)</td>
<td>0.46</td>
</tr>
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<td>Back-transformed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d 14</td>
<td>44.6</td>
<td>44.6</td>
<td>30.4</td>
<td>56.7</td>
<td>----</td>
</tr>
<tr>
<td>d 28</td>
<td>234.7</td>
<td>171.3</td>
<td>124.3</td>
<td>56.7</td>
<td>----</td>
</tr>
<tr>
<td>d 42</td>
<td>1086.6</td>
<td>725.1</td>
<td>1626.0</td>
<td>124.3</td>
<td>----</td>
</tr>
<tr>
<td>d 56</td>
<td>4013.9</td>
<td>1470.3</td>
<td>2430.6</td>
<td>171.3</td>
<td>----</td>
</tr>
<tr>
<td><strong>Lambs not dewormed</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCV d 56</td>
<td>-10.7(^a)</td>
<td>-3.2(^b)</td>
<td>-10.9(^a)</td>
<td>-2.5(^b)</td>
<td>1.06</td>
</tr>
<tr>
<td>FEC d 56</td>
<td>8.9(^a)</td>
<td>7.3(^b)</td>
<td>8.7(^a)</td>
<td>5.2(^c)</td>
<td>0.46</td>
</tr>
<tr>
<td>Transformed, log (x+10)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d 14</td>
<td>7322</td>
<td>1470</td>
<td>5993</td>
<td>171</td>
<td>----</td>
</tr>
</tbody>
</table>

\(^{a, b, c}\) Means within a row with different superscripts differ (P < 0.05)

\(^1\) Pooled standard error of the mean

\(^2\) 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 3.10. Effects of alternative weaning strategies on lamb performance during the feedlot phase of the trial in Exp. 2

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

<sup>a, b, c</sup> Means within a row with different superscripts differ (P < 0.05)
Bibliography


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Lewandowski, R., 2010. Use FAMACHA© correctly. The Ohio State University Extension OARDC.


