Sheep & Goat Research Journal
Volume 24, 2009

Wool Price Differences by Preparation in the United States

David P. Anderson[1], Oral Capps, Jr.[2], Ernest E. Davis[3], Shayla D. Teichelman[4]

[1] David P. Anderson is Associate Professor in Department of Agricultural Economics at Texas A&M University.

[2] Contact Author: Oral Capps, Jr. is Professor and Southwest Dairy Marketing Endowed Chair in the Department of Agricultural Economics, Texas A&M University 2124 TAMU, 330 Blocker Building, College Station, Texas 77843-2124.

[3] Ernest E. Davis is Regents Professor Emeritus in the Department of Agricultural Economics at Texas A&M University.

[4] Shayla D. Teichelman is a former graduate student in the Department of Agricultural Economics at Texas A&M University.

Acknowledgements:

Recognition is in order to the American Sheep Industry Association, especially Rita Kourlis-Samuelson, for funding this study and for providing access to wool warehouses.

Summary

Price differences for U.S. wools by preparation and type were examined using data collected from warehouses and pool sales across the United States over the period 1993 to 2002. The goal was to determine premium/discounts in wool prices by preparation and type, controlling for season, year, region, average-fiber diameter, and lot size. Unlike previous research efforts, a hedonic model was used in this investigation.

The hedonic price model explained about 83 percent of the variation in U.S. wool prices. Seasonality in U.S. clean wool prices was evident. Wool prices received by producers from January to March as well as from October to December were significantly lower from 5.9 percent to 17.4 percent than those prices in September. Wool prices in June were roughly 8 percent higher than those of September. In accord with prior expectations, U.S. clean wool prices were highest in 1995 and 1997. Prices in remaining years from 1993 to 2002 were significantly lower from 11.8 percent to 52.2 percent relative to the base year of 1997. Further, U.S. clean wool prices were discounted by 7.9 percent and 9.8 percent respectively, in the Eastern and Western regions of the United States relative to the Central region.

In line with prior research, prices of table-skirted and classed wool were significantly higher than original bag wool by slightly more than 8 percent. Significant differences among wool types also were evident. In particular, U.S. clean prices of TSC and BOU Main Line Wool were higher by 23.5 percent over the OB wool breed. Significant differences were noted as well among wool types from OB. Among wool types, the premiums/discounts relative to OB wool breed type were quite large in magnitude.

U.S. clean wool prices were sensitive to change in average diameter. The elasticity of clean price with respect to average fiber diameter was estimated to be roughly -1.42. Lot size, as measured by grease weight, also positively affected U.S. clean prices. The elasticity of clean price with respect to lot size was estimated as 0.16.

Key Words: U.S. Wool Prices, Hedonic Price Model.

Introduction

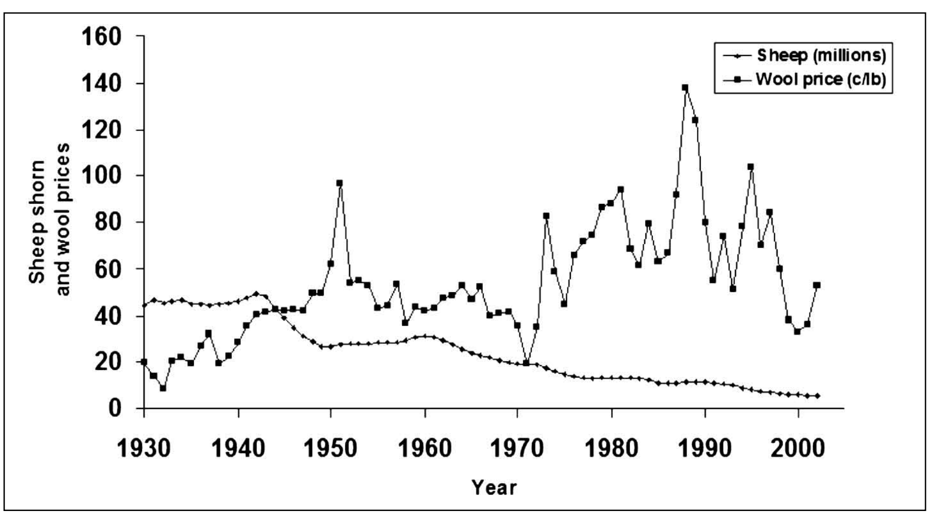
U.S. wool production has been on a steady decline since the 1940s, due in large part to the decline in sheep numbers. The number of sheep shorn from 1930 to the early 1940s was in the neighborhood of 40 to 50 million. Since the early 1940s, the number of sheep shorn dropped almost monotonically from a peak of nearly 50 million to roughly 6 million at present (Figure 1). Income support through the passage of the National Wool Act of 1954 stemmed the decline in sheep numbers until the early 1960s (Hager, 2003). This time frame coincided with the advent of man-made fibers, such as polyester and rayon, which have been well received by the apparel and home furnishings industry. The cotton industry was able to combat the onset of man-made fibers through the passage of the Cotton Research and Promotion Act of 1966 and the amended Act of 1990 (Capps and Williams 2006). Additionally, as a joint product with lamb, U.S. wool production also fell due to continued declines in the domestic demand for lamb (Hager, 2003; Williams et al, 2008).

With the signing of P.L. 103-130 into law by President Clinton in November 1993, which phased out over a two-year period wool and mohair incentive payments implemented by the National Wool Act of 1954, U.S. wool production experienced further declines. Wool production fell from 78 million pounds in 1993 to 47 million pounds in 2000, a 40 percent decline in this short time span. The loss of most domestic mills due to international competition and out-sourcing led to further difficulties (Hager, 2003; Williams, et al, 2008).

Support price schemes in Australia, New Zealand, and South Africa also contributed to wool market difficulties. Because support prices in these countries were set well above market levels, stockpiles of wool occurred, particularly induced by the Australian Wool Council (AWC) in the 1980s and early 1990s. After 1991, these stockpiles gradually were placed on the world market over the next decade, with the consequence of depressing wool prices. With the collapse of the former Soviet Union in the early 1990s, which contributed to a notable decline in demand, as well as the aforementioned repeal of the National Wool Act of 1954 in November 1993, world market prices of wool declined from 1995 to 2000. With the liquidation of the Australian stock piles in August 2001, however, wool prices began to rebound (Figure 1).

The United States is a small producer of wool in the world, with about 0.7 percent of world production. Australia, New Zealand, and China are the largest producing countries with 27.5 percent, 13.6 percent, and 12.7 percent of production, respectively. Australia and New Zealand also account for slightly more than 90 percent of world exports of wool. Australia is not only the largest exporter of wool in the world but also sets the international standard in the marketing of wools through preparation and class. In Australia, most wool is skirted and then subjectively classed by fineness, staple length, color, condition, style, and soundness. Classers produce as few lines as possible from the wool, while maintaining uniformity within a line and eliminating contamination of the clip with stained, pigmented fibers and all foreign material. (Lupton et al, 1996). Subsequently, most lots are objectively measured (prior to sale) for clean yield, vegetable matter content, average-fiber diameter (and variability), staple length, staple strength and color (Lupton et al, 1989).

Figure 1: Annual U.S. Sheep Shorn and Annual Nominal Wool Prices (Greasy Price), 1930 to 2002.



When a sheep is properly shorn, the fleece can be laid out on a table or floor and be seen as one piece. Skirting is the process of removing from fleeces the stained or inferior wool that grows on the belly and legs of the sheep (Lupton et al, 1992). Table skirting is simply placing the fleece on a table and finishing the skirting process. Classing is the preliminary sorting of fleece according to its quality.

Most wool in the United States continues to be sold as original bag, termed OB. OB wool is just as it sounds, wherein the sheep is shorn and the fleece is bagged without any further processing. "Bellies out" means that the wool from the belly, which is generally dirty, stained, and has more contaminants, is removed. Most of the wool produced in the United States is in the rangelands of the Western and Great Plains States.

Lupton et al, (1996) compared clean prices of skirted and classed wool to OB wool over a four-year period ending in 1996 using Texas Agricultural Experiment Station sheep flocks in San Angelo, Texas. They found that skirted and classed wool prices were higher by 6.6 percent to 26.9 percent per year over OB wool (equivalent to 9 to 30 cents per pound.) The potential to add value to the wool by skirting and classing is attributed to the fact that less sorting of skirted and classed wool is required when the wools clip reaches the textile mills. The resulting labor cost savings then could be passed back to producers in the form of higher prices.

Pfeiffer and Lupton (1999) found that skirted and classed wool may not produce more net income to producers than selling wool in OB form. Lupton et al, (1989) concluded that skirting could be profitable when applied to fine-wool fleeces and is reduced as wool prices decrease, as skirting costs increase, and when the wool is most coarse.

Another factor to be considered is the way wool is presented to buyers. One experiment conducted by Lupton et al, (1993) elicited subjective measurements from buyers for all wool lots. Objective measurements were available on only half the lots. The wool lots that were accompanied by objective measurements consistently received higher prices.

The literature suggests that skirting and classing wool generally produce higher prices compared to OB wool. We build on the literature through the use of a hedonic price model to determine the premiums/discounts among different levels of preparation and wool types, controlling for seasonality, year, region, average-fiber diameter, and grease weight (lot size). Previous research failed to account for these other factors in affecting clean-wool prices. Consequently, this work is the most definitive to date in considering U.S. clean-wool prices.

According to Kott (1997), "Getting the most for your wool is a complete process that involves growing it, proper harvesting and packaging, and then proper marketing." By understanding this process, marketing strategies can be developed to enhance prices to U.S. wool producers, especially given the decline in U.S. wool production over the past 70 years. In this light, the objective of this research was to examine price differences for U.S. wools by preparation and by type. Specifically, the goal of this research was to determine the size of the premium in wool prices, if any, between skirted and classed wools (Australian practice) versus original-bag wools (U.S. practice). The results from this research also can provide evidence on the economic gains to producers from adopting various wool preparation practices. As such, this research may also shed light on the competitiveness of the U.S. wool industry versus other countries, particularly Australia

Materials and Methods

Data

A comprehensive survey was sent to wool warehouses and pool sales across the United States to collect historical data on skirted and classed, as well as original-bag wool sales. A researcher from Texas A&M University was sent to locations that did not have the resources to collect the information. The data span was a ten-year period starting in January 1993 and ending in January 2002. Clean-wool prices were gathered noting region, season (month of year), year, wool preparation, wool type, average-fiber diameter (AFD), and grease weight (GW). The number of observations indigenous to this analysis was 8,589.

To consider the possible impact of region on wool prices, the United States was divided into three regions: Eastern, Central, and Western. The Eastern region included all states east of the Mississippi River. The Central region was separated from the Western region by a line that ran west of the Dakotas, Nebraska, Kansas, and New Mexico. The regions were chosen on the basis of demographic and market attributes as well as the location of the marketing warehouse or wool pool.[5]

The Eastern market was made up of smaller volumes of wool that typically were combined to obtain shipping volume. Eastern producers have few market outlets except in niche areas. The wool produced in this region was variable in quality and style. In the Central region, more uniform wool in terms of quality, style, and quantity was generally produced. In this region, most producers raise sheep on privately owned land. Marketing outlets typically have been well established in the central region, and generally producers, warehousemen, and buyers have well-established relationships.[6] Wool from the Western region was more variable in terms of all quality attributes. In the Western region, wool production typically occurred on federally-owned land. Maintaining a uniform flock was not usually a high priority, either because of producer preference or because federal landlords could change the conditions for leasing the grazing rights from year to year.[7]

As exhibited in , nearly 80 percent of the observations were associated with the Central region, about 18 percent were linked to the Western region, and roughly 3 percent were tied to the Eastern region. About 50 percent of the observations occurred in May and June, when wool was shorn and sold. More than 50 percent of the observations occurred over the last three years, due to the availability of historic records from the warehouses and pools across the United States. Warehouses and pools only saved records from three to five years back, and they discarded more dated records.

The data were separated into three levels of preparation: Original Bag (OB), Bellies-Out Untied (BOU), and Table Skirted and Classed (TSC). OB, BOU, and TSC wool corresponded to 22.5 percent, 56 percent, and 21.5 percent of the observations, respectively. OB refers to wool that has been sheared off the sheep and put into a bag with nothing removed. A fleece that is BOU has had the belly wool removed, packaged, and sold separately from the remainder of the fleece. The belly wool often is lower quality, stained, and contains more foreign matter.

TSC refers to wool with the highest level of preparation, corresponding to the aforementioned skirting and classing practices corresponding to wool types from BOU and TSC (wool breed); meat breed; and wool types from OB. Seventeen different wool types were identified. The highest percentage of the observations, slightly more than 60

[5] *Despite this regional delineation, there is probably as much variation within a region as there is across regions. The regional breakdown is not without problems. For instance, eastern South Dakota is considered to be in the central region geographically; however, the wool typically is marketed through warehouses in the Eastern region, while a considerable amount of the wools marketed in western South Dakota are produced in the western region as defined in this study. Also, the quality of eastern South Dakota wool is quite different from that of Texas and New Mexico and even western South Dakota.*

[6] *The marketing structure in Texas is a consigned warehouse system, but not for Kansas, Oklahoma, Nebraska, eastern South Dakota, and North Dakota (Hager, 2003).*

[7] *This production system reflects western Colorado, Utah, Idaho, and California but not necessarily Wyoming and Montana.*

Table 1: A Breakdown of the Number of Observations by Region, Year, Level of Preparation and Wool Type from Surveyed Wool Warehouses, January 1992 to January 2002.

	Number of Observations	Percentage of Observations
Region		
Western	1,547	18.13
Central	6,705	78.58
Eastern	281	3.29
Year		
1993	432	5.06
1994	425	4.98
1995	436	5.11
1996	405	4.75
1997	537	6.29
1998	646	7.57
1999	827	9.69
2000	1,621	19
2001	1,442	16.9
2002	1,762	20.65
Level of Preparation		
Original Bag (OB)	1,919	22.49
Bellies Out Untied (BOU)	4,779	56.01
Table Skirted Classed (TSC)	1,835	21.5
Wool Type		
Wool Breed (Wool Type from BOU and TSC)		
Main Line	5,281	61.89
Tender or Short Line	733	8.59
Bellies	603	7.07
Pieces	146	1.71
Stains	76	0.89
Locks	446	5.23
Clothing	77	0.9
Main Line Lamb	220	2.58
Meat Breed		
Main Line	132	1.55
Bellies	1	0.01
Wool Types from OB		
Wool Breeds	564	6.61
Meat Breeds (White Face)	91	1.07
Meat Breeds (Black Face)	91	1.07
Cross Bred	41	0.48
Wool Breed Lamb	18	0.21
Meat Breed Lamb	3	0.04
Black	10	0.12

percent, was in the Wool Breed, Main Line category. Nearly 9 percent of the observations were associated with the Tender or Short Line category. Tender means the fiber content was not strong enough and could easily be broken. Short line means that the staple length was shorter than three inches. Wool Breed Bellies and OB Wool Breeds each constituted about 7 percent of the observations, respectively.

Some of the original 8,589 observations were eliminated from further consideration. Observations pertaining to the years 1990, 1991, and 1992 were eliminated due to the paucity of data. Missing observations pertaining to U.S. clean price, average-fiber diameter, and grease weight (lot weight) were discarded as well. Thus, the number of useable observations for the analysis was 8,533.

Descriptive statistics for U.S. clean price, U.S. grease price, average-fiber diameter, and grease weight, are exhibited in Table 2. On average, U.S. clean price for this sample was $1.35 per pound ($0.70 per pound, greasy). The average-greasy price corresponds with Figure 1. On average, the average-fiber diameter was slightly more than 22 microns. The average-lot weight (grease weight) was close to 8,500 pounds. For prices, average-fiber diameter, and grease weight, considerable variation among the 8,533 observations was evident.

Empirical Model

A hedonic-price model is used to determine the premium and discounts associated with wool characteristics, controlling for region, year, season, average-fiber diameter, and grease weight (lot size). Past research considered prices only to be a function of wool preparation. Shulte (2001)) similarly used a hedonic-price model to investigate premiums/discounts of breed, color, frame size, muscle score, and lot weight on commingled/background cattle sales.

This statistical model employed in this analysis is given by:

$$\begin{aligned}
&\log \text{U.S. Clean Price}_{it} = \alpha_0 + \alpha_1 \text{January} + \alpha_2 \text{February} + \alpha_3 \text{March} + \alpha_4 \text{April} + \alpha_5 \text{May} + \\
&\alpha_6 \text{June} + \alpha_7 \text{July} + \alpha_8 \text{August} + \alpha_9 \text{October} + \alpha_{10} \text{November} + \alpha_{11} \text{December} + \alpha_{12} \text{YR1993} + \\
&\alpha_{13} \text{YR1994} + \alpha_{14} \text{YR1995} + \alpha_{15} \text{YR1996} + \alpha_{16} \text{YR1998} + \alpha_{17} \text{YR1999} + \alpha_{18} \text{YR2000} + \\
&\alpha_{19} \text{YR2001} + \alpha_{20} \text{YR2002} + \alpha_{21} \text{WESTERN} + \alpha_{22} \text{EASTERN} + \alpha_{23} \log \text{AFD}_{it} + \alpha_{24} \log \text{GW}_{it} + \\
&\alpha_{25} \text{BOU} + \alpha_{26} \text{TSC} + \alpha_{27} \text{WT MAIN LINE} + \alpha_{28} \text{WT TENDER OR SHORT LINE} + \alpha_{29} \text{WT BELLIES} + \alpha_{30} \text{WT PIECES} + \alpha_{31} \text{WT STAINS} + \\
&\alpha_{32} \text{WT LOCKS} + \alpha_{33} \text{WT CLOTHING} + \alpha_{34} \text{WT MAIN LINE LAMB} + \alpha_{35} \text{WT MB MAIN LINE} + \alpha_{36} \text{WTMB BELLIES} + \alpha_{37} \text{WTOBMB WHITE FACE} + \alpha_{38} \text{WTOBMB BLACK FACE} + \\
&\alpha_{39} \text{WTOB CROSS BRED} + \alpha_{40} \text{WTOB WOOL BREED LAMB} + \alpha_{41} \text{WTOB MEAT BREED LAMB} + \alpha_{42} \text{WTOB BLACK} + \varepsilon_{it}
\end{aligned}$$

The right-hand side variables in the regression model correspond to seasonal

Table 2: Descriptive Statistics for U.S. Wool Prices, Average Fiber Diameter, and Grease Weight (Lot Weight) for the Useable Sample of 8,533 Observations.

Variable	Mean	Median	Standard Deviation	Minimum	Maximum
U.S. Clean Price[a]	$1.35	$1.25	$0.64	$0.17	$4.80
U.S. Grease Price[a]	$0.70	$0.65	$0.38	$0.07	$2.87
Average Fiber Diameter[b]	22.28	21.80	2.39	17.6	38.0
Grease Weight[c]	8,407	4,982	10,112	1	45,345

[a] units are dollars per pound
[b] units are microns
[c] units are pounds

dummy or indicator variables (January, February, March, April, May, June, July, August, October, November, and December); dummy variables corresponding to year (YR1993, YR1994, YR1995, YR1998, YR1999, YR2000, YR2001, and YR2002); regional indicator variables (WESTERN and EASTERN); level of preparation indicator variables (BOU and TSC); wool-type-indicator variables (wool breed [types from BOU and TSC] - Main Line; Tender or Short Line; Bellies; Pieces; Stains; Locks; Clothing; and Main Line Lamb; Meat Breeds [Black Face]; Cross Bred; Wool Bred Lamb; Meat Breed Lamb; and Black).

The base year and month for the analysis were chosen to be 1997 and September, respectively. The Central region was chosen to be the base region. The bases for level of preparation and wool type were Original Bag and Original-bag wool Breeds. Original Bag corresponds to the lowest level of preparation and the Original-bag wool Breeds correspond to the highest-quality wool for the OB level of preparation. We hypothesize that U.S. clean prices are the highest in the third quarter of the year, where wool supply is less abundant. The majority of the world wool production is clipped and sold during the first and fourth quarters of the year. A large proportion of U.S. wool is clipped in April and May. From the previous discussion about wool prices exhibited in Figure 1, we expect U.S. wool prices to be higher in 1995 and 1997 relative to other years. We hypothesize prices in the Eastern and Western regions of the United States to be lower compared to prices in the Central region. In general, marketing outlets for wool in the Central region have been well established relative to other regions. As well, in the Central region, more uniform wool in terms of quality, style, and quantity is generally produced relative to other regions.

Importantly, we expect, a priori, BOU and TSC prepared wools to command a premium to OB wool. As well, we expect BOU and TSC Main Line wool and BOU and TSC Tender on Short Line wool to command a premium over wool types from OB. Further, average-fiber diameter (AFD) is hypothesized to be inversely related to U.S. clean price. Finally, it is hypothesized that lot size, as measured by grease weight, to be positively related to U.S. clean price. The closer a lot is to a truckload, the less money buyers spend on transportation per pound.

Results and Discussion

Empirical Results

The hedonic-price model explains about 83 percent of the variation in U.S. wool prices. The estimated coefficients and their associated P-values are exhibited in Table 3. The level of significance chosen for this analysis to conduct statistical tests is 0.01, given the rather sizeable sample of 8,533 observations. Given that the dependent variable is the logarithm of U.S. clean price, the interpretation of the estimated coefficients for each of the qualitative variables (season, year region, level of preparation, and wool type) is in terms of percentage changes. To calculate the premium/discount or the percentage difference relative to the base category for each of the qualitative categories from the base or reference category, use the transformation $\exp(a_i-1) \times 100$ percent, where a_i is the estimated coefficient of the *i*th indicator variable.

Seasonal Effects

The months of April, May, July, and August were not different *(P > .01)* from the base month of September. The month corresponding to highest U.S. clean prices was June, roughly 8 percent higher *(P <.01)* than those of September. Wool prices received by producers tended to be higher in May and July, relative to September, but not significantly *(P > .01)*. In accord with prior expectations, wool prices received by producers from January to March, as well as from October to December, were lower *(P<.01)* than those in September. The range of differences was from 5.9 percent lower (in March) to 17.4 percent lower (in January). Unequivocally, seasonality in U.S. clean prices for wool was evident.

Yearly Effects

In accord with prior expectations, U.S. clean wool prices were highest in 1995 and 1997. Controlling for other factors, prices in 1995 were higher by 17.7 percent *(P<.01)* relative to the base year of 1997. Prices in all remaining years from 1993 to 2002 were lower *(P<.01)* relative to the base year of 1997. Annual price differences ranged from 11.8 percent lower (in 1996) to 52.2 percent lower (in 2000).

Regional Effects

As expected, U.S. clean wool prices received by producers were discounted by 7.9 percent and 9.8 percent respectively in the Eastern and Western regions relative to the Central region. Clearly, regional price differences were evident. In the Central region, recall that more uniform wool, in terms of quality, occurs relative to other regions. Also, marketing outlets have been well-established in the Central region vis-à-vis other regions.

Effects of Level of Preparation

In line with most prior research studies, prices of table-skirted and classed wool (TSC) were higher *(P<.01)* than original bag (OB) wool by slightly more than 8 percent. Although prices of bellies out untied (BOU) wool were

Table 3: Estimated Coefficients and p-Values in the Hedonic Price Model

	Estimated Coefficients	Premium/Discount (%) Relative to Base	p-value
Month			
January	-0.1913	-17.4	<0.001
February	-0.0789	-7.6	<0.001
March	-0.0608	-5.9	<0.001
April	-0.0156	-1.5	0.212
May	0.0065	0.6	0.532
June	0.0779	8.1	<0.001
July	0.0039	0.45	0.756
August	-0.024	-2.4	0.081
September	Base	Base	Base
October	-0.0624	-6	<0.001
November	-0.1154	-10.9	<0.001
December	-0.1267	-11.9	<0.001
Year			
1993	-0.4947	-39	<0.001
1994	-0.1923	-17.5	<0.001
1995	0.1629	17.7	<0.001
1996	-0.126	-11.8	<0.001
1997	Base	Base	Base
1998	-0.2702	-23.7	<0.001
1999	-0.7014	-50.4	<0.001
2000	-0.7379	-52.2	<0.001
2001	-0.6249	-46.5	<0.001
2002	-0.2921	-25.3	<0.001
Level of Preparation			
Original Bag	Base	Base	Base
Bellies Out Untied	0.0209	2.1	0.27
Table Skirted Classed	0.0811	8.4	<0.001
Region			
Central	Base	Base	Base
Western	-0.1036	-9.8	<0.001
Eastern	-0.0823	-7.9	<0.001
Wool Breed (Wool Types from BOU and TSC)			
Main Line	0.2114	23.5	<0.001
Tender or Short Line	0.0551	5.7	<0.013
Bellies	-0.2903	-25.2	<0.001
Pieces	-0.4179	-34.2	<0.001
Stains	-0.6808	-49.4	<0.001
Locks	-0.9894	-62.8	<0.001
Clothing	0.1986	22	<0.001
Main Line Lamb	0.1432	15.4	<0.001
Meat Breed			
Main Line	0.0394	4	0.174
Bellies	-0.1288	-12.1	0.545
Wool Types from OB			
Wool Breed	Base	Base	Base
Meat Breeds (White Face)	-0.2325	-20.7	<0.001
Meat Breeds (Black Face)	-0.3826	-31.8	<0.001
Cross Bred	-0.3226	-27.6	<0.001
Wool Breed Lamb	-0.179	-16.4	<0.001
Meat Breed Lamb	-0.6988	-50.3	<0.001
Black	-1.1606	-68.7	<0.001
Log of Average Fiber Diameter	-1.416		<0.001
Log of Grease Weight	0.0162		<0.001
Constant	4.809		<0.001
R^2	0.8303		

higher by about 2-percent relative to OB wool, this difference was not statistically different from zero *(P>.01)*. Importantly, as the level of preparation of wool increases, U.S. clean-wool price increases. But, the only significant price premium was associated with TSC wool over the reference category OB wool. Even controlling for other factors, a price premium of 8 percent for TSC wool over OB wool was evident.

Wool Type Effects

As expected, U.S. clean prices of TSC and BOU Main Line wool were higher by 23.5 percent over the base category of OB wool breed. U.S. clean prices of TSC and BOU clothing and Main-line Lamb also were higher by 22.0 percent and 15.4 percent respectively over OB wool breed. Wool prices of TSC and BOU bellies, pieces, stains, and locks, all lower quality types, were discounted from slightly more than 25 percent (bellies) to just under 6.3 percent (locks) relative to prices of the reference category OB wool breeds.

Significant differences in wool types from OB were evident, as well. Relative to prices associated with the base wool type (wool breeds from OB), prices of other wool types from OB were lower, ranging from roughly 16 percent lower (Wool breed lamb) *(P<.01)* to nearly 70 percent lower (black) *(P<.01)*. Prices of OB wool breed and those from meat breeds, either main line or bellies, were not different *(P>.01)*. Differences in U.S. clean prices were evident among wool types. The premium and discounts among wool types relative to the OB wool breed type were quite large in magnitude.

Effects of Average-fiber diameter

As hypothesized, U.S. clean prices and average-fiber diameter (AFD) were negatively related. This relationship is depicted in Figure 2. Given that U.S. clean price and average-fiber diameter are expressed in terms of logarithms, the estimated coefficient of AFD in the hedonic-price model represents the elasticity. The elasticity of clean price to average-fiber diameter was estimated to be -1.416. Consequently, controlling for all other influences on clean prices, a 10-percent change in average-fiber diameter (e.g. a change from the sample mean of

22 microns to either 20 microns or 24 microns) leads to nearly a 14.2-percent change in price in the opposite direction (e.g. a change from the sample mean of $1.35 per pound to either $1.16 per pound or $1.54 per pound). Thus, U.S. clean-wool prices are sensitive to changes in average-fiber diameter.

Lot Size Effects

Again, as hypothesized, clean wool price and lot size, as measured by grease weight (GW), were positively related. This relationship is presented in Figure 3. Given that clean wool price and lot size are expressed in logarithms, the estimated coefficient in the hedonic-pricing model represents the elasticity. The elasticity of clean price to grease weight was estimated to be 0.0162. Hence a 10-percent change in lot size (e.g. a change from the sample mean of 8,490 pounds to either 7,640 pounds or 9,340 pounds) leads to a 0.16 percent change in clean-wool price. Although, this elasticity is statistically significant, practically speaking, U.S. clean-wool prices were not heavily influenced by lot size.

In summary, we pictorially represent the effects of season, year, region, level of preparation, and wool type on U.S. clean-wool prices in Figures 4 through 8. Each of these factors was statistically significant in influencing U.S. clean-wool prices. The hedonic-price model explained more than 80 percent of the variability in U.S. clean-wool prices.

Conclusion

We examined price differences for U.S. wools by preparation and type using data collected from warehouses and pool sales across the United States over the period 1993 to 2002. The goal was to determine premiums/discounts in wool prices by preparation and type controlling for season, year, region, average fiber diameter, and lot size. Unlike previous research efforts, a hedonic price model was used to ascertain these premiums/discounts due to wool characteristics.

Our model allows producers to ascertain premiums or discounts relative to the current practice of marketing OB wool. This information then can be used to determine marketing strategies to enhance prices to U.S. wool producers. Improvements in record keeping and a

Figure 2: Relationship between U.S. Clean Wool Price and Average Fiber Diameter-Based on the Sample of 8,533 Observations.

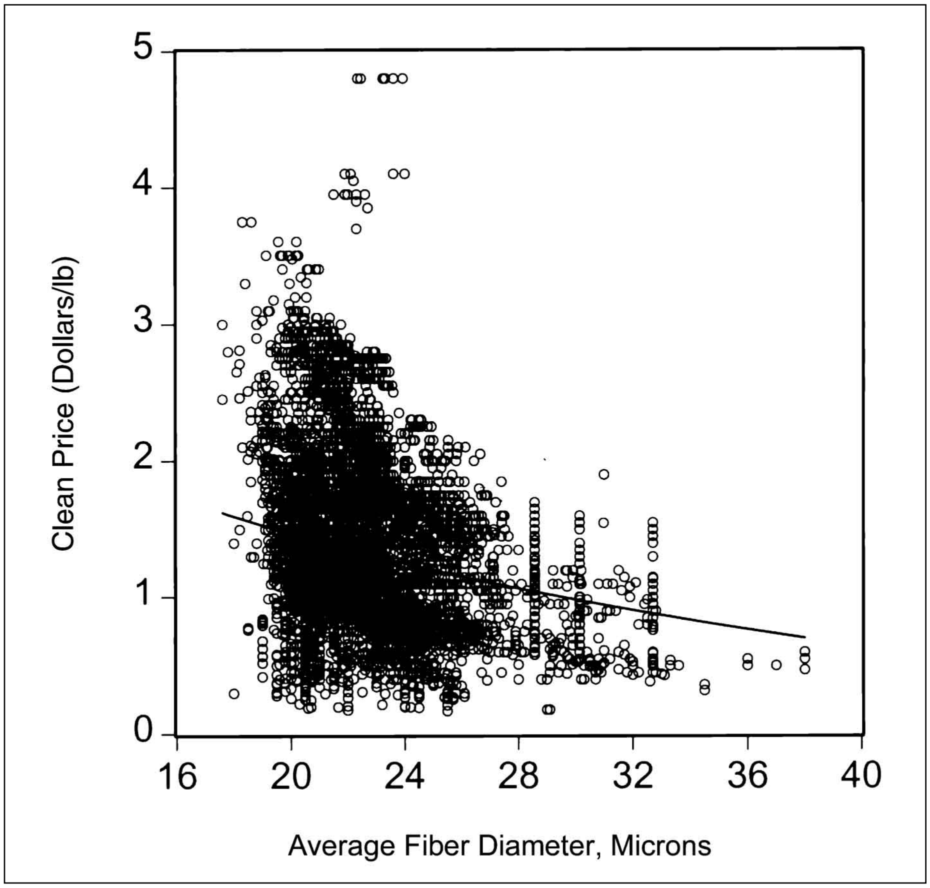


Figure 3: Relationship between Lot Size as Measured by Grease Weight and U.S. Clean Wool Price Based on the Sample of 8,533 observations.

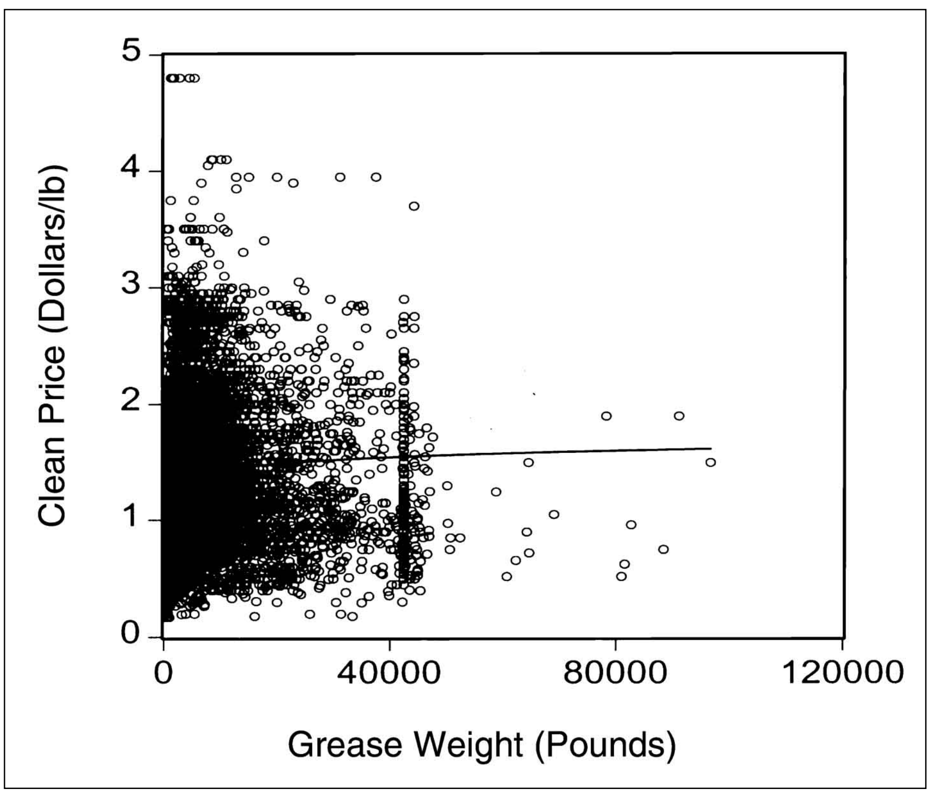


Figure 4: Percentage Differences in U.S. Clean Wool Price by Month Relative to the Base Month of September.

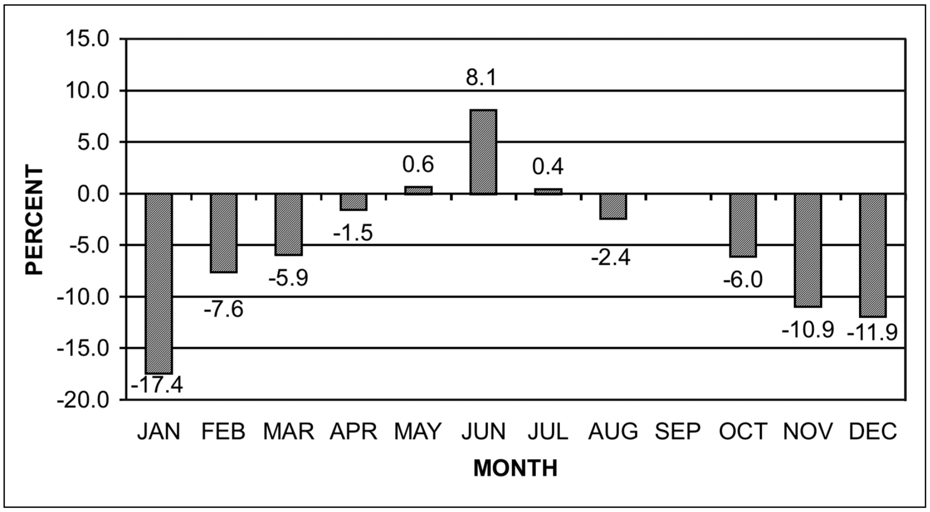


Figure 5: Percentage Difference in U.S. Clean Wool Price by Year Relative to the Base Year of 1997.

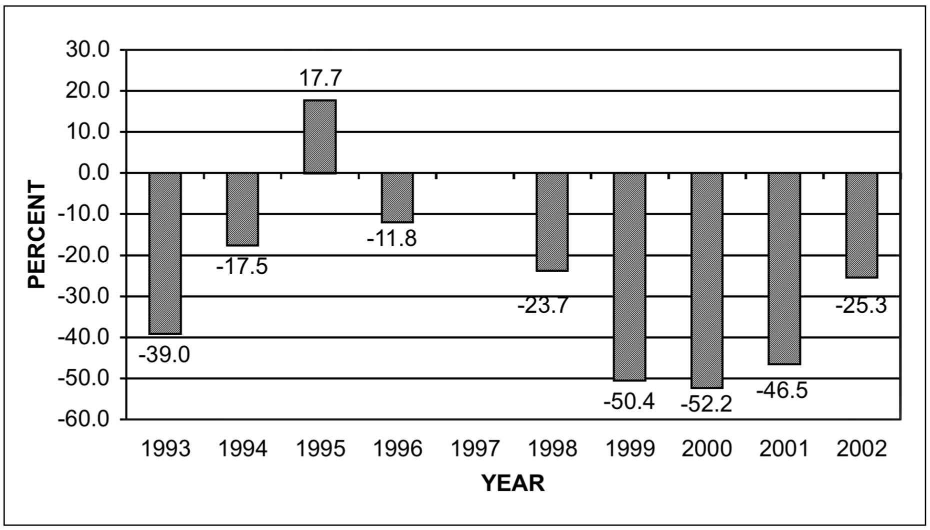
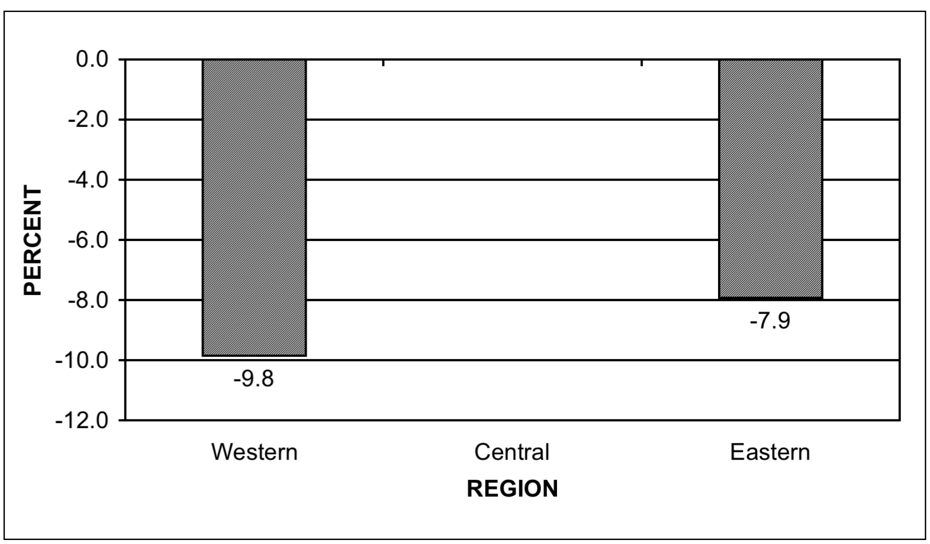


Figure 6: Percentage Difference in U.S. Clean Wool Price by Month Relative to the Base Region of the Central United States.



more uniform description system are needed in order to continue to monitor premiums/discounts of U.S. clean prices due to wool characteristics.

Producers and marketers alike need to find more consistent ways to present U.S. wool to buyers. Many U.S. producers sell their wool on a sealed-bid basis after subjective evaluation by warehouse managers or buyers. It may be worthwhile to determine if alternative marketing practices such as open auction, sealed bid, private treaty, subjective description, and objective description are influential on U.S. wool practices.

LITERATURE CITED

Capps, Jr., O., and G.W. Williams. October 2006. The effectiveness of the cotton checkoff program, report prepared for the Cotton Board.

Hager, S.D. December 2003. Determining price differences among different classes of wool from the United States and Australia. M.S. Thesis, Texas A&M University.

Kott, R. 1997. Wool - what is it worth? Sh. Ind. J. 1:15.

Lupton, C.J., F.A. Pfeiffer, and N.E. Blakeman. 1993. Economic impact of pre-sale fiber measurements on prices paid for wool. Sh. Res. J. 9:35-37.

Lupton, C.J., F.A. Pfeiffer, and N.E. Blakeman. 1989. Optimizing the value of grease wool trough preparation and marketing. SID Res. J. 5. Special Issue: 1-20.

Lupton, C.J., F.A. Pfeiffer, N.E. Blakeman, D.N. Ueckert, and J.E. Huston. 1992. Effects of skirting on yield, fineness, and value of wool from fine-wool range ewes. J. Anim. Sci. 70: 2657-3664.

Lupton, C.J., F.A. Pfeiffer, and S. Byrns. 1996. Adding value to wool clips by fleece skirting and classing. Research Reports Sheep and Goat, Wool and Mohair, 5, 257: 51-52.

Pfeiffer, F.A., and C.J. Lupton. 1999. Results of skirting and classing fleeces on the value of wool from fine-wool range ewes. J. of Anim. Sci. 77: 245.

Schulte, J.R. May 2001. Economic viability of a commingled/backgrounded cattle sale. M.S. Thesis, Texas A&M University.

Figure 7: Percentage Difference in U.S. Clean Wool Price by Level of Preparation Relative to the Base Preparation of Original Bag (OB).

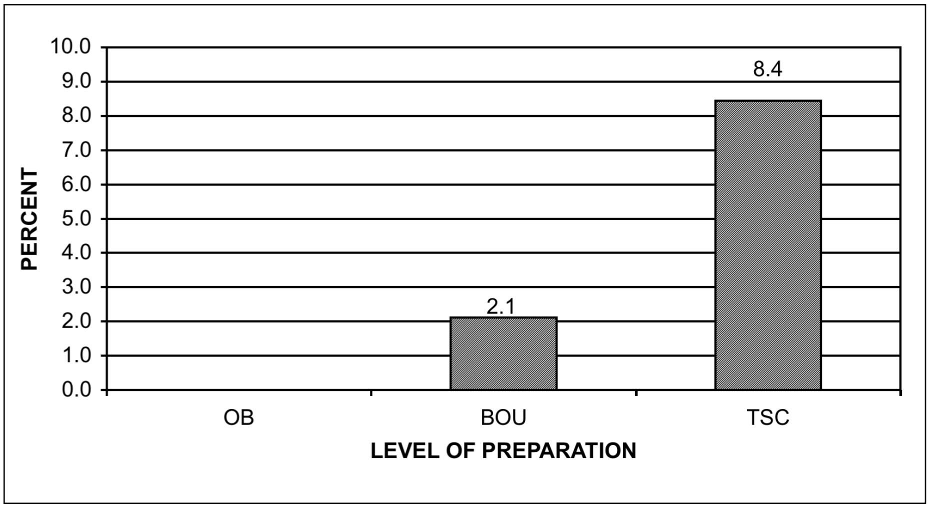
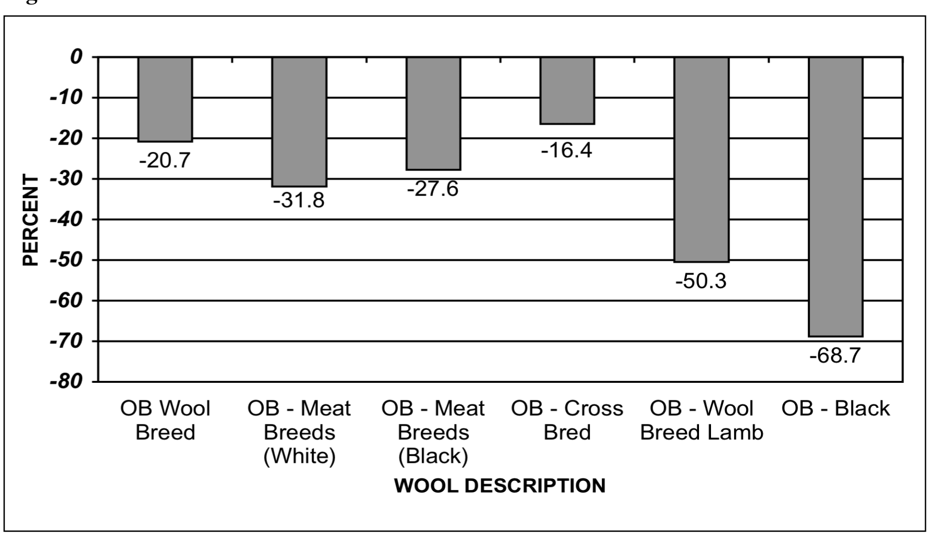


Figure 8: Percentage Difference in U.S. Clean Wool Price by Types Relative to the Base OB-Wool Breed.

Figure 8: Continued.



Williams, G.W., D. Baily, O. Capps, Jr., L.A. Detwiler, H.A. Glimp, T. Hammonds, D.D. Hedley, H.H. Jensen, P.S. Kuber, and D.L. Thomas. 2008. Changes in the sheep industry in the United States: making the transition from tradition. Committee on the Economic Development and Current Status of the Sheep Industry in the United States, National Research Council of the National Academies, The National Academics Press

Sheep & Goat Research Journal
Volume 24, 2009

Evaluating Nutritional Status of Dorper and Rambouillet Ewes in Range Sheep Production

T. R. Whitney[1,2], and D. F. Waldron[1] and T. D. Willingham[1]

[1] *Texas AgriLife Research and Extension Center, 7887 U.S. Hwy. 87 N., San Angelo, TX 76901.*

[2] *Corresponding Author Email: trwhitney@ag.tamu.edu*

Summary

Mature Dorper and Rambouillet ewes were maintained together for 2 years in a range environment to evaluate their nutritional status before and during gestation. During Years 1 and 2, nutritional status of mature Dorper (n = 46 and 71, respectively) and Rambouillet (n = 33 and 81, respectively) ewes were evaluated during pre- (August), mid- (late October) and late gestation (December). Ewes were selected from multiple Dorper (n = 20) and Rambouillet (n = 13) flocks. All ewes performed well while grazing and did not lose weight or BCS during gestation, except in Year 1 during late gestation when Dorper and Rambouillet ewes both lost weight. Compared to Rambouillet ewes, Dorper ewes had higher BCS ($P < 0.03$) during pre-gestation in Year 1 and throughout Year 2 ($P < 0.01$), but similar BW ($P > 0.10$) during both years. Dorper ewes tended to have greater IGF-1 concentrations ($P < 0.08$) during Year 1 in pre-gestation, and maintained greater IGF-1 concentrations ($P < 0.005$) than Rambouillet ewes throughout Year 2. Dorper ewes had less serum NEFA and serum urea nitrogen ($P < 0.05$) than Rambouillet ewes during mid- and late gestation in Year 2. Results suggest that nutritional status differed at times, between Dorper and Rambouillet ewes in a range production system during gestation. Reasons for Dorper ewes having higher BCS and serum IGF-1 concentrations throughout gestation need to be investigated further.

Key Words: Dorper, Rambouillet, Insulin-like Growth Factor-1, Metabolites, Rangelands, Sheep

Introduction

The Dorper breed is a hair sheep that was developed in South Africa and recently imported into the United States (1990s). The Rambouillet is the predominant breed in many traditional sheep-raising areas of the United States. The Dorper is being considered as an alternative to the Rambouillet by some U.S. sheep producers because the Dorper breed has been selected for its adaptability to harsh environmental conditions (Milne, 2000), is reported to have high productivity, and because it does not need shearing.

Differences in grazing behavior and adaptability, nutritional requirements, and ability to digest forages and metabolize plant chemicals exist among livestock and are some factors that can affect performance and nutritional status of grazing animals. Nutritional status of grazing animals can be evaluated by analyzing changes in BCS, BW, and concentrations of serum metabolites and IGF-1. If an animal is unable to consume enough forage to meet maintenance requirements, it uses body reserves, resulting in increased concentrations of serum non-esterified fatty acids (NEFA) and serum urea nitrogen (SUN) due to adipose and protein catabolism, respectively (Richards et al., 1989; Caldeira et al., 2007b). Utilizing body energy reserves (fat and muscle) can be detrimental to maternal performance (Gunn et al., 1995; Rhind et al., 2001) and can permanently alter fetal development (Barker and Clark, 1997; McMillen et al., 2001). Nutrient consumption below maintenance and that needed for mandatory production (such as pregnancy) also decreases circulating IGF-1 concentration (Harvey and Hull, 1995), which has been associated with poor reproductive performance (McGuire et al., 1992; Funaba et al., 1996).

No research has been reported comparing Dorper to Rambouillet ewes to determine their relative nutritional status while grazing rangelands. Production decisions and nutritional programs can be more effective if differences in nutritional status are known. Thus, nutritional status of Dorper and Rambouillet ewes in a range-sheep-production system was evaluated.

Materials And Methods

Grazing Site

This study was conducted during 2005 (Year 1) and 2006 (Year 2) at the Hill Ranch near the Texas AgriLife Research Center, located 45 km southeast of Sonora, TX (lat 31.14°N; long 100.19°W). This area is located within the Edwards Plateau Region and has an elevation of approximately 632 meters. Vegetation is a mosaic of juniper and oak mottes interspaced with mid- and shortgrasses. During fall months and winter months of Years 1 and 2, forage cover was dominated by Texas wintergrass (Stipa leucotricha, Trin and Rupr) with very few intermittent forbs. Table 1 displays average monthly precipitation for Years 1 and 2. Nutrient compositions of key forages are listed in Table 2. Detailed descriptions of climate, soils, and vegetation were described by Smeins et al. (1976) and Riddle et al. (1996).

Table 1. Monthly precipitation (cm) for Year 1 (2005), Year 2 (2006) and 10-year averages, at the Texas AgriLife Research Center, Sonora, TX[a]

Month	2005	2006	10-year average
January	2.57	5.08	2.24
February	4.98	1.22	3.26
March	3.71	3.53	5.13
April	2.39	10.85	5.05
May	16.51	1.19	6.07
June	0.86	5.89	6.74
July	2.92	3.51	5.54
August	9.32	5.99	7.46
September	6.53	9.25	5.04
October	8.26	6.96	8.53
November	trace	trace	9.56
December	0.38	1.50	1.64
TOTAL	58.42	54.97	62.82

[a] Year 1: pre- (8-9-05 and 8-16-05), mid- (10-28-05 and 11-9-05), and late gestation (12-13-05 and 12-20-05); Year 2: pre- (8-8-06 and 8-15-06), mid- (10-19-06 and 10-26-06), and late gestation (12-11-06 and 12-18-06).

Animals and Management

From 2003 through 2005, Dorper and Rambouillet ewe lambs were obtained from different Dorper (n = 20) and Rambouillet (n = 13) flocks, and were managed as a single flock. Ewes had been mated for the first time at approximately 18 mo of age to lamb in January and February at approximately 2 years of age. All ewes had been managed together for a minimum of 4 months before this study started.

Year 1.

Dorper (n = 46; initial mean BW ± SD = 70.8 ± 11.4 kg) and Rambouillet (n = 33; initial mean BW ± SD = 68.6 ± 8.0 kg) ewes were composed of 2-year olds (n = 28 and 19, respectively) and 3-year olds (n = 18 and 14, respectively). Ewes were moved to the study area on April 19, 2005 and always grazed together with no supplementation, because forage availability was not considered to be limiting. Rams were introduced on August 16, 2005 and remained with the ewes until October 28, 2005. Pregnancy was determined by ultrasound on October 30, 2005 and only ewes that were predicted to lamb within the first 45 days of the lambing season (i.e., those bred in the first 45 days of exposure to the rams) continued to be evaluated. In addition, ewes were evaluated regardless of number of fetuses, since ewes with single, twin, or triplet fetuses were similar for most measured parameters at each sampling date. Blood samples were collected, and ewes were weighed and evaluated for BCS during pre- (August 9 and 16), mid- (October 28 and November 9), and late (December 13 and 20) gestation. The final sampling date occurred 23 days before the first ewe lambed, to minimize inherent variability in serum hormones and metabolite concentrations, which are associated with the

Table 2. Nutrient composition (% DM basis) of clipped forages during Years 1 (2005) and 2 (2006)

Item[a]	Year 1 CP	Year 1 NDF	Year 1 ADF	Year 2 CP	Year 2 NDF	Year 2 ADF
Pre-gestation						
TX wintergrass	11.5	64.8	41.3	5.0	62.6	43.5
warm season grasses	8.1	67.6	50.6	3.8	67.5	48.7
live oak	9.5	40.9	33.4	7.1	43.5	36.8
Mid-gestation						
TX wintergrass	8.1	63.1	46.0	8.1	64.8	40.0
warm season grasses	7.7	61.2	45.2	6.0	63.1	44.4
live oak	10.1	37.2	32.6	9.0	40.9	35.0
Late-gestation						
TX wintergrass	5.9	61.4	44.1	5.5	69.7	46.4
warm season grasses	4.0	69.1	54.6	4.7	69.3	48.7
live oak	8.2	46.3	37.2	8.9	42.2	34.2

[a] Texas wintergrass *(Nassella leucotricha)* was dominant grass; Warm season grasses were mainly buffalo grass *(Buchloe dactyloides)*, big bluestem *(Adropogon gerardii)*, little bluestem *(Adropogon soparius)*, and sideoats gramma *(Bouteloua curtipendula)*; live oak *(Quercus fusiformis)*.
[b] Year 1: pre- (8-9-05 and 8-16-05), mid- (10-28-05 and 11-9-05), and late gestation (12-13-05 and 12-20-05); Year 2: pre- (8-8-06 and 8-15-06), mid- (10-19-06 and 10-26-06), and late gestation (12-11-06 and 12-18-06).

periparturient period. On days when blood was collected and BW and BCS were recorded, all ewes were gathered and penned by approximately 0830. Ewes were returned to pasture approximately 2 h after being gathered.

Year 2.

Dorper (n = 71; initial mean BW ± SD = 65.9 ± 10.9 kg) and Rambouillet (n = 81; initial mean BW = 66.0 kg ± 9.4 S.D.) ewes were composed of 2-year olds (n = 22 and 27, respectively), 3-year olds (n = 32 and 33, respectively), and 4-year olds (n = 17 and 21, respectively). Ewes were moved to the study area on May 15, 2006 and always grazed together with no supplementation, because forage availability was not limiting. Rams were introduced on August 15, 2006 and remained with the ewes until October 20, 2006. In contrast to Year 1, pregnancy was not determined by ultrasound. All ewes were evaluated and collected on each sampling date, and only data from ewes that lambed within the first 45 d of the lambing season were analyzed. Ewes were again evaluated during pre- (August 8 and 15), mid- (October 19 and 26), and late- (December 11 and 18) gestation. The final sampling date occurred 22 d before the first ewe lambed. Ewes were handled as described for Year 1.

Sample Collection and Measurements

Forages.

During years 1 and 2, random grab samples of forages were collected and combined separately according to the following groups: dormant Texas wintergrass (*Nassella leucotricha L.*) and warm season grasses, and Texas live oak (*Quercus fusiformis*) leaves. Warm season grasses consisted mainly of buffalo grass (*Buchloe dactyloides* [Nutt.] Engelm.), big bluestem (*Adropogon gerardii Vitma*.), little bluestem (*Schizachyrium scoparium* [Michx] Nash.), and sideoats gramma (*Bouteloua curtipendula* [Michx.] Torr.). Cool season grasses, other than Texas wintergrass and forbs, were either absent or extremely sparse during both years of this study, thus nutrient composition of these species is not reported. Samples remained separated by group as previously described, oven-dried at 55°C for 48 h, stored at -20°C, and ground in a Wiley Mill (Arthur H. Thomas Co., Philadelphia, Pa.) to pass a 1-mm screen. Crude protein was analyzed by a standard method (AOAC, 1990) and NDF and ADF were analyzed by Ankom (Ankom Technology Corp., Fairport, N.Y.) procedures. In addition, a sub-sample was dried in a forced-air oven at 103°C until weight was constant to determine DM content.

Animal, Hormone, and Metabolite Measures.

During Year 1, BW was recorded for each ewe on August 9, 2005 (pre-gestation) and January 1, 2006 (late gestation). During Year 2, body weight was recorded on August 8 (pre-gestation), October 19 (mid-gestation), and December 11 (late gestation). The BCS (1 = emaciated to 5 = obese) was evaluated by two trained technicians during Year 1 on August 9, 2005 and during Year 2 on August 8, 2006, October 19, and December 11. During Year 1, blood was collected on August 9 and 16 (pre-gestation), October 28 and November 9 (mid-gestation), and December 13 and 20 (late gestation). During Year 2, blood was collected on August 8 and 15 (pre-gestation), October 19 and 26 (mid-gestation), and December 11 and 18 (late gestation). To account for inherent variability in blood serum IGF-1 and metabolites that occurs with a single blood sample, IGF-1, SUN, and NEFA were analyzed by date, but results were averaged by gestation period (two blood collections per gestation period) before statistical analysis.

A 10-ml blood sample was collected in the morning (at 0900) from each ewe via jugular venipuncture using a non-heparinized vacutainer collection tube (serum separator tube, gel and clot activator; Becton Dickenson, Franklin Lakes, N.J.). Blood samples were allowed to clot and then centrifuged (Beckman Coulter TJ6 refrigerated centrifuge, Fullerton, Calif.) at 970 x *g* for 25 min at 4°C. Serum was decanted and frozen at -20°C until analyzed for IGF-1, SUN, and NEFA concentrations. Serum concentrations of IGF-1 were determined by RIA using procedures of Berrie et al. (1995). Intra-assay CV for IGF-1 was 5.6 percent and 13.4 percent (years 1 and 2, respectively) with a 95 percent recovery rate. For year 2005, serum NEFA and SUN concentrations were analyzed using an auto-analyzer (Technicon Autoanalyzer Ill., Bran Luebbe, Buffalo Grove, Ill.). For Year 2, serum concentrations of SUN were analyzed using a commercial kit (Teco Diagnostics, Anaheim, Calif.) with intra- and inter-assay CV < 7 percent. Serum NEFA concentrations for Year 2 were also analyzed using a commercial kit (NEFA C; Waco Chemicals, Neuss, Germany) with intra- and inter-assay CV < 9 percent.

Statistical Analyses

Values for IGF-1, NEFA, and SUN were averaged for each ewe within each of the three periods (pre-, mid-, and late gestation). These average values were then analyzed using Proc Mixed of SAS (SAS Inst. Inc., Cary, N.C.) with a model that included breed, age, and number of lambs born as fixed effects; and flock of origin and residual as random effects. Partial correlations between NEFA, SUN, IGF-1, BC, and BW were estimated using Proc Corr of SAS within breed and after age and number of lambs were taken into account.

Results And Discussion

Rainfall during Years 1 and 2 was typical for the Edwards Plateau region of Texas, except for lower than average rainfall from mid-October through December (Table 1). Cumulative spring rains were below the 10-year average during both years, but were still sufficient to allow for good warm- and cool-season grass growth. In contrast, forbs were either sparse or non-existent during this two-year trial. During Year 1, forage quality was low, while ewes were in late gestation (December), and low during Year 2, while ewes were in pre- and late gestation (August and December respectively; Table 2). Low-quality forages during winter months is common in this region of Texas (Huston et al., 1981).

Year 1

Animal Performance.

Body weight was similar between Dorper and Rambouillet ewes during pre- and late gestation ($P > 0.63$; Table 3). Rambouillet ewes tended ($P < 0.07$) to gain more BW than Dorper ewes from pre- to late gestation, but this difference was only 1.44 kg. Dorper ewes had higher ($P < 0.03$) BCS than Rambouillet ewes during pre-gestation.

Serum Insulin-like Growth Factor-1, Non-esterified Fatty Acids, and Urea Nitrogen.

During pre-gestation, Dorper ewes had greater ($P = 0.01$) serum NEFA than Rambouillet ewes. The SUN values were similar between Dorper and Rambouillet ewes ($P > 0.13$) throughout Year 1. Dorper ewes tended to have greater ($P = 0.09$) serum IGF-1 than Rambouillet ewes during pre- gestation and had greater ($P < 0.009$) serum IGF-1 during mid- and late gestation (Table 4).

Table 3. Least squares means of body condition score (BCS), change in BCS, body weight (BW), change inBW, and average daily gain (ADG) in Dorper and Rambouillet ewes grazing in the Edwards Plateau Region of Texas during Years 1 (2005) and 2 (2006).

	Year 1				Year 2			
Item[a]	Dorper	Ramb	SEM[b]	*P*-value	Dorper	Ramb	SEM[b]	*P*-value
Pre-gestation								
BCS, 1-5	3.47	3.05	0.18	0.03	3.15	2.67	0.10	<0.001
BW, kg	70.7	69.3	2.53	0.63	65.2	66.6	1.68	0.46
Mid-gestation								
BCS					3.39	2.96	0.12	0.002
BCS change					0.25	0.30	0.09	0.57
BW, kg					67.5	69.5	1.75	0.29
BW change, kg					2.46	3.03	0.55	0.26
Late gestation								
BCS					3.35	2.92	0.12	0.004
BCS change					-0.04	-0.07	0.10	0.82
BW, kg	74.5	74.6	2.38	0.98	77.2	79.7	1.84	0.20
BW change, kg					9.57	10.13	0.62	0.40
Overall								
BCS change					0.21	0.23	0.09	0.75
BW change, kg	3.56	5.00	0.77	0.07	11.85	13.05	0.61	0.06

[a] Year 1: pre- (8-9-05 and 8-16-05), mid- (10-28-05 and 11-9-05), and late gestation (12-13-05 and 12-20-05); Year 2: pre- (8-8-06 and 8-15-06), mid- (10-19-06 and 10-26-06), and late gestation (12-11-06 and 12-18-06).
[b] Greatest standard error of least squares means reported.
[c] P-values for change BW were derived using log transformation and data are reported as actual BW change.

Year 2

Animal Performance.

Body weights were similar for Dorper and Rambouillet ewes during pre-, mid-, and late gestation ($P > 0.19$; Table 3). Rambouillet ewes tended ($P < 0.06$) to gain more BW than Dorper ewes from pre- to late gestation, but this gain was only 1.20 kg greater than Dorper ewes. Dorper ewes had higher ($P < 0.004$) BCS than Rambouillet ewes during pre-, mid-, and late gestation (Table 3). Changes in BCS were similar ($P = 0.75$) between the two breeds.

Serum Insulin-like Growth Factor-1, Non-esterified Fatty Acids, and Urea Nitrogen.

During mid- and late gestation, Dorper ewes had less ($P < 0.05$) serum NEFA and SUN than Rambouillet ewes (Table 4). Dorper ewes had greater ($P < 0.006$) serum IGF-1 during pre-, mid-, and late gestation (Table 4).

Even though nutritional status differed at times between Rambouillet and Dorper ewes during gestation, all ewes seemed to have performed well while grazing. It is unclear why Dorper ewes had greater NEFA concentrations than Rambouillet ewes during pre-gestation in Year 1, except that they had greater body condition than Rambouillet ewes at this time and may have been able to mobilize fat depots more effectively. Another explanation could be that Dorper ewes began losing body condition just prior to blood sampling, thus elevating NEFA while maintaining greater BCS than Rambouillet ewes. For exam-

Table 4. Least squares means of insulin-like growth factor-1 (IGF-1), non-esterified fatty acids (NEFA) and urea nitrogen (SUN) in Dorper and Rambouillet ewes grazing in the Edwards Plateau Region of Texas during Years 1 (2005) and 2 (2006).[a]

	Year 1				Year 2			
Item[a]	Dorper	Ramb	SEM[b]	*P*-value	Dorper	Ramb	SEM[b]	*P*-value
Pre-gestation								
IGF-1, ng/mL	159.1	141.8	10.2	0.09	154.0	130.1	8.7	0.005
NEFA, μEq/L	710.6	574.3	50.9	0.01	290.7	287.4	25.2	0.90
SUN, mg/dL	12.3	13.4	0.7	0.13	8.9	9.3	0.4	0.25
Mid-gestation								
IGF-1, ng/mL	174.6	131.5	11.0	<0.001	200.4	161.7	7.3	<0.001
NEFA, μEq/L	575.6	534.3	40.0	0.29	200.0	239.8	17.4	0.02
SUN, mg/dL	11.4	11.8	0.7	0.59	15.5	16.9	0.4	0.001
Late gestation								
IGF-1, ng/mL	194.5	150.6	15.6	0.008	197.2	139.1	8.2	<0.001
NEFA, μEq/L	787.1	812.1	77.1	0.75	334.5	391.7	27.3	0.04
SUN, mg/dL	9.0	10.4	0.8	0.14	10.6	12.1	0.5	0.001

[a] Year 1: pre- (8-9-05 and 8-16-05), mid- (10-28-05 and 11-9-05), and late gestation (12-13-05 and 12-20-05); Year 2: pre- (8-8-06 and 8-15-06), mid- (10-19-06 and 10-26-06), and late gestation (12-11-06 and 12-18-06). SUN = serum urea nitrogen.
[b] Greatest standard error of least squares means reported.

ple, Caldeira et al. (2007b) discovered that an increase in NEFA concentrations was the first reaction to undernutrition.

During late gestation (Year 1), NEFA concentrations were similar for Dorper and Rambouillet ewes, but > 780 μEq/L, suggesting that ewes in both breeds had mobilized body fat. For example, non-pregnant and non-lactating ewes fed restricted diets to induce a BCS change from 4 to 2 had NEFA concentrations of 750 μEq/L (Caldeira et al., 2007b). Therefore, according to NEFA values reported by Russel (1984) and Firat and Özpinar (2002), ewes seemed to have been unable to satisfy nutrient requirements for maintenance and late-gestation-fetal growth during Year 1, resulting in fat mobilization. During year 2, Rambouillet ewes had NEFA concentrations that were only 40 to 50 μEq/L greater than Dorper ewes, thus the biological significance is questionable.

Serum urea nitrogen is an indicator of protein status, especially during stable vs. dynamic conditions (Caldeira et al., 2007b). Dorper and Rambouillet ewes always had SUN concentrations within normal values (Carlson, 1996; Kaneko, 1997) and within ranges reported for pastured ewes during late pregnancy (Antunovic et al., 2002). Rambouillet ewes had greater SUN than Dorper ewes during mid- and late gestation in Year 2, suggesting they were consuming higher-quality forages, such as oak leaves, which are desirable to livestock in the Edwards Plateau region (Vallentine, 1960). Greater SUN concentrations can also be a result of catabolizing muscle protein when large amounts of body reserves are mobilized, but results suggest that large amounts of body reserves were not mobilized. Greater SUN may also be due to Rambouillet ewes having lower BCS than Dorper ewes throughout this study, since previous reports suggest that ewes with lower BCS can have greater SUN (Caldeira et al., 2007a).

Moderate heritability exists for serum IGF-1 in livestock (Herd et al., 1995; Spicer, 2002; Davis et al., 2003). Afolayan and Fogarty (2008) reported 0.28 ± 0.10 for IGF-1 heritability in young crossbred ewes. Given the existence of genetic variation in this trait, it is possible that Dorper ewes may have inherently greater serum IGF-1 concentrations than Rambouillet ewes, which could be directly related to differences in metabolism, grazing behavior, or nutrient requirements during gestation. For instance, during mid-gestation in Year 2, NEFA concentration and BW were not correlated (r = 0.07, $P > 0.10$) in Dorper ewes, but negatively correlated (r = -0.23, $P < 0.04$) in Rambouillet ewes, which suggests possible differences in metabolism. In addition, IGF-1 concentration was not correlated to BW in Rambouillet ewes ($P > 0.10$) during this study, but was correlated to BW in Dorper ewes during late gestation in Year 1 (r = 0.36, $P < 0.02$) and during pre-, mid-, and late gestation in Year 2 (r = 0.32, $P < 0.006$; r = 0.37, 0.40, $P < 0.006$).

Afolayan and Fogarty (2008) suggest that selecting young ewes for low IGF-1 may reduce feed intake and improve maintenance efficiency of mature ewes while grazing, without greatly affecting other production traits. However, low-serum IGF-1 during gestation can be detrimental to dam performance (Gunn et al., 1995; Rhind et al., 2001) and permanently alter fetal development (Barker and Clark, 1997; Gallaher et al., 1998; McMillen et al., 2001). Because Dorper ewes seemed to have performed as well as Rambouillet ewes on rangelands (e.g., always had higher BCS than Rambouillet ewes) and had greater IGF-1 concentrations, further research is warranted.

Nutritional status has pronounced effects on serum IGF-1 (McGuire, 1992; Wallace et al. 1997; Spicer et al., 2002). Even though NEFA values during late gestation in Year 1 suggest ewes moblized body reserves, BW change and serum IGF-1 concentrations imply that body reserve mobilization was not severe when compared to previous results (Gallaher et al., 1998). Furthermore, ewes with low BCS can have less serum IGF-1 than ewes with high BCS (Snyder et al., 1999; Caldeira et al., 2007a). Thus, greater IGF-1 concentrations in Dorper vs. Rambouillet ewes also suggests that Dorper ewes could have been in a better nutritional state, since they maintained greater BC and had lower NEFA concentrations than Rambouillet ewes throughout gestation (Year 2). In contrast, Rambouillet ewes may have greater genetic potential for growth, since NRC (2008) suggests that ewes with greater genetic potential for growth can have greater nutrient requirements that are more affected by nutritional status. Although we did not measure frame size, the greater BCS of Dorper ewes when there was not a significant breed difference in BW, suggests that Rambouillet ewes were larger framed than Dorper ewes.

Dorper and Rambouillet ewes both seemed to have performed well during gestation in a range-sheep-production system without supplementation. Results imply that negative effects associated with mobilization of body reserves, such as poor fetal development probably did not occur (Gunn et al., 1995; McMillian et al., 2001; Rhind et al., 2001). However, high NEFA values during late gestation in Year 1 warrant supplementation of range forages, since maternal nutrition during pregnancy affects overall production potential of the fetus (growth and fiber), mammary gland development, and gestation length (Prosser and Davis, 1992; NRC 2008).

Conclusion

Understanding both nutritional status and physiological differences between Dorper and Rambouillet sheep is important. Results suggest that nutritional status differed at times between Dorper and Rambouillet ewes in a range-production system during gestation. Dorper ewes may have a slight production advantage during gestation, due to maintaining better body condition and greater IGF-1 concentrations. In contrast, Rambouillet ewes may have greater genetic potential for growth, thus greater nutrient requirements that are more effected by nutritional status. Further research is needed to determine genetic differences between these two breeds in a monoculture pasture (eliminating variability in grazing behavior) by evaluating metabolism and hormonal regulations, fetal development, lamb production, and nutrient requirements for maintenance and pregnancy. Evaluating differences in grazing behavior and forage preferences between Dorper and Rambouillet ewes in a range production system would also be beneficial.

Literature Cited

Afolayan, R. A., and N. M. Fogarty. 2008. Genetic variation of plasma insulin-like growth factor-1 in young crossbred ewes and its relationship with their maintenance feed intake at maturity and production traits. J. Anim. Sci. 86:2068–2075.

Antunovic, Z., D. Sencic, M. Speranda, and B. Liker. 2002. Influence of the season and the reproductive status of ewes on blood parameters. Small Rumin. Res. 45:39–44.

AOAC. 1990. Official Methods of Analysis. 15th ed. Assoc. Offic. Anal. Chem., Arlington, VA.

Barker, D. J. P., and P. M. Clark. 1997. Fetal under-nutrition and disease in later life. Reviews of Reproduction. 2:105–112.

Berrie, R. A., D. M. Hallford, and M. L. Galyean. 1995. Effects of zinc source and level on performance and metabolic hormone concentrations of growing and finishing lambs. Prof. Anim. Sci. 11:149–156.

Caldiera, R. M., A. T. Belo, C. C. Santos, M. I. Vazques, and A. V. Portugal. 2007a. The effect of body condition score on blood metabolites and hormonal profiles in ewes. Small Rumin. Res. 68:233–241.

Caldiera, R. M., A. T. Belo, C. C. Santos, M. I. Vazques, and A. V. Portugal. 2007b. The effect of long-term feed restriction and over-nutrition on body condition score, blood metabolites and hormonal profiles in ewes. Small Rumin. Res. 68:242–255.

Carlson, G. P. 1996. Clinical Chemistry Tests. Pages 441–469 in Large Animal Internal Medicine. 2nd ed. B. Smith, ed. Mosby-Year Book, Inc., St. Louis, MO.

Davis, M. E., S. L. Boyles, S. J. Moeller, and R. C. M. Simmen. 2003. Genetic parameter estimates for serum insulin-like growth factor-1 concentration and ultrasound measurements of backfat thickness and longissimus muscle area in Angus beef cattle. J. Anim. Sci. 81:2161–2170.

Firat, A., and A. Özpinar. 2002. Metabolic profile of pre-pregnancy, pregnancy and early lactation in multiple lambing Sakiz ewes. 1. Changes in plasma glucose, 3-hydroxybutyrate and cortisol levels. Ann. Nutr. Metab. 46:57–61.

Funaba, M., S. Saito, K. Kagiyama, T. Iriki, and M. Abe. 1996. Bone growth rather than myofibrillar protein turnover is strongly affected by nutritional restriction at early weaning of calves. J. Nutr. 126:898–905.

Gallaher, B. W., B. H. Breier, C. L. Keven, J. E. Harding and P. D. Gluckman. 1998. Fetal programming of insulin-like growth factor (IGF)-1 and IGF-binding protein-3: evidence of an altered response to undernutrition in late gestation following exposure to periconceptual undernutrition in the sheep. J. Endocrinol. 159:501–508.

Gunn, R. G., D. A. Sim, and E. A. Hunter. 1995. Effects of nutrition in utero and in early-life on the subsequent lifetime reproductive-performance of Scottish Blackface ewes in two management-systems. Anim. Sci. 60:223–230.

Harvey, S., and K. L. Hull. 1995. Growth hormone action: Growth hormone receptors. Pages 303–335 in Growth Hormone. S. Harvey, C. G. Scanes, and W. H. Daughaday, ed. CRC Press Inc., Boca Raton, FL.

Herd, R. M., P. F. Arthur, K. Zirkler, C. Quinn, and V. H. Oddy. 1995. Heritability of IGF-1 in beef cattle. Proc. Aust. Assoc. Anim. Breed Genet. 11:694–695.

Huston, J. E., B. S. Rector, L. B. Merrill, and B. S. Engdahl. 1981. Nutritional value of range plants in the Edwards Plateau region of Texas. Texas Agric. Exp. Sta. Bull. B-1357.

Kaneko, J. J. 1997. Page 890–894 in Clinical Biochemistry of Domestic Animals. 5th ed. Academic Press, San Diego.

McGuire, M. A., J. L. Vicini, D. E. Bauman, and J. J. Veenhuizen. 1992. Insulin-like growth factors and binding proteins in ruminants and their nutritional regulation. J. Anim. Sci. 70:2901–2910.

McMillen, I. C., M. B. Adams, J. T. Ross, C. L. Coulter, G. Simonetta, J. A. Owens, J. S. Robinson, and L. J. Edwards. 2001. Fetal growth restriction: adaptations and consequences. Reproduction. 122:195–204.

Milne, C. 2000. The history of the Dorper sheep. Small. Rumin. Res. 36:99–102.

NRC. 2008. Pages 232–243 in Nutrient Requirements of Small Ruminants: Sheep, Goats, Cervids, and New World Camelids. Natl. Acad. Press, Washington, DC.

Prosser, C. G., and S. R. Davis. 1992. Milking frequency alters milk yield and mammary blood flow response to intrammary infusion of insulin-like growth factor-1 in the goat. J. Endocrinol. 135:311–316.

Rhind, S. M., M. T. Rae, and A. N. Brooks. 2001. Effects of nutrition and environmental factors on the fetal programming of the reproductive axis. Reproduction. 122:205–214.

Richards, M. W., R. P. Wettemann, and H. M. Schoenemann. 1989. Nutritional anestrus in beef cows: Concentrations of glucose and nonesterified fatty acids in plasma and insulin in serum. J. Anim. Sci. 67:2354–2362.

Riddle, R. R., C. A. Taylor, M. M. Kothmann, Jr., and J. E. Huston. 1996. Volatile oil contents of Ashe and redberry juniper and its relationship to preference by Angora and Spanish goats. J. Range Manage. 49:35–41.

Russel, A. J. F. 1984. Means of assessing the adequacy of nutrition of pregnant ewes. Livest. Prod. Sci. 11:429–436.

Smeins, F. E., T. W. Taylor, and L. B. Merrill. 1976. Vegetation of a 25-year exclosure on the Edwards Plateau, Texas. J. Range Manage. 29:24–29.

Spicer, L. J., C. C. Chase, Jr., and L. M. Rutter. 2002. Relationship between serum insulin-like growth factor-1 and genotype during the postpartum interval in beef cows. J. Anim. Sci. 80:716–722.

Snyder, J. L., J. A. Clapper, A. J. Roberts, D. W. Sanson, D. L. Hamernik, and G. E. Moss. 1999. Insulin-like growth factor-I, insulin-like growth factor-binding proteins, and gonadotropins in the hypothalamic-pituitary axis and serum of nutrient-restricted ewes. Biol. Repro. 61:219–224.

Vallentine, J. F. 1960. Live Oak and Shin Oak as desirable plants on Edwards Plateau Ranges. Ecol. 41:545–548.

Wallace, J. M., P. Da Silva, R. P. Aitken, and M. A. Cruickshank. 1997. Maternal endocrine status in relation to pregnancy outcome in rapidly growing adolescent sheep. J. Endocrinol. 155:359–368.

Sheep & Goat Research Journal
Volume 24, 2009

Effect of Expected Peripheral Concentrations of Progesterone on Ovulation Rate and Litter Size in Barbados Blackbelly Ewes[1]

E. H. Devonish[2], M. Knights[2], and E. K. Inskeep[2,3]

[1] *Published with the approval of the Director of the West Virginia Agricultural and Forestry Experiment Station as Scientific Paper No. 3029. Supported by Hatch Project 427 (NE-1007). This work was done in partial fulfillment of requirements for the M.S. degree (EHD) in reproductive physiology at West Virginia University.*

[2] *Division of Animal and Nutritional Sciences, West Virginia University, Morgantown WV 26506-6108;*

[3] *Corresponding author: Keith Inskeep; Phone 304-293-2406, ext 4422, e-mail einskeep@wvu.edu*

Acknowledgements

The sheep and reagents were provided by the Ministry of Agriculture and Rural Development, Graeme Hall, Christ Church, Barbados. The authors thank the Ministry, the staff of the Greenland Livestock Research Station, Greenland, St. Andrew, Barbados (where Ezra Devonish is the Agricultural Officer) for animal care and assistance in treatment, and the late Dr. George Seidel of the West Virginia Agricultural and Forestry Experiment Station for advice and assistance in statistical analyses.

Summary

To determine whether luteal phase concentrations of progesterone (P_4) altered ovulation rate and litter size in ewes, mature Barbados Blackbelly ewes were assigned to groups treated so that they would be expected to have low, medium or high P_4 (n = 23 or 33 per group in two seasons). Each ewe on low and high P_4 received a P^4-containing intravaginal insert from d 4 through d 14 after estrus. Ewes in low group were given PGF2α on d 6 to regress corpora lutea (CL). Ewes with medium P_4 were untreated. Ovaries in 10 or 8 ewes per group (in seasons 1 and 2, respectively) were observed by transrectal ultrasonography from d 6 of the pre-breeding cycle until ovulation, and in all ewes on d 7 after breeding (one ram to 10 to 16 ewes). Numbers of follicles that disappeared at estrus ($P < 0.02$) and of CL formed ($P < 0.001$) increased linearly with decreasing P_4. As P_4 decreased, more follicles disappeared from the penultimate than the final wave of development. Disappearance of follicles was correlated with CL formed (0.53; $P < 0.0001$). Conception rates did not differ with expected concentration of P_4. Lambs born per CL decreased linearly ($P < 0.001$) with decreasing concentrations of P_4. Prolificacy did not differ ($P > 0.32$) among ewes treated to have low, medium or high concentrations of P_4 (2.0, 1.9, and 1.9 ± 0.1 lambs, respectively), despite greater ovulation rates. On a practical basis, altering progesterone before breeding did not change productivity of the ewe in terms of number of lambs born.

Key Words: Barbados Blackbelly, Ovulation Rate, Progesterone, Prolificacy, Ewe, Sheep

Introduction

Patterns of follicular development and ovulation rates in ewes have varied with dosages of exogenous progestogens (Robinson et al., 1968; Allison and Robinson, 1970), an effect probably mediated by regulation of tonic secretion of luteinizing hormone (LH; Baird and Scaramuzzi, 1976). In anestrous ewes induced to ovulate by introduction of rams, prior treatment with progesterone appeared to increase ovulation rate compared to ram introduction alone (Knights et al., 2001). More follicles were recruited early and late in the estrous cycle, periods when concentrations of progesterone are low (Brand and de Jong, 1973; Schrick et al., 1993). Bartlewski et al. (1999) found an inverse association of ovulation rates with concentrations of progesterone across breed types, with greater progesterone and fewer ovulations in western white-faced ewes and less progesterone and more ovulations in Finnsheep ewes.

Ewes exposed to low concentrations of progestogens had greater pulse frequencies of LH and concentrations of estradiol, and ovulated older and sometimes had more follicles than control ewes (Johnson et al., 1996; Levya et al., 1998; Viñoles at al., 1999; Bartlewski et al., 2003). These findings might explain reduced pregnancy rates in ewes on low concentrations of progestogens observed by some authors (Johnson et al., 1996; Viñoles at al., 1999), but not by others (Evans et al., 2001), as well as differences in pregnancy rates among exogenous progestogens (Crosby et al., 1991).

In the present study, patterns of follicular development and ovulation and lambing rates were investigated after experimental manipulation of concentrations of progesterone in cycling ewes of a relatively prolific breed, Barbados Blackbelly, in Barbados, where seasonal breeding is not expressed in non-lactating ewes of the breed (Patterson, 1983). The aim was to test the null hypothesis that concentrations of progesterone did not affect numbers or ages of follicles that ovulated or subsequent litter size.

Materials and Methods

The experiment was conducted in Barbados (latitude 10° north) with 168 Barbados Blackbelly ewes in two seasons. Sixty nine ewes were studied in the dry season (December 2003, season 1) and 99 different ewes were studied in the wet season (July 2004, season 2). The ewes had average ages of 2.5 yr, parities of 1.8, and BW of 43 kg, which did not differ among groups or between seasons. Ewes were penned in an enclosed barn and received a daily ration of 2 kg of concentrates (corn and soybean meal formulated to contain 18 percent crude protein plus minerals), with water and pangola hay available ad libitum.

Ewes were randomized among three groups of 23 or 33 ewes each for seasons 1 and 2, respectively. Ewes in these groups were expected to have low, medium, or high progesterone as a result of treatment. All ewes were treated twice, 8 d apart, to synchronize estrus before the study, each time with two injections of 5 mg PGF2α (Lutalyse®, Pfizer Animal Health, New York, N.Y.) 3 h apart (Hawk, 1973). Ewes that would be expected to have medium progesterone received no further treatment; progesterone in those ewes was provided by the corpora lutea (CL) in their ovaries. Each ewe assigned to low progesterone received a progesterone-containing insert (Controlled Internal Drug Releasing Device [CIDR-G; InterAg, Hamilton, New Zealand] containing 0.3 g of progesterone) on d 4 after the synchronized estrus and was given PGF2 on d 6 (as in the estrous synchronization protocol) to regress the CL and remove endogenous progesterone. These ewes were expected to have low circulating concentrations of progesterone throughout the luteal phase (Van Cleeff et al., 1998). Ewes in the high progesterone group received a CIDR on d 4 to provide additional progesterone to that produced by the CL. In each group, the CIDR was removed on d 14. Because the study was conducted in Barbados, it was not possible to conduct radioimmunoassays to determine exact concentrations of progesterone in peripheral blood. Biological response, as indicated by interval from removal of the CIDR insert to estrus, was used to confirm that concentrations of progesterone differed as expected.

Breeding Soundness Examination, Ram Introduction and Observation for Estrus

A breeding soundness examination (testicular size, sperm concentration and motility; Salamon, 1976) was performed on six Barbados Blackbelly rams, to verify that each was in breeding condition. On d 7 after estrus, a Sire-Sine® harness with a crayon in the area of the brisket was placed on each of the rams and the rams were allotted to six pens. Each 5 x 9 m pen contained 5 or 6 ewes from each group, for a maximum ewe-to-ram ratio of 17:1. Ewes were observed on d 7 through d 21 at 6:00 a.m. and 6:00 p.m. for crayon marks. Time and date of observed estrus were recorded to determine the interval from CIDR removal to post-treatment estrus (marked by a ram; 0.5 d increments). Once each day, after observation for estrus, crayons on the briskets of the rams were replaced with a different color to distinguish ewes that subsequently came into estrus and to ensure that crayon marks were visible.

Observations of Follicular Development and CL

Follicles in the ewe develop at least in part in wave-like patterns, with cohorts growing beyond 3 mm in diameter approximately every four days during the estrous cycle (e.g., Ginther et al., 1995). Follicles that ovulate normally come from the final and the penultimate (next to last) wave (Bartlewski et al., 1999; Gibbons et al., 1999). Thus, it was of interest to determine whether any change in ovulation rate was due to retention of older follicles or recruitment of more follicles in the final follicular wave. Follicular development was observed by transrectal ultrasonography using an Aloka 500 SSD (Corometrics Medical Systems, Wallingford, Conn.) equipped with a 7.5 MHz linear-array transducer, as described by Schrick et al. (1993). Ultrasonographic observations were done by two operators in season 1, but by only one operator in season 2. Ovaries of 10 ewes per group in season 1 and of 8 ewes per group in season 2 were scanned daily from d 6 through subsequent estrus and ovulation (up to d 18 for some ewes). Ovarian follicular diameters were measured and recorded in three categories; small (2 to 3 mm), medium (4 to 5 mm), and large (≥ 6 mm), and their relative positions and those of CL were recorded on an ovarian map.

Data recorded included numbers of

small, medium and large follicles; day of emergence of each ovulatory follicle; and maximum size of each ovulatory follicle prior to ovulation. After estrus, follicles ≥ 4 mm were recorded as ovulated if not observed on the ovary at the subsequent scanning (Schrick et al., 1993). Growth rates of follicles were determined by retrospective comparisons of the follicle sizes recorded up to the point of plateau in diameter or ovulation. The interval (d) from appearance (at 2 or 3 mm in diameter) to disappearance was termed the life span of the follicle. Follicles that were first detected at 4 mm were recorded as 3 mm on the previous day, because average growth rate approximates 1 mm/d (Schrick et al., 1993). The interval from CIDR removal to ovulation was measured from these observations. Ovulation rate was confirmed by the number of CL observed by ultrasonography 7 d after estrus.

Lambing dates and numbers of lambs born were recorded. Conception rate was determined by ewes lambing, as a percentage of ewes in estrus. Pregnancy rate was measured as the percentage of ewes treated that lambed. Prolificacy was expressed as the number of lambs born per ewe that lambed. Lambing rate was defined as lambs born per ewe treated, and lambs born per CL (counted on d 7) also was evaluated.

Statistical Analysis

The basic statistical model used throughout was a two-way analysis of variance or categorical analysis (Chi-square) comparing values in ewes among the three expected concentrations of progesterone, and the two seasons in which the study was conducted. When significant differences were detected by analysis of variance, differences among individual groups were evaluated by Duncan's multiple range test. Transformations were utilized when the raw data were not normally distributed. Linear and quadratic components of the variance were tested when appropriate for continuous variables. All analyses were conducted using SAS version 8.1 (SAS Inst. Inc., Cary, NC). Comparisons of the intervals from CIDR removal to estrus or to ovulation and the growth rate of follicles in the final and penultimate waves utilized Poisson regression in the GENMOD procedure, because the data followed a Poisson distribution. Average diameter of all ovulatory follicles and growth rates of follicles were analyzed with ANOVA using the MIXED procedure. Counts of follicles were transformed to square roots for analyses. Numbers of follicles in each size class per day and numbers of ovulatory follicles were compared in GENMOD using Poisson regression: in these analyses the model included day as a repeated measure within ewes. The effects of expected progesterone on the numbers of small (2 to 3 mm), medium (4 to 5 mm), large (≥ 6 mm) and total follicles during d 6 through d 14 were determined. Conception and pregnancy rates were examined by Chi-square analyses using the FREQ procedure. Lambs born per CL and per ewe lambing (prolificacy), and partial embryonic loss were compared in GENMOD using logistic regression. Numbers of follicles in the final and penultimate waves and the interval (d) that each follicle was observed were examined using analysis of variance in the MIXED procedure. Effects of expected progesterone on proportions of disappearing large (ovulatory) follicles arising from the final and penultimate follicular waves were examined by Chi Square. A correlation coefficient was calculated to examine the relationship between numbers of CL formed and numbers of follicles that disappeared.

Results and Discussion

None of the variables examined differed between seasons or revealed interactions of season with expected concentration of progesterone. Therefore all data are reported as means over both the dry and wet seasons.

Intervals to Estrus and Ovulation

The percentage of ewes marked by rams (mean 90 percent) and the percentage of scanned ewes observed to ovulate (mean 85 percent), did not differ with expected concentration of progesterone. Intervals from removal of the CIDR to estrus exhibited a quadratic pattern ($P < 0.005$) over groups expected to provide increasing concentrations of progesterone (low 1.5 ± 0.1, medium 2.2 ± 0.2 and high 1.9 ± 0.1 d, respectively). Likewise, intervals from CIDR removal to ovulation increased linearly ($P < 0.05$) with increasing expected concentrations of progesterone (2.0 ± 0.3, 2.9 ± 0.6 and 3.2 ± 0.2 d, respectively). These data, in agreement with those of Deaver et al. (1986), confirmed that the treatments applied altered progesterone in the manner expected.

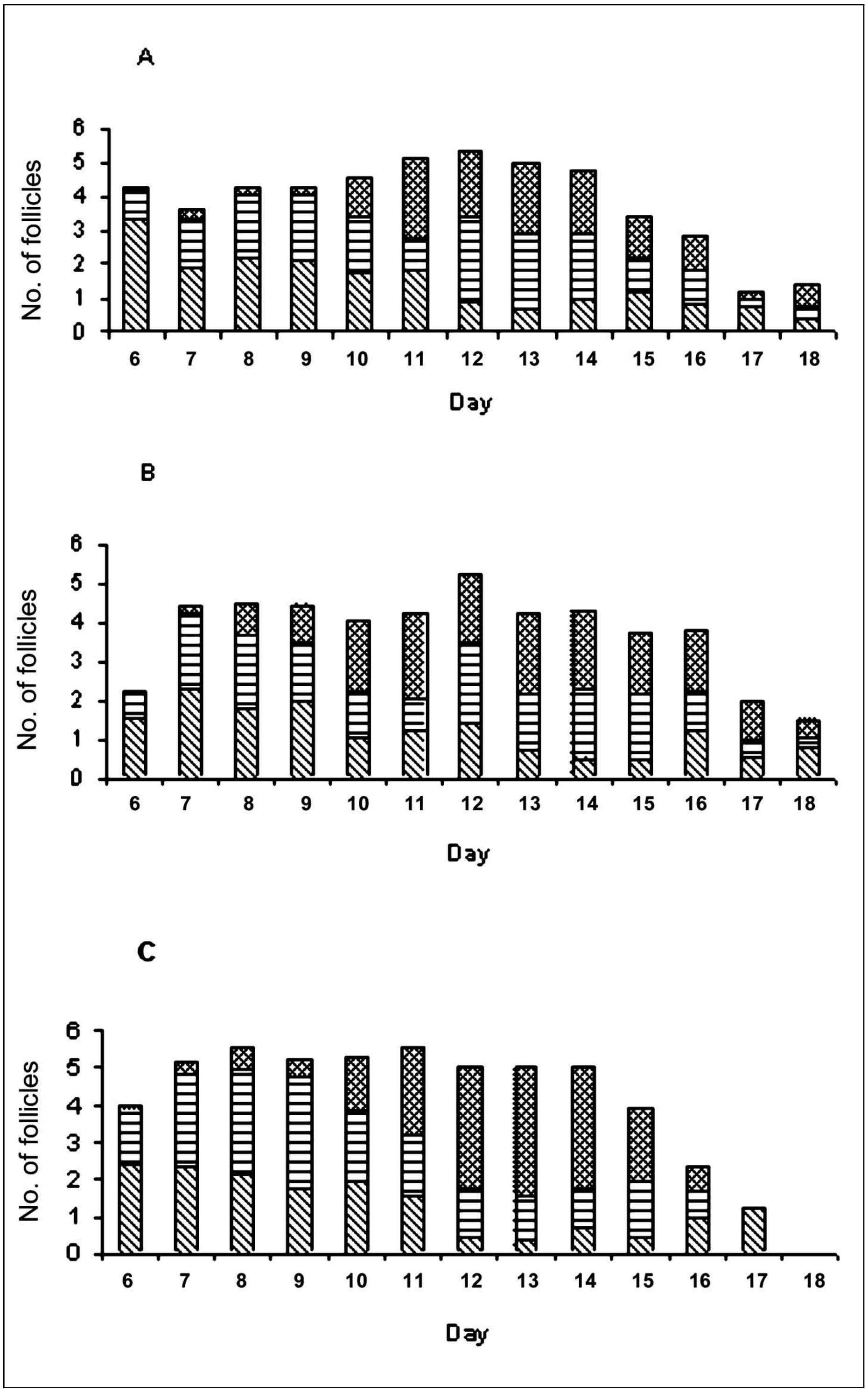
Numbers of Follicles, Growth Rates, and Lifespan of Ovulatory Follicles

Numbers of large (≥ 6 mm in diameter) and medium (4 to 5 mm) follicles present during d 6 to d 14 varied, and the pattern differed, as indicated by the day x expected progesterone interaction ($P < 0.0001$), but number of small (2 to 3 mm) follicles did not differ (Figure 1). A day x expected progesterone interaction was observed for total number of follicles on the ovary ($P < 0.001$; Figure 1). Specifically, numbers of medium follicles on d 6 through d 9 and of large follicles on d 9 through d 13 increased as concentrations of progesterone decreased.

Last diameters of ovulatory follicles did not differ among expected concentrations of progesterone (4.8 ± 0.6 mm). In contrast, Johnson et al. (1996) observed that diameters of ovulatory follicles were greater in ewes that had concentrations of progesterone < 1 ng/mL from d 6. In the present study, growth of follicles in the penultimate wave might have been limited by relatively greater concentrations of progesterone during the mid- to late-luteal phase of the cycle. In comparison, most growth of ovulatory follicles from the final wave occurred during the very late luteal and follicular phases of the estrous cycle, when progesterone concentrations were waning and frequency of pulsatile secretion of LH would have increased.

Mean intervals from detection at 2 or 3 mm to ovulation were 9.0 ± 0.2 and 5.0 ± 0.3 d for ovulatory follicles of the penultimate and final waves, respectively ($P < 0.05$). Mean intervals that ovulatory follicles from both waves were present prior to ovulation increased linearly ($P < 0.05$) as concentrations of progesterone decreased (5.7 ± 0.6, 7.6 ± 0.6 and 8.1 ± 0.2 d for ewes with high, medium and low progesterone, respectively). Thus, follicles from the penultimate wave were an average of 4 d older at ovulation than follicles from the final

Figure 1. Numbers of total follicles (height of each bar at each day) and numbers in each size class summed over both ovaries (diagonal bars - 2 and 3 mm [small]; horizontal bars - 4 and 5 mm [medium]; and cross hatched - ≥ 6 mm [large]) on d 6 through estrus and ovulation (up to d 18) in ewes with expected high (A), medium (B), or low (C) progesterone. Numbers of medium, large, and total follicles varied with the day by expected progesterone interaction (*P < 0.001, 0.001,* and *0.0001,* respectively). Note the patterns by which follicles moved from smaller to larger categories as the cycle progressed and that more large follicles were present later in the cycle in groups with expected lower progesterone. Then as ewes returned to estrus, the total number and the numbers of medium and large follicles decreased due to ovulation.



wave, and ovulatory follicles were retained on the ovary for about 1.5 d longer in ewes with low concentrations of progesterone than in ewes with high or medium progesterone. Similarly, in earlier studies, lifespan of the largest follicles in the penultimate wave (Bartlewski et al., 1999) or that arose earlier (Johnson et al. 1996) was increased, which allowed them to ovulate with follicles from the final wave.

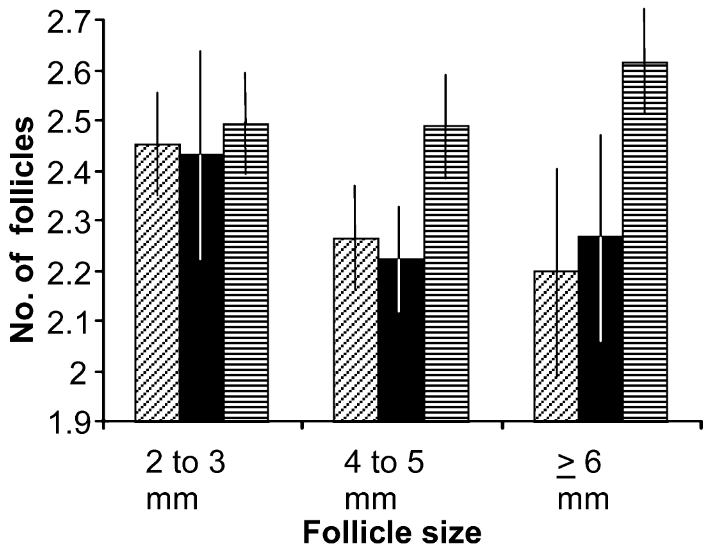
Ewes with low progesterone had more (*P < 0.01*) medium and large follicles prior to ovulation than ewes with high or medium concentrations of progesterone (Figure 2). Follicles from the penultimate wave that disappeared after estrus had grown more slowly (0.7 ± 0.1 mm/day) than those from the final wave (0.9 ± 0.1 mm/d; *P < 0.05*). However, mean growth rates of follicles that disappeared after estrus did not differ with expected progesterone within either wave, or for both waves combined (high, 0.7 ± 0.1, medium, 0.8 ± 0.1, low, 0.6 ± 0.2 mm/d).

In cows, lower progestogen led to increased pulse frequency of LH, maintenance of dominant follicles, and greater secretion of estradiol (Stock and Fortune, 1993; Kinder at al., 1996). Taft et al. (1996) found that frequent injections of bovine LH during normal luteal phases maintained the largest (dominant) follicle and suppressed recruitment of other follicles in cows. Although follicles are recruited in the ewe despite the presence of other large follicles (Duggavathi et al., 2003, 2005), follicles in the penultimate wave might have been protected from atresia by a greater frequency of secretion of pulses of LH in ewes with lower concentrations of progesterone (Johnson et al., 1996 and Van Cleeff et al., 1998). In contrast, more follicles in the 2-mm to 5-mm classes during the mid-luteal phase were observed in Merino ewes with 2 CL than in ewes with 1 CL (Turnbull et al., 1978).

Ovulation Rates

As shown in Table 1, the increase in ovulation rate as progesterone decreased was clearly due to greater persistence of follicles from the penultimate wave. The proportion of disappearing large follicles that came from the penultimate wave increased from 36.3 percent in the high progesterone group to 53.7 percent in

Figure 2. Mean (± SEM) numbers of follicles in each size class on the day prior to ovulation by expected concentrations of progesterone (diagonal bars - high; solid bars -medium; horizontal bars - low). Numbers of medium and large follicles were greater in ewes with expected low progesterone than in ewes with expected high or medium progesterone (*P < 0.01*).



ewes on medium progesterone and 76.7 percent in ewes on low progesterone (*P < 0.005*). The effect of expected progesterone on ovulation rate was linear (*P < 0.01*), regardless of whether ovulation rate was estimated by disappearance of follicles after estrus (Figure 3 A) or numbers of CL on d 7 after estrus (Figure 3 B). The number of follicles (≥ 4 mm) that disappeared in relation to estrus increased linearly (*P < 0.05*) with decreasing concentrations of progesterone. Number of CL formed was correlated to number of follicles that disappeared (r = 0.53; *P < 0.0001*).

The increase in ovulation rate in ewes with lower expected concentrations of progesterone was due to retention and ovulation of more follicles from the penultimate wave of follicular development. This finding is in agreement with Johnson et al. (1996) and Bartlewski et al. (1999; 2003), who reported that follicles of varying ages, or originating from both the penultimate and final follicular waves, ovulated in the cycling ewe. Additionally, it extends to a relatively prolific breed of ewes the finding by Bartlewski et al. (1999) in less prolific ewes that exposure to low concentrations of progestogens during the luteal phase can increase ovulation rate.

The number of follicles that disappeared and was presumed to have ovulated was an overestimate of the number of CL observed on d 7 after estrus, which was used as a final measure of ovulation rate. Similarly, Bartlewski et al. (2003) observed that not all follicles that disappeared at estrus formed CL. The accuracy of observation of disappearance of follicles as a measure of ovulation rate might have been reduced, because some follicles ≥ 4 mm did not ovulate, but regressed in size and might have been assumed to be new 2 or 3 mm follicles. Alternatively, some ovulated follicles might not form a CL. In earlier research, Murdoch et al. (1983) observed that ewes injected with LH or FSH on d 15 ovulated, but were unable to develop sufficient luteal function. They suggested that the pre-ovulatory follicle was forced to ovulate prematurely and lacked gonadotropin receptors on follicular cells, which reflected follicular maturity

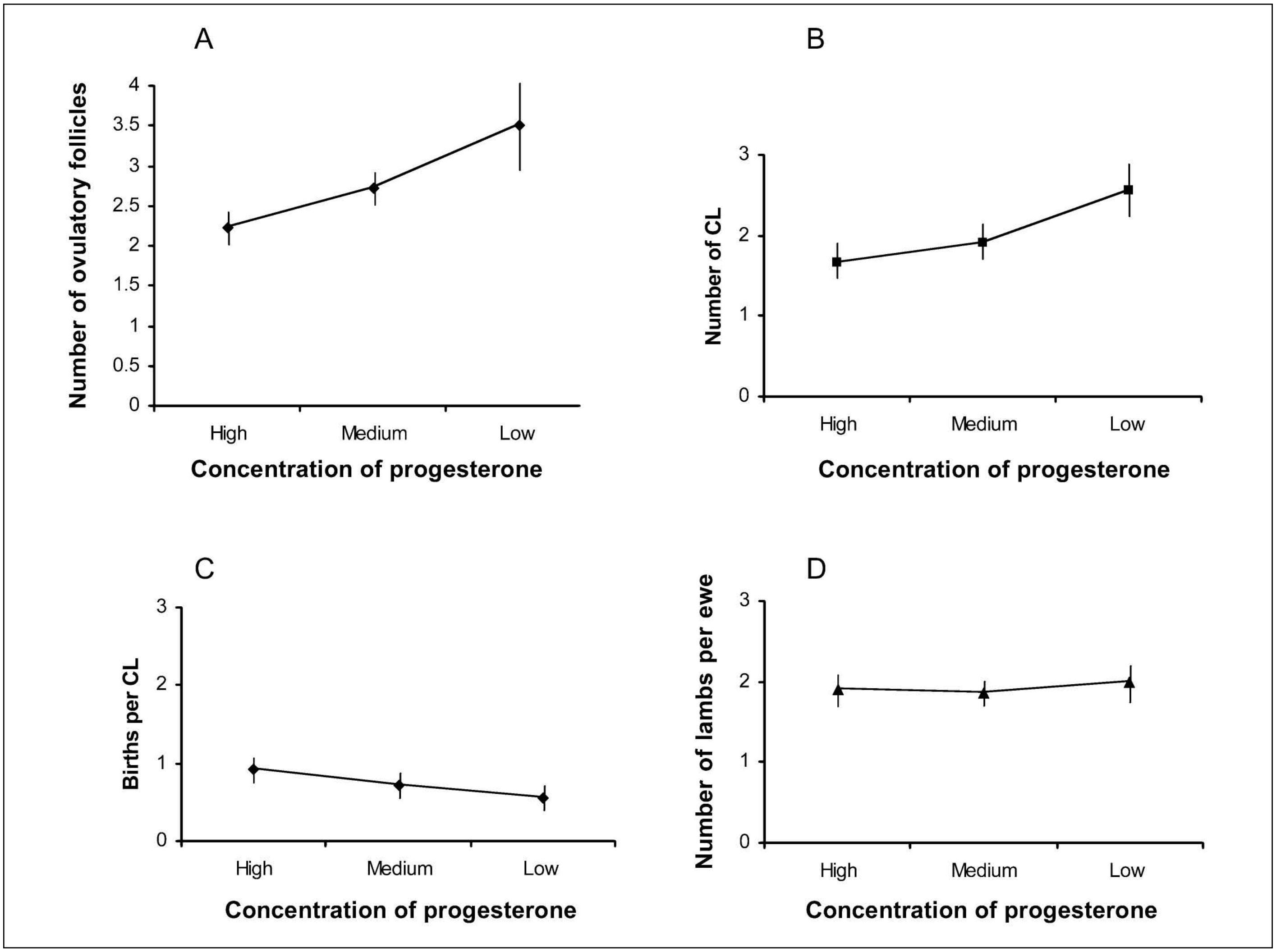
Table 1. Intervals from emergence to disappearance of presumed ovulatory follicles from the final or penultimate waves.

	Expected concentration of progesterone			
	High	Medium	Low	All Groups
Number of ewes observed	15	15	16	46
Time from emergence to ovulation:				
Final follicular wave:				
Total number of follicles observed	21	19	13	53
Interval (days ± SEM)	4.6 ± 0.5	5.2 ± 0.3	5.5 ± 0.3	5.0 ± 0.3[c]
Penultimate follicular wave:				
Total number of follicles observed	12	22	43	77
Interval (days ±SEM)	8.2 ± 0.3	9.0 ± 0.3	9.2 ± 0.2	9.0 ± 0.2[d]
Both waves:				
Total number of follicles observed	33	41	56	130
Interval (days ± SEM)	5.7 ± 0.6[a]	7.6 ± 0.6[b]	8.1 ± 0.2[b]	7.2 ± 0.4

*Proportions of disappearing follicles arising from the penultimate and final waves differed with expected concentration of progesterone (χ^2 = 14.76, 2 df, *P < 0.005*).

[a,b] Means in the same row with different superscripts differed (*P < 0.05*; Duncan's multiple range test).
[c,d] Overall means for waves differed (*P < 0.05*).

Figure 3. Characteristics (mean ± SEM) of ewes with expected high, medium or low concentrations of progesterone. A. Numbers of follicles disappearing after estrus in 15, 15, and 16 ewes, respectively, observed by ultrasonography. The number of follicles that disappeared increased linearly with decreasing expected concentrations of progesterone ($P < 0.02$). B. Numbers of CL in ewes that lambed to first service (n = 39, 44, or 41 ewes, respectively) increased linearly with decreasing expected concentrations of progesterone ($P < 0.001$). C. Numbers of lambs born per CL in ewes that lambed to first service decreased linearly with decreasing expected concentrations of progesterone ($P < 0.01$). D. Numbers of lambs born per ewe lambing (prolificacy) did not differ with expected progesterone.



and inherent ability to luteinize. When follicular synthesis of estrogen was reduced by treatment with an aromatase inhibitor and follicles were ovulated/luteinized by injection of hCG (Benoit et al., 1992), estrus did not occur and the onset of luteal function was delayed. However, ewes showed estrus naturally after withdrawal of progesterone in the present study, and, as discussed below, pregnancy rates in the normal range indicated that functional CL were formed.

Conception and Pregnancy Rates, Embryonic and Fetal Losses, Prolificacy and Lambing Rates

Conception and pregnancy rates to the single service averaged 76 percent and 74 percent, respectively, and did not differ with expected concentrations of progesterone during the pre-breeding cycle in the present study. Evans et al. (2001) found that lower dosages of progestogen had no deleterious effects on embryo quality or fertility and concluded that age of follicles was less critical in sheep than in cattle. In contrast, reduced conception and pregnancy rates in ewes were associated with lower-luteal-phase concentrations of progesterone or progestogens before breeding and the ovulation of older follicles (Johnson et al., 1996; Ungerfeld and Rubianes 1999; Viñoles et al., 2001). Similarly, cows with low concentrations of progesterone during the luteal phase ovulated an older follicle and had decreased pregnancy rates (Cooperative Regional Research Project, NE-161, 1996) due to death of embryos during the 2 to 16 cell stage (Ahmad et al., 1995). Lower conception rates were observed in studies using immunization against androgens to increase ovulation rate (Boland et al., 1986; Meyer and Lewis, 1988; Wilkins, 1997), but not in trials using immunization against inhibin (Kusina et al., 1995a,b). Wilkins

(1997) reported that some nutritional treatments that increased ovulation rate depressed conception rates, but in his study, ewes with twin ovulations had a greater conception rate than ewes with single ovulations.

Births per CL decreased linearly (*P<0.001*) with decreasing concentrations of progesterone (Figure 3 C) during the luteal phase preceding ovulation. Thus, reproductive wastage (CL not represented by lambs born) was greater for ewes with low (1.3 ± 0.2; *P < 0.01*) than for ewes with either high (0.8 ± 0.2) or medium (0.9 ± 0.2) concentrations of progesterone. As a result, the greater ovulation rates (Figure 3 B) observed with lower concentrations of progesterone did not produce a corresponding increase in number of lambs born per ewe lambing (Figure 3 D). Prolificacy (lambs born per ewe lambing) did not differ among groups and averaged 1.90 ± 0.12, 1.86 ± 0.11 and 2.00 ± 0.14 for ewes with high, medium or low progesterone, respectively. Lambing rate (lambs born per ewe treated) did not differ among ewes on high (1.3 ± 0.1), medium (1.5 ± 0.1) or low (1.5 ± 0.2) concentrations of progesterone. Quintuplets were born to one ewe with high and one ewe with low concentrations of progesterone and quadruplets were born to one ewe with medium concentrations of progesterone.

An increase in partial rather than total pregnancy loss was associated with decreasing progesterone in the cycle before ovulation, because pregnancy rates did not differ with concentrations of progesterone, older ovulatory follicles (oocytes) originating from the penultimate wave may not be as healthy and may be a causative factor of more reproductive wastage. Greater reproductive wastage in ewes with lower-luteal-phase concentrations of progesterone, which ovulated more follicles from the penultimate wave, might have been due to reduced fertilization rate (Hulet et al., 1956; Boland et al., 1986; Mitchell et al., 2002), greater embryonic death (Hulet et al., 1956), delayed embryonic development (Boland et al., 1986), greater fetal death (Dixon et al., 2007), or a combination of those factors (Kleemann and Walker, 2005a,b). It may be important to note the report by Carrillo et al. (2006) that both lambing rate and prolificacy were increased by treatment with 125 mg bovine GH 5 d before the end of treatment with intravaginal sponges containing 45 mg flurogestone acetate. Growth hormone is required in addition to FSH and LH in order to produce ovulable follicles in the ewe (Eckery et al., 1993).

Negative relationships between ovulation rate and lambs born per ovulation have been reported in numerous studies (Meyer, 1985; Knights et al., 2003; Dixon et al., 2007). In addition to the effects on follicles and oocytes discussed above, uterine capacity might have influenced litter size through the inability to sustain additional embryos. Nawaz and Meyer (1991) and Meyer et al. (1994) observed differences among breed-types in "uterine efficiency" (lambs born per CL), with greater efficiency in genotypes known to have larger litter sizes in each study.

Other Considerations

Rams were introduced to the ewes in this study 7 d before withdrawal of progesterone or regression of CL. Based upon a study by Evans et al. (2004), exposure to rams for 3 d before progestogen withdrawal might have been expected to limit fertility or prolificacy. They found 14-percentage- and 9-percentage-point reductions in ewes lambing to first service in two trials and 0.23 fewer lambs born per ewe lambing in one of those trials, which they attributed to increased LH pulse frequency in response to ram introduction during treatment with progestogen. However, their results might have been influenced in part by the fact that they delayed introduction of intact rams for breeding until 48 h after sponge withdrawal (Hawken et al., 2005). In the present study, the same intact rams remained with the ewes throughout and overall pregnancy rate was quite acceptable, similar to that reported for hair sheep in the tropics (74 percent; Godfrey et al., 1997), and greater than that observed in ewes treated with intravaginal inserts (CIDRs) in the breeding season (57 percent; Rhodes and Nathanielsz, 1988).

Conclusions

In summary, removal of endogenous progesterone and use of intravaginal inserts to lower circulating concentrations of progesterone increased ovulation rate through more follicles being maintained from the penultimate wave, likely due to greater LH pulse frequency, which regulates follicular and oocyte maturation. However, increased ovulation rate did not increase litter size. Older oocytes, from follicles of the penultimate wave, might have been incapable of either fertilization or embryonic development, the latter being more likely, based upon the research with cows. Furthermore, uterine capacity might have limited litter size. In practical terms, even though most progesterone delivery systems provide lower progesterone than the corpora lutea in a ewe's ovaries, and lower progesterone raised ovulation rate, there was no net gain or loss in lambs born.

Literature Cited

Ahmad, N., F. N. Schrick, R. L. Butcher, and E. K. Inskeep. 1995. Effect of persistent follicles on early embryonic losses in beef cows. Biol. Reprod. 52:1129-1135.

Allison, A. J., and T. J. Robinson. 1970. The effect of dose level of intravaginal progestagen on sperm transport, fertilization and lambing in the cyclic Merino ewe. J. Reprod. Fertil. 22:515-531.

Baird, D. T., and R. J. Scaramuzzi. 1976. Changes in the secretion of ovarian steroid and pituitary luteinizing hormone in the peri-ovulatory period in the ewe: The effect of progesterone. J. Endocrinol. 70:237-245.

Bartlewski, P. M., A. P. Beard, S. J. Cook, R. K. Chandolia, A. Honaramooz, and N. C. Rawlings. 1999. Ovarian antral follicular dynamics and their relationships with endocrine variables throughout the oestrous cycle in breeds of sheep differing in prolificacy. J. Reprod. Fertil. 115:111-124.

Bartlewski, P. M., R. Duggavathi, J. Aravindakshan, D. M. W. Barrett, S. J. Cook, and N. Rawlings. 2003. Effects of a 6-day treatment with medroxyprogesterone acetate after prostaglandin F2α-induced luteolysis at midcycle on antral follicular development and ovulation rate in nonprolific western white-faced ewes. Biol. Reprod. 68:1403-1412.

Benoit, A. M., E. K. Inskeep, and R. A. Dailey. 1992. Effect of a nonsteroidal aromatase inhibitor on in vitro and in vivo secretion of estradiol and on the estrous cycle in ewes. Domest. Anim. Endocrinol. 9:313-327.

Boland, M. P., C. D. Nancarrow, J. D. Murray, R. J. Scaramuzzi, R. Sutton, R. M. Hoskinson, and I. G. Hazelton. 1986. Fertilization and early embryonic development in androstenedione-immunized Merino ewes. J. Reprod. Fertil. 78:423-431.

Brand, A., and W. H. R de Jong. 1973. Qualitative and quantitative micromorphological investigations of the tertiary follicle population during the oestrous cycle in sheep. J. Reprod. Fertil. 33:431-439.

Carrillo, F., J. Hernández-Cer n, V. Orozco, J. A. Hernández, and C. G. Gutiérrez. 2006. A single dose of bovine somatotropin 5 days before the end of progestin-based estrous synchronization increases prolificacy in sheep. Anim. Reprod. Sci. doi: 10.1016/j.anireprosci.2006.09.024.

Cooperative Regional Research Project, NE-161. 1996. Relationship of fertility to patterns of ovarian follicular development and associated hormonal profiles in dairy cows and heifers. J. Anim. Sci. 74:1943-1952.

Crosby, T. F., M. P. Boland, and I. Gordon. 1991. Effect of progestagen treatments on the incidence of oestrus and pregnancy rates in ewes. Anim. Reprod. Sci. 24:109-118.

Deaver, D. R., N. J. Stilley, R. A. Dailey, E. K. Inskeep, and P. E. Lewis. 1986. Concentration of ovarian and pituitary hormones following prostaglandin F2α luteal regression in ewes varies with day of the estrous cycle at treatment. J. Anim. Sci. 62:422-427.

Dixon, A. B., M. Knights, J. L. Winkler, D. J. Marsh, J. L. Pate, M. E. Wilson, R. A. Dailey, G. Seidel, and E. K. Inskeep. 2007. Patterns of late embryonic and fetal mortality and association with several factors in sheep. J. Anim. Sci. 85:1274-1284.

Duggavathi, R., D. M. W. Barrett, N. C. Rawlings, S. Flint, P. M. Bartlewski, and E. Agg. 2005. The effect of the manipulation of follicle-stimulating hormone (FSH)-peak characteristics on follicular wave dynamics in sheep: does an ovarian-independent endogenous rhythm in FSH secretion exist? Biol. Reprod. 72:1466-1474.

Duggavathi, R., P. M. Bartlewski, D. M. W. Barrett, and N. C. Rawlings. 2003. Use of high-resolution transrectal ultrasonography to assess changes in numbers of small ovarian antral follicles and their relationships to the emergence of follicular waves in cyclic ewes. Theriogenology 60:495-510.

Eckery D. C., C. L. Moeller, T. M. Nett, and H. R. Sawyer. 1993. Recombinant bovine somatotropin (rbST, Sometribove) maintains the sensitivity of ovarian follicles to gonadotropins in hypophysectomized ewes. Biol. Reprod.; 48(suppl. 1):abstract 337.

Evans, A. C. O., P. Duffy, T. F. Crosby, P. A. R. Hawken, M. P. Boland, and A. P. Beard. 2004. Effect of ram exposure at the end of progestagen treatment on estrus synchronisation and fertility during the breeding season in ewes. Anim. Reprod. Sci. 84:349-358.

Evans, A. C. O., J. D. Flynn, K. M. Quinn, P. Duffy, P. Quinn, S. Madgwick, T. F. Crosby, M. P. Boland, and A. P. Beard. 2001. Ovulation of aged follicles does not affect embryo quality or fertility after a 14-day progestagen estrus synchronization protocol in ewes. Theriogenology 56:923-936.

Gibbons, J.R., K. Kot, D.L. Thomas, M.C. Wiltbank, and O.J. Ginther. 1999. Follicular and FSH dynamics in ewes with a history of high and low ovulation rates. Theriogenology 52:1005-1020.

Ginther, O.J., K. Kot, and M.C. Wiltbank. 1995. Associations between emergence of follicular waves and fluctuations in FSH concentrations during the oestrous cycle in ewes. Theriogenology 43:689-703.

Godfrey, R. W., M. L. Gray, and J. R. Collins. 1997. A comparison of two methods of oestrous synchronisation of hair sheep in the tropics. Anim. Reprod. Sci. 47:99-106.

Hawk, H. W. 1973. Uterine motility and sperm transport in the estrous ewe after prostaglandin induced regression of corpora lutea. J. Anim. Sci. 37:1380-1385.

Hawken, P. A. R., A. P. Beard, C. M. O'Meara, P. Duffy, K. M. Quinn, T. F. Crosby, M. P. Boland, and A. C. O. Evans. 2005. The effects of ram exposure during progestagen oestrus synchronisation and time of ram introduction post progestagen withdrawal on fertility in ewes. Theriogenology 63:860-871.

Hulet, C. V., H. P. Voightlander, Jr., A. L. Pope, and L. E. Casida. 1956. The nature of early-season infertility in sheep. J. Anim. Sci. 15:607-616.

Johnson, S. K., R. A. Dailey, E. K. Inskeep, and P. E. Lewis. 1996. Effect of peripheral concentrations of progesterone on follicular growth and fertility in ewes. Domest. Anim. Endocrinol. 13:69-79.

Kinder, J. E., F. N. Kojima, E. G. Bergfeld, M. E. Wehrman, and K. E. Fike. 1996. Progestin and estrogen regulation of pulsatile LH release and development of persistent ovarian follicles in cattle. J. Anim. Sci. 74:1424-1440.

Kleemann, D. O., and S. K. Walker. 2005a. Fertility in South Australian commercial Merino flocks: Sources of reproductive wastage. Theriogenology 63:2075-2088.

Kleemann, D. O., and S. K. Walker. 2005b. Fertility in South Australian commercial Merino flocks: Relationships between reproductive traits and environmental cues. Theriogenology 63:2416-2433.

Knights M., Q. S. Baptiste, A. B. Dixon, J. L. Pate, D. J. Marsh, E. K. Inskeep, and P. E. Lewis. 2003. Effects of dosage of FSH, vehicle and time of treatment on ovulation rate and prolificacy in ewes during the anestrous season. Small Ruminant Res. 50:1-9.

Knights, M., T. Hoehn, P. E. Lewis, and E. K. Inskeep. 2001. Effectiveness of intravaginal progesterone inserts and FSH for inducing synchronized estrus and increasing lambing rate in anestrous ewes. J. Anim. Sci. 79:1120-1131.

Kusina, N. T., R. L. Meyer, K. M. Carlson, and J. E. Wheaton. 1995a. Effects of passive immunization of ewes against an inhibin-like peptide on gonadotropin levels, ovulation rate, and prolificacy. Biol. Reprod. 52:878-884.

Kusina, N. T., R. L. Meyer, K. M. Carlson, and J. E. Wheaton. 1995b. Passive immunization of ewes against an inhibin-like peptide increases follicle-stimulating hormone concentrations, ovulation rate, and prolificacy in spring-mated ewes. J. Anim. Sci. 73:1433-1439.

Leyva, B., B. C. Buckrell, and J. S. Walton. 1998. Regulation of follicular activity and ovulation in ewes by exogenous progestogen. Theriogenology 50:395-416.

Meyer, H. H. 1985. Breed differences in ovulation rate and uterine efficiency and their contribution to fecundity. In: Genetics of Reproduction in Sheep. R. B. Land, and D. W. Robinson, eds. Butterworths, London.

Meyer, H. H., and R. D. Lewis. 1988. Reproductive responses of ewes to immunization with Fecundin (Ovandrotone). J.Anim. Sci. 66:2742-2749.

Meyer, H. H., L. R. Piper, B. M. Bindon, and R. R. Woolaston. 1994. Litter size and uterine efficiency of Booroola Merinos, control Merinos and their crosses with Border Leicester and Dorset. Livest. Prod. Sci. 38:217-223.

Mitchell, L. M. W. S. Dingwall, M. J. A. Mylne , J. Hunton, K. Matthews, F. E. Gebbie, G. J. McCallum, and T. G. McEvoy . 2002. Season affects characteristics of the pre-ovulatory LH surge and embryo viability in superovulated ewes. Anim. Reprod. Sci. 74:163-174.

Murdoch, W. J., M. De Silva, and T. G. Dunn. 1983. Luteal phase insufficiency in the ewe as a consequence of premature induction of ovulation by intrafollicular injection of gonadotropins. J. Anim. Sci. 57:1507-1511.

Nawaz, M., and H. H. Meyer. 1991. Effects of genotype and mating weight on ovulation rate, litter size, and uterine efficiency of Coopworth, Polypay, and crossbred ewes J. Anim. Sci. 69:3925-3930.

Patterson, H. C. 1983. Barbados Blackbelly and crossbred sheep performance in an experimental flock in Barbados. In: Hair Sheep of Western Africa and the Americas: A Genetic Resource for the Tropics. (H.A. Fitzhugh and G.E. Bradford, eds.), A Winrock International Study, Westview Press Inc., 5500 Central Ave., Boulder, Colorado, 80301. pp 151-162.

Rhodes L., and P. W. Nathanielsz. 1988. Comparison of a controlled internal drug release device containing progesterone with intravaginal medroxyprogesterone sponges for estrus synchronization in ewes. Theriogenology. 30:831-836.

Robinson, T. J., T. D. Quinlivan, and C. Baxter. 1968. The relationship between dose of progestagen and method of preparation of intravaginal sponges on their effectiveness for the control of ovulation in the ewe. J. Reprod. Fertil. 17:471-483.

Salamon, S. 1976. Artificial Insemination of Sheep. Publicity Press Ltd. Chippendale, N.S.W., Australia.

Schrick, F. N., R. A. Surface, J. Y. Pritchard, R. A. Dailey, E. C. Townsend, and E. K. Inskeep. 1993. Ovarian structures during the estrous cycle and early pregnancy in ewes. Biol. Reprod. 49:1133-1140.

Stock, A. E., and J. E. Fortune. 1993. Ovarian follicular dominance in cattle: relationship between prolonged growth of the ovulatory follicle and endocrine parameters. Endocrinology 132:1108-1114.

Taft, R., N. Ahmad, and E. K. Inskeep. 1996. Exogenous pulses of luteinizing hormone cause persistence of the largest bovine ovarian follicle. J. Anim. Sci. 74:2985-2991.

Turnbull, K. E., P. E. Mattner, J. M. George, and R. J. Scaramuzzi. 1978. The relation between patterns of ovarian follicle growth and ovulation rate in sheep. Aust. J. Biol. Sci. 31:649-655.

Ungerfeld, R., and E. Rubianes. 1999. Effectiveness of short-term progestogen primings for the induction of fertile oestrus with eCG in ewes during late seasonal anoestrus. Anim. Sci. 68:349-353.

Van Cleeff, J., F. J. Karsch, and V. Padmanabhan. 1998. Characterization of endocrine events during the periestrous period in sheep after estrous synchronization with controlled internal drug release (CIDR) device. Domest. Anim. Endocrinol. 15:23-34.

Viñoles, C., A. Meikle, M. Forsberg, and E. Rubianes. 1999. The effect of subluteal levels of exogenous progesterone on follicular dynamics and endocrine patterns during the early luteal phase of the ewe. Theriogenology 51:1351-1361.

Viñoles, C., M. Forsberg, G. Banchero, and E. Rubianes. 2001. Effect of long-term and short-term progestagen treatment on follicular development and pregnancy rate in cyclic ewes. Theriogenology. 55 :993-1004.

Wilkins, J. F. 1997. Method of stimulating ovulation rate in Merino ewes may affect conception but not embryo survival. Anim. Reprod. Sci. 47:31-42.

Sheep & Goat Research Journal
Volume 23, 2008

Post-weaning Management of Lambs Alters Subsequent Feedlot Performance and Tissue Deposition[1]

R. R. Redden[2,3], R. W. Kott[2], L.M.M. Surber[2], J. A. Boles[2], A. W. Layton[4], and P. G. Hatfield[2]

[1] *Research was funded by the Montana Sheep Institute, Bozeman, MT*

[2] *Department of Animal and Range Sciences, Montana State University, Bozeman, MT 59717;*

[3] *Corresponding author: reid_redden@yahoo.com*

[4] *Montana Department of Livestock, Bozeman, MT 59717*

Summary

Backgrounding lambs on forage-based diets after weaning may provide producers with alternatives to traditional marketing of lambs directly to feedlots. Our objective was to evaluate feedlot performance of lambs from different backgrounding treatments. Seventy-two crossbred lambs were randomly assigned to one of four backgrounding treatments. Treatments were imposed after traditional, range-weaning practice (140 d of age). Treatments were: 1) drylot ad libitum access to 80:20 alfalfa:barley pellets (PELLET); 2) cool-season, grass-paddock grazing (GRASS); 3) unweaned, dormant-range grazing (LATE WEAN); and 4) weaned, dormant-range grazing (RANGE). After 29 d of backgrounding, lambs within backgrounding treatment were assigned to feedlot pens (3 pens/treatment). Lamb-BW and ultrasound measurements were taken at weaning (d-29), after backgrounding (d 0), after transition to 70 percent grain diet (d 19), and at the end of the feedlot period (d 68). Lambs backgrounded on PELLET had greater BW *($P < 0.10$)* at d 0 and d 68 than lambs assigned to other treatments. Feedlot DMI of PELLET lambs was greater than all other treatments, and feedlot ADG of PELLET lambs was greater than LATE WEAN and RANGE lambs *($P < 0.10$)*. At the end of the feedlot period (d 68), ultrasound measures of LM were greater *($P < 0.05$)* for GRASS than either LATE WEAN or RANGE when BW on d 68 was included as a covariable. No differences *($P > 0.10$)* in 12th-rib-fat thickness were detected among treatments at d 68. Results from our 2007 study indicate that 29-d-background treatments on dormant range diminished subsequent-feedlot performance; however, GRASS backgrounding had similar feedlot performance to PELLET backgrounding.

Key Words: Backgrounding, Feedlot Performance, Tissue Deposition, Lamb

Introduction

Western-range-sheep producers typically sell lambs immediately after weaning, and the majority of these lambs go directly to feedlots. The USDA National Animal Health Monitoring System (2004) reported that 17 percent of the feedlot lambs per year had been weaned two weeks prior to shipping to the feedlot. Maintenance of lambs on forage-based diets post-weaning prior to feedlot entry (backgrounding) has the potential to improve feedlot performance (Turgeon et al., 1986), carcass merit (McClure et al. 1995), and producer profitability (Blackburn et al., 1991). Moreover, Mathis et al. (2008) reported that steers backgrounded on range had lower feedlot mortality rates, similar feedlot productivity, and were more profitable than steers backgrounded in a drylot.

However, there is limited published research reporting the effects of different backgrounding systems on subsequent lamb-feedlot performance. Therefore our objective was to evaluate the effects of dormant range, improved pasture, and drylot backgrounding vs. late weaning on lamb-feedlot performance and tissue deposition.

Table 1. Chemical composition (DM basis) of feedlot diet ingredients.[1]

	Feedlot Diet[2]		
	Whole Corn	Alfalfa: Barley Pellet	Supplemental Pellet
DM, %	85	90	86
CP, %	9.96	17.80	22.80
CF, %	3.97	1.40	2.30
ADF, %	3.48	30.50	19.10
Ash, %	1.32	8.35	10.40
TDN, %	91.90	71.20	73.20
Sulfur, %	0.12	0.32	0.44
Phosphorus, %	0.29	0.30	0.66
Potassium, %	0.36	2.20	1.39
Magnesium, %	0.13	0.36	0.36
Calcium, %	0.01	1.96	1.38
Sodium, %	<0.01	0.06	1.29
Iron, ppm	24	133	276
Manganese, ppm	8	40	108
Copper, ppm	4	6	15
Zinc, ppm	21	20	86
Bovatec, mg/kg			264

[1] Chemical analysis conducted by Midwest Laboratories Inc. (Omaha, Neb.).
[2] Feedlot diets consisted of 80 percent alfalfa: 20percent barley pellets, whole corn, and a supplemental pellet designed to be fed at 0.227 kg/(lamb•d) on an as-fed basis. Diets were hand mixed and placed in self-feeders, which allowed ad libitum access. Diets started at 30-percent concentrate (corn and barley) and moved up 10 percentage points in concentrate for every 26.7 kg of pen intake (~4.45 kg/lamb; as fed basis). Finishing-lamb diets were held constant at 70 percent concentrate.

Materials and Methods

The Institutional Animal Care and Use Committee at Montana State University approved activities involving the live animals.

Animals, Treatments, and Research Sites

Seventy-two (Black-face X Western white-face) wether and ewe lambs were randomly selected at weaning (average BW, 31 kg ± 0.67 kg, respectively) from the Red Bluff Research Ranch ewe flock. Lambs were assigned to treatments in such a manner that average-lamb BW and the number of wethers and ewe lambs were similar in all backgrounding treatments (18 lambs per treatment). All background treatments lasted 29 d, starting when lambs were 140 ± 5.9 d of age and lasting until the beginning of the feedlot period. Treatments were: 1) lambs not separated from their dams at Red Bluff Research Ranch (LATE WEAN); 2) lambs removed from the ewes for 4 d then returned to graze with the ewe flock at Montana State University Red Bluff Research Ranch (RANGE); 3) lambs weaned and moved to grass paddocks at Montana State University Fort Ellis Research and Teaching Farm (GRASS); 4) lambs weaned and allowed ad libitum access to an 80 percent alfalfa: 20 percent barley pellet (Table 1) in a drylot at Fort Ellis Research Farm (PELLET).

Montana State University Red Bluff Research Ranch (latitude 45°35' N, longitude 111°38' W) elevation ranges from 1,402 m to 1,889 m, and annual precipitation ranges from 35.5 cm to 43.1 cm. Vegetation is a typical, foothill-bunchgrass type. Bluebunch wheatgrass (*Pseudoroegneria spicata*) and Idaho fescue (*Festuca idahoensis*) are the major grasses. Rubber rabbit brush (*Ericameria nauseosus*), prairie sagewort (*Artemisia frigida*), lupine (*Lupinus spp.*), milkvetch (*Astragalus spp.*), and western yarrow (*Achillea millefolium*) are commonly occurring shrubs and forbs (Harris et al., 1989). Previous literature determined the chemical composition of this dormant range to be approximately 5.7 percent CP, 68.8 percent NDF, and 45.6 ADF percent (Soder et al., 1995).

Montana State University Fort Ellis Research and Teaching Farm (latitude 45° 38' N, longitude 110° 58' W, altitude 1505 m) received 61 cm of precipitation in 2007 (NCDC, 2009). Sheep pastures were predominantly smooth brome (*Bromus inermis*), crested wheat (*Agropyrom cristatum*), and Kentucky blue (*Poa pratensis*) grasses. Prior to the experiment, paddocks A and B (0.53 ha and 1.42 ha, respectively) were grazed by sheep in the spring and summer. Fall regrowth produced most of the forage available for the GRASS backgrounded lambs. Previous literature conducted on the same paddocks at a similar time of year determined the paddocks to be approximately 13.8 percent CP, 63.5 percent NDF, and 33.4 percent ADF (Hatfield et al., 2002).

Backgrounding

On September 6, 2007 all lambs except LATE WEAN were moved from Red Bluff to Fort Ellis (56 km). At Fort Ellis, PELLET, RANGE, and GRASS treatment lambs were placed on paddock B for 4 d. Then on September 10, RANGE lambs were returned to the ewe herd at the Red Bluff Research Ranch, PELLET lambs were moved to a drylot pen with self-feeders containing 80 percent alfalfa: 20 percent barley pellets (Table 1), and GRASS lambs were moved to paddock A. Lambs remained on their respective treatments for 29 d.

Feedlot

On October 9, 2007 all lambs were removed from their respective backgrounding treatment, orally drenched with an anthelmintic (Valbazen; Pfizer Animal Health, Exton, Pa.), vaccinated against Clostridial perfringens C and D (Bar-Vac CDT; Boehringer Ingelheim Vetmedica, Inc., St. Joseph, Mo.), and allowed to graze paddock B for 48 h. On October 11 (d 0) lambs were then removed from feed and water for 12 h and shrunk BW were obtained. Lambs within backgrounding treatments were randomly assigned to pens (6 lambs per pen and 3 pens per treatment). Feedlot diets consisted of 80 percent alfalfa: 20 percent barley pellets, whole corn, and a supplemental pellet (Table 1) designed to be fed at 0.227 kg/(lamb•d) on an as-fed basis. Each ingredient was sampled and composited over time. Feed samples were stored in a dry location at room temperature. Proximate analysis and mineral concentrations were determined by Midwest Laboratories, Inc (Omaha, Neb.; Table 1). Diets were hand mixed and placed in self-feeders, which allowed ad libitum access. Diets started at 30-percent concentrate (whole corn and barley fraction of pellet) and moved up 10 percentage points in concentrate for every 26.7 kg of pen intake (≈4.45 kg/lamb; as-fed basis). Finishing-lamb diets were held constant at 70-percent concentrate.

After all pens had reached the 70-percent-concentrate diet (October 30, 2007; d 19 post start of feedlot period), the step-up period was concluded. On d 19, all lamb-unshrunk BWs were recorded and lambs were vaccinated against Clostridial perfringens C and D (Bar-Vac CDT; Boehringer Ingelheim Vetmedica, Inc., St. Joseph, Mo.). On December 18 (d 68), ultrasonography (Aloka Co., LTD, Wallingford, Conn.) determined that more than half of the lambs had achieved the target 0.5 cm 12th-rib-fat thickness and the feedlot period was concluded. Lambs were removed from the feedlot pens and weighed. Lambs were then held off feed and water over night and shrunk BW were measured. Percent shrink was averaged on each lamb, and a pencil shrink was applied to d 19 lamb BW.

On d 19 and d 68, feed refusals were removed from the self-feeders and weighed. Pen intakes during the step-up, finishing and total feedlot periods were determined by subtracting feed refusals from feed offered.

Lamb health was monitored during the feedlot period. Lambs showing signs of acidosis were drenched with sodium bicarbonate saturated in water. One RANGE lamb died during the step-up period, and its data were removed from the study.

Carcass and Ultrasound Evaluation

At the conclusion of the feedlot period, 20 lambs (5 lambs/treatment) of similar BW (average 53 ± 4 kg) were selected for slaughter. On December 20, slaughter lambs were taken to a local abattoir (96 km) and harvested the next morning. After an approximate 24 h chill, carcass weight, kidney fat, 12th-rib-fat thickness, and LM (longissimus muscle) area were recorded.

Ultrasound measurements of LM area and 12th-rib-fat thickness were taken at 12th/13th rib transverse using an Aloka SSD-500V real-time ultrasound device with a 3.5 MHz, 12.5-cm linear array transducer and standoff guide. On d-29, d 0, d 19, and d 68, lamb LM area was measured using ultrasonography. On d 19 and d 68, lamb-fat thickness was measured using ultrasonography. All ultrasound measurements were collected and interpreted by the same technician. Technician bias was -0.018 cm and 0.12 cm for LM area and 12th-rib-fat thickness, respectively. Standard error of prediction was 0.63 and 0.17 cm for LM area and 12th-rib-fat thickness, respectively. Standard error of repeatability was 0.55 cm and 0.07 cm for LM area and 12th-rib-fat thickness, respectively.

Statistical Analysis

Data were analyzed as a completely random design using the GLM procedure of SAS (SAS Inst. Inc., Cary, N.C.). Means were separated by the LSD procedure, and differences were considered different at $P < 0.10$. Pen was the experimental unit for growth and feed intake data, with 3 pens per treatment. Lamb was the experimental unit for ultrasound and carcass data. The main effect for all analysis was backgrounding treatment. Body weight at the time of scan was added as a covariable for all ultrasound data to identify tissue deposition independent of BW.

Results and Discussion

Lamb Growth

Lambs backgrounded on the PELLET treatment had the greatest ($P \leq 0.06$) BW among treatments (Table 2) at the start of the feedlot period (d 0). After lambs were stepped up onto the 70 percent concentrate diet (d 19), PELLET and GRASS lambs had greater BWs ($P \leq 0.05$) than RANGE and LATE WEAN lambs. At d 68, PELLET lambs weighed more ($P \leq 0.02$) than lambs with other backgrounding treatments.

Feedlot Performance

No differences ($P > 0.35$) among backgrounding treatments (Table 3) were detected for DMI, ADG, or G:F during the step-up (d 0 to d 19) or finishing (d 19 to d 68) periods. Differences were detected for the total-feedlot period (d 0 to d 68). Lambs backgrounded on PELLET treatments had the greatest DMI ($P \leq 0.08$). Average-daily gain was greater ($P \leq 0.10$) for PELLET than RANGE and LATE WEAN lambs. Feed efficiency was greater ($P = 0.08$) for GRASS than RANGE lambs.

Ultrasonography Data

After backgrounding (d 0), PELLET and GRASS lambs had greater ($P \leq 0.01$) LM areas than RANGE and LATE WEAN lambs (Table 4). After the step-up period (d 19), no differences ($P > 0.30$) were detected for LM areas. At the conclusion of the feedlot period (d 68),

Table 2. Effects of backgrounding treatment on feedlot lamb BW.[1,2]

	Treatment				
	GRASS	LATE WEAN	PELLET	RANGE	SE
No. of Pens	3	3	3	3	
Weaning BW, kg	32	31	31	31	
Feedlot BW, kg					
d 0	33[a]	33[a]	35[b]	33[a]	0.59
d 19	36[b]	35[a]	36[b]	34[a]	0.60
d 68	48[a]	47[a]	51[b]	46[a]	0.87

[ab] Row means with different superscripts differ (*P < 0.10*).

[1] Treatments were applied to lambs for 29 d after weaning.
GRASS lambs were maintained on grass paddocks at the Fort Ellis Research Center.
LATE WEAN lambs were not weaned from dams during background period.
PELLET lambs were self-fed alfalfa:barley pellets.
RANGE lambs were weaned from dams for 4 d and returned to range with ewe flock.

[2] *Weaning* (d -29) represents removal of lambs from ewes when lambs were 140 ± 5.9 d; except LATE WEAN lambs.
d 0 lambs were removed from backgrounding treatments and began step-up diets.
d 19 lambs finished the transition period and began the finishing diet.
d 68 was the conclusion feedlot period.

Table 3. Effects of backgrounding treatment on lamb DMI, ADG, and G:F during feedlot periods.[1]

	Treatment[2]				
	GRASS	LATE WEAN	PELLET	RANGE	SE
No. of Pens	3	3	3	3	
Step-up					
DMI, kg	1.31	1.24	1.34	1.15	0.08
ADG, kg/d	0.16	0.10	0.08	0.06	0.05
G:F	0.120	0.079	0.049	0.048	0.024
Finishing					
DMI, kg	1.66	1.68	1.79	1.65	0.06
ADG, kg/d	0.24	0.25	0.28	0.25	0.02
G:F	0.144	0.148	0.156	0.152	0.009
Total					
DMI, kg	1.56[a]	1.56[a]	1.67[b]	1.51[a]	0.04
ADG, kg/d	0.22[ab]	0.20[a]	0.23[b]	0.20[a]	0.01
G:F	0.139[a]	0.132[ab]	0.135[ab]	0.131[b]	0.003

[ab] Row means with different superscripts differ (*P < 0.10*).

[1] Step-up was 19 d period during which lambs were adjusted from 30 to 70% concentrate diets.
Finishing was 47-d period that lambs remained on the 70 percent concentrate diet.
Total was 68 d-feedlot period.

[2] Treatments were applied to lambs for 29 d after weaning.
GRASS lambs were maintained on grass paddocks at the Fort Ellis Research Center.
LATE WEAN lambs were not weaned from dams during the background period.
PELLET lambs were self-fed alfalfa:barley pellets.
RANGE lambs were weaned from dams for 4 d and returned to range with ewe flock.

GRASS lambs had greater *($P \leq 0.05$)* LM areas than RANGE and LATE WEAN lambs; however, PELLET lambs did not differ *($P \geq 0.28$)* from all other treatments.

PELLET lambs had the greatest *($P < 0.01$)* 12th-rib-fat thickness among treatments at the end of the step-up phase (d 19). At the conclusion of the feedlot, there were no differences *($P > 0.21$)* in 12th-rib-fat thickness among treatments.

Carcass data

No differences *($P > 0.18$)* were detected among backgrounding regimens for chilled carcass weight, LM area, or kidney fat (Table 5). Lambs from GRASS, RANGE, and LATE WEAN treatments had greater 12th-rib-fat thickness *($P \leq 0.10$)* than PELLET lambs.

Discussion

After the 29 d backgrounding period, PELLET lambs had greater lamb BW than did all other treatments. Similarly, Mathis et al. (2008) reported that steers backgrounded in a drylot were heavier than steers backgrounded on native range for 45 d after weaning. After the feedlot step-up period, both PELLET and GRASS lambs were heavier than RANGE and LATE WEAN lambs. Similarly, Mathis et al. (2008) reported that range-backgrounded steers had lower interim steer BW than drylot-backgrounded steers. At the conclusion of the present study, PELLET lambs had greater lamb BW than did GRASS, LATE WEAN, and RANGE lambs. In contrast, Mathis et al. (2008) reported similar final steer BW between background treatments. One reason for the difference in final BW could be that Mathis and others supplemented protein to the background treatment, whereas, our dormant-range treatments were not supplemented.

In the present study, lamb backgrounding treatment did not affect step-up DMI or G:F. However, Drouillard et al. (1991) restricted lamb growth for 35 d with either deficiencies in protein or energy prior to feedlot entry. They reported that d 0 to d 14 feedlot DMI was less in the unrestricted treatment than both energy- and protein-restricted treatments and feedlot G:F was greater

Table 4. Ultrasound measurements of LM area and 12th-rib fat thickness of backgrounded lambs.[1]

	Treatment[2]				
	GRASS	LATE WEAN	PELLET	RANGE	SE
No. of Lambs	18	18	18	17	
LM area, cm^2					
Weaning	8.08	7.66	7.96	7.81	0.23
d 0	9.52[a]	8.62[b]	9.61[a]	8.64[b]	0.24
d 19	10.87	10.57	10.91	10.67	0.24
d 68	16.50[a]	15.65[bc]	16.02[ac]	15.57[bc]	0.32
12th-rib fat thickness, cm					
d 19	0.28[a]	0.28[a]	0.35[b]	0.27[a]	0.01
d 68	0.53	0.51	0.49	0.51	0.02

[ab] Row means with different superscripts differ ($P < 0.10$).

[1] *Weaning* (d -29) represents removal of lambs from ewes when lambs were 140 ± 5.9 d.
d 0 lambs were removed from backgrounding treatments and began step-up diets.
d 19 lambs finished the transition period and began the finishing diet.
d 68 was the conclusion feedlot period.

[2] Treatments were applied to lambs for 29 d after weaning.
GRASS lambs were maintained on grass paddocks at the Fort Ellis Research Center.
LATE WEAN lambs were not weaned from dams during the background period.
PELLET lambs were self-fed alfalfa:barley pellets.
RANGE lambs were weaned from dams for 4 d and returned to range with ewe flock.

[3] Lamb BW at time of ultrasound measurement was added as a covariable to analyze LM and FD independent of BW.

Table 5. Effects of backgrounding treatment on lamb carcass characteristics taken after a 68 d feedlot period.

	Treatment[1]				
	GRASS	LATE WEAN	PELLET	RANGE	SE
No. of lambs	5	5	5	4	
Chilled carcass wt, kg	26.4	26.3	26.6	25.8	0.47
LM area, cm2	17.4	16.1	16.0	15.8	0.76
12th-rib fat thickness, cm	0.48[a]	0.48[a]	0.33[b]	0.46[ab]	0.06
Kidney fat, kg	1.14	0.97	1.16	1.00	0.11

[ab] Row means with different superscripts differ *($P < 0.10$)*.

[1] Treatments were applied to lambs for 29 d after weaning.
GRASS lambs were maintained on grass paddocks at the Fort Ellis Research Center.
LATE WEAN lambs were not weaned from dams during the background period.
PELLET lambs were self-fed alfalfa:barley pellets.
RANGE lambs were weaned from dams for 4 d and returned to range with ewe flock.

in protein than energy-restricted lambs (Drouillard et al. 1991). Their restricted treatments lost BW during the 35-d period, whereas, the RANGE, LATE WEAN, and GRASS lambs maintained BW during the backgrounding period. Therefore, lamb-BW change during background could very well affect feedlot performance during the first few weeks upon feedlot finishing.

During the 68-d feedlot period, RANGE, LATE WEAN, and GRASS lambs had less feedlot DMI. Drouillard et al. (1991) found that protein- and energy-restricted lambs had lower d 0 to d 42-feedlot DMI than unrestricted lambs, but total feedlot was not different among treatments (approximately 110 d). Therefore, intensity and duration of lamb restriction appears to influence subsequent feedlot DMI.

Lambs on the RANGE and LATE WEAN treatments had lower feedlot ADG than PELLET lambs; whereas, GRASS lambs were similar among treatments. Mathis et al. (2008) found higher initial feedlot ADG in range than drylot backgrounding; however, no difference in total-feedlot ADG was found between range- and drylot-backgrounded steer treatments. It is not clear why the present study's range background treatments did not have compensatory ADG. However, Turgeon et al. (1986) found that greater duration and intensity of growth restriction prior to feedlot entry was associated with higher levels of compensatory gain.

Ultrasound measurements of LM area indicate that LATE WEAN and RANGE treatments had less LM areas than GRASS and PELLET lambs at the start of the feedlot period. In addition, GRASS lambs maintained larger LM areas to the conclusion of the feedlot period. Drouillard et al (1991) reported that restricted lambs (35 d) had less protein tissue than unrestricted lambs after the restriction period and that difference in protein tissue between treatments was not regained during the feedlot period. However, Turgeon et al. (1986) reported higher rates of protein deposition during the feedlot period in restricted (100 d and 200 d) vs. unrestricted lambs. Differences in carcass LM area among studies are most likely due to length and intensity of background restriction prior to feedlot entry.

Fat thickness on d 19 was lower in RANGE, LATE WEAN, and GRASS lambs than PELLET lambs; however, upon feedlot completion all treatments reached a similar fat thickness. Similarly, Drouillard et al. (1991) and Turgeon et al. (1986) reported that restricted lambs had less fat than unrestricted lambs after the restriction period; however, after feed restriction ceased, fat was deposited at a greater rate in the previously restricted lambs.

Lambs of similar BW were selected for harvest, and comparison of treatment among similar BW can be made. Although, PELLET lambs had less carcass-fat thickness than all other treatments, ultrasound measurement of fat thickness across the entire treatment group was not different among treatment. Indicating that selection of similar BW among treatments may have artificially selected the leanest lambs from the PELLET treatment. Carcass weight, LM area, and kidney fat were all similar among treatments. Similarly, Mathis et al. (2008) reported similar carcass weight, LM area, and fat thickness between steer-background treatments.

Conclusions

Lambs on the PELLET-background treatment allowed for greater feedlot ADG, as compared to RANGE- and LATE WEAN-backgrounding treatments. The study also showed that GRASS lambs had similar feedlot ADG to PELLET lambs and higher G:F ratios than RANGE lambs. In addition, GRASS lambs had similar BW to RANGE and LATE WEAN lambs after backgrounding; however, GRASS lambs deposited more LM during the backgrounding and feedlot phases. Although, PELLET lambs deposited more LM than RANGE and LATE WEAN during the background treatment, feedlot LM deposition was similar among PELLET, LATE WEAN, and RANGE lambs. All lamb treatments reached a similar FD at the conclusion of the feedlot phase. In conclusion, results from this study conducted in 2007 showed that different background-management strategies will alter feedlot-lamb performance and LM deposition. Producers must factor in cost of backgrounding in relation to improvements in feedlot performance.

Literature Cited

Blackburn, H. D., G. D. Snowder and H. Glimp. 1991. Simulation of lean lamb production systems. J. Anim. Sci. 69:115-124.

Drouillard, J. S., T. J. Klopfenstein, R. A. Britton, M. L. Bauer, S. M. Gramlich, T. J. Wester, and C. L. Ferrell. 1991. Growth, body composition, and visceral organ mass and metabolism in lambs during and after metabolizable protein or net energy restriction. J. Anim. Sci. 69:3357-3375.

Harris, K. B., V. M. Thomas, M. K. Petersen, M. J. McInerney, R. W. Kott, and E. Ayers. 1989. Influence of supplementation on forage intake and nutrient retention of gestating ewes grazing winter range. Can. J. Anim. Sci. 89:673-678.

Hatfield, P. G., B. L. Robinson, D. L. Minikiem, R. W. Kott, N. I. Roth, J. T. Daniels, and C. K. Swenson. 2002. Serum alpha-tocopherol and immune function in yearling ewes supplemented with zinc and vitamin E. J. Anim. Sci. 80:1329-1334.

Mathis, C. P., S. H. Cox, C. A. Loest , M. K. Petersen, R. L. Endecott, A. M. Encinias, and J. C. Wenzel. 2008. Comparison of low-input pasture to high-input drylot backgrounding on performance and profitability of beef calves through harvest. Prof. Anim. Sci. 24:169-174.

McClure K. E., M. B. Solomon, N. A. Parrett, and R. W. Van Keuren. 1995. Growth and tissue accretion of lambs fed concentrate in drylot, grazed on alfalfa or ryegrass at weaning, or after backgrounding on ryegrass. J. Anim. Sci. 73:3437-3444.

NCDC, 2009. National Climatic Data Center. www.ncdc.noaa.gov/ Accessed July 2, 2009.

Soder, K. J., V. M. Thomas, R. W. Kott, P. G. Hatfield, and B. Olson. 1995. Influence of energy or protein supplementation during midpregnancy on forage intake of ewes grazing Montana winter range. J. Anim. Sci. 73:2853-2859.

Turgeon, O. A., D. R. Brink, S. J. Bartle, T. J. Klopfenstein, and C. L. Ferrell. 1986. Effects of growth rate and compensatory growth on body composition in lambs. J. Anim. Sci. 63:770-780.

USDA/NAHMS. 2004. Highlights of NAHMS sheep 2001: Part IV baseline reference of 2001 sheep feedlot health and management. *http://nahms.aphis.usda.gov/sheep/sheep01/sheep01hi4.pdf* Accessed September 16, 2008.

Sheep & Goat Research Journal
Volume 24, 2009

Substituting distillers dried grains for cottonseed meal in lamb-finishing diets: growth, wool characteristics, and serum NEFA, urea N, and IGF-1 concentrations[1]

J. K. McEachern[3], T. R. Whitney[2,4], C. B. Scott[3], C. J. Lupton[4], and M. W. Salisbury[3]

[1] Funded in part by the U.S. Department of Transportation, Office of the Secretary, Grant No. DT0S59-07-G-00053. Appreciation is expressed to Dr. John Walker (TX AgriLife Research and Extension Center, San Angelo) for reviewing an early draft of the manuscript.

[2] Corresponding Author: trwhitney@ag.tamu.edu

[3] Angelo State University, Agriculture Department, ASU Station #10888, San Angelo, TX 76909-0888

[4] Texas AgriLife Research and Extension Center, 7887 U.S. Hwy 87 N., San Angelo, TX 76901

Summary

Effects of replacing cottonseed meal (CSM) with corn distillers dried grains (DDG) on growth, wool, and serum NEFA, urea N (SUN), and IGF-1 concentrations were investigated in Rambouillet wether lambs. Lambs (n = 44) were individually fed *ad libitum* diets for 84 d containing DDG that replaced 0 percent (0DDG), 33 percent (33DDG), 66 percent (66DDG), or 100 percent (100DDG) of the CSM in a completely randomized design. Diet × day interactions were not observed ($P > 0.12$) for BW, ADG, DMI, degradable protein intake, or G:F. As DDG increased in the diet, ADG and G:F decreased quadratically ($P = 0.08$), but no difference ($P = 0.13$) in daily DMI was observed. Lambs fed 100DDG diet had similar ($P > 0.23$) ADG, average DMI, and G:F compared to lambs fed 0DDG diet. A diet × day interaction ($P < 0.001$) was observed for SUN, but not for serum NEFA or IGF-1 concentrations ($P > 0.16$). At times, SUN increased ($P < 0.10$) as DDG increasingly replaced CSM, which was attributed to an increase (quadratic, $P < 0.001$) in degradable protein intake. Serum NEFA decreased linearly ($P < 0.08$) and serum IGF-1 decreased quadratically ($P < 0.05$) as DDG increasingly replaced CSM in the diets. Wool characteristics were not affected ($P > 0.10$) by diet. Results indicated that DDG can replace all the CSM in lamb-finishing diets without negatively affecting growth, efficiency of gain, or wool characteristics, and can potentially reduce cost of feed•kg^{-1} gain.

Key Words: Cottonseed Meal, Distillers Dried Grains, IGF-1, Lambs, Wool

Introduction

Up to 80 million tons of distillers dried grains (DDG) are expected to be produced by 2014 (FAPRI, 2009; Neeley, 2009), which should continue making DDG an economical feed due to market saturation. Research evaluating the use of distillers byproducts in beef- and dairy-cattle diets is extensive, and performance has been variable (Firkins et al., 1985; Ham et al., 1994; Depenbusch et al., 2009). A limited amount of research has evaluated effects of using DDG in lamb-finishing diets (NASS, 2007); however, the sheep industry has demonstrated an interest to use this feed resource to lower the cost of gain.

Cottonseed meal is a common protein source for lamb-finishing diets, especially in Texas. Even though CSM contains a greater concentration of CP and degradable protein than DDG (NRC, 2007), potential exists for DDG to completely replace CSM as the protein source in finishing diets. For example, Huls et al. (2006) reported that DDG with solubles (DDGS) could be effectively fed to lambs at 23 percent of diet DM by replacing soybean meal and a portion of corn in diets where soy hulls were the only fiber source. Others have reported that DDGS could be fed to lambs with alfalfa hay and replace 20 percent of the barley (Schauer et al., 2005) or fed at 60 percent of diet DM without affecting final BW, G:F, or mortality, or causing lambs to exhibit signs of acidosis, polioencephalomalacia, or urinary calculi (Schauer et al., 2008). Furthermore, DDG contain high levels of bypass protein and sulfur, both of which have enhanced growth and animal-fiber production (Throckmorton, et al., 1982; Reis and Sahlu, 1994). If DDG can effectively replace all of the CSM in lamb-finishing diets without negatively affecting lamb growth and end products, it would benefit corn growers and the ethanol industry and reduce feed costs associated with growing lambs. The objective of this study was to determine the effect of replacing CSM with DDG in lamb-finishing diets.

Materials and Methods

Animals and Management

The experimental protocol was approved by the Texas A&M University Institutional Animal Care and Use Committee (#2007-92). Rambouillet wether lambs (n = 44; approximate age = 4 mo; initial BW = 28.8 kg ± 3.5 kg) were weighed at the beginning of the adaptation period 28 d before study initiation, stratified by BW, and randomly assigned to diets (n = 11•trt^{-1}). Lambs developed coccidiosis during the adaptation period and were treated orally for 5 d with amprolium (Corid, Merial, Duluth, Ga.); one lamb had to be removed from the study due to the coccidia infection. Lambs received an ear tag and a subcutaneous injection of a clostridial vaccine (Vision 7 with SPUR, Inervet Inc., Millsboro, Del.). Lambs were randomly assigned to individual, completely covered dirt pens (2.44 × 2.97 m) with automatic watering systems and feed bunks. Pelleted diets contained corn DDG that replaced 0 percent (0DDG), 33 percent (33DDG), 66 percent (66DDG), or 100 percent (100DDG) of the cottonseed meal (CSM; Table 1). Urea was added at the rate of 0.09 percentage units for each 1 percentage unit increase in DDG to keep diets isonitrogenous. Monensin (Rumensin 80, Elanco, Indianapolis, Ind.) was added to each diet at 22g•metric ton^{-1} of feed. Lambs were individually fed once daily at 0800 at *ad libitum* intake, calculated for each lamb as the previous day's intake plus approximately 15 percent of dietary DM. Feed refusals were collected twice per week and weighed.

During the adaptation period, percentage of concentrate in the diet was gradually increased in non-amalgamated feed, and pelleted diets were gradually introduced. Lamb BW was recorded and blood serum collected on d 0, d 14, d 28, d 56, and d 84. Lamb BW on d 84 was adjusted by adding final grease fleece weight to shorn BW. Average daily gain and DMI were calculated between days that BW was recorded. Average-daily, degradable-protein intake (DPI) was calculated for each lamb as [((dietary CP × (degradable CP/100))/100) × average DMI]. Clinical signs related to coccidiosis, acidosis, and bloat were recorded daily. Lambs were shorn 5 d before study initiation and on d 82. Lambs were also evaluated for carcass characteristics and fatty acid profiles, the results of which will be presented in a companion paper.

Sample Collection and Measurements

Feeds

The DDG samples were randomly collected prior to feed pelletizing, and CSM samples were collected from a different source than that used in these diets. Samples of diets were randomly collected on d 0, d 19, d 41, and d 69, dried at 55°C in a forced-air oven for 48 h, ground in a Wiley Mill (Arthur H. Thomas Co., Philadelphia, Penn.) to pass a 1-mm screen, and stored at -20°C. Samples of each diet were combined for d 0 and 19 and for d 41 and 69, thus chemical analyses were evaluated for two pooled sets of samples, averaged, and presented in Table 1. Nitrogen was analyzed by a standard method (AOAC, 2006) and CP calculated as 6.25 × N. Sodium borate-Na phosphate buffer and enzymatic digestion procedures were used to analyze soluble and degradable feed protein, respectively (Roe et al., 1990). Crude fat was measured by ether extraction (AOAC, 2006). The NDF and ADF were analyzed using Van Soest et al. (1991) procedures modified for an Ankom 2000 Fiber Analyzer (Ankom Technol. Corp., Fairport, N.Y.) without correcting for residual ash and using -amylase and Na sulfite. Sulfur was evaluated by a Leco (model SC-432, St. Joseph, Mich.) analyzer and all other minerals were analyzed by a Thermo Jarrell Ash IRIS Advantage HX Inductively Coupled Plasma Radial Spectrometer (Thermo Instrument Systems, Inc., Waltham, Mass.). Distillers dried grains and diets were also evaluated for individual fatty acids, and these data will be presented in a companion paper.

Serum Collection and Laboratory Analysis.

A 15-mL blood sample was collected from each lamb 4 h after feeding via jugular venipuncture using a non-heparinized vacutainer collection tube (serum separator tube, gel and clot activator; Becton Dickenson, Franklin Lakes, N.J.). Blood samples were allowed to clot and then centrifuged (Beckman Coulter TJ6 refrigerated centrifuge, Fullerton, Calif.) at 970 × g for 25 min at 4°C. Serum was decanted and frozen at -20°C until analyzed for serum urea N (SUN), NEFA, and IGF-1 concentrations. Serum urea N concentrations were

Table 1. Ingredient, chemical composition (% DM basis), and cost of distillers dried grains (DDG), cottonseed meal (CSM) and diets[1]

			Diet (% of CSM replaced by DDG)			
Item	DDG[2]	CSM[2]	0DDG	33DDG	66DDG	100DDG
Cottonseed hulls			25.00	25.00	25.00	25.00
DDG			0.00	6.60	13.20	20.00
CSM			20.00	13.40	6.80	0.00
Milo, crushed			47.40	46.95	46.51	46.04
Molasses			3.00	3.00	3.00	3.00
Limestone			2.00	1.85	1.69	1.54
Ammonium Cl			0.75	0.75	0.75	0.75
Salt			0.85	0.85	0.85	0.85
Urea			0.00	0.60	1.20	1.82
Mineral premix			1.00	1.00	1.00	1.00
CP, %	22.50	50.80	18.75	17.94	18.65	18.98
Soluble protein, %	35.0	21.0	29.5	30.5	44.5	47.0
Degradable protein, %	49.0	49.0	57.5	45.5	60.5	68.0
Crude fat, %	4.4	5.3	4.6	4.95	4.55	5.2
NDF, %	41.80	17.00	25.35	26.55	25.15	27.10
ADF, %	14.50	14.00	14.85	17.45	14.30	15.02
TDN, %	71.0	76.0	85.0	85.0	85.5	85.0
Ca, %	0.10	0.34	0.83	1.02	0.86	1.00
P, %	0.80	1.66	0.44	0.48	0.41	0.44
Ca:P	0.13	0.21	1.89	2.13	2.10	2.27
Mg, %	0.30	0.86	0.25	0.26	0.22	0.22
K, %	1.13	1.76	0.89	0.91	0.84	0.88
Na, %	0.48	0.27	0.51	0.44	0.52	0.52
S, %	0.40	0.58	0.28	0.29	0.28	0.30
Fe, ppm	171.0	145.0	423.5	503.5	325.0	284.0
Zn, ppm	90.0	72.0	59.5	59.0	57.5	59.5
Cu, ppm	5.0	15.0	4.0	5.0	3.5	4.0
Mn, ppm	53.0	22.0	48.0	55.5	50.0	54.5
Mo, ppm	1.0	2.4	0.60	0.85	0.70	0.80
Cost•metric ton^{-1} feed	$180.78	$254.63	$221.46	$219.07	$216.68	$214.22
Cost of feed•kg^{-1} gain			$1.14	$1.23	$1.21	$1.13

[1] Mineral premix ingredients: sodium chloride, potassium chloride, sulfur, manganous oxide, zinc oxide, vitamins A, D, and E, calcium carbonate, cottonseed meal, cane molasses, animal fat, and 22g of Monensin (Rumensin 80)•metric ton^{-1} of feed. Soluble and degradable protein fractions = % of CP. Cost•metric ton^{-1} feed estimated using information from local markets and current Feedstuffs magazines: cottonseed hulls ($116), DDG ($181), CSM ($255), milo ($240), molasses ($265), limestone ($198), ammonium Cl ($1086), salt ($243), urea ($695), mineral premix ($591). Cost of feed•kg^{-1} gain = ([Cost/metric ton of feed/1000] x [feed/gain]).

[2] The random sample of DDG that was used in the diets was collected when feed was pelleted; the random CSM samples were from a different source than that used in the diets.

analyzed using a commercial kit (Teco Diagnostics, Anaheim, Calif.) with intra- and inter-assay CV less than 3.1 percent. Serum NEFA concentrations were also analyzed using a commercial kit (NEFA C; Wako Chemicals, Neuss, Germany) with intra- and inter-assay CV less than 7.6 percent. Serum IGF-1 concentrations were determined by RIA using procedures of Berrie et al. (1995). Intra- and inter-assay CV for IGF-1 were 9.4 percent and 19.2 percent, respectively, with a 95 percent recovery rate.

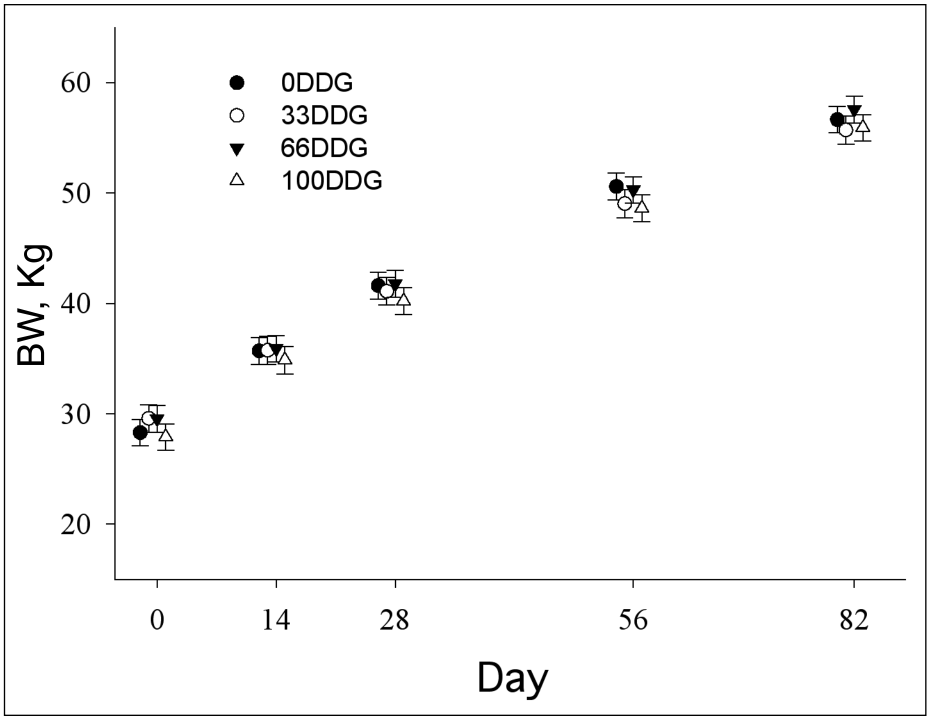
Wool

Fleece and fiber measurements were made at the Texas AgriLife Research Center in the Wool and Mohair Research Laboratory, San Angelo. After grease-fleece weights were obtained for each individual fleece, staples (n = 10) were removed from random positions in each fleece for staple strength (Agritest, 1988) and length measurements (ASTM, 2007b). The remainder of the fleece was then pressure-cored (32 × 13 mm cores, Johnson and Larsen, 1978) to obtain a 50-g random sample. Two 25-g sub-samples were used to determine scoured yield (ASTM, 2007a). One of the washed and dried duplicates was mini-cored (ASTM, 2008) to obtain a few milligrams of 2-mm snippets that represented the whole fleece. These snippets were washed in a Buchner funnel with 1,1,1-trichloroethane (10 ml) and acetone (10 ml), dried at 105°C for 1 h and cooled and conditioned for 12 h in a standard atmosphere of 21 ± 1°C and 65 ± 2 percent rh (ASTM, 2007c). Conditioned snippets were then spread onto microscope slides (7 cm × 7 cm) and measured for fiber diameter distribution (mean, SD, and CV), comfort factor (percent fibers < or = 30 μm), and average-fiber curvature, SD, and CV, using an OFDA 100 (BSC Electronics, Ardross, Western Australia; Baxter et al., 1992; ASTM, 2008).

Statistical Analyses

Data were analyzed using PROC MIXED (SAS Inst. Inc., Cary, N.C.). Lamb BW, ADG, daily DMI, G:F, and SUN, NEFA, and IGF-1 were initially analyzed using a model that included diet, day, and diet × day interaction, with day as the repeated measure and lamb within diet as the subject. Only SUN had a diet × day interaction ($P < 0.001$), thus the SUN model was analyzed by day. Wool characteristics were analyzed using a model that included diet with lamb as the experimental unit. Average-fiber diameter evaluated on a mid-side sample at the start of the study was initially used as a covariate for average-fiber diameter of the fleece, and initial BW was used as a covariate for clean- fleece weight, but covariates were removed because they were not significant. Wool production per unit of BW ($g \bullet kg^{-1}$) was calculated as clean-wool production divided by final shorn BW. Non-normal data were transformed using natural-log or arcsin square-root functions. Covariance structures (compound symmetry, heterogeneous-compound symmetry, and heterogeneous-autoregressive order-1) were used to determine the most appropriate structure for each model. Data are reported as least squares means with greatest standard errors, except for BW where all standard errors are reported in Figure 1. Treatment effects were tested using the following single degree of freedom non-orthogonal contrasts: 1) linear and 2) quadratic effects of replacing CSM with DDG, and 3) 0DDG vs. 100DDG. PROC IML was used to generate coefficients for the linear and quadratic contrasts with unequal spacing (DDG replacing 0 percent, 33 percent, 66 percent, 100 percent of the CSM). Only the highest order contrast that was significant ($P < 0.10$) was discussed.

Figure 1. Effect on lamb BW of replacing dietary cottonseed meal with distillers dried grains. Distillers dried grains replaced 0% (0DDG), 33% (33DDG), 66% (66DDG), or 100% (100DDG) of the cottonseed meal. A diet x d interaction (*P* > 0.43) was not observed and BW were similar (*P* > 0.50) among diets throughout the study.



Results and Discussion

Lamb growth

No diet × d interactions ($P > 0.12$) were observed for lamb BW (Fig. 1), ADG, daily DMI, DPI or G:F (Table 2). By design, initial lamb BW was similar ($P > 0.30$) among treatments and relative weights remained similar ($P > 0.50$) throughout the study, even though ADG and G:F decreased quadratically ($P = 0.08$). All lambs had similar average-daily DMI ($P > 0.70$). Huls et al. (2006) discussed possible palatability issues related to ammonium chloride fed at 0.5 percent of diet DM, but diets in the current study containing 0.75 percent ammonium chloride did not reduce intake. The unexpected quadratic trends for ADG and G:F are attributed to the lesser ADG of lambs fed 33DDG diet and the lesser G:F of lambs fed 33DDG and 66DDG diets, respectively. These results suggest that negative associative effects occurred, which reduced growth (33DDG diet) and efficiency (33DDG and 66DDG diets) of lambs fed diets containing both CSM and DDG.

Growth rates in the current study did not increase as percentage of DDG increased in the diets. Schauer et al. (2008) reported no linear or quadratic trends in ADG or G:F in wether lambs fed diets (> 20 percent CP) with DDGS replacing portions of barley and soybean meal, but did report a linear increase in DMI and greater ADG for lambs fed the highest level of DDGS (60 percent) than those fed the lowest level (0 percent). Differences in ADG and G:F observed in the experiment of Schauer et al. (2006) was attributed to low CP (11.7 percent) in the control diet (no DDGS), which increased to 18.4 percent CP in the diet with the greatest DDGS concentration. In the current study, lambs fed the diet in which all of the CSM was replaced by DDG (100DDG) had similar ($P > 0.23$) ADG, average DMI, and G:F compared to lambs fed the 0DDG diet.

Huls et al. (2006) replaced all the soybean meal and a portion of the corn with DDGS (22.9 percent of DM) in pelleted wether lamb diets that included

10 percent soy hulls. There were no differences in lamb final BW, average daily DMI, ADG, or G:F among diets. Even though no signs of acidosis were observed, they discuss the possibility that the greater fermentability of soy hulls could have contributed to subclinical acidosis. The 100DDG diet fed in the current study was 75 percent concentrate and used 25 percent CSH as the sole roughage source. Cottonseed hulls contain greater NDF and ADF than soy hulls (Hsu et al., 1987; NRC, 2007), and 48-hr true *in vitro* DM digestibility of CSH has been reported to be 20.8 percent (Whitney and Muir, 2010). Apparent *in situ* digestibilities before the duodenum of CSH and soy hulls have been reported to be 16.4 percent and 40.2 percent, respectively (Hsu et al., 1987). The nutrient composition of CSH suggests a low feeding value (Torrent et al., 1994; NRC, 2007; Whitney and Muir, 2010). However, feeding a less rumen-fermentable roughage source than soy hulls (i.e. CSH) in high-energy rations containing DDG may be beneficial due to positive associative effects. For example, Hsu et al. (1987) reported greater ruminal pH and less total VFA for sheep fed a CSH diet compared to a soy hull diet. These results can be attributed to CSH fiber characteristics, which can increase rumen buffer capacity (Van Soest, 1994).

Chemical compositions of diets (Table 1) were not statistically analyzed, but are similar except for a few nutritional differences. For example, percentage of dietary urea was increased in the diets as DDG increasingly replaced CSM to make diets isonitrogenous, which resulted in greater soluble and degradable protein (Table 1), except for 33DDG diet having the least degradable protein. This resulted in a quadratic increase ($P < 0.001$) of DPI and greater DPI ($P < 0.001$) for lambs fed 100DDG diet compared to lambs fed 0DDG diet (Table 2), because average DMI was similar among all lambs. All lambs consumed at least twice as much degradable protein as required for lambs gaining between 0.34 kg•d^{-1} to 0.38 kg•d^{-1} (NRC, 2007). Therefore, additional dietary urea in diets containing DDG could have probably been excluded without reducing growth, which would have further reduced the cost of diets containing DDG; especially the 100DDG diet, which contained the most dietary urea and was the least expensive diet with the lowest cost•kg^{-1} gain (Table 1). In contrast, some dietary urea may be needed when roughages, such as CSH, are used in diets containing DDG, because urea can enhance cellulose digestion (Burroughs et al., 1951; Belasco, 1954).

Consuming an excessive amount of DPI can negatively affect rumen and tissue metabolism and increase energy expenditure related to excretion (McBride and Kelly 1990; Reynolds, 2002). Even though lambs fed 100DDG diet consumed the greatest ($P < 0.001$) amount of degradable protein, their growth rate was similar ($P > 0.23$) to lambs fed 0DDG diet. One explanation may be related to the condensed tannin (CT) concentration of CSH. Previous reports indicate that CSH contained 5.63 percent CT (percent of DM, no cotton fiber included in analysis; data not shown; Whitney and Muir, 2010), which can bind nutrients (Yu et al., 1993; Yu et al., 1996) and reduce solubility and degradability of protein (Yu et al., 1995a,b) and ruminal NH3-N concentrations (Waghorn et al., 1987). Research evaluating the use of feeds containing CT, in diets containing high concentrations of DDG (thus, high CP concentrations) and interactions and associative effects of CT, degradable CP, fermentable carbohydrates, and source and concentration of roughage is warranted.

Dietary crude fat was greater in 100DDG diet than 0DDG diet (Table 1), but lambs fed 100DDG diet had ADG and G:F similar ($P > 0.23$) to lambs fed 0DDG diet. Therefore, dietary crude fat concentrations up to 5.2 percent of diet DM did not reduce growth or efficiency of gain. Schauer et al. (2008) reported that wether lambs consuming diets containing 60 percent

Table 2. Effects of replacing cottonseed meal (CSM) with distillers dried grains (DDG) on lamb growth and serum urea N (SUN), NEFA, and IGF^{-1} concentrations

	Diet (% of CSM replaced by DDG)					*P*-value		
Item	0DDG	33DDG	66DDG	100DDG	SEM	Linear	Quadratic	0DDG vs. 100DDG
ADG, kg	0.38	0.34	0.36	0.36	0.01	0.46	0.08	0.23
DMI, kg	1.978	1.924	2.057	1.966	0.063	0.70	0.73	0.90
DP intake, kg	0.213	0.157	0.233	0.254	0.006	<0.001	<0.001	<0.001
G:F, kg•kg^{-1}	0.195	0.178	0.179	0.190	0.007	0.80	0.08	0.75
SUN, mg•dL^{-1}								
d 0	9.6	12.3	14.1	17.4	1.2	<0.001	0.85	<0.001
d 14	16.4	18.1	20.2	18.5	1.5	0.22	0.25	0.33
d 28	18.3	17.4	20.5	19.7	1.0	0.11	0.99	0.33
d 56	18.6	15.1	21.0	23.7	0.9	<0.001	0.002	<0.001
d 84	18.2	17.3	18.7	22.4	1.0	0.003	0.03	0.004
NEFA, mEq•L^{-1}	97.3	97.2	86.9	84.3	6.4	0.08	0.96	0.15
IGF^{-1}, ng•mL^{-1}	217.0	183.8	191.9	199.4	11.0	0.45	0.05	0.33

DP intake = degradable protein intake; calculated as [((dietary CP x (degradable CP/100))/100) x lamb DMI].

DDGS and 8.3 percent crude fat actually had greater daily DMI compared to diets containing 2.5 percent to 6.7 percent crude fat. These results are in contrast to others, which have indicated reduced feed consumption and ADG of lambs fed diets with 5 percent or more added fat (Hale et al., 1954; Jordan et al., 1958). Growth performance inconsistencies across studies could be associated with large variations that exist in DDG nutritive value (Spiehs et al., 2002), yet environmental and physiological differences would likely have greater significance on performance outcomes.

Serum Urea N, NEFA, and IGF-1

A diet × day interaction was observed for SUN concentration ($P < 0.001$; Table 2). Serum urea N increased on d 0 (linear, $P < 0.001$) and d 56 and d 84 (quadratic, $P < 0.04$). Lambs fed 100DDG diet had greater ($P < 0.005$) SUN than lambs fed 0DDG diet on d 0, d 56, and d 84. Differences in SUN can be attributed to DPI. For example, lambs fed 33DDG diet consumed the least amount of degradable protein, which was the primary reason for quadratic trends observed for SUN on d 56 and d 84. As percentage of DDG increased in diets, dietary urea was also increased to make the diets isonitrogenous. Dietary urea is rapidly hydrolyzed in the rumen and can rapidly increase rumen NH3-N, which is then absorbed by the liver and detoxified mainly to urea (Carter et al., 1989; Awawdeh et al., 2005). In addition, SUN was correlated (0.51, $P < 0.001$) to average-daily, degradable-protein intake.

Bunting et al. (1992) reported that dietary fat increased rumen NH3-N concentrations in lambs, but reduced circulating urea N concentrations, which was attributed to greater N accretion rates. Dietary fat did not seem to affect SUN in the current study because 100DDG diet had a greater concentration of crude fat, but lambs consuming this diet had greater SUN than 0DDG at times. The contrast between the current study and Bunting et al. (1992) supports the fact that DPI was the primary factor affecting SUN.

Greater SUN can be beneficial to ruminants by recycling urea to the rumen, but can also increase urinary N excretion (Cocimano and Leng, 1967; Kohn et al., 2005), which is an inefficient use of nutrients. The transfer of circulating urea N into the rumen reaches a plateau when it reaches 16 mg to 18 mg N $100•mL^{-1}$ serum (Weston and Hogan, 1967; Vercoe, 1969). Harmeyer and Martens (1980) discussed upper limits of 16.8 mg N•100 mL^{-1} serum where urea transfer into the rumen stops being linearly related to circulating urea N. Therefore, urinary N excretion of lambs in the current study was likely greater where urea was added to diets containing DDG.

A diet × day interaction was not observed for serum NEFA concentrations ($P > 0.16$), but NEFA slightly decreased (linear, $P = 0.08$), as percentage of DDG increased in the diet. Lambs fed 100DDG diet had similar ($P = 0.15$) serum NEFA concentrations compared to lambs fed 0DDG diet. Minimal NEFA concentrations indicate that very little fat mobilization was occurring (Chilliard et al., 2000) and that effects were mainly related to dietary nutrient intake. Greater degradable protein consumption did not result in greater NEFA concentrations, which contradicted results of Fernandez et al. (2001).

A diet × day interaction was not observed for serum IGF-1 concentrations ($P > 0.30$), but serum IGF-1 decreased (quadratic, $P = 0.05$), as percentage of DDG increased in the diet. Lambs fed 100DDG diet had similar ($P = 0.33$) serum IGF-1 concentrations compared to lambs fed 0DDG diet. Serum IGF-1 was not correlated ($P > 0.72$) with growth, even though similar quadratic trends were observed for ADG and IGF-1 concentration. Others described serum IGF-1 as an indicator of growth rate (Breier, 1999), and it is positively correlated to ADG and G:F (Bishop et al., 1989; Stick et al., 1998; Hersom et al., 2004).

Wool Production and Characteristics

Genotype dictates the capacity of a sheep to produce wool. However, the expression of genetic potential for wool growth and its physical characteristics can be modified by plane of nutrition. In fact, rate of fiber growth in an adult Merino sheep has been shown to vary by as much as four-fold due to changes in nutrient supply (Reis, 1982). Wool growth can be influenced markedly by amount and specific type of protein in

Table 3. Effects of replacing cottonseed meal with distillers dried grains on lamb wool characteristics

	Diet (% of CSM replaced by DDG)					*P*-value[2]		
Item/d[3]	0DDG	33DDG	66DDG	100DDG	SEM	Linear	Quadratic	0DDG vs. 100DDG
Grease fleece weight, kg	1.40	1.28	1.23	1.27	0.06	0.10	0.15	0.12
Clean wool fiber, %	38.36	39.66	42.39	40.36	1.71	0.24	0.31	0.39
Clean fleece weight, kg	0.53	0.50	0.52	0.51	0.03	0.59	0.76	0.48
Clean wool production•unit BW^{-1}, $g•kg^{-1}$	9.74	9.26	9.23	9.29	0.51	0.53	0.58	0.51
Avg fiber diameter, µm	19.92	19.52	19.81	19.61	0.41	0.72	0.80	0.58
SD fiber diameter, µm	4.24	4.54	4.60	4.37	0.21	0.64	0.27	0.69
Avg staple length, mm	31.24	31.93	29.03	30.90	1.20	0.45	0.60	0.83
SD staple length, mm	3.12	3.12	3.23	3.35	0.30	0.21	0.51	0.19
Avg fiber curvature, $deg•mm^{-1}$	108.33	104.41	108.96	106.13	2.97	0.87	0.86	0.59
SD fiber curvature, $deg•mm^{-1}$	64.27	65.40	66.46	63.73	1.37	0.91	0.15	0.77

the diet, and to a lesser degree, by amount of accompanying energy. Other components in the diet, including tannins (Min et al., 1998), organic and inorganic S (Qi and Lupton, 1994), vitamins and trace elements (especially Cu and Zn; Reis, 1989) have also been shown to affect wool growth. In the current study, the range in CP among the four diets was small (17.94 percent to 18.98 percent) but the ranges in soluble (29.5 percent to 47.0 percent of CP) and degradable (45.5 percent to 68.0 percent of CP) protein were relatively large (Table 1). Condensed tannins from the CSH component of the diet were constant across diets. Dietary S ranged from 0.28 percent to 0.30 percent, and the concentrations of Cu and Zn were very similar. The measured differences in the types and amounts of protein supplied in the four diets did not produce any differences in clean-wool production or any of the measured-fiber characteristics. The important conclusion is that substituting CSM with DDG did not alter wool production or quality characteristics in these growing lambs.

Conclusions

Results indicated that DDG can replace all of the CSM in lamb-growing diets without negatively affecting ADG, efficiency of gain, or wool characteristics and has the potential to lower cost of feed•kg^{-1} gain. In contrast, lamb ADG and G:F were reduced when DDG replaced a portion of the dietary CSM, which needs to be further investigated. Lamb feeders can potentially reduce feed costs without sacrificing growth, feed efficiency, or wool characteristics, because at the time of this study, DDG was \$74•ton^{-1} less than CSM when averaged across various U.S. markets. At times, SUN was greater in diets containing higher percentages of DDG, which was attributed to an increase in soluble and degradable protein fractions and intakes. Further research is warranted to determine if dietary urea is required in lamb diets when DDG replaces all of the CSM. If dietary urea is not required or can be reduced, feed costs and the cost of feed•kg^{-1} gain would be reduced and SUN would decline, which would reduce N intake and excretion. Since nutrient concentrations of DDG from different sources can be highly variable, DDG composition should be reported independent of the overall ration composition.

Literature Cited

Agritest Pty. Ltd. 1988. Manual for the Agritest Staple Breaker System. 14 pp.

AOAC. 2006. Official Methods of Analysis. 18th ed. Assoc. Offic. Anal. Chem., Arlington, VA.

ASTM. 2007a. Designation: D584. Standard test method for wool content of raw wool – laboratory scale. Ann. Book of Amer. Soc. Testing and Materials Standards. Sec. 7. Vol. 07.01:160-165. ASTM Intern., West Conshohocken, PA.

ASTM. 2007b. Designation: D1234. Standard test method of sampling and testing staple length of grease wool. Ann. Book of Amer. Soc. Testing and Materials Standards. Sec. 7. Vol. 07.01:256-259. ASTM Intern., West Conshohocken, PA.

ASTM. 2007c. Designation: D1776. Standard practice for conditioning and testing textiles. Sec. 7. Vol. 07.01:413-416. ASTM Intern., West Conshohocken, PA.

ASTM. 2008. Designation: D6500. Standard test method for diameter of wool and other animal fibers using an Optical Fiber Diameter Analyzer. Ann. Book of Amer. Soc. Testing and Materials Standards. Sec. 7. Vol. 07.02:702-713. ASTM Intern., West Conshohocken, PA.

Awawdeh, M. S., E. C. Titgemeyer, K. C. McCuistion, and D. P. Gnad. 2005. Ruminal ammonia load affects leucine utilization by growing steers. J. Anim. Sci. 83:2448-2454.

Baxter, B. P., M. A. Brims, and T. B. Taylor. 1992. Description and performance of the Optical Fiber Diameter Analyzer (OFDA). J. Text. Inst. 83:507-526.

Belasco, I. J. 1954. Comparison of urea and protein meals as nitrogen sources for rumen micro-organisms: urea utilization and cellulose digestion. J. Anim. Sci. 13:739-747.

Berrie, R. A., D. M. Hallford, and M. L. Galyean. 1995. Effects of zinc source and level on performance and metabolic hormone concentrations of growing and finishing lambs. Prof. Anim. Sci. 11:149-156.

Bishop, M. D., R. C. M. Simmen, F. A. Simmen, and M. E. Davis. 1989. The relationship of insulin-like growth factor-I with postweaning performance in Angus beef cattle. J. Anim. Sci. 67:2872-2880.

Breier, B. H. 1999. Regulation of protein and energy metabolism by the somatotropic axis. Domest. Anim. Endocrinol. 17:209-219.

Bunting, L. D., L. S. Sticker, and P. J. Wozniak. 1992. Effect of ruminal escape protein and fat on nitrogen utilization in lambs exposed to elevated ambient temperatures. J. Anim. Sci. 70:1518-1525.

Burroughs, W., N. C. Arias, P. de Paul, P. Gerlaugh, and R. M. Bethke. 1951. In vitro observations upon the nature of protein influences upon urea utilization by rumen microorganisms. J. Anim. Sci. 10:672-682.

Carter, M. L., S. N. McCutcheon, and R. W. Purchas. 1989. Plasma metabolite and hormone concentrations as predictors of genetic merit for lean meat production in sheep: effect of metabolic challenges and fasting. New Zeal. J. Agric. Res. 32:343-353.

Chilliard, Y., A. Ferlay, Y. Faulconnier, M. Bonnet, J. Rouel, and F. Bocquier. 2000. Adipose tissue metabolism and its role in adaptations to undernutrition in ruminants. Proc. Nutr. Soc. 59:127-134.

Cocimano, M. R., and R. A. Leng. 1967. Metabolism of urea in sheep. Brit. J. Nutr. 21:353-371.

Depenbusch, B. E., E. R. Loe, J. J. Sindt, A. Cole, J. J. Higgins, and J. S. Drouillard. 2009. Optimizing use of distillers grains in finishing diets containing steam-flaked corn. J. Anim. Sci. 87:2644-2652.

FAPRI. 2009. Food and Agricultural Policy Research Institute. World agricultural outlook. Staff Report 09-FSR 1. Iowa State Univ. and Univ. of Missouri-Columbia, Ames, IA. http://www.fapri.iastate.edu

Fernandez, J. M., T. Sahlu, S. P. Hart, M. J. Potchoiba, H. M. El Shaer, N. Jacquemet, and H. Carneiro. 2001. Experimentally-induced subclinical hyperammonemia in dairy goats. Small Rumin. Res. 42:5-20.

Firkins, J. L., L. Berger, and G. C. Fahey, Jr. 1985. Evaluation of wet and dry distillers grains and wet and dry corn gluten feeds for ruminants. J. Anim. Sci. 60:847-860.

Ham, G. A., R. A. Stock, T. J. Klopfenstein, E. M. Larson, D. H. Shain, and R. P. Huffman. 1994. Wet distillers byproducts compared with dried corn distillers grains with solubles as a source of protein and energy for ruminants. J. Anim. Sci. 72:3246-3257.

Hale, W. H., C. C. Culbertson, and W. E. Hammond. 1954. Ground corn cobs, packing animal feeding fat and diethylstilbestrol in the rations of fattening lambs. A. H. Iowa State College, Ames.

Harmeyer, J., and H. Martens. 1980. Aspects of urea metabolism in ruminants with reference to the goat. J. Dairy Sci. 63:1707-1728.

Hersom, M. J., R. P. Wettemann, C. R. Krehbiel, G. W. Horn, and D. H. Keisler. 2004. Effect of live weight gain of steers during winter grazing: III. Blood metabolites and hormones during feedlot finishing. J. Anim. Sci. 82:2059-2068.

Hsu, J. T., D. B. Faulkner, K. A. Garleb, R. A. Barclay, G. C. Fahey, Jr., L. L. Berger. 1987. Evaluation of corn fiber, cottonseed hulls, oat hulls, and soybean hulls as roughage sources for ruminants. J. Anim. Sci. 65:244-255.

Huls, T. J., A. J. Bartosh, J. A. Daniel, R. D. Zelinsky, J. Held, and A. E. Wertz-Lutz. 2006. Efficacy of dried distiller's grains with solubles as a replacement for soybean meal and a portion of the corn in a finishing lamb diet. Sheep and Goat Res. J. 21:30-34.

Johnson, C. L., and S. A. Larsen. 1978. Clean wool determination of individual fleeces. J. Anim. Sci. 47:41-45.

Jordan, R. M., H. G. Croom, and H. Hanke. 1958. High-oil bearing seeds and tallow-soybean oil meal in lamb fattening rations. J. Anim. Sci. 17:819-824.

Kohn, R. A., M. M. Dinneen, and E. Russek-Cohen. 2005. Using blood urea nitrogen to predict nitrogen retention, excretion, and efficiency of nitrogen utilization in cattle, sheep, goats, horses, pigs, and rats. J. Anim. Sci. 83:879-889.

McBride, B. W., and J. M. Kelly. 1990. Energy Cost of absorption and metabolism in the ruminant gastrointestinal tract and liver: a review. J. Anim. Sci. 68:2997-2010.

Min, B. R., T. N. Barry, W. C. McNabb, and P. D. Kemp. 1998. Effect of condensed tannins on the production of wool and on its processing characteristics in sheep grazing Lotus corniculatus. Aust. J. Agric. Res. 49:597-605.

NASS. 2007. National Agricultural Statistics Service, Washington, DC. http://www.nass.usda.gov/tx

Neeley, T. 2009. Distiller's grain marketing vital to U.S. ethanol. The Progressive Farmer. http://www.dtn progressivefarmer.com/dtnag

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

Qi, K., and C. J. Lupton. 1994. A review of the effects of sulfur nutrition on wool production and quality. Sheep and Goat Res. J. 2:133-140.

Reis, P. J. 1982. Pages 205-223 in Sheep and Goat Production: World Animal Science, C1. I. E. Coop, ed. Elsevier Scientific Publishing Company, Amsterdam, Holland.

Reis, P. J. 1989. Pages 200-201 in The Biology of Wool and Hair. G. E. Rogers, P. J. Reis, K. A. Ward, and R. C. Marshall, ed. Chapman and Hall, New York, NY.

Reis, P. J., and T. Sahlu. 1994. The nutritional control of growth and properties of mohair and wool fibers: A comparative review. J. Anim. Sci. 72:1899-1907.

Reynolds, C. K. 2002. Economics of visceral energy metabolism in ruminants: toll keeping or internal revenue service? J. Anim. Sci. 80 (E. Supp. 2):E74-E84.

Roe, M. B., C. J. Sniffen, and L. E. Chase. 1990. Techniques for measuring protein fractions in feedstuffs. Pages 81-88 in Proc. Cornell Nutr. Conf., Ithaca, NY.

Schauer, C. S., L. P. Anderson, D. M. Stecher, D. Pearson, and D. Drolc. 2005. Influence of dried distillers grains on feedlot performance and carcass characteristics of finishing lambs. Western Dakota Sheep and Beef Day. 46:31-33.

Schauer, C. S., P. B. Berg, M. Stamm, D. M. Stecher, D. Pearson, and D. Drolc. 2006. Influence of dried distillers grains on feedlot performance and carcass characteristics of finishing lambs. Western Dakota Sheep and Beef Day. 47:34-37.

Schauer, C. S., M. M. Stamm, T. D. Maddock, and P. B. Berg. 2008. Feeding of DDGS in lamb rations: Feeding dried distillers grains with solubles as 60 percent of lamb finishing rations results in acceptable performance and carcass quality. Sheep and Goat Res. J. 23:15-19.

Spiehs, M. J., M. H. Whitney, and G. C. Shurson. 2002. Nutrient database for distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J. Anim. Sci. 80:2639-2645.

Stick, D. A., M. E. Davis, S. C. Loerch, and R. C. M. Simmen. 1998. Relationship between blood serum insulin-like growth factor-I concentration and postweaning feed efficiency of crossbred cattle at three levels of dietary Intake. J. Anim. Sci. 76:498-505.

Throckmorton, J. C., D. F. Foulkes, R. A. Leng, and J. V. Evans. 1982. Response to bypass protein and starch in Merino sheep and Angora goats. Proc. Aust. Soc. Anim. Prod. 14:661.

Torrent, J., D. E. Johnson, and M. A. Kujawa. 1994. Co-product fiber digestibility: Kinetic and in vivo assessment. J. Anim. Sci. 72:790-795.

Van Soest, P. J. 1994. Nutritional Ecology of the Ruminant. Cornell Univ. Press, Ithaca, NY.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy. Sci. 74:3583-3597.

Vercoe, J. E. 1969. The transfer of nitrogen from the blood to the rumen of cattle. Aust. J. Agric. Res. 20:191-197.

Waghorn, G. C., M. J. Ulyatt, A. John, and M. T. Fisher. 1987. The effect of condensed tannins on the site of digestion of amino acids and other nutrients in sheep fed on *Lotus corniculatus* L. Brit. J. Nutr. 57:115-126.

Weston, R. H., and J. P. Hogan. 1967. The transfer of nitrogen from the blood to the rumen in sheep. Aust. J. Biol. Sci. 20: 967-973.

Whitney, T. R., and J. P. Muir. 2010. Redberry juniper as a roughage source in lamb feedlot rations: performance and serum NEFA, urea N, and IGF-1 concentrations. J. Anim. Sci. In press.

Yu, F., T. N. Barry, W. C. McNabb, P. J. Moughan, and G. F. Wilson. 1995a. Effect of bound condensed tannin from cottonseed upon *in situ* protein solubility and dry matter degradation in the rumen. J. Sci. Food Agric. 69:311-319.

Yu, F., T. N. Barry, P. J. Moughan, and G. F. Wilson. 1993. Condensed tannin and gossypol concentrations in cottonseed and in processed cottonseed meal. J. Sci. Food Agric. 63:7-15.

Yu, F., W. C. McNabb, T. N. Barry, and P. J. Moughan. 1996. Effect of heat treatment upon the chemical composition of cottonseed meal and upon the reactivity of cottonseed condensed tannins. J. Sci. Food Agric. 72:263-272.

Yu, F., W. C. McNabb, T. N. Barry, and G. C. Waghorn. 1995b. Effect of bound condensed tannin from cottonseed hulls upon the *in vitro* degradation of cottonseed kernel proteins by rumen microorganisms. J. Sci. Food Agric. 69:223-234.