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American Sheep Industry Association

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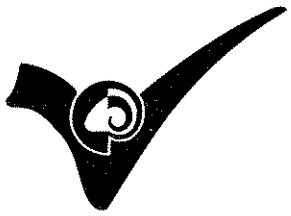

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# Gelatinized Wheat Flour as an Energy and Protein Source in Milk Replacer Diets for Growing Lambs[1]

C. Johnston[2,3] and M. Michonski[2]

## Summary

Two experiments involving ten 1/2 Polypay-1/4 Dorset-1/4 Romanov wethers and eight Polypay ram lambs (initial body weight [BW] = 6.0 ± 0.3 kg and 4.1 ± 0.2 kg, respectively) were used to determine the value of gelatinized wheat flour as an ingredient in milk replacer diets for lambs from 3 to 24 days of age and the growth rate of lambs fed only these milk replacers until 105 days of age. Digestibility and performance data were measured where lambs were fed either a milk replacer that contained 12.5% gelatinized wheat flour or a reference milk replacer. In Experiment 1, wheat starch was 99.6% digestible and the inclusion of wheat flour did not affect ($P > 0.1$) dry matter (DM), nitrogen (N), fat digestibility, N metabolism, average daily gain (ADG), dry matter intake (DMI) or feed efficiency. In Experiment 2, wheat starch was 98% digestible which resulted in slightly lower average ($P < 0.1$) DM and fat digestibilities. This reduction in utilization was caused by differences between the diets ($P < 0.05$) that occurred before 10 days of age. However, there were no differences ($P > 0.1$) between the diets in N digestibility or N retention. Lambs fed the wheat flour diet had lower ADG ($P < 0.01$), DMI and feed efficiency ($P < 0.1$) but no differences in ADG or feed efficiency ($P < 0.1$) after 14 days of age. Gelatinized wheat flour appears to be highly digestible for the neonatal lamb, making it a possible ingredient for use in lamb milk replacers.

**Key words:** lambs, milk replacer, wheat flour.

## Introduction

The increase in the use of more prolific breeds of sheep has increased the number of lambs available to be reared artificially. However, the cost of milk replacers has become a consideration in this practice, indicating that more economical milk replacers need to be developed. Provided that the cost for rearing lambs when fed only milk replacer are reasonable, there may be opportunities for producing market lambs in this manner.

Lambs are capable of using corn starch and a partially hydrolyzed mixed starch (corn and wheat) as energy sources in milk diets (Soliman et al., 1979; Nitsan et al., 1990). Improvements in utilization may occur by feeding wheat flour instead of corn because of the greater availability of its protein and starch (Herrera-Saldana et al., 1990).

The objectives of this research were to: 1) determine if gelatinized wheat flour is a suitable milk replacer ingredient for lambs; and 2) explore the effect of feeding milk replacers to lambs for an extended period of time.

## Materials and Methods

### *Animals and Feeding*

For Experiment 1, ten 10-day-old 1/2 Polypay-1/4 Dorset-1/4 Romanov wether lambs (initial BW = 6.0 ± 0.3 kg) were used to determine the digestibility and growth rate of an all-milk reference milk replacer (M1) or a milk replacer containing gelatinized wheat flour (W1). Eight lambs were randomly selected for digestibility measurements, while all were included for measuring performance.

At birth the navels of the lambs were sprayed with iodine and 1 mL of BO-SE (Vitamin E and selenium; Schering-Plough Animal Health, Kenilworth, NJ) was administered subcutaneously. At one and ten days of age they were inoculated with

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*Clostridium perfringens* Types C and D antitoxin (Bio-Ceutic, St. Joseph, MO). At 14 and 44 days of age they were immunized against enterotoxemia and tetanus using *Clostridium perfringens* Types C and D and Tetanus toxoid (Bio-Ceutic, St. Joseph, MO). Tails were docked (White's Emasculator) and the male lambs castrated at three to seven days of age.

To permit the lambs to receive colostrum they were left with their dam for 12 to 24 hours. After removal from the ewes, the lambs were individually housed in 1.2 × 1.2 m pens with raised expanded metal flooring in a temperature controlled room (18 to 20 °C). Lambs were hand-fed a commercial lamb milk replacer (Advance Lamb Milk Replacer; Milk Specialties, Inc., Dundee, IL) three times daily until four days of age. For the remainder of the experiment the lambs were individually fed ad libitum from a separate self feeder. Each feeder consisted of a covered pail with a tube connected to a mounted rubber nipple. At 10 days of age the lambs were abruptly placed on the experimental diets. Weights were taken at 10 and 14 days of age and then weekly until 105 days of age. Daily feed intakes were averaged by week. To monitor the rate of fat accretion and muscle growth, subjective body condition scores (1 = very thin, 15 = very fat) and leg scores (7 = Good$^-$, 15 = Prime$^+$) were measured at 64 and 90 days of age.

Diet composition is shown in Table 1. Diets were formulated to meet or exceed the industry standards for lamb milk replacers. The 12.5% level of wheat flour chosen for the diets was the maximum amount which could be included while maintaining the desired concentration of protein, fat and energy. The wheat diet (W1) contained only coconut oil as a fat source instead of the Marola 13/60 (13% CP, 60% fat) used in the M1 diet. This was necessary to maintain the desired fat level and keep the diets isonitrogenous and isocaloric. Citric acid and potassium sorbate were added as preservatives.

All diets were prepared in a stainless steel steam-heated double-walled mixing tank. To prepare diet, wheat flour was added to 80 °C water and mixed vigorously. The mixture was then continuously stirred slowly at 80 °C for three hours to gelatinize the wheat flour. After three hours, the temperature of the mixture was reduced to 60 °C and the remaining ingredients added to give a final DM content of the finished diet of 19.5%. The mixture was cooled to about 20 °C and stored at 5 °C in sealed 20-liter containers. Diet M1 was prepared in the same manner starting with 60 °C water.

During collection periods the lambs were housed in elevated wooden metabolism crates. Feces were collected in tared plastic bags held in place by cloth collection bags and harnesses.

Collection bags were removed at least once daily. They were weighed to the nearest gram and frozen. For urine collection, metal funnels were placed under the wire mesh floor of the crates and over screened collection containers containing 15 mL of 50% HCl. Each day, urine volume was

**Table 1. Diet compositions and analysis.[a]**

| | Treatments[b] | | | |
|---|---|---|---|---|
| | Trial 1 | | Trial 2 | |
| Item | M1 | W1 | M2 | W2 |
| Percent of dry matter: | | | | |
| Wheat flour | – | 12.50 | – | 12.50 |
| Whey protein concentrate | 52.12 | 62.00 | 51.55 | 45.15 |
| Marola 13/60[c] | 39.17 | – | 40.00 | 36.60 |
| Coconut oil | – | 19.0 | – | – |
| Lactose | 2.48 | – | 3.02 | – |
| DL-Methionine | 0.40 | 0.40 | 0.38 | 0.40 |
| L-Lysine·HCl | 0.91 | 1.06 | 0.70 | 0.91 |
| Calcium carbonate | 1.68 | 1.79 | 1.60 | 1.70 |
| Mineral + vitamin premix[d] | 0.56 | 0.56 | 0.56 | 0.56 |
| Potassium sorbate | 0.63 | 0.63 | 0.63 | 0.63 |
| Citric acid | 1.56 | 1.56 | 1.56 | 1.56 |
| Ammonium chloride | 0.50 | 0.50 | – | – |
| Total | 100.00 | 100.00 | 100.00 | 100.00 |
| Chemical analysis: | | | | |
| Crude protein, % | 26.03 | 26.50 | 23.49 | 23.88 |
| Fat, % | 26.27 | 22.00 | 26.48 | 24.04 |
| Starch, % | – | 8.83 | – | 9.5 |
| Calculated analysis: | | | | |
| Metabolizable energy, kcal/kg | 4,411 | 4,519 | 4,453 | 4,432 |
| Lactose, % | 38.2 | 32.86 | 38.74 | 31.62 |
| Lysine, % | 2.86 | 2.87 | 2.81 | 2.80 |
| Methionine, % | 0.86 | 0.85 | 0.84 | 0.84 |
| Calcium, % | 0.97 | 0.96 | 0.95 | 0.94 |
| Phosphorus, % | 0.45 | 0.45 | 0.45 | 0.41 |

[a] Pre-experiment commercial milk replacer had a guaranteed analysis of: Crude protein > 23%; Crude fat > 30%; Crude fiber < 0.2%; Vitamin A > 44,000 IU/kg; Vitamin D3 > 11,000 IU/kg; Vitamin E > 110 IU/kg.

[b] M1 = experiment 1 reference diet; W1 = experiment 1 wheat flour diet; M2 = experiment 2 reference diet; W2 = experiment 2 wheat flour diet.

[c] Commercially available dry fat product containing: 13.25% protein (from whey protein concentrate) and 60% fat (32.5% lard, 32.5% tallow, 25% coconut oil, 8% emulsifier, 2% lecithin).

[d] Commercial premix containing: 0.32% calcium; 1.25% magnesium; 1,777.8 ppm iron; 204.4 ppm cobalt; 0.44 ppm copper; 6,888.9 ppm manganese; 17,780 ppm zinc; 53.33 ppm selenium; 800 ppm iodine; 0.04% B-complex vitamin; 5,866.7 kIU/kg Vitamin A; 1,173.3 kIU/kg Vitamin D3; 3,911.2 IU/kg Vitamin E.

measured and adjusted to a constant volume with distilled water. Five percent of the urine volume was stored at 20 °C until the daily samples could be composited by animal and period. Feed samples (100 mL) from each diet were retained daily and frozen.

The four collection periods began when the lambs reached 22, 47, 72 and 97 days of age. At the beginning of period 1, each lamb was fed 454 grams of their respective diets containing 1% ferric oxide as a fecal color marker. After the initial feeding, lambs were fed by the self-feeders, but intake was restricted for the remainder of the period based on individual consumption from the previous week. Fecal collection began once the marker appeared in the feces. Urine collection began 24 hours after the initial feeding. Feces and urine were collected until 24 hours after the fourth day of feeding.

For the remaining three collection periods no marker was added to the feed and the lambs were allowed ad libitum access to their diets. Unconsumed feed was not an important concern because of the uniformity of the diets. Urine and feces were collected for seven-day periods beginning 24 hours after the first feeding and ending 24 hours after the last day's feeding. At the end of each collection period, the lambs were returned to their original pens.

After completing the first experiment, the objective of the second experiment was to determine the acceptability of gelatinized wheat flour as an ingredient in milk replacer for 3- to 22-day-old lambs. Eight intact Polypay ram lambs (initial BW = 4.1 ± 0.2 kg) were used to compare changes in diet digestibility and performance from 3 to 22 days of age when fed either a milk replacer that included gelatinized wheat flour (W2) or a reference milk replacer (M2).

As in Experiment 1, the lambs were given access to ewe colostrum prior to removal from their dams within 12 to 24 hours of birth. After removal from the ewes, the lambs were housed in the same pens used in Experiment 1 and were hand-fed milk replacer (Advance Lamb Milk Replacer; Milk Specialties, Inc., Dundee, IL) three times daily on days 1 and 2. At 3 days of age, the lambs were abruptly changed to their respective experimental diets. They were moved into the wooden metabolism crates on the following day. At this time they were given ad libitum access to their individual self feeders. After 14 days of age they were given access to water. Lamb weights were recorded at 3, 7, 14 and 21 days of age. Lamb treatment at birth and the vaccination schedule were similar to those followed for Experiment 1 except that at 14 days of age an additional 0.5 cc of BO-SE was administered subcutaneously.

Diet formulation for Experiment 2 was modified from Experiment 1 (Table 1) by deleting ammonium chloride and reducing the crude protein content. This was necessary so that Marola 13/60 could be included to replace coconut oil in the wheat flour diet. These changes were made to improve uniformity between the diets while maintaining a similar energy content. Diets were prepared and stored as in Experiment 1.

To determine if and/or when a shift in digestibility of the diets occurred in young lambs, it was necessary to have a continuous total collection of urine and feces for the duration of the experiment. The collection was divided into five periods of four days each beginning at 3, 7, 11, 15 and 19 days of age. Collection procedures were the same as for periods 2, 3 and 4 of Experiment 1.

*Laboratory analysis*

Sampling and handling procedures were the same for both experiments. Fecal samples were thawed and composited for each lamb by period. Composite samples were placed in tared pans, weighed and refrozen. The frozen samples were lyophilized to a constant weight for DM determination. Feed samples were composited by period and lyophilized to determine DM. After being ground with a mortar and pestle, feed and feces were stored in sealed containers. Daily urine samples were thawed and composited by animal and period and then refrozen at -20 °C for N determination.

Starch digestibility was determined by a modified method of Herrera-Saldana (1990). Triplicate 400-mg feed and fecal samples were individually placed in screw-capped culture tubes. Triplicate wheat starch standards of 0, 5, 10, 20, 30, 40 and 50 mg were also placed in screw-capped culture tubes. After adding 20 mL of 0.2M acetate buffer, each sample was gelatinized in a 90 °C water bath for three hours. Following gelatinization, the starch was converted back to glucose by enzyme hydrolysis by adding 1 mL aliquot of a solution containing alpha amylase (Sigma, St. Louis, MO) and Diazyme L200 (a liquid mixture of glucoamylases; Solvay Enzymes, Elkhart, IN) to each sample. The samples were heated to 60 °C for 36 hours in a water bath, then centrifuged at 500 g, and a 1-mL aliquot of supernatant was diluted 1:10 with distilled water. Glucose concentration was determined by the colorimetric procedure of glucose trinder (Sigma, St. Louis, MO). A 100-µL aliquot of diluted sample was added to 1 mL of glucose trinder reagent and allowed to incubate at ambient temperature for 18 minutes. The concentration of starch was thus determined by the absorbance at 505 nm on a Beckman DU50 spectrophotometer (Beckman, Fullerton, CA).

Nitrogen was determined on duplicate feed, fecal and urine samples by the Macro Kjeldahl method (AOAC, 1984). Since the two sources of proteins used contained different concentrations of N, protein digestibility was determined as N digestibility.

Fat in the feed and feces was determined by a modified method of Radin (1981) using an acidified (0.1% HCL) 3:2 hexane:isopropyl alcohol extraction solvent. Duplicate 750-mg dried samples were weighed into tared 13 × 100 mm test tubes and a 300-liter aliquot of distilled water was added. This was followed by the addition of 7 mL of solvent. Each tube was vortexed and allowed to stand overnight. Samples were then vortexed again and centrifuged at 500 g and the solvent was decanted into

tared aluminum weighing dishes. An additional 7 mL of solvent was added to each tube and the samples were vortexed and centrifuged again. The solvent was decanted into the original pans and allowed to evaporate in the fume hood at ambient temperature. Fat percentage was calculated by dividing the weight of the fat by the dry sample weight.

*Statistical analysis*

Data from Experiments 1 and 2 were analyzed as completely randomized designs using the GLM procedures of SAS (1991). Treatment responses within periods or weeks were determined using Repeated Measures. Period or week effects were determined by Polynomial Comparisons. There were no time-by-treatment effects, but data was still represented by period and by experimental average to show changes over time across treatments. Changes in starch digestibility over time were represented as period differences using GLM. The starch data were further analyzed by Least Significant Difference (SAS, 1991).

# Results and Discussion

Dry matter, starch, fat and N digestibilities are shown in Table 2. Because starch is the major energy source in wheat, its digestibility is important. The lambs fed the W1 diet were found to have lower ($P < 0.003$) starch digestibility during period 1 than during periods 2, 3 or 4 (99.3 vs. 99.9, 99.8 or 99.7, respectively). Comparison of the DM or N digestibility of W1 and M1 diets between the collection periods and for the duration of the collections indicated that the addition of wheat flour did not alter their digestibility ($P > 0.1$). These findings confirm that wheat starch was well digested and that the protein of wheat did not affect N digestibility. The average digestibility of fat in the M1 diet was greater ($P < 0.05$) than that of the W1 diet. This was caused by differences between period 2 ($P < 0.01$) and period 3 ($P < 0.05$). Neither DM nor fat digestibilities changed ($P > 0.1$) over time. However,there was a quadratic period effect ($P < 0.1$) for N digestibility, where N digestibility was greater for both diets during periods 2 and 3 than for periods 1 or 4. The percentage of fecal DM has been used as an indirect method to confirm diet digestibility in the small versus large intestine (Thivend et al., 1979). No differences ($P > 0.1$) in the percentage of fecal DM were noted between the diets or periods, indicating that the diets may have been well digested in the small intestine.

The feeding of wheat flour did not effect ($P > 0.1$) N metabolism (Table 3). Across treatments, a quadratic period effect ($P < 0.001$) for N intake occurred coupled with a linear increase ($P < 0.01$) in fecal N output and a quadratic period effect ($P < 0.01$) for urinary N loss. Nitrogen retention doubled from period 1 to period 2, decreased from period 2 to period 3, and decreased again from period 3 to period 4 (quadratic period effect ;$P < 0.01$). When measured as a percentage of N intake and digested N, N retention decreased ($P < 0.001$) at a linear rate over the duration of the experiment with the greatest decrease between periods 2 and 3.

**Table 2. Nutrient digestibilities and percentage of fecal dry matter over time for lambs fed two milk replacers (Experiment 1).**

| Item | Diet[a] | Period 1 22 to 25 days | Period 2 47 to 53 days | Period 3 72 to 78 days | Period 4 97 to 103 days | Average |
|---|---|---|---|---|---|---|
| Digestibility: | | | | | | |
| DM, % | M1 | 95.4 | 96.1 | 96.0 | 91.7 | 94.8 |
| | W1 | 95.1 | 97.7 | 95.3 | 94.5 | 95.2 |
| | SEM | 0.8 | 0.4 | 0.4 | 2.7 | 0.7 |
| Starch, % | M1 | – | – | – | | |
| | W1 | 99.3[b] | 99.8[c] | 99.8[c] | 99.7[c] | 99.6 |
| | SEM | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Fat, % | M1 | 98.0 | 98.4[d] | 98.6[f] | 97.2 | 98.0[f] |
| | W1 | 96.8 | 97.3[e] | 96.7[g] | 97.6 | 97.1[g] |
| | SEM | 0.5 | 0.3 | 0.4 | 1.1 | 0.2 |
| Nitrogen,[h] % | M1 | 95.1 | 95.9 | 96.0 | 93.9 | 95.2 |
| | W1 | 95.0 | 96.1 | 96.2 | 95.0 | 95.6 |
| | SEM | 0.9 | 0.4 | 0.5 | 1.4 | 0.4 |
| Fecal DM, % | M1 | 47.0 | 55.3 | 50.1 | 54.8 | 51.8 |
| | W1 | 42.5 | 61.0 | 48.9 | 51.4 | 50.9 |
| | SEM | 6.7 | 2.8 | 4.1 | 4.6 | 2.5 |

[a] Four lambs per treatment; M1 = reference diet; W1 = wheat flour diet.
[b,c] For each variable measured, means in the same row with different superscripts differ ($P < 0.003$).
[d,e] For each variable measured, means in the same column with different superscripts differ ($P < 0.01$).
[f,g] For each variable measured, means in the same column with different superscripts differ ($P < 0.05$).
[h] Quadratic period effect ($P < 0.1$).

The overall ADG of the lambs fed the W1 diet did not differ (P > 0.1) from that of those fed the M1 diet (Table 4). However, for weeks 10 and 11 the lambs fed the W1 diet had greater (P < 0.1) ADG than those fed M1 (Table 5). During week 11 the lambs fed the M1 diet had greater (P < 0.1) ADG than lambs fed the W1 diet. With both diets, the lambs grew faster during the middle weeks (5 through 9) than during the beginning or ending weeks. This was demonstrated by a quadratic week effect (P < 0.001) with a peak at about 70 days of age, followed by an ADG decrease for the remainder of the experiment.

Overall feed efficiency (gain per feed) was not affected (P > 0.1) by treatment. However, lambs fed the M1 diet had greater feed efficiency than the lambs fed the W1 diet during week 2 (P < 0.1) as well as during weeks 10 and 11 (P < 0.01) (Table 5). Feed efficiency was greater (P < 0.05) for the W1 diet than for the M1 diet during week 12. A cubic week effect (P < 0.01) was expressed for gain-per-feed resulting from variability between weeks.

The feeding of wheat flour did not hinder (P > 0.1) daily DMI or DMI as a percentage of BW (Table 4). Across treatments, DMI exhibited a cubic week effect (P < 0.01) where it remained steady for 3 weeks then increased by about 100 grams per day (Table 5). This pattern continued to week 9, then DMI decreased to week 14. Dry matter intake as a percentage of BW decreased linearly (P < 0.001) over time.

The lambs fed the M1 diet had greater (P < 0.1) body condition scores at 64 days of age than those fed the W1 diet, but there were no difference between the treatments at 90 days of age (Table 6). There were no differences (P > 0.1) due to treatment for leg scores at 64 or 90 days of age. At 90 days of age the lambs had body condition scores indicating that they were finished but leg scores indicating that they may not have had the necessary muscle to produce a choice carcass grade.

Dry matter, starch, fat and N digestibilities of the all-milk or wheat-flour-containing diets for Experiment 2 are shown on Table 7. Digestibility of starch by the lambs fed the W2 diet was lower (P < 0.01) during period 1 than for periods 2, 3, 4 and 5 (91.1 vs. 99.2, 99.5, 99.9 and 98.6%, respectively). The average DM digestibility of the W2 diet was lower (P < 0.1) than the M2 diet. This was caused by differences (P < 0.05) during periods 1 and 2 since there were no DM digestibility differences (P > 0.1) during the remaining periods. The average fat digestibility for the W2 diet was also lower (P < 0.1) than for the M2 diet based on the difference (P < 0.05) during period 1. Average N digestibility did not differ (P > 0.1) between diets. However, N digestibility for the W2 diet was lower than for the M2 diet during period 1 (P < 0.05) and period 2 (P < 0.1). There were no period

**Table 3. Nitrogen metabolism over time for lambs fed two milk replacers (Experiment 1).**

| Item | Diet[a] | Period 1 22 to 25 days | Period 2 47 to 53 days | Period 3 72 to 78 days | Period 4 97 to 103 days | Average |
|---|---|---|---|---|---|---|
| Nitrogen intake, grams/day[b] | M1 | 9.1 | 20.3 | 23.4 | 19.3 | 18.0 |
| | W1 | 9.6 | 19.8 | 23.3 | 19.9 | 18.2 |
| | SEM | 0.8 | 1.0 | 1.5 | 2.0 | 1.5 |
| Fecal nitrogen, grams/day[c] | M1 | 0.43 | 0.83 | 0.95 | 1.08 | 0.82 |
| | W1 | 0.48 | 0.75 | 0.88 | 1.00 | 0.78 |
| | SEM | 0.08 | 0.08 | 0.13 | 0.18 | 0.08 |
| Urinary nitrogen, grams/day[d] | M1 | 3.4 | 9.0 | 15.1 | 13.3 | 10.2 |
| | W1 | 3.7 | 8.6 | 13.1 | 13.7 | 9.8 |
| | SEM | 0.30 | 0.49 | 1.51 | 1.64 | 1.22 |
| Nitrogen retention, grams/day[d] | M1 | 5.3 | 10.4 | 7.2 | 5.0 | 7.0 |
| | W1 | 5.4 | 10.5 | 9.2 | 5.3 | 7.6 |
| | SEM | 0.58 | 0.69 | 1.06 | 0.82 | 0.68 |
| Intake, %[e] | M1 | 57.3 | 51.4 | 31.1 | 26.2 | 41.5 |
| | W1 | 56.3 | 52.9 | 40.0 | 26.0 | 43.8 |
| | SEM | 2.8 | 1.9 | 4.6 | 2.7 | 3.5 |
| Digested, %[e] | M1 | 60.3 | 53.6 | 32.4 | 28.0 | 43.6 |
| | W1 | 59.3 | 55.0 | 41.6 | 27.4 | 45.8 |
| | SEM | 3.1 | 2.1 | 4.7 | 3.0 | 3.7 |

[a] Four lambs per treatment; M1= reference diet; W1 = wheat flour diet.
[b] Quadratic period effect (P < 0.001).
[c] Linear period effect (P < 0.01).
[d] Quadratic period effect (P < 0.01).
[e] Linear period effect (P < 0.001).

effects (P > 0.1) for DM digestibility. Fat digestibility for both diets increased (P < 0.1) at a linear rate. Nitrogen digestibility decreased from periods 1 to 2, changed little to period 3, increased to period 4 and remained steady to period 5 (quadratic period effect; P < 0.01).

As indicated by coefficients of fecal DM, the lambs fed the W2 diet had lower (P < 0.1) overall percentage of fecal DM than the lambs fed the M2 diet. This was due to the differences (P < 0.05) in the percentage of fecal DM between diets during periods 1 and 2. Low percentage of fecal DM of lambs fed the W2 diet coincided with low DM digestibility during the first two periods. There was a linear period increase (P < 0.05) across treatments for the percentage of fecal DM.

Nitrogen metabolism of the lambs (Table 8) indicates that those fed the W2 diet consumed less N (P < 0.1) and had no overall difference in fecal N output (P > 0.1), but they had similar N retention (P > 0.1) as the lambs fed the M2 diet. This may have been caused by the lambs receiving the M2 diet losing more (P < 0.01) N in their urine. Period effects for N metabolism indicate that changes in N retention, N retention as a percentage of N intake, and N retention as a percentage of N digested all followed the pattern of N intake by exhibiting a quadratic period effect (P < 0.01). All decreased from period 1 to period 2, remained steady to period 3, increased to period 4, then increased again to period 5. Urinary N loss increased at a linear rate (P < 0.001).

The overall ADG of the lambs fed the W2 diet in Experiment 2 was lower (P < 0.05) than that of the lambs fed the M2 diet (Table 9). This could be attributed to differences (P < 0.05) during weeks 1 and 2. Even though the lambs fed the W2 diet had lower (P < 0.1) DMI than the lambs fed the M2 diet, there was no difference (P > 0.1) in DMI when measured as a percentage of BW. Lambs fed the W2 diet also had lower (P < 0.1) overall feed efficiency than those fed the M2 diet. This was caused by differences (P < 0.05) during week 2. Across treatments there was a quadratic week effect (P < 0.001) for ADG, DMI, DMI as a percentage of BW, and gain/feed resulting from lower values for each measurement during week 2 as compared to weeks 1 and 3.

Gelatinized wheat starch was well digested in lambs from 7 to 22 days of age when fed at 9.5% of the dietary DM (Experiment 2). Although wheat starch was well digested from 3 to 6 days of age, starch digestibility was the

**Table 4. Performance of lambs fed two milk replacers from 10 to 105 days of age (Experiment 1).**

| Item | Diet | | |
|---|---|---|---|
| | M1[a] | W1[b] | SEM |
| Number of lambs | 5 | 5 | – |
| Initial weight, kg | 5.6 | 6.4 | 0.35 |
| Final weight, kg | 31.5 | 32.9 | 1.45 |
| ADG, grams/day | 278 | 271 | 13.3 |
| Gain per gram feed | 0.67 | 0.64 | 0.03 |
| DMI, grams/day | 433 | 437 | 18.2 |
| DMI, % BW | 2.9 | 2.8 | 0.11 |

[a] M1 = reference diet.
[b] W1 = wheat flour diet.

**Table 5. Average daily gain (ADG), dry matter intake( DMI) and gain per feed over time for lambs fed two milk**

| Item | Diet[a] | Week 1 10 to 14 days | Week 2 15 to 21 days | Week 3 22 to 28 days | Week 4 29 to 35 days | Week 5 36 to 42 days |
|---|---|---|---|---|---|---|
| ADG, grams/day[c] | M1 | 165 | 237 | 302 | 263 | 344 |
| | W1 | 159 | 182 | 237 | 266 | 324 |
| | SEM | 23.7 | 27.8 | 27.7 | 20.8 | 27.7 |
| DMI, grams/day[h] | M1 | 258 | 260 | 304 | 400 | 4410 |
| | W1 | 262 | 252 | 282 | 382 | 394 |
| | SEM | 10.3 | 13.4 | 18.6 | 22.6 | 15.0 |
| DMI, % BW[i] | M1 | 4.4 | 3.7 | 3.4 | 3.6 | 3.2 |
| | W1 | 3.9 | 3.3 | 3.1 | 3.5 | 3.0 |
| | SEM | 0.25 | 0.19 | 0.19 | 0.11 | 0.12 |
| Gain/feed[h] | M1 | 0.64 | 0.90[f] | 0.99 | 0.66 | 0.84 |
| | W1 | 0.61 | 0.70[g] | 0.84 | 0.71 | 0.82 |
| | SEM | 0.09 | 0.08 | 0.08 | 0.06 | 0.05 |

[a] Five lambs per treatment; M1 = reference diet; W1 = wheat flour diet.
[b] Missing weeks are due to lambs not being weighed during collection periods.
[c] Quadratic week effect (P < 0.001).
[d,e] For each variable measured, means in the same column with different superscripts differ (P < 0.01).

lowest and had the most variability among the lambs during this period. Two lambs digested the starch quite well, whereas the other two had lower starch digestibility. Four days after the initial feeding, variability was much less and starch digestibility nearly complete. The lower digestibility during period 1 may indicate that lambs lack sufficient enzymes to completely digest starch when less than seven days old. Because of the sharp rise in digestibility at seven to ten days of age, it is more probable that they simply needed time to adjust to the new diets. The results from Experiment 1 demonstrated that wheat starch was uniformly well digested by lambs from 22 to 105 days of age.

Wheat starch digestibility values reported for Experiment 1 and 2 are slightly higher than those reported for goat kids fed corn starch when compared at similar ages (Nitsan et al., 1990). However, starch digestibilities in both experiments were similar to the digestibility of partially hydrolyzed corn and wheat starch included in a lamb milk replacer by Soliman et al. (1979). Wheat starch was much better digested by lambs in Experiment 1 and 2 than the reported 80% digestibility for calves fed other types of starch at similar concentrations (Huber et al., 1961, 1968). Age differences for starch digestibility were considerably less for the lambs in these two experiments than those reported for calves (Huber et al., 1968; Hinks et al., 1975) where calves had much lower starch digestibilities before 21 days of age (55 to 70%) than when older (70 to 80%). Results from these studies contrast with those of Walker (1959) who found that lambs under 5 weeks of age lacked sufficient amylase and maltase activities to digest starch. Therefore it may be argued that the starch digested by the lambs was not digested by enzymes in the small intestine but was digested by microbes in the large intestines. This was not examined in either experiment. However, the results of Thivend et al. (1979) indicate that hydrolyzed corn and wheat starch was digested in the small intestine and the role of the large intestine only became significant as starch was increased to over 20% of the dietary DM.

The lower digestibilities and percentage of fecal DM of the lambs fed the W2 diet from three to ten days of age was caused by the low values of two of the four lambs with the other two exhibiting values similar to the lambs fed the M2 diet. These findings indicate there might be a seven-day adjustment period before all the lambs could fully utilize the wheat flour.

It has been suggested by Hinks et al. (1974) and Thivend et al. (1979) that lower percentage of fecal DM can occur when intact starch or partially hydrolyzed starch enters the large intestine, which leads to microbial fermentation and the production of low molecular weight acids which are osmotic regulators. Lower diet digestibility and percentage of fecal DM of the Experiment 2 lambs fed wheat flour during periods 1 and 2 was not the result of low starch digestibility. Once the lambs in Experiment 1 and 2 adjusted to the diets, there was no difference between them in DM or N digestibility. This contrasts the results of Golan et al. (1990) and Nitsan et al. (1990) who found that feeding a mixture of corn starch and soybean meal to 18- to 22-day-old lambs or to 15- to 26-day-old goat kids decreased DM and N digestibilities when included in a milk replacer diet (Nitsan, 1985). The decreased fat digestibility during periods 2 and 3 of Experiment 1 may have been the result of using only coconut oil instead of blended fats containing emulsifiers and lecithin. Soliman et al. (1979) and Golan et al. (1990) found that adding starch to milk replacers did not affect fat

**replacers (Experiment 1).**

| Weeks 6 to 7[b] 43 to 56 days | Week 8 57 to 63 days | Week 9 64 to 70 days | Weeks 10 to 11[b] 71 to 84 days | Week 12 85 to 91 days | Weeks 13 to 14[b] 92 to 105 days |
|---|---|---|---|---|---|
| 319 | 347 | 405 | 196[d] | 305[f] | 178 |
| 315 | 379 | 373 | 328[e] | 195[g] | 224 |
| 28.0 | 42.2 | 37.5 | 29.0 | 42.2 | 41.2 |
| 458 | 531 | 570 | 554 | 501 | 517 |
| 427 | 533 | 572 | 586 | 539 | 573 |
| 21.3 | 27.5 | 33.5 | 33.0 | 58.1 | 54.3 |
| 2.8 | 2.7 | 2.5 | 2.2 | 1.8 | 1.7 |
| 2.6 | 2.7 | 2.5 | 2.3 | 1.9 | 1.8 |
| 0.07 | 0.09 | 0.10 | 0.08 | 0.17 | 0.11 |
| 0.70 | 0.66 | 0.72 | 0.35[d] | 0.62[j] | 0.34 |
| 0.74 | 0.72 | 0.66 | 0.56[e] | 0.36[k] | 0.38 |
| 0.06 | 0.09 | 0.08 | 0.04 | 0.07 | 0.05 |

[f,g] For each variable measured, means in the same column with different superscripts differ ($P < 0.1$).
[h] Cubic week effect ($P < 0.01$).
[i] Linear week effect ($P < 0.003$).
[j,k] For each variable measured, means in the same column with different superscripts differ ($P < 0.05$).

digestibility. Based on the results from both experiments, N retention did not appear to be influenced by the feeding of wheat flour to lambs from 7 to 105 days of age. This suggests that wheat protein may be well utilized by the lamb.

The lower DM, fat and N digestibilities of the M1 diet during period 4 as compared to period 3 was caused by the poor digestibility of one lamb. This lamb had DM, fat and N digestibilities of 80, 93 and 88%, respectively. It is speculated because of its atypical suckling behavior and white fecal pellets that this lamb's diet was leaking into its rumen (Lawlor et al., 1971). Nitsan et al. (1990) also found evidence of rumen leaking in goat kids, but it was only significant when the corn starch and soybean meal mixture composed 40% of the dietary DM of a milk replacer. Johnston and Schultz (1992) found that 2.4% of the milk replacer entered the rumen of lambs before 13 weeks of age and 8.8% after 13 weeks of age. They did not observe symptoms associated with rumen leaking.

There are several possible reasons why ADG was lower for the lambs fed the W2 diet in Experiment 2. All of the lambs gained at a slow rate during week 1 with one lamb markedly lower than the others (ADG = 16 grams/day). This lamb's performance may not have been diet-related since its weakness improved after receiving its second injection of BO-SE. Feed efficiency, like ADG, was not affected by the addition of wheat flour except during week 1, which was mainly due to the poor performance of the one lamb. Average daily gain of the lambs fed the W2 diet appeared to be linked to low DMI. However, there was no difference between the diets when DMI was measured as a percentage of BW. This suggests that the differences in ADG and DMI could be influenced by the smaller body size of the lambs fed the W2 diet. Another factor in the reduced DMI values was the greater viscosity of the wheat flour diet, which may have made it more difficult to consume at a young age. Diet viscosity appeared to have no effect on the lambs in Experiment 1. Lambs fed the W2 diet had a relatively high feed efficiency and a low rate of DMI. Therefore the low ADG may be caused by low intake instead of their ability to utilize the diet.

No differences in lamb growth, DMI or feed efficiency were found from 10 to 105 days of age during Experiment 1. This suggests that wheat flour is a readily utilizable feed source for growing milk replacer-fed lambs when included at 12.5% of the dietary DM. Others (Golan et al., 1990; Nitsan et al., 1990) have found that growth was improved when a corn starch and soybean meal mixture replaced 20% of the DM of a commercial milk replacer when fed to lambs and goat kids. However, growth was depressed when this same mixture was added at 40% of

**Table 7. Nutrient digestibilities and percentage of fecal dry matter over time for lambs fed two milk replacers (Experiment 2).**

| Item | Diet[a] | Period 1 3 to 6 days | Period 2 7 to 10 days | Period 3 11 to 14 days | Period 4 15 to 18 days | Period 5 19 to 22 days | Average |
|---|---|---|---|---|---|---|---|
| Digestibility: | | | | | | | |
| DM, % | M2 | 97.6[b] | 96.1[b] | 96.0 | 96.8 | 96.9 | 96.7[d] |
| | W2 | 94.4[c] | 95.0[c] | 95.6 | 96.9 | 96.3 | 95.6[e] |
| | SEM | 0.87 | 0.36 | 0.90 | 0.53 | 0.49 | 0.32 |
| Starch, % | M2 | – | – | – | – | – | – |
| | W2 | 91.1[f] | 99.2[g] | 99.5[g] | 99.9[g] | 98.6[g] | 97.7 |
| | SEM | 3.6 | 0.4 | 0.2 | 0.1 | 1.3 | 1.0 |
| Fat, %[h] | M2 | 98.8[b] | 98.0 | 98.4 | 98.6 | 98.7 | 98.5[d] |
| | W2 | 97.3[c] | 98.0 | 98.3 | 98.7 | 98.5 | 98.1[e] |
| | SEM | 0.41 | 0.16 | 0.21 | 0.18 | 0.22 | 0.14 |
| Nitrogen, %[i] | M2 | 95.9[b] | 92.4[b] | 92.1 | 95.1 | 96.1 | 94.3 |
| | W2 | 92.8[c] | 91.0[c] | 92.3 | 95.0 | 94.7 | 93.2 |
| | SEM | 0.78 | 0.57 | 1.55 | 0.44 | 0.70 | 0.52 |
| Fecal DM, %[j] | M2 | 40.3[b] | 40.7[b] | 34.0 | 37.9 | 47.8 | 40.1[d] |
| | W2 | 15.4[c] | 23.5[c] | 28.9 | 39.0 | 38.1 | 29.0[e] |
| | SEM | 2.80 | 4.28 | 6.51 | 6.16 | 6.59 | 2.71 |

[a] Four lambs per treatment; M2 = reference diet; W2 = wheat flour diet.
[b,c] For each variable measured, means in the same column with different superscripts differ ($P < 0.05$).
[d,e] For each variable measured, means in the same column with different superscripts differ ($P < 0.1$).
[f,g] For each variable measured, means in the same row without a common superscript are different ($P < 0.01$).
[h] Linear period effect ($P < 0.1$).
[i] Quadratic period effect ($P < 0.01$).
[j] Linear period effect ($P < 0.05$).

the dietary DM. Soliman et al. (1979) found that partially hydrolyzed corn and wheat starch could make up to 41% of the diet's DM without depressing growth or efficiency.

Both diets included in Experiment 1 were inadequate for optimum growth and efficiency after 70 days of age. This may have been caused by the concentration of nutrients not being adjusted over time. The percentage of fat and protein was therefore greater than that normally found in diets for finishing lambs (NRC, 1985). This may have caused the high body condition for their age (90 days old) and weight (30 kg). Welch et al. (1963) found that lambs fed milk replacer containing 30% fat had higher quality grade carcasses at 10 weeks of age than lambs fed a diet containing 12% fat with equal protein. Goat kids that were slaughtered at a weight of 19 kg had heavier finished carcasses when fed milk replacer than kids that were fed an all-dry concentrate diet (Nitsan et al., 1985). This suggests that a high fat ration can produce a finished carcass at a lower live BW, which may not be advantageous if a heavier market weight is desired. Based on high body condition and low N retention, the lambs appeared to have deposited mainly fat and not muscle after 70 days of age. This might explain why ADG and feed efficiency decreased. The effects on the lambs of reduced DMI are apparent, but the available information does not allow for a clear interpretation of the cause(s) of this reduction.

# Conclusions

Lambs can be fed milk replacer containing gelatinized wheat flour as early as 3 days of age. Gelatinized wheat flour appeared to be highly digestible and did not affect performance after 14 days of age. It cannot be determined from these two experiments if the slightly lower digestibility of the W2 diet (Experiment 2) was caused by a faster rate of passage or if the lower digestibility caused the faster rate of passage. Provided that costs are low enough and the diets are formulated to closely meet the animals' requirements at different stages of growth, milk replacer diets might be developed which can be fed to lambs from birth to market.

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**Table 8. Nitrogen metabolism over time for lambs fed two milk replacers (Experiment 2).**

| Item | Diet[a] | Period 1 3 to 6 days | Period 2 7 to 10 days | Period 3 11 to 14 days | Period 4 15 to 18 days | Period 5 19 to 22 days | Average |
|---|---|---|---|---|---|---|---|
| Nitrogen intake, grams/day[b] | M2 | 7.9[c] | 6.3 | 6.9[c] | 9.3[c] | 11.5 | 8.4[c] |
| | W2 | 6.9[d] | 5.1 | 5.4[d] | 6.5[d] | 9.2 | 6.6[d] |
| | SEM | 0.42 | 0.52 | 0.55 | 0.97 | 0.99 | 0.48 |
| Fecal nitrogen, grams/day | M2 | 0.32[c] | 0.47 | 0.53 | 0.47 | 0.44 | 0.45 |
| | W2 | 0.51[d] | 0.46 | 0.43 | 0.33 | 0.47 | 0.44 |
| | SEM | 0.06 | 0.03 | 0.11 | 0.07 | 0.05 | 0.03 |
| Urinary nitrogen, grams/day[f] | M2 | 1.9[f] | 2.6[f] | 3.3[f] | 3.5[c] | 4.0[h] | 3.0[h] |
| | W2 | 1.6[g] | 2.0[g] | 2.3[g] | 2.5[d] | 2.9[i] | 2.1[i] |
| | SEM | 0.08 | 0.16 | 0.23 | 0.31 | 0.22 | 0.16 |
| Nitrogen retention: | | | | | | | |
| Grams/day[b] | M2 | 6.0[d] | 3.3 | 3.1 | 5.4 | 7.0 | 4.8 |
| | W2 | 4.8[e] | 2.6 | 2.7 | 3.7 | 6.5 | 4.1 |
| | SEM | 0.34 | 0.38 | 0.42 | 0.81 | 0.87 | 0.41 |
| Intake, %[b] | M2 | 71.7 | 51.3 | 43.0 | 56.4 | 61.1[c] | 56.7 |
| | W2 | 69.7 | 52.1 | 50.8 | 54.8 | 69.0[d] | 59.3 |
| | SEM | 1.19 | 2.73 | 4.13 | 4.36 | 2.66 | 2.42 |
| Digested, %[b] | M2 | 74.7 | 55.5 | 46.8 | 59.3 | 63.6[f] | 60.0 |
| | W2 | 75.1 | 57.2 | 55.0 | 57.7 | 72.8[g] | 63.6 |
| | SEM | 1.04 | 2.69 | 4.46 | 4.57 | 2.59 | 2.43 |

[a] Four lambs per treatment; M2 = reference diet; W2 = wheat flour diet.
[b] Quadratic period effect ($P < 0.01$).
[c,d] For each variable measured, means in the same column with different superscripts differ ($P < 0.1$).
[e] Linear period effect ($P < 0.001$).
[f,g] For each variable measured, means in the same column with different superscripts differ ($P < 0.05$).
[h,i] For each variable measured, means in the same column with different superscripts differ ($P < 0.01$).

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**Table 9. Average daily gain (ADG), dry matter intake (DMI), DMI as a percent of body weight (BW), gain/feed, initial weights and ending weights over time for lambs fed two milk replacers (Experiment 2).**

| Item | Diet[a] | Week 1 3 to 7 days | Week 2 8 to 14 days | Week 3 15 to 21 days | Average |
|---|---|---|---|---|---|
| ADG, grams/day[b] | M2 | 242[c] | 130[c] | 248 | 206[c] |
| | W2 | 192[d] | 49[d] | 215 | 152[d] |
| | SEM | 11.3 | 20.5 | 32.1 | 22.9 |
| DMI, grams/day[b] | M2 | 189[e] | 172[e] | 257[e] | 206[e] |
| | W2 | 160[f] | 136[f] | 192[f] | 163[f] |
| | SEM | 10.6 | 11.8 | 27.1 | 13.2 |
| DMI,% BW[b] | M2 | 3.9 | 2.9 | 3.5 | 3.4 |
| | W2 | 3.9 | 2.9 | 3.4 | 3.4 |
| | SEM | 0.23 | 0.15 | 0.17 | 0.15 |
| Gain/feed[b] | M2 | 1.29 | 0.74[e] | 1.0 | 1.00[e] |
| | W2 | 1.21 | 0.35[d] | 1.1 | 0.89[f] |
| | SEM | 0.09 | 0.08 | 0.09 | 0.11 |
| Initial + ending weight, kg | M2 | 4.5 | – | 8.1[e] | – |
| | W2 | 3.8 | – | 6.4[f] | – |
| | SEM | 0.32 | – | 0.59 | – |

[a] Four lambs per treatment; M2 = reference diet; W2 = wheat flour diet.
[b] Quadratic period effect ($P < 0.001$).
[c,d] For each variable measured, means in the same column with different superscripts differ ($P < 0.05$).
[e,f] For each variable measured, means in the same column with different superscripts differ ($P < 0.1$).

# Composition of Milk Fat from Ewes Fed a Diet Supplemented with Calcium Salts of Palm Oil Fatty Acids[1]

L.A. Appeddu[2], D.G. Ely[2,3], D.K. Aaron[2], W.P. Deweese[2] and E. Fink[2]

## Summary

Eight fall-lambing Polypay ewes with twin lambs were individually fed a control (C) diet of alfalfa hay, cracked corn and soybean meal from day 19 to day 54 of lactation. Eight ewes were fed the same basal diet supplemented (S) with 4.1% calcium salts of palm oil fatty acids (CaSPO) to compare dietary effects on milk fatty acid (FA) composition. The fat content of C and S diets was 4.0 and 7.1%, respectively, but daily intakes were isocaloric and isonitrogenous. Ewes were machine-milked on days 19, 26, 33, 42 and 54 postpartum. Diets and milk samples were analyzed for FA. The S diet had a higher percentage of 16:0 (carbon chain length-to-number of unsaturated bonds ratio) and 18:1, whereas C was predominant in 18:2. Proportions of 14:0, 16:0 and 16:1 in both C and S milk were lowest in the first part of the experimental period and rose to highest levels by day 54. The longer chain FAs exhibited opposite trends. Milk produced by S ewes was higher in 16:0 ($P < 0.01$) and 18:2 ($P < 0.05$), but lower ($P < 0.01$) in 14:0 and 18:3 when compared with C. Content and yield of dry matter (DM) and milk fat (MF) by S ewes tended to increase after peak lactation on day 26, but 24-hour milk yields were negatively affected. Dietary effects were greatest on the last collection day, when S ewes tended to produce more energy-dense milk (46.3 vs. 43.1% fat; $P < 0.10$). Although CaSPO supplementation altered the FA composition of MF, the benefits of this change on lamb performance were most apparent when ewes possessed the potential for higher levels of milk production.

**Key words:** fat, fatty acids, milk, ewe, lamb.

## Introduction

Glucose is often the most limiting nutrient for ruminant milk production (Faulkner and Pollock, 1989; Kronfield, 1982). Addition of dietary lipids offers an exogenous alternative to conserve this substrate and increase milk and fat yields in dairy cows (Palmquist et al., 1993a; Coppock and Wilks, 1991). Increased efficiency of milk production (MP) is achieved by increasing the direct incorporation of dietary preformed FAs into MF triglycerides (Chilliard, 1993; Kronfield, 1982). A concurrent decreased de novo synthesis of short-chain FAs in the mammary gland spares energy, reducing equivalents and carbon sources, which in turn can be used to support additional milk synthetic processes. The overall response to lipid supplementation depends both on the amount and the directing of these spared substrates (Chilliard, 1993). Spared glucose may be directed toward lactose synthesis, resulting in a higher milk yield, whereas spared substrates used to support higher levels of FA and triglyceride synthesis cause a higher MF content.

When Hernandez et al. (1986) supplemented ewes with a rumen inert lipid, the calcium salts of palm oil fatty acids (CaSPO; Megalac; Church and Dwight Inc., Princeton, NJ), MF content and yield were higher than in milk produced by the unsupplemented ewes. These researchers also found lambs of supplemented ewes to be heavier by five weeks of age. The objective of this study was to investigate the metabolic changes elicited during CaSPO supplementation by determining the extent of incorporation of dietary FAs into ewe milk and evaluating subsequent effects on efficiency of milk and lamb production.

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## Materials and Methods

The experimental design, using 16 Polypay ewes nursing twin lambs, has been described by Appeddu et al (1995). The control (C) diet contained ground alfalfa hay, cracked corn, soybean meal, liquid molasses and trace mineral salt + Se in approximately a 50:50 roughage-to-concentrate ratio. The test diet contained the same ingredients and was supplemented (S) with 4.1% CaSPO. After a five-day adjustment period when diets were fed in increasing amounts, both diets were fed twice daily, in equal portions, from day 19 to day 54 postpartum. Ewes were offered C and S diets at 3.69 and 3.54% of body weight (BW) daily (DM basis). Diet composition, lamb management and milk collection procedures have been previously described (Appeddu et al., 1995).

The CaSPO supplement, ewe diets and fresh milk samples were analyzed for FAs 14:0, 16:0, 16:1, 18:0, 18:1, 18:2 and 18:3 (carbon chain length-to-number of unsaturated bonds ratio). The fat component of these samples was transesterified into FA methyl esters (Lepage and Roy, 1986). Hexane fractions were extracted and analyzed on a Perkin Elmer gas chromatograph using a temperature-programmed, carbowax-fused, silica capillary column. The methyl ester peaks were identified by comparison with the retention time of the reference standard. Peak areas were determined and individual concentrations calculated as percentages of the total FA areas.

The procedures of Appeddu et al. (1995) were used to determine fat content of the CaSPO supplement and diets. Previously described procedures (Appeddu et al., 1995) were used to determine ewe 24-hour milk production (MP) and the content and 24-hour yield of milk DM and MF. Twin lamb weights taken on day 54 were combined so lamb performance could be expressed on a per-ewe basis.

Data were analyzed, using the GLM procedure of SAS (1985), as a completely randomized design with a one-way treatment structure and repeated measures over time. "Ewe" was considered the experimental unit. The error term for testing treatment differences was ewe nested within treatment. Linear, quadratic, cubic and quartic contrasts were performed to delineate effects of time of collection during the 35-day experimental period.

Subsequent to the planned analysis described above, post-data comparisons were conducted to investigate the possible interaction of treatment (C vs. S) and level of MP (high vs. low). In order to do this, ewes within C and S treatments were grouped as high or low producers based on average MP for the 35-day experimental period (four ewes per group). Variable means were analyzed for the resultant 2 (C vs. S) x 2 (high vs. low) factorial arrangement using a one-way analysis of variance (SAS, 1985). Variables included MP and the contents and yields of DM, MF and milk protein (MPR). Production efficiencies for milk variables and milk FA proportions were also analyzed, as were lamb ADG, 60-day adjusted weaning weight (WW) and efficiency of gain. Comparisons made for each variable were: 1) C versus S; 2) high versus low MP; and 3) interaction of supplement type and level of MP. Because differences between C and S were evaluated in the original analysis, only the latter two contrasts are discussed relative to this post-data investigation.

## Results and Discussion

The FA composition of CaSPO and C and S diets is presented in Table 1. The S diet contained 78 and 27% more 16:0 and 18:1, respectively, than C because CaSPO is a rich source of these FAs. The relatively moderate levels of 18:0 and 18:2 in CaSPO allowed the composition of the S diet to be influenced more by other feed ingredients than by CaSPO. While 18:0 was slightly higher in the S diet, it contained only 53% as much 18:2 as the C diet. Relatively small amounts of 14:0 and 18:3, and only trace amounts of 16:1, were detected in CaSPO. Although 14:0 was higher, and 18:3 lower, in the S diet, neither made up a large proportion of the FAs in the C or S diet. The 16:1 was not detectable in either diet.

The CaSPO addition caused the S diet to be 78% higher in total fat content, resulting in a greater daily fat consumption by S ewes (0.18 vs. 0.10 kg/day). Although actual DM intake (DMI) was slightly lower than offered (3.48 and 3.43% of initial ewe weight for C and S diets, respectively), C and S ewes still consumed isocaloric and isonitrogenous rations.

**Table 1. Fatty acid composition and fat content of the lipid supplement and control and supplemented diets.**

| | | Treatment[a] | |
|---|---|---|---|
| Item | CaSPO[b] | C | S |
| Fatty acid:[c,d] | | | |
| 14:0 | 1.68 | 0.59 | 1.08 |
| 16:0 | 50.83 | 21.41 | 38.05 |
| 16:1 | 0.04 | – | – |
| 18:0 | 8.59 | 3.30 | 4.09 |
| 18:1 | 30.06 | 23.19 | 29.53 |
| 18:2 | 8.57 | 45.83 | 24.38 |
| 18:3 | 0.23 | 5.67 | 2.87 |
| Fat[e] | 87.19 | 3.98 | 7.10 |

[a] CaSPO = control; S = CaSPO-supplemented.
[b] CaSPO = calcium salts of palm oil fatty acids (Megalac; Church and Dwight Company, Incorporated, Princeton, NJ).
[c] Carbon chain length-to-number of unsaturated bonds ratio.
[d] Percent of total FA.
[e] Percent of DM.

Quadratic trends ($P < 0.01$) were found for 14:0, 16:1, 18:0 and 18:2 FAs in milk collected on different days from day 19 through day 54 of lactation (Table 2). A linear increase ($P < 0.01$) was found for 16:0 as lactation length increased. In contrast, percentages of 18:1 and 18:3 decreased linearly ($P < 0.01$) with lactation length. The predominant FAs found in both C and S milk samples were 16:0, 18:0 and 18:1. The percentages of 14:0, 16:0 and 16:1 were lowest on either day 26 or 33 of lactation (Table 2). Peak MP occurred on day 26 (Figure 1). In contrast, 18:0 and 18:1 were highest on 26 and 33 days postpartum (Table 2). The percentages of 18:2 and 18:3 were highest on day 42 and day 19, respectively. As lactation proceeded, and MP declined (Figure 1), 14:0 and 16:0 increased to their highest levels on the last collection day (Table 2). Likewise, percentage of 16:1 increased after day 33 postpartum. On the other hand, 18:0, 18:1 and 18:3 decreased to their lowest levels, and 18:2 to its second lowest percentage, by day 54. No treatment-by-time interactions were found. These results substantiate the opposite relationship noted by Palmquist et al. (1993a) between de novo synthesis of 14:0 and uptake of preformed 18:0, 18:1, 18:2 and 18:3 by the mammary gland for incorporation into MF triglycerides. Percentages of 16-C chain length FAs generally increase as the level of de novo synthesis increases with lactation length, although approximately half of these FAs are taken up, preformed, by the mammary gland (Grummer, 1991).

The milk FA profile within lactation stages is highly dependent on carbon substrate and energy availability (Palmquist et al., 1993a; Garnsworthy, 1988; Bauman and Currie, 1980). The high nutrient demands of early and peak lactation limit the synthesis of 16:0 and shorter chain FAs in the mammary gland. De novo synthesis is further inhibited metabolically by a large supply of preformed 16:0, 18:0 and 18:1, derived from the diet and mobilized adipose stores, which are directly incorporated into MF triglycerides (Grummer, 1991; Hansen and Knudsen, 1987). In contrast, as lactation proceeds, a decreasing MP (Figure 1) requires a smaller amount of nutrients for milk synthesis. In turn, homeorhetic mechanisms within the lactating female cause less nutrient partitioning to the mammary gland and decrease the efficiency of FA uptake by the mammary gland. The resultant reduced supply of preformed FAs relieves the inhibition of de novo FA synthesis and the proportion of shorter chain FAs increases relative to the decrease in 18-C FA.

Supplementation with CaSPO, however, significantly altered the proportions of synthesized FAs measured in MF of S ewes (Table 2). Percentages of 14:0 were lower ($P < 0.01$) in S milk samples than in C on all collection days. In contrast, 16:0 levels in S milk were higher than in C on days 19 ($P < 0.01$), 26 ($P < 0.05$) and 42 ($P < 0.05$). Although 16:1 made up only a small proportion of the total FAs measured, it was numerically higher in S milk on all collection days except day 19. These results agree with those obtained by Tomlinson et al. (1994) and Schauff and Clark (1992) with dairy cows.

The lower proportion of 14:0 found in S milk indicates a reduced synthesis in the mammary glands of S ewes by provision of more dietary FAs via CaSPO supplementation (Schauff and Clark, 1992). Although dietary FAs may inhibit the activity of enzymes involved in FA synthesis at the mammary gland level (Grummer, 1991), a reduced supply of carbon sources for de novo synthesis may result when ruminally fermentable carbohydrates are replaced with dietary fat (Palmquist et al., 1993b; Khorasani et al., 1992; Clapperton and Banks, 1985). Because only about half of the 16:0 and 16:1 found in

**Table 2. Fatty acid composition of ewe milk by collection day (% of total).**

| | Treatment[a] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | | | | | | S | | | | | | |
| Fatty acid[b] | Day 19 | Day 26 | Day 33 | Day 42 | Day 54 | $\bar{x}$ | Day 19 | Day 26 | Day 33 | Day 42 | Day 54 | $\bar{x}$ | SEM[c] |
| 14:0[d] | 14.4[e] | 12.8[e] | 13.5[e] | 14.3[e] | 16.9[e] | 14.4[e] | 12.1 | 10.0 | 10.1 | 10.3 | 11.9 | 10.9 | 0.14 |
| 16:0[f] | 34.1[e] | 33.4[g] | 34.7 | 36.2[g] | 40.7 | 35.7[e] | 38.4 | 37.0 | 36.1 | 38.9 | 42.3 | 38.5 | 0.27 |
| 16:1[d] | 1.8 | 1.4 | 1.5 | 1.6 | 1.6 | 1.6 | 1.8 | 1.6 | 1.6 | 1.7 | 1.9 | 1.7 | 0.02 |
| 18:0[d] | 15.4 | 17.0[g] | 16.0 | 15.1[g] | 12.9 | 15.3 | 14.1 | 15.2 | 16.0 | 13.7 | 13.2 | 14.4 | 0.18 |
| 18:1[f] | 30.9 | 31.5 | 30.5 | 29.0 | 24.5 | 29.3 | 30.5 | 32.2 | 32.2 | 31.0 | 27.0 | 30.6 | 0.28 |
| 18:2[d] | 2.6 | 3.2 | 3.2 | 3.3[g] | 2.9[g] | 3.1[g] | 2.8 | 3.5 | 3.5 | 3.8 | 3.3 | 3.4 | 0.04 |
| 18:3[f] | 0.8[e] | 0.7[e] | 0.6 | 0.6[g] | 0.5[e] | 0.6[e] | 0.6 | 0.5 | 0.5 | 0.5 | 0.4 | 0.5 | 0.01 |

[a] C = Control; S = CaSPO-supplemented.
[b] Carbon chain length-to-number of unsaturated bonds ratio.
[c] SEM = standard error of mean.
[d] Quadratic ($P < 0.01$).
[e] C versus S ($P < 0.01$).
[f] Linear ($P < 0.01$).
[g] C versus S ($P < 0.05$).

milk is normally derived from de novo synthesis in the mammary gland (Bauman and Davis, 1974), the dietary provision of larger amounts of preformed 16:0 (Table 1) appeared to offset a portion of the reduced de novo synthesis of this FA (Grummer, 1991). Consequently the proportion of 16:0 was overall higher ($P < 0.01$) in S milk than in C (Table 2). The increased supply of 16:0 may also have led to higher percentages of 16:1 because the latter is formed from dehydrogenation of 16:0 by intestinal or mammary gland desaturases (Bauman and Davis, 1974). Although an increase in FA de novo synthesis caused higher levels of 14:0 and 16-C chain length FAs in both C and S milk as lactation progressed, the inhibitory effects of the FA levels of CaSPO remained great enough to suppress ($P < 0.01$) 14:0 in the MF of S ewes for the entire 35-day collection period.

Treatment differences were also found in the proportions of the total FAs as 18-C (Table 2). Overall percentages of 18:0 tended to be lower ($P < 0.09$) in S milk and were lower ($P < 0.05$) on days 26 and 42. In contrast, the proportion of 18:1 was numerically higher for S after the first collection day, with differences between S and C ewes appearing to increase as lactation proceeded. By day 54 postpartum the MF produced by S ewes tended ($P < 0.08$) to have a greater 18:1 content. Likewise, 18:2 was numerically higher in S samples in early lactation and higher ($P < 0.05$) on days 42 and 54. Overall, 18:2 was increased ($P < 0.05$) by CaSPO supplementation. However, the smallest proportional FA measured, 18:3, was lowered ($P < 0.01$) with CaSPO supplementation. The pattern of changes found in FA proportions in this experiment is similar to that observed by Schauff and Clark (1992) when feeding CaSPO to dairy cows, except these researchers reported no treatment differences for 18:3 levels.

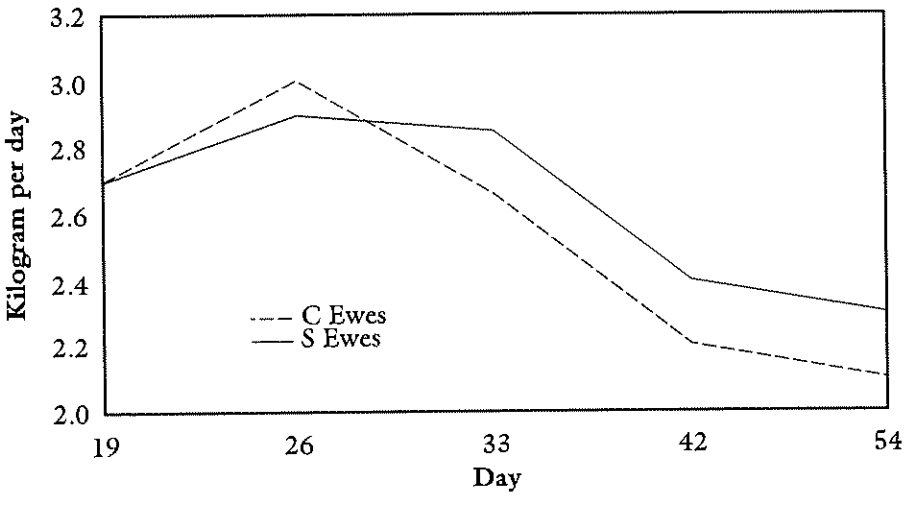
The different effects elicited among the FA proportions by adding CaSPO to ewe lactation diets relate to their different origins. When evaluating changes in the predominant FA of milk, decreases in the percentage of 18:0 are often observed when feeding CaSPO to dairy cows (Tomlinson et al., 1994; Schauff and Clark, 1992; Schauff et al., 1992), whereas 18:1 is often increased (Schauff and Clark, 1992; Schauff et al., 1992). A larger supply of 18:1, if it resisted alteration by ruminal microbes, was provided to the mammary gland by feeding CaSPO (Table 1). This may have complemented the normal supply of 18:1 derived from the desaturation of 18:0 by intestinal and mammary gland cells (Table 2). The 18:0 present in ewe milk could have originated from the diet, the ruminal biohydrogenation of unsaturated 18-C dietary FA and/or mobilized adipose stores (Pedron et al., 1993; Garnsworthy and Huggett, 1992; Grummer, 1991). The lower 18:0 level in S milk, relative to C, was not entirely due to a decreased mobilization of body stores in S ewes because weight changes of C and S ewes over the 35-day experimental period were not statistically different (-0.17 vs. 1.45 kg). Instead, the proportion of 18:0 may have been diluted by the relatively greater incorporation of 16:0 and 18:1 into the MF of S ewes, a result of CaSPO supplementation.

The opposite relationship observed between 18:0 and 18:1 in CaSPO-fed ewes may have also been influenced by a hypothesized regulatory mechanism within the mammary gland that maintains a relatively constant level of milk viscosity (Palmquist et al., 1993a; Grummer, 1991; Hermansen and Lund, 1990). It has been suggested that this mechanism operates by increasing the desaturation of 18:0 to 18:1 when the proportion of shorter chain FAs is lowered in early lactation or as a result of feeding diets high in fat or concentrates.

The increased level of 18:2 in S milk (Table 2) appears to be a response to the greater provision of ruminally unmodified dietary 18:1 (Table 1), which can subsequently be dehydrogenated by small intestine and mammary gland desaturases to 18:2 (Grummer, 1991). Post-ruminal delivery of 18:2, protected in the form of CaSPO, may have also contributed to the increase. The small percentage of 18:2 detected in C milk (Table 2), relative to its predominance in the C diet (Table 1), illustrates the extent of free FA biohydrogenation which can occur in the rumen when FAs are not protected from microbial activity (Grummer, 1991). On the other hand, the CaSPO supplement had only trace amounts of 18:3 (Table 1) and therefore had little influence on the 18:3 level in the milk (Table 2).

While treatment differences in FA profiles substantiate the theory that CaSPO provides some protection of dietary FAs from ruminal biohydrogenation, the overall changes in ewe MP and nutrient yield determine the effectiveness of CaSPO supplementa-

**Figure 1. Fresh milk yield by collection day of control (C) and CaSPO-supplemented (S) ewes.**



tion to increase the efficiency of MP. Coppock and Wilks (1991) reported increases in milk yield and fat content for CaSPO-fed dairy cows. However, not all results are positive for both variables (Teh et al., 1994; Holter et al., 1993; Schauff and Clark, 1992). The extent of increased transfer of dietary FAs into MF triglycerides, as opposed to inhibition of de novo synthesis of short chain FAs in the mammary gland, determines the overall response to fat supplementation (Palmquist et al., 1993a). One result of this action may be increased MP due to the sparing effect preformed FA incorporation can have on reducing glucose oxidation so it can in turn be directed toward lactose synthesis and other anabolic processes. Another outcome of CaSPO supplementation could be changes in milk composition, specifically increases in DM% and MF%.

Although fresh milk yields were not changed by CaSPO supplementation in this experiment (2.65 and 2.56 kg/day for C and S, respectively), MF% was increasingly enhanced by CaSPO supplementation as the length of lactation increased (Figure 2). On day 54, S milk had a higher MF content than C (46.3 vs. 43.1%; $P < 0.08$). Milk DM% was similarly affected by CaSPO (Figure 3), and the greatest numerical difference between C and S was found on the last collection day (24.2 vs. 22.2%; $P < 0.12$). Being the largest component of ewe milk DM, MF appeared to have a dominant influence on final DM%, and both measures in C and S treatments increased linearly ($P < 0.05$) as lactation progressed. Overall, S ewes tended to produce milk with higher MF (45.3 vs. 43.9%) and DM (21.6 vs. 20.7%) contents. However, a slightly lower MP in S ewes resulted in similar 24-hour yields of MF (0.25 vs. 0.24 kg/day) and DM (0.55 vs. 0.55 kg/day) for S and C ewes, respectively.

**Figure 2. Fat content of milk from control (C) and CaSPO-supplemented (S) ewes.**

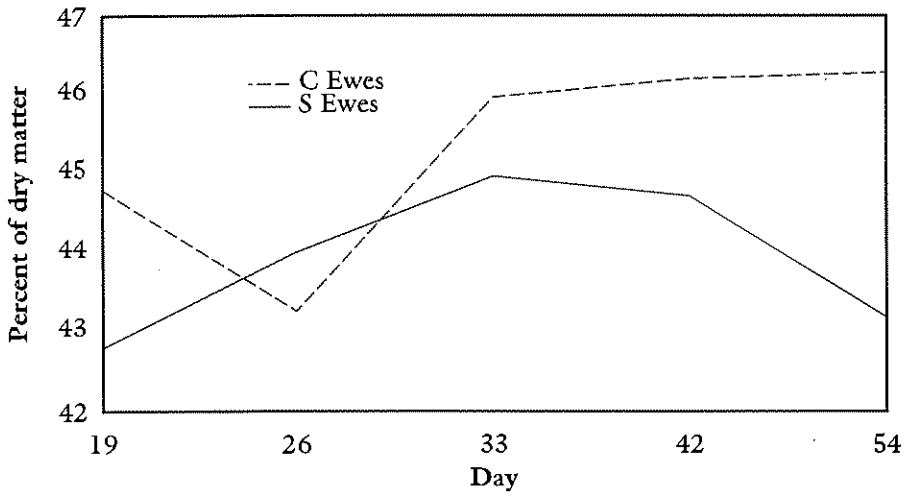
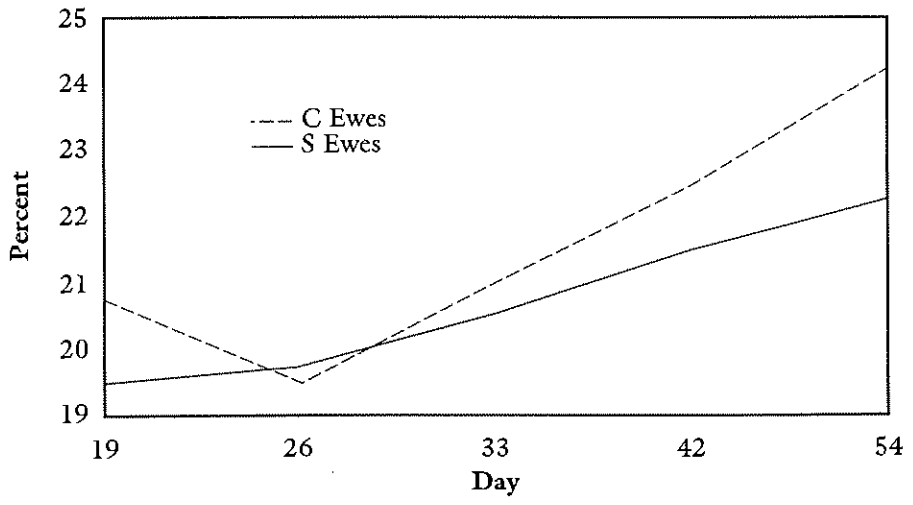



**Figure 3. Dry matter content of milk from control (C) and CaSPO-supplemented (S) ewes.**




The production response obtained when feeding lipids depends on how much glucose is spared and the synthetic processes to which it is directed. Both are influenced by genetic factors and the energy status of the lactating female (Chilliard, 1993; Schauff and Clark, 1992; Garnsworthy and Huggett, 1992). In dairy cows, an increase in MP appears most likely to result from lipid supplementation when energy is the most limiting factor. Therefore, milk yields would be expected to increase most in cows when energy intake is enhanced in early and peak lactation (Holter et al., 1993; Schauff and Clark, 1992; Kim et al., 1990), when a higher production potential exists (Austin et al., 1990; Schneider et al., 1990), and/or when condition score is low (Pedron et al., 1993; Garnsworthy and Huggett, 1992). Under these circumstances spared glucose is directed to synthesize lactose which in turn increases milk yields (Faulkner and Pollock, 1989; Kronfield, 1982; Linzell and Peaker, 1971).

In contrast, MF content often increases when MP is not enhanced by dietary lipid addition (Teh et al., 1994; Schauff and Clark, 1992; Hernandez et al., 1986). This may result when not enough glucose is spared to elicit a detectable difference in MP, whereas the incorporation of FAs into MF is greater than the simultaneous decrease in FA synthesis (Storry et al., 1971). Increased MF%,

but not MP, may also occur when another dietary nutrient is deficient (Teh et al., 1994; Palmquist et al., 1993b), when an adequate energy status exists (Garnsworthy and Huggett, 1992) and/or when the genetic potential for MP has already been realized (Schauff and Clark, 1992). Spared glucose would then be used to support FA synthesis and triglyceride formation, as observed during late lactation in this experiment. An opposite relationship is well-documented in dairy cows between milk yield and MF% (Palmquist et al., 1993a; Schmidt, 1971; Palmiter, 1969), while a positive relationship exists between the contents of MF and shorter chain FAs (Palmquist et al., 1993a; Hermansen and Lund, 1990).

To investigate the relationship between production potential and CaSPO supplementation in the present experiment, C and S ewes were further equally divided into high- and low-producing groups based on fresh milk yields averaged over the 35-day experiment. The averages of the milk variables of the eight high- and eight low-producing ewes are presented in Table 3. The higher ($P < 0.05$) DM and MF contents in the milk of high producers were opposite to what is commonly observed in dairy cows (Schmidt, 1971; Palmiter, 1969). The lower ($P < 0.01$) MPR% found in high-producing ewes was expected (Palmiter, 1969). High-producing ewes yielded more ($P < 0.01$) 24-hour fresh milk, DM, MF and MPR. Efficiencies of milk and DM production per ewe DMI were also greater ($P < 0.01$) in high producers.

Furthermore, milk of high producers contained a higher ($P < 0.10$) proportion of 18:0 and a higher ($P < 0.05$) 18:0-to-18:1 ratio (Table 3). These results contrast those from studies involving high-yielding dairy cows, which have a higher proportion of 18:1 at the expense of shorter-chain synthesized FAs (Palmquist et al., 1993a; Palmquist and Beaulieu, 1992; Hermansen and Lund, 1990). The concurrently greater 18:0 incorporation into ewe MF triglycerides may be possible because ewe MF has a higher percentage of 4:0 through 14:0 FAs relative to cow's milk (Galvano and Scerra, 1984). Also, an increase in MF%, as found when ewe MP was higher, is directly related to higher proportions of these synthesized FAs (Palmquist et al., 1993a; Hermansen and Lund, 1990).

**Table 3. Milk variable averages for high- and low-producing ewes.**

| Variable | Ewe productivity | | |
|---|---|---|---|
| | High | Low | SEM[a] |
| Nutrient content, %:[b] | | | |
| DM[c] | 21.96 | 20.25 | 0.851 |
| MF[c] | 46.16 | 43.19 | 1.483 |
| MPR[d] | 20.90 | 22.78 | 0.940 |
| Component yield, kg/day: | | | |
| Milk[d] | 2.99 | 2.27 | 0.361 |
| DM[d] | 0.64 | 0.45 | 0.091 |
| MF[d] | 0.29 | 0.20 | 0.049 |
| MPR[d] | 0.13 | 0.10 | 0.016 |
| Efficiency of production, kg/kg: | | | |
| Milk yield/ewe DMI[d] | 1.14 | 0.95 | 0.095 |
| DM yield/ewe DMI[d] | 0.25 | 0.19 | 0.029 |
| FA composition:[e,f] | | | |
| 18:0, %[g] | 15.33 | 14.49 | 0.422 |
| 18:0/18:1[c] | 0.52 | 0.48 | 0.017 |

[a] SEM = standard error of mean (N = eight ewes per group).
[b] Percent of DM for fat and protein.
[c] $P < 0.05$.
[d] $P < 0.01$.
[e] Percent of total.
[f] Carbon chain length-to-number of unsaturated bonds ratio.
[g] $P < 0.10$.

**Table 4. Effect of lipid supplementation on twin lamb performance from high- and low-producing ewes.**

| Variable | Treatment[a] | | |
|---|---|---|---|
| | C | S | $\bar{x}$ |
| ADG, kg:[b] | | | |
| High | 0.42 | 0.46 | 0.44 |
| Low | 0.38 | 0.35 | 0.37 |
| $\bar{x}$ | 0.40 | 0.41 | – |
| 60-day adjusted WW, kg/ewe:[c,d] | | | |
| High | 39.40 | 43.42 | 41.41 |
| Low | 39.81 | 36.18 | 38.00 |
| $\bar{x}$ | 39.61 | 39.80 | – |
| ADG/ewe DMI, kg:[c,d,e] | | | |
| High | 0.153 | 0.175 | 0.164 |
| Low | 0.155 | 0.135 | 0.145 |
| $\bar{x}$ | 0.154 | 0.155 | – |

[a] C = control; S = CaSPO-supplemented.
[b] High versus low ($P < 0.05$).
[c] High versus low ($P < 0.10$).
[d] Combined twin lamb performance.
[e] Interaction ($P < 0.10$).

In addition to milk compositional data, lamb performance was also evaluated (Table 4). Although daily gains of C and S lambs were similar (0.40 vs. 0.41 kg, respectively), gains of lambs from high-producing ewes were higher ($P < 0.05$) than those of lower producers (0.44 vs. 0.37 kg, respectively). High-producing S ewes tended to produce lambs with heavier 60-day adjusted WW (43.42 kg) than unsupplemented high producers (39.40 kg). On the other hand, a negative effect of CaSPO supplementation was found in low producers. A similar interaction ($P < 0.10$) was found for lamb ADG per unit of ewe DMI.

While interactions of milk variables were nonsignificant, the DM and MF yields of CaSPO-supplemented high-producing ewes averaged 104.8% of the unsupplemented high producers. Low producers supplemented with CaSPO produced only 101.0% of the yields of unsupplemented low producers. Similarly, the proportion of 18:1 FA in MF of high-producing CaSPO-supplemented ewes was 106.1% of high-producing controls. The proportion of 18:1 in MF of supplemented low producers was only 101.4% of the unsupplemented low-producing ewes. These results point to more efficient MP when CaSPO is fed to high-producing ewes (Chilliard, 1993; Grummer and Carroll, 1991; Kronfield, 1982). Because lambs received no creep feed, the tendencies of MP traits appeared to culminate in greater lamb performance when CaSPO was fed to high-producing ewes. Therefore the benefits of supplementing lactation diets with rumen inert fats may best be realized when ewes possess the genetic potential for high milk production.

# Conclusions

Ewe milk FA composition is altered during lipid supplementation by a greater incorporation of preformed dietary FAs into MF triglycerides, positively influencing DM and fat content as lactation proceeds. However, no overall enhancement was observed in this experiment for either ewe lactational or lamb performance when feeding the calcium salts of palm oil. Post-trial comparisons between high- and low-producing ewes demonstrated CaSPO supplementation of lactating ewe diets may be a more economical strategy when nutrient demands are not currently being met, whether due to a high potential for lactational performance or to a deficient energy intake.

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# The Effect of Britch Removal in Rambouillet Fleeces on Clip and Fleece Fiber Diameter and Its Variability

R.W. Kott[1,2], V.M. Thomas[1] and C.M. Schuldt[1]

## Summary

Fleeces from 240 mature range Rambouillet ewes were visually appraised and side and britch fiber diameter estimated. Fleeces were allocated into two types: 1) more variable fleeces (those having the most variation in estimated side and britch diameters); and 2) more uniform fleeces (those having the least variation in estimated side and britch diameters). Within each type (n = 120), fleeces were randomly allocated into 12 lots, each containing 10 fleeces. Britches were removed from fleeces within six lots while the fleeces in the remaining six lots were left with britches intact (unskirted lots). Fleeces from one lot within each of the four sub-treatment combinations were individually core tested and evaluated for yield, fiber diameter, fiber variability and prickle. Remaining lots were baled, core tested and evaluated for objective characteristics as previously described. Removal of britches did not affect fiber diameter in either individual fleece cores (21.32 vs. 22.06 microns; for britch removed vs. unskirted fleeces, respectively; $P > 0.10$) or lot cores (20.69 vs. 20.54 micron for britches removed vs. unskirted lots, respectively; $P > 0.10$). Britch removal tended ($P > 0.10$) to reduce fiber diameter variability as measured by fiber diameter coefficient of variation in both individual fleece and lot cores (18.1 vs. 19.3% and 19.0 vs. 20.1%, respectively). Percentage of fibers greater than 30 microns (prickle) was reduced in individual fleeces (2.9 vs. 5.3% for britches removed vs. unskirted fleeces, respectively; $P > 0.05$). A similar comparison in lot cores did not differ (2.3 vs. 2.2 for britches removed vs. unskirted lots, respectively; $P = 0.91$). It is doubtful that differences observed in this study are biologically significant. Therefore these results indicate that britch removal in this typical Rambouillet sheep flock does not reduce mean fiber diameter and may only slightly reduce fiber diameter variability and prickle effect.

**Key words:** sheep, wool, skirting.

## Introduction

Fiber diameter is one of the most important physical characteristics of raw apparel wool in terms of fabric into which it may be processed. Fineness or diameter and variation in diameter of wool fibers governs the thickness of yarn and the limiting count that can be spun (Turpie, 1976, 1977, 1978; Turpie and Hunter, 1980). Prickle is a specific fault or condition resulting from course fibers and is defined as the percentage of fibers which have a diameter greater than 30 microns. Fleet et al. (1982) indicated that a clip's coarse edge causes problems in processing, as fibers greater than 30 μm in diameter increase yarn breakage.

Variation in fiber diameter within a clip of wool can be categorized as follows: 1) fleece-to-fleece (between sheep); 2) site-to-site within a fleece (between locations on a sheep); 3) point-to-point along a fiber (between locations along a fiber); and 4) fiber-to-fiber within a site (between fibers within a staple). Australian workers (Dunlop and McMahon, 1974) found that, in Merino sheep, variation between fibers and along a fiber constitutes two-thirds of the total variation within a clip of wool. Similar results were reported by Stobart et al. (1985) for Rambouillet and Columbia flocks in Wyoming and by Kott et al. (1988) for Targhee flocks in Montana.

Major strides have been made in the preparation of domestic wool in the past five years. However, in many cases it is uncertain to what degree these preparation methods are actually affecting the measurable quality of the end product. One such practice is the

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removal of britches at the skirting table in an attempt to reduce fiber diameter variation. Preliminary research suggests this practice will only slightly reduce clip fiber diameter variation. The objective of this study was to evaluate the effect of britch removal on fiber diameter, fiber diameter variability and prickle.

## Materials and Methods

Rambonillet ewes located at the Montana Experiment Station, Red Bluff Experimental Ranch, MT, were visually appraised and side and britch fiber diameter estimated. Ewes whose fleeces were not typical of the Rambouillet breed were removed. During classing and skirting these fleeces would be packaged separately from the main lot of wool. Fleeces were allocated in two types: 1) most variable fleeces (those having the most variation in estimated side and britch diameters); and 2) most uniform fleeces (those having the least variation in estimated side and britch diameters). Within each type (n = 120), fleeces were randomly allocated into 12 lots of 10 fleeces each. A staple was removed from the side and britch of each fleece and number of crimps per inch was measured. Fleeces from six lots within each type were placed on a skirting table and britches removed, while fleeces from the remaining six lots were left with britches intact (unskirted lots). Fleeces from one lot within each treatment-by-type combination were individually placed in a subsampler, compressed and cored. The remaining lots were sacked by lot, compressed and cored. In each case approximately 50 half-inch cores were taken per sample. Core samples were processed for yield, fiber diameter, fiber variability and prickle in accordance with standard test procedures D-584 and D-2130 (ASTM, 1993).

Biometric examinations of data were conducted using the GLM procedure of SAS (1984). The model used for analyses included the fixed effects of treatment (unskirted or britches removed) and type (uniform and variable) plus treatment-by-type interaction. Treatment-by-type interaction was not significant and therefore evaluations were conducted across treatment or type.

## Results and Discussion

In this study approximately 0.45 kg (12%) of wool was removed as britches. More britch wool was removed than is normally the case to assure that no britch wool remained in the "britches removed" lots. Willingham et al. (1984) indicated that removing britches accounted for approximately 5.7% of the total fleece weight. Table 1 shows the estimated average fiber diameter and crimp score for individual fleeces by fleece type and position on the sheep. Estimated side fiber diameter was similar for uniform and variable fleeces while uniform fleeces had finer britch fiber diameter ($P < 0.01$) and less variation between side and britch ($P < 0.01$) than variable fleeces. These data indicate that the variable fleeces are in fact more variable than uniform fleeces.

In all analyses treatment-by-type interactions were not significant ($P > 0.10$) and therefore data comparisons were made across type and treatment. The lack of a significant type-by-treatment interaction suggests that results obtained from britch removal were not affected by type of fleece. Type of fleece had no affect on fiber diameter, standard deviation or coefficient of variation (Table 2). In cored lots, uniform fleeces had fewer > 30 µm fibers (prickle) than did variable fleeces (1.82 vs. 2.72% respectively; $P < 0.10$). However, a similar trend was not observed in individual fleece cores.

Table 3 shows the effect of britch removal on core test results. Removal of britches did not affect fiber diameter in either individual fleece cores (21.32 vs. 22.06 µm for britches removed vs. skirted lots, respectively; $P > 0.10$) or cored lots (20.69 vs. 20.54 µm for britch removed vs. unskirted lots, respectively; $P > 0.10$). Willingham et al. (1984), reported similar results in flocks with average fiber diameters of 20.5 µm or less. Standard deviations were reduced ($P < 0.10$) in fleece cores with a similar trend, although not significant in lot cores ($P > 0.10$). Coefficient of variation was reduced in both fleece cores (18.11 vs. 19.30%; $P = 0.06$) and lot cores (19.02 vs. 20.14%; $P = 0.06$) by britch removal. Fiber diameter variation, measured by coefficient of variation, was reduced by about 6%. Australian research has shown that britch removal will only reduce total clip variation by 4% (Andrews et al., 1979). Percentage of fibers greater than 30 microns (prickle) was reduced in individual fleeces (2.87 vs. 5.30% for britches removed vs. unskirted fleeces, respectively; $P = 0.01$). A similar comparison in lot cores did not differ (2.3 vs. 2.2% for britches removed vs. unskirted lots, respectively; $P = 0.91$).

## Conclusions

Although the reduction in fiber diameter variation and prickle due to britch

**Table 1. Estimated grade and crimp score for individual fleece type and position on sheep.**

| | Fleece type | | | |
|---|---|---|---|---|
| | Uniform | Variable | SE | Pr |
| Number of fleeces | 120 | 120 | – | – |
| Estimated average fiber diameter, µm: | | | | |
| Side | 22.16 | 21.99 | 0.07 | 0.126 |
| Britch | 24.05 | 25.09 | 0.08 | 0.001 |
| Difference | 1.89 | 3.10 | 0.05 | 0.001 |
| Crimp score, crimps/inch: | | | | |
| Side | 14.94 | 14.35 | 0.22 | 0.066 |
| Britch | 11.22 | 10.46 | 0.23 | 0.011 |
| Difference | 3.72 | 3.95 | 0.24 | 0.495 |

removal observed in this trial was significant, it is doubtful that the magnitude of the differences are great enough to be biologically or economically significant. These results suggest that britch removal in a typical Rambouillet sheep flock may only slightly reduce fiber diameter variability and prickle effect. Excessive britch removal will have little affect on a clip's processing performance and will also reduce producers income.

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**Table 2. The effect of type of fleece on core test results.[a]**

| | Lot cores | | | | Fleece cores | | | |
|---|---|---|---|---|---|---|---|---|
| Item | Uniform | Variable | SE | Pr | Uniform | Variable | SE | Pr |
| Number | 10 | 10 | – | – | 20 | 20 | – | – |
| Yield, % | 48.99 | 50.33 | 0.66 | 0.17 | 49.82 | 49.84 | 0.70 | 0.98 |
| Fiber diameter, µm | 20.41 | 20.82 | 0.19 | 0.14 | 21.68 | 21.71 | 0.39 | 0.97 |
| Standard deviation, µm | 3.99 | 4.08 | 0.09 | 0.53 | 4.03 | 4.08 | 0.10 | 0.71 |
| Coefficient of variation, % | 19.55 | 19.60 | 0.39 | 0.93 | 18.53 | 18.88 | 0.44 | 0.58 |
| Fibers > 30 µm, % | 1.82 | 2.72 | 0.34 | 0.08 | 4.50 | 3.67 | 0.66 | 0.38 |

[a] Type comparisons were made across treatments since type-by-treatment interactions were not significant (P > 0.10).

**Table 3. The effect of britch removal on core test results.[a]**

| | Lot cores | | | | Fleece cores | | | |
|---|---|---|---|---|---|---|---|---|
| Item | Unskirted | Britches removed | SE | Pr | Unskirted | Britches removed | SE | Pr |
| Number | 10 | 10 | – | – | 20 | 20 | – | – |
| Yield, % | 49.97 | 49.35 | 0.66 | 0.52 | 48.69 | 50.97 | 0.70 | 0.03 |
| Fiber diameter, µm | 20.54 | 20.69 | 0.19 | 0.57 | 22.06 | 21.32 | 0.39 | 0.18 |
| Standard deviation, µm | 4.13 | 3.94 | 0.09 | 0.16 | 4.25 | 3.86 | 0.10 | 0.01 |
| Coefficient of variation, % | 20.14 | 19.02 | 0.39 | 0.06 | 19.30 | 18.11 | 0.44 | 0.06 |
| Fibers > 30 µm, % | 2.24 | 2.30 | 0.35 | 0.91 | 5.30 | 2.87 | 0.66 | 0.01 |

[a] Treatment comparisons were made across types as treatment-by-type interactions were not significant (P > 0.10).

# Dietary Chromium-Picolinate Does Not Influence Growth or Carcass Composition in Feedlot Lambs[1,2]

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## Summary

The purpose of this study was to determine if chromium-picolinate (CrP) influences performance and carcass composition of growing market lambs. Twenty-seven Polypay wethers were fed a cracked corn-alfalfa diet that contained 0, 500 or 1,000 ppb of CrP for 63 days, from 34 to approximately 50 kg of live weight. Feeding CrP did not affect average daily gain (ADG), dry matter intake (DMI) or ADG:DMI ratios. Liver Cr concentrations were greater (P = 0.02) for lambs fed either 500 or 1,000 ppb CrP than for lambs fed no CrP. Carcass values and carcass composition were not affected by feeding CrP. Others have reported positive effects of CrP in swine. Thus it is possible that in sheep the concentration of dietary CrP may have to be much greater to significantly change carcass composition.

**Key words:** lambs, growth, carcass, composition, chromium picolinate.

## Introduction

Dietary Cr has been shown to augment the rate of insulin-stimulated glucose clearance in humans and pigs (Mertz, 1993; Lindeman et al., 1995). In pigs, dietary Cr as chromium-picolinate (CrP) increased ADG and decreased fat deposition when fed at a level to provide up to 200 ppb Cr (Page et al., 1993). Feeding growing calves up to 1 ppm of supplemental Cr from high-Cr yeast ameliorated stress, which resulted in increased DMI and ADG (Moonsie-Shageer and Mowat, 1993). Improved immune function in stressed calves, dairy heifers and cows also has been attributed to Cr supplementation (Moonsie-Shageer and Mowat, 1993; Burton et al., 1993). Bunting et al. (1994) recently reported that CrP had minimal effects on growth performance and plasma metabolites of growing Holstein calves, but that total plasma cholesterol was lowered and glucose tolerance improved. Kitchalong et al. (1993) reported decreased kidney, pelvic and heart fat and improved carcass yield grades in lambs fed CrP in a diet based on corn-cotton seed hull; however, CrP effects on overall carcass composition are not known. The purpose of this study was to determine if dietary CrP influences growth and carcass composition in feedlot lambs.

## Materials and Methods

Twenty-seven Polypay wether lambs, each weighing approximately 24 kg, were fed alfalfa hay ad libitum for 10 days. From day 11 to day 18, lambs were adjusted gradually to a control diet of 66% cracked corn, 33% dehydrated alfalfa pellets and 1% ground limestone. The basal diet contained 2.6 ppb Cr. At 34 ± 1 (SEM) kg of body weight the lambs were randomly assigned to one of three treatments: 0, 500 or 1,000 ppb CrP (12% Cr; Nutrition 21, San Diego, CA). A CrP premix was prepared and mixed at appropriate levels with the cracked corn, alfalfa pellets and ground limestone to produce the total mixed experimental diets. Nine lambs per diet were housed indoors with three lambs per pen (1.2 × 4.8 m). Animals were allowed to consume their diets on an ad libitum basis and had free access to fresh water and salt block (NaCl).

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All lambs were fed the experimental diets for 63 days. Full weights of lambs and feed refusals were determined every 14 days. After final weighing, lambs were shorn and transported to the University of Wyoming Meats Laboratory (approximately 10 km). The following morning they were slaughtered by electrical stunning and exsanguination according to federal standards for humane slaughter of lambs (CFR, 1987). Jugular blood was sampled by venipuncture and serum was harvested for cholesterol determination; cholesterol data were reported previously (Olsen, 1993).

After chilling for 24 hours, carcasses were measured between the 12th and 13th ribs to determine ribeye area and backfat thickness. Kidney and pelvic fat was removed and weighed, and flank streaking and leg scores were recorded for calculating yield and quality grades. Samples of liver and longissimus muscle were taken for Cr analysis.

The left side of each carcass was weighed and boned. Soft tissue was weighed and ground three times, once through a 9.5-mm mesh plate and twice through a 3-mm mesh plate. After each grind, the entire sample was thoroughly mixed. After the final mixing, eight random samples were taken, homogenized and stored at -20 °C for later analysis of carcass dry matter, crude protein (Kjeldahl N × 6.25) and ether extract (AOAC, 1990). Concentrations of Cr in longissimus muscle and liver samples were determined by AA spectrometry of acid-dissolved, dry-ash samples using a Perkin Elmer 3030 AA instrument (Anderson et al., 1985). Data were analyzed by ANOVA for a completely randomized design (SAS, 1985). Pen was used as the experimental unit in analyses of ADG, DMI and ADG:DMI ratio data. Carcass data and tissue Cr content were analyzed using individual animals as the experimental unit with animal-within-pen as error term. When ANOVA model probabilities were less than 0.1, linear and quadratic contrasts were calculated.

# Results and Discussion

Liver Cr concentration (Table 1) was greater (P = 0.02) for lambs fed either the 500 or 1,000 ppb CrP diets than for lambs fed the control diet. Muscle Cr concentration was not affected by dietary CrP (P = 0.4). Few reports on muscle Cr levels are available. The Cr concentration in bovine muscle was reported to be similar to that in bovine liver, but no indication of variability was indicated (Toepfer et al., 1973). Furthermore, muscle and liver Cr concentrations as reported by Toepfer et al. (1973) were a hundred-fold greater than values in the present study. More recent studies have shown human liver Cr concentration to be of similar magnitude as values observed in the present study (Iyengar and Woittiez, 1988). Sample preparation methods that circumvent contamination of samples with Cr likely contributed to the lower values reported in the later literature. No differences were observed for ADG, DMI or ADG:DMI ratios for either concentration of CrP.

Carcass values and carcass soft tissue composition (Table 2) were not affected by dietary CrP. Carcass fat appeared to decrease as dietary CrP increased, but no linear effect was observed (P = 0.5). Serum cholesterol concentrations were decreased by feeding CrP to lambs in the present

**Table 1. Tissue Cr levels and performance of lambs fed chromium-picolinate.**

| | Dietary chromium-picolinate, ppb | | | |
|---|---|---|---|---|
| Item | 0 | 500 | 1,000 | SEM |
| Fresh liver Cr, ng/g | 9.1[a] | 13.8[b] | 13.2[b] | 0.8 |
| Fresh Muscle Cr, ng/g | 8.2 | 5.2 | 6.8 | 1.6 |
| Performance: | | | | |
| Beginning BW, kg | 34.7 | 35.1 | 33.6 | 0.8 |
| Ending BW, kg | 51.1 | 49.8 | 48.9 | 1.0 |
| ADG, kg | 0.26 | 0.23 | 0.24 | 0.03 |
| DMI, kg | 1.16 | 1.11 | 1.11 | 0.10 |
| Gain-to-feed ratio | 0.22 | 0.21 | 0.22 | 0.01 |

[a,b] Liver Cr was greater with dietary CrP (P = 0.02).

**Table 2. Carcass values and carcass soft tissue composition of lambs fed chromium-picolinate.**

| | Dietary chromium-picolinate, ppb | | | |
|---|---|---|---|---|
| Item | 0 | 500 | 1,000 | SEM |
| Carcass values: | | | | |
| Hot carcass weight, kg | 26.2 | 25.3 | 24.6 | 0.6 |
| Dressing percentage | 51.4 | 50.7 | 50.4 | 1.0 |
| Body wall thickness, mm | 22.4 | 22.4 | 20.8 | 1.1 |
| Fat depth, mm | 5.8 | 5.8 | 5.1 | 0.8 |
| Kidney and pelvic fat, % | 3.4 | 3.4 | 3.2 | 0.2 |
| Ribeye area, $cm^2$ | 5.8 | 5.6 | 5.5 | 0.1 |
| Yield grade | 3.4 | 3.3 | 3.2 | 0.2 |
| Quality grade[a] | 12.0 | 12.0 | 12.2 | 0.2 |
| Carcass composition:[b] | | | | |
| Moisture, % | 50.9 | 51.1 | 51.9 | 1.2 |
| Protein, % | 14.9 | 14.7 | 15.1 | 0.4 |
| Fat, % | 34.0 | 33.4 | 31.8 | 1.3 |

[a] $Choice^0$ = 11; $Choice^+$ = 12; $Prime^-$ = 13.
[b] Boneless carcass.

study as previously reported by Olsen (1993), indicating that a metabolic response to CrP occurred. Bunting et al. (1994) reported no changes in ADG, DMI or ADG:DMI ratios in growing Holstein steers and heifers fed CrP in diets that consisted of 60 to 70% concentrates. Moreover, their cattle were fed 370 ppb of Cr as CrP, which is approximately 3,000 ppb CrP or threefold the CrP fed in the present study. Chang et al. (1992) found supplemental Cr ineffective in growing steers and attributed the lack of response to the low stress level of the steers.

With dietary concentrations of CrP similar to those used in the present study, decreased fat deposition and increased longissimus muscle areas in pigs were reported (Page et al., 1993; Lindeman et al., 1995). Page et al. (1993) demonstrated that the effects were due to CrP and not merely to the presence of Cr because $CrCl_3$ did not influence fat deposition or muscle area. Samsell and Spears (1989) observed minimal effects of $CrCl_3$ on blood parameters in lambs fed either low- or high-fiber diets.

The differences in responses to CrP between pigs and ruminants may occur because of the markedly different digestive systems and associated metabolism. In ruminants, CrP may be susceptible to ruminal microbial degradation or dilution due to the large ruminal volume. Feeding much larger doses of CrP to growing calves and lambs may change carcass composition. However, if ruminal degradation occurs, then a delivery system to protect the compound would be required. On the other hand, the lack of response to CrP in the present study may be attributed to low stress level in the lambs, similar to work by Chang et al. (1992) in steers.

## Conclusions

Whereas CrP was shown by others to alter carcass composition in pigs, feeding growing lambs 500 or 1,000 ppb CrP did not influence performance or carcass composition of lambs. Further studies with much greater dietary concentrations than 1,000 ppb CrP are needed to determine if this compound can be used successfully as a growth repartitioning feed additive for market lambs. The variation in muscle Cr concentration and the relatively small magnitude of change in liver Cr concentration in lambs fed CrP indicates that meat and organ residues of Cr would not have an impact on human health at the levels fed in this study.

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# Reproductive Performance and Wool Production of First Cross versus Selected *Inter se* Mated Finncross Ewes[1]

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## Summary

Reproductive performance of first-generation 1/4- and 1/2-Finnish Landrace crossbred ewes (F1) is generally improved due in part to favorable heterosis and/or breed complementarity. However, reproductive performance often decreases in later generations (F2, F3, etc.) because of genetic recombination and loss of heterotic effects. This study examined the efficacy of selection for total weight of litter weaned in *inter se* mated generations of crossbred ewes (1/2 Finnish Landrace-1/2 Rambouillet [1/2-FR], 1/2 Finnish Landrace-1/2 Targhee [1/2-FT], 1/4 Finnish Landrace-3/4 Targhee [1/4-FT], 1/4 Finnish Landrace-3/4 Columbia [1/4-FC]) to recover any loss of performance as observed in Finncross ewes (F2). The data consisted of 3,520 ewe matings from 1,436 ewes. Selection was based on dam's lifetime performance for total litter weight weaned. Traits observed included: prolificacy (lambs born per ewe lambing); net reproductive rate (lambs weaned per ewe exposed); total litter weight weaned; ewes' fall body weight; grease fleece weight; and wool grade score. Reproductive performance of F2 ewes was lower than that of F1. Selected *inter se* matings resulted in comparable reproductive performance of F1 with F3 and F4 generations. Associated responses of wool and body weight traits to selection were generally positive except for 1/2-FR fleece weight which decreased linearly to increasing F generations. Selective *inter se* breeding of Finn crossbred ewes recovers lost reproductive performance within three generations of selection for total litter weight weaned. Selective *inter se* mating of F1 cross ewes would be a relatively minor economic impediment in a transition from purebred ewes to a highly prolific composite two-breed type.

**Key words:** heterosis, selection, lamb, reproduction, wool.

## Introduction

Crossing meat-type sires on adapted western range breed ewes is a common strategy for utilizing heterosis in lamb growth and improving ewe traits and maternal characteristics. Three-breed cross programs are less frequently used even though near-maximum performance can be expected from a superior sire breed mated to two-breed cross females having desirable economic combinations of F1 maternal and transmitted performance characteristics (Dickerson, 1969). Use of such three-breed crossing strategies with range sheep has been complicated because of the economic importance of producing both meat and wool and the need for a strong flocking behavior for herding on large open range areas.

Phase-out of the wool incentive payment program has decreased the relative economic importance of wool production compared to lamb production. This has increased possible economic benefits for high levels of lamb production that can be achieved with a crossbreeding program (Knight and Snowder, 1995).

Logistic implementation of a three-breed crossing program might be simplified if replacement ewes could be selected from among an *inter se* mated maternal line of crossbreds rather than maintaining adequate selected purebred populations necessary for repeatedly creating first generation crossbreds. Although most of the penalty for *inter se* mating is included in the difference between heterosis of the F1 ewes and that

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retained in the more advanced generation *inter se* crosses (Dickerson, 1969), the system does exploit much of the crossbred maternal advantage. A composite genotype of high reproductive potential may make possible the needed selection intensity to rapidly retrieve a reproductive performance among advanced generation *inter se* ewes equal or even superior to F1 ewes (Mohd-Yusuff and Dickerson, 1991). The important question to be answered in the present study was whether or not selection over a relatively short period of time could offset the reduced heterosis increment and recombination loss resulting from *inter se* mating of the two breed cross.

## Materials and Methods

A study was commenced in 1973 to evaluate lifetime lamb and wool production of first generation 1/4- and 1/2-Finnish Landrace crossbred ewes (F1) in comparison with local purebred Rambouillet, Targhee and Columbia controls managed under range conditions (Ercanbrack and Knight, 1985). This breeding program was expanded in 1978 to eight contemporary breeding lines which included four F1 lines and four *inter se* mated selection lines of 1/2 Finn-1/2 Rambouillet (1/2-FR), 1/2 Finn-1/2 Targhee (1/2-FT), 1/4 Finn-3/4 Targhee (1/4-FT) and 1/4 Finn-3/4 Columbia (1/4-FC) ewes. The *inter se* mated lines consisted of individuals of F2 or greater generations and they were compared to F1 individuals of similar age. *Inter se* matings were defined as the mating within lines of crossbred rams of any generation with nonrelated crossbred ewes of any generation.

By 1982, mature ewe numbers had increased to approximately 70 head in each line (F1 and *inter se* mated). At that time, selection was commenced to regain any reduction of reproductive performance as measured as the difference between contemporary F1 and later-generation *inter se* mated ewes. Ultimately a total of 1,436 ewes were included in the study (Table 1), commencing from the base year (1982) and continuing through 1988. There were 3,520 mature ewe matings during the period, or an average of 2.45 matings per ewe.

Selection of replacement ewes and breeding rams was based on their dam's total litter weight at weaning (120 days); ewe records having been evaluated on the basis of lifetime average weight of lamb weaned regressed according to repeatability and number of records. Replacement ewe lambs were selected only from offspring of mature ewes (two years or older). Four breeding rams within each *inter se* mated genotype (1/2-FR, 1/2-FT, 1/4-FT, 1/4-FC) were annually selected from among all sound ram lambs available.

Selection criteria were modified only to minimize relationship of sires to ewes in their mating group (relationship coefficient of not more than 0.03) and to limit use of related sires within lines. During the course of the study a total of 26 Finn rams were used to produce Finncross rams of the various genotypes. Of 112 crossbred sires used in breeding groups, within-year sire relationship coefficient for five of the sires was 0.06; for 33 of the sires it was 0.03; and for 74 of the sires it was less than 0.03. Rams were mated at approximately seven months of age to minimize the generation interval. The F1 and *inter se* mated ewes of each genotype (1/2-FR, 1/2-FT, 1/4-FT, 1/4-FC) were equally divided among four single-sire breeding pens of approximately 34 ewes. The purpose for breeding rams only from the *inter se* mated genotype to F1 and later generation ewes was to remove any possible ram-within-line effect; it is doubtful that such an effect would be large on the response variables measured on the dam. Lamb growth can be influenced by sire effect which may bias the litter-weight-weaned variable. No data were observed on ewe lambs because they were flock-mated to Suffolk rams.

The study was intended to continue until the majority of the *inter se* mated population was of the F3 generation or greater. The replacement rate of F1

**Table 1. Numbers of ewes and lambs by crossbred generation.**

| Genotype[b] | Crossbred generation[a] 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1/2-FR: | | | | |
| Individual ewes | 180 | 50 | 44 | 90 |
| Ewe joinings | 410 | 140 | 132 | 186 |
| Lambs born[c] | 931 | 290 | 286 | 399 |
| 1/2-FT: | | | | |
| Individual ewes | 187 | 54 | 36 | 92 |
| Ewe joinings | 438 | 144 | 114 | 207 |
| Lambs born[c] | 1,009 | 300 | 248 | 464 |
| 1/4-FT: | | | | |
| Individual ewes | 172 | 52 | 52 | 76 |
| Ewe joinings | 407 | 154 | 142 | 174 |
| Lambs born[c] | 818 | 322 | 293 | 349 |
| 1/4-FC: | | | | |
| Individual ewes | 174 | 68 | 81 | 28 |
| Ewe joinings | 408 | 209 | 205 | 50 |
| Lambs born[c] | 756 | 376 | 392 | 91 |

[a] *Inter se* generation evaluated in coded groupings according to ewe Fn value where: 1 = F1; 2 = F2; 3 > F2 and ≤ F3; 4 > F3.

[b] Purebreds used in breed crosses were: Finnsheep (F), Rambouillet (R), Targhee (T), Columbia (C). Crossbreds were 1/2-F (half-Finns) or 1/4-F (quarter-Finns).

[c] Of the 7,324 total lambs born during the study period, 236 were grafted to foster dams not of their own cross generation and genotype (including lambs from each of the eight breeding groups and ranging from 18 that were F1 1/4-FT to 38 that were F1 1/2-FT). This small bias is included in analysis results.

and *inter se* groups was about 22% per year. It was hypothesized that decreased reproductive performance in F2 ewes would gradually improve as later generations selected for pounds of lamb weaned came into the line.

Three reproductive performance measurements were used annually to determine reproductive merit of each breeding group: 1) prolificacy = lambs born per ewe lambing; 2) net reproductive rate = lambs weaned per ewe exposed; and 3) litter weight weaned = total litter weight of lambs weaned (120 days) per ewe exposed. Three additional ewe traits recorded annually were: 1) ewes' fall live weight (approximately November 1); 2) grease fleece weight; and 3) wool grade (determined at shearing in mid-May). Wool grade was expressed as a code of visually estimated spinning count and ranged from 1 = 70s through 9 = 48s.

A breeding program with prolific ewes generally produces more lambs than the ewes are capable of sustaining. Therefore orphan lambs are common. When possible, extra lambs were fostered to ewes with a single or no surviving lamb. Remaining surplus lambs were reared artificially as orphans. For analytical purposes, all orphan lambs were considered to have died before weaning.

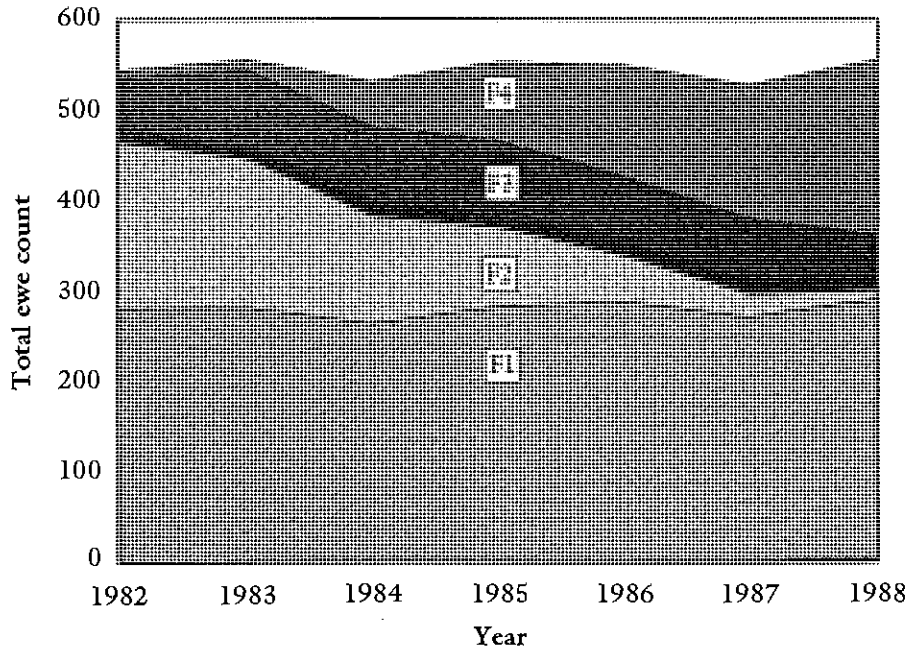
Fostering, a routinely used industry practice, is especially important to increasing the reproductive advantage of highly prolific ewes. Method of choosing lambs for fostering has been previously discussed by Snowder and Knight (1995). All lambs reared were included in number and litter weight of lambs weaned with credit partitioned equally among natural and foster mothers (Ercanbrack and Knight, 1985). Weight and numbers of lambs weaned were determined on the summer range in August when lambs were near an average age of 120 days.

*Inter se* mated ewes were classified according to their crossbred generation (Fn). An individual's Fn generation was determined by the formula: $Fn = [(F^{sire} + F^{dam})/2] + 1$. Individual Fn values and generation-coded Fn values were used for statistical analyses. Fn values were classified into four discrete coded generation groups: 1 = F1; 2 = F2; 3 > F2 and ≤ F3; 4 > F3. The distribution of animals by genotype and generation code are shown in Table 1.

All traits (prolificacy, net reproductiove rate, litter weight weaned, ewe fall weight, grease fleece weight, coded wool grade) were analyzed using least squares methods of analysis of variance (Harvey, 1990). Two statistical models were analyzed. Statistical model 1 included fixed effects for year, age of dam, coded Fn generation level (1, 2, 3, 4) and interactions. The use of coded Fn generation level permitted statistical comparison of selected *inter se* mated generation means. When the year-by-coded Fn generation level interaction was not significant ($P > 0.05$), individual Fn values were regressed on response variables to determine the rate of changes in response variables to increasing Fn generation values. Therefore, in statistical model 2 the coded Fn level was dropped and individual Fn values were included as a continuous independent variable as a linear and quadratic term. The best regression equation for describing the relationship among Fn values and the response variables was selected with significant effects of P-values greater than 0.08.

In evaluating total weight weaned, individual lamb weaning weights were previously corrected by least-squares procedures on a yearly basis for effects of age of lamb at weaning, sex and grazing band. Type of birth and rearing and breed group effects were also included in the model for weaning weight so that estimates of corrections for all other effects (age of lamb, sex, grazing band) would be unbiased by the latter effects. However, no correction for type of birth and rearing or genotype were made so that the relative merit of single or multiple birth and rearing and genotype would be properly reflected in total weight of lamb weaned by each ewe.

**Figure 1. Total ewe count pooled over genotype by crossbred Fn generation code.[a]**




[a] Where: 1 = F1; 2 = F2; 3 > F2 and ≤ F3; 4 > F3.

# Results and Discussion

By the end of the study, most *inter se* mated F2 ewes had been replaced by more advanced generation ewes

(Figure 1). The average Fn value increased for ewes and sires, respectively, of each group to 4.0 and 3.7 for 1/2-FR, 4.0 and 3.8 for 1/2-FT, 3.3 and 3.8 for 1/4-FT and 2.9 and 3.8 for 1/4-FC (Figures 2 and 3).

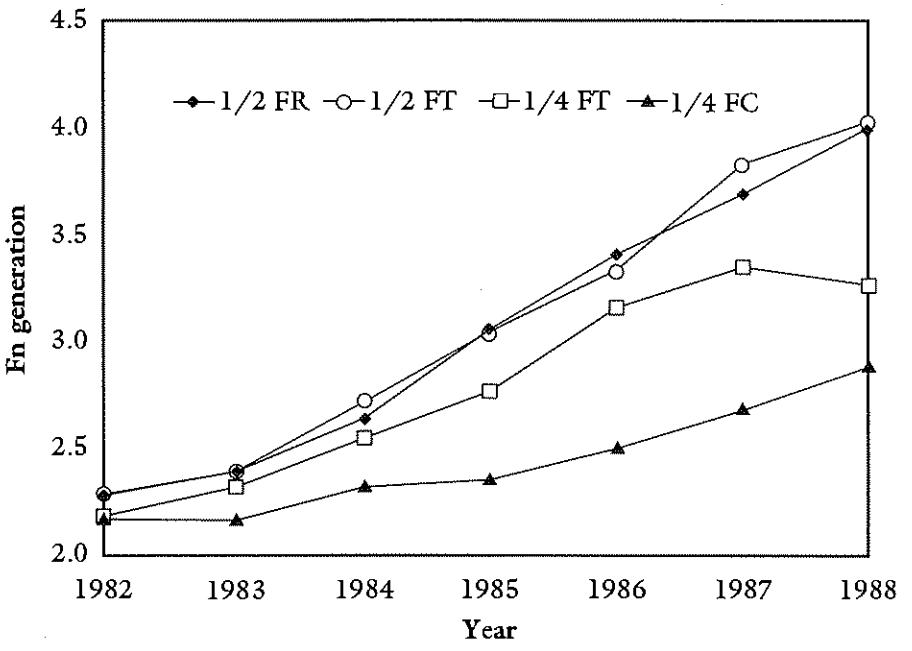
Selection intensities were similar among genotypes throughout the study. Of those available for each genotype, the 28 *inter se* rams used represented 6.86% of 1/2-FR, 6.28% of 1/2-FT, 6.56% of 1/4-FT and 7.98% of 1/4-FC. Superiority of rams selected for litter weight weaned, as measured in standard deviation units from the overall mean, was 1.0 for 1/2-FR, 1.1 for 1/2-FT, 1.2 for 1/4-FT and 1.1 for 1/4-FC.

There were no significant age of dam-by-generation level interactions within any genotype for any of the measured traits. Some significant year effects during the period reflect changes in management and/or other environmental conditions as previously noted by Ercanbrack and Knight (1994).

Heterosis for reproductive performance has been reported in the literature for Finnsheep crossed to U.S. adapted breeds in farm flock and range production systems (Fogarty et al., 1984; Young et al., 1986). Because of the absence in this study of information from reciprocal crosses and pure Finnsheep females, definitive measures of heterotic effects in F1 or *inter se* groups are not given. However, the loss in merit of reproductive traits from F1 to *inter se* F2 and subsequent recovery in later generation *inter se* groups are presented in this study.

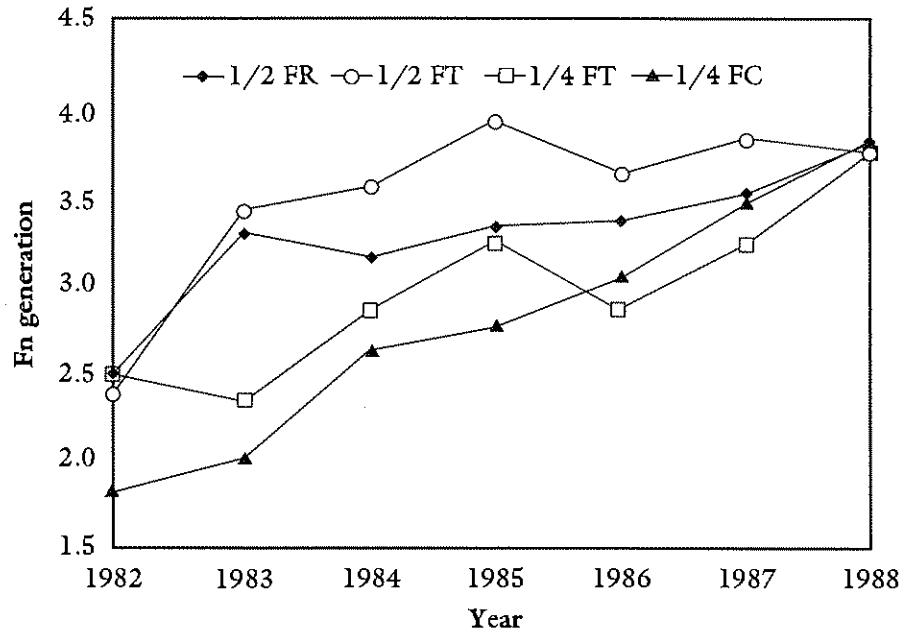
Reproductive trait means among Fn-coded generation of each genotype are presented in Table 2. Prolificacy was lower among selected *inter se* F2 generations compared to F1 (0 to -9%). Prolificacy was significantly different between F1 and *inter se* F2 1/2-FR ($P < 0.05$). An apparent response to selection among *inter se* ewes is indicated by the consistent increase in prolificacy across generations. Three generations of selection (the F4 generation) were necessary before prolificacy of *inter se* 1/2-FR ewes was equal to that of F1 ewes. Only two generations of selection (the

**Figure 2. Increase in average Fn value[a] by year for *inter se* mated ewes of 1/2 FR[b], 1/2 FT[c], 1/4 FT[d] and 1/4 FC[e].**




[a] Fn = [($F^{sire}$ + $F^{dam}$)/2] + 1.
[b] 1/2-FR = 1/2 Finn-1/2 Rambouillet.
[c] 1/2-FT = 1/2 Finn-1/2 Targhee.
[d] 1/4-FT = 1/4 Finn-3/4 Targhee.
[e] 1/4-FC = 1/4 Finn-3/4 Columbia.

**Figure 3. Increase in average Fn value[a] by year for *inter se* mated sires of 1/2 FR[b], 1/2 FT[c], 1/4 FT[d] and 1/4 FC[e].**




[a] Fn = [($F^{sire}$ + $F^{dam}$)/2] + 1.
[b] 1/2-FR = 1/2 Finn-1/2 Rambouillet.
[c] 1/2-FT = 1/2 Finn-1/2 Targhee.
[d] 1/4-FT = 1/4 Finn-3/4 Targhee.
[e] 1/4-FC = 1/4 Finn-3/4 Columbia.

F3 generation) were required for *inter se* 1/2-FT ewes to have prolificacy rates similar to F1 1/2-FT ewes. The selection response in prolificacy was more pronounced among quarter-Finns compared to half-Finns. Inasmuch as the reduced heterosis increment and recombination loss among *inter se* quarter-Finns would not be expected to be as great as among half-Finns, the quarter-Finns should be expected to perform better relative to initial F1 ewes than comparable half-Finns.

Net reproductive rate (lambs weaned per ewe exposed) means followed a pattern similar to that of prolificacy. The F2 *inter se* mated populations had an equal or lower net reproductive rate (0 to -16%) when compared to F1 populations. Significant mean differences were found among 1/2-FT ewes where the F1 net rate (1.59) was greater than that of *inter se* F2 (1.34) and F3 (1.47; $P < 0.05$). Net rate was comparable among late generation *inter se* ewes and F1; the implication is that the performance loss had been recovered by selection in later generation *inter se* mated ewes.

Litter weight weaned mean differences also followed a similar pattern among F1 and *inter se* mated groups as prolificacy and net rate. The greatest differences between F2 and F1 ewes for litter weight weaned were observed for half-Finn ewes (1/2-FR and 1/2-FT; 15% and 20%, respectively). Selection for litter weight weaned among *inter se* mated populations was positive and F3 and F4 production levels were equal to that of F1. The largest selection responses were among half-Finn crossbreds.

Regression of Fn values on prolificacy and net rate indicated selection responses for reproductive traits were curvilinear, but were significant for only two genotypes. Year effects were not significant ($P > 0.10$); and age of dam was only of significance in examining prolificacy. Regression lines for prolificacy of 1/2-FR ewes ($y = 2.05 - 0.07\ Fn + 0.04\ Fn^2$; $R = 0.20$) and net reproduction rate of 1/2-FT ewes ($y = 1.37 - 0.09\ Fn + 0.05\ Fn^2$; $R = 0.11$) had a quadratic relationship with Fn values (Figure 4). Regression analyses confirms the results of statistical model 1 analyzing coded Fn generation (1, 2, 3, 4) in that reproductive traits did improve in latter selected generations.

Favorable response to selection for litter weight weaned was expected because it was the single trait of selection emphasis. Therefore, increases in litter weight weaned occurred in every generation and genotype. Selection responses of associated reproductive traits (prolificacy and net reproduction rate) were also expected because litter weight weaned is dependent upon fertility and prolificacy, as well as maternal ability, milk production, lamb growth and survival. Although the small increases in prolificacy and net reproduction rate after F2 generations were not always statistically significant, the trend suggests a positive genetic relationship with litter weight weaned.

The decrease in reproductive performance among F2 generations when compared to F1 is consistent with reported heterosis and recombination effects (Dickerson, 1969; Dickerson, 1973). Fogarty (1984) observed significant heterosis for reproduction traits of composite genotypes, but suggested that lack of decline in merit in advancing generations of Finncross composite lines beyond what would be explained by the expected reduction from first-cross heterozygosity indicated unimportant loss due to recombination effects. This suggests that selection can be effective in offsetting heterosis loss, thus making composite dam lines a possible alternative to the continual production of F1 replacement ewes. In our study, selection resulted in reproductive traits being similar among late-generation *inter se* (F3 or F4) and F1 groups of the same genotype.

**Table 2. Least squares means of reproductive traits by crossbred generation.**

| Trait and genotype[b] | *Inter se* generation[a] 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Prolificacy: | | | | |
| 1/2-FR | 2.35[c] | 2.11[d] | 2.21[d,e] | 2.30[c,e] |
| 1/2-FT | 2.31 | 2.20 | 2.30 | 2.34 |
| 1/4-FT | 2.03 | 1.98 | 2.08 | 2.07 |
| 1/4-FC | 1.95 | 1.97 | 2.00 | 2.01 |
| SE range | 0.03 to 0.04 | 0.05 to 0.13 | 0.04 to 0.08 | 0.05 to 0.09 |
| Net rate: | | | | |
| 1/2-FR | 1.56 | 1.43 | 1.46 | 1.56 |
| 1/2-FT | 1.58[c] | 1.34[d] | 1.47[c,d] | 1.48[c,d] |
| 1/4-FT | 1.47 | 1.47 | 1.49 | 1.50 |
| 1/4-FC | 1.44 | 1.34 | 1.43 | 1.47 |
| SE range | 0.04 to 0.05 | 0.07 to 0.08 | 0.06 to 0.07 | 0.06 to 0.11 |
| Litter weight, lb: | | | | |
| 1/2-FR | 108.6[c,d] | 94.1[e] | 100.0[c,e] | 112.1[d] |
| 1/2-FT | 110.0[c] | 91.9[d] | 100.0[c,d] | 108.8[c] |
| 1/4-FT | 107.1 | 106.2 | 109.5 | 108.9 |
| 1/4-FC | 109.2 | 102.1 | 106.5 | 110.1 |
| SE range | 2.53 to 3.24 | 4.75 to 5.72 | 4.18 to 5.04 | 3.94 to 8.37 |

[a] *Inter se* generation evaluated in coded groupings according to ewe Fn value where: 1 = F1; 2 = F2; 3 > F2 and ≤ F3; 4 > F3.

[b] Purebreds used in breed crosses were: Finnsheep (F), Rambouillet (R), Targhee (T), Columbia (C).

[c,d,e] Row means with different superscripts differ ($P < 0.05$).

Fall body weight, fleece weight and wool grade means are presented in Table 3. Body weight of each F2 genotype was significantly less ($P < 0.05$) than F1s; but weight had recovered among the later-generation *inter se* groups. Increased ewe body weights at breeding were associated with selection for 120-day litter weight weaned among purebred Rambouillet, Targhee, Columbia and Polypay during the same time period (Ercanbrack and Knight, 1994).

Changes in fleece weight and wool grade were more random among the F1 and *inter se* groups. Fleece weights of F2 ewes were lower than that of F1 ewes; but later-generation ewes had similar fleece weights except for 1/2-FR ewes. Fleece weight declined among later-generation 1/2-FR ewes ($P < 0.05$) when compared with F1, but wool grade was unchanged. Wool grade of the other genotypes was slightly coarser among the late-generation *inter se* ewes.

Statistical model 2 identified a negative linear association between grease fleece weight and Fn values of 1/2-FR ewes ($y = 8.2 - 0.27$ Fn; $R = 0.32$; Figure 5). Because selection was for reproductive performance, negative genetic correlations among reproduction and fleece traits can explain the downward trend in fleece weights among 1/2-FR ewes. Genetic correlations among reproductive traits and fleece weights are mostly small and negative estimates ranging from -0.52 to 0.27 with a mean of -0.10 (Land et al., 1983).

Wool grade scores had a small positive linear relationship with Fn values for 1/2-FT ($y = 5.39 + 0.112$ Fn; $R = 0.34$) and 1/4-FC ($y = 5.74 + 0.121$ Fn; $R = 0.22$; Figure 5). These results were similar to those observed in statistical model 1 using LSM for Fn generation codes. Little or no change in fiber diameter in the presence of selection for total weight weaned is explained by small negative correlations among reproduction traits and fiber diameter (average genetic r = -0.10; Turner and Young, 1969).

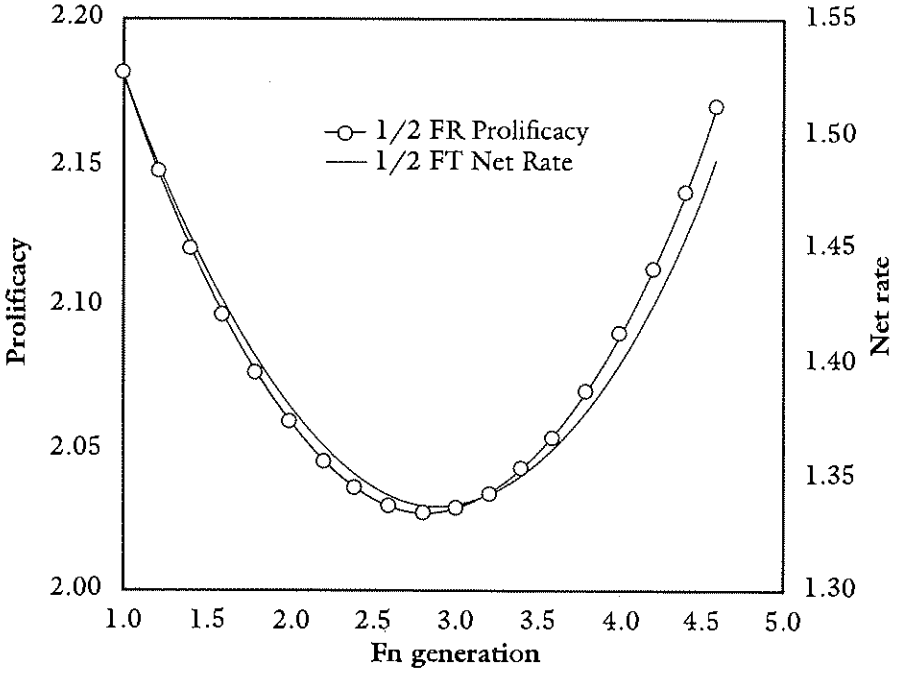
Changes in fall body weight were also curvilinear to Fn values ($P < 0.05$) for 1/2-FR ($y = 147 - 2.34$ Fn $+ 1.09$ $Fn^2$; $R = 0.23$) and 1/4-FT ($157 - 2.08$ Fn $+ 2.64$ $Fn^2$; $R = 0.38$; Figure 6). Significant fixed effects included year, age of dam and their interaction for 1/4-FT genotypes; but only year was a significant effect for 1/2-FR. These regression analyses also confirmed the results of statistical model 2; a decrease in body weight occurs in early generations, but increases in later generations. The increase in body weight associated with increasing Fn values is attributed to the positive genetic relationship between body weight and number of lambs born (genetic r = 0.35; Shelton and Menzies, 1968) and fertility (genetic r = 0.17; Turner and Young, 1969).

The associated responses of fleece weight, wool grade and fall body weight to direct selection for total litter weight weaned were in agreement with published estimates of genetic correlations among the traits. The only unfavorable production response was observed in fleece weight for 1/2-FR genotypes. However, based on the present economic value for lamb and wool, the additional economic profit in lamb production from 1/2-FR ewes compared to purebred Rambouillet ewes offsets any loss in wool production (Knight and Snowder, 1995).

# Conclusions

Lambing performance of F1 quarter-Finn and half-Finn crossbred ewes results in an increase of 34 and 46% in numbers of lambs weaned and 30 and 38% heavier total litter weight weaned for quarter- and half-Finn crossbred ewes, respectively, when compared to the average performance of Rambouillet, Targhee and Columbia purebreds (Ercanbrack and Knight, 1989). However, reproductive performance is decreased in following generations due to genetic recombination and decreased heterosis. This study shows that selective *inter se* breeding of Finn crossbred ewes can recover the lost reproductive performance within three generations of

**Figure 4. Regression lines estimating changes in prolificacy for 1/2-FR ewes and net reproductive rate for 1/2-FT that occur as the average Fn generation value[a] increases for selected *inter se* mated ewes.[b]**




[a] $Fn = [(F^{sire} + F^{dam})/2] + 1$.

[b] Prolificacy is defined as lambs born per ewe lambing and net reproductive rate is the number of lambs weaned per ewe exposed at breeding.

selection for total litter weight of lamb weaned. This breeding approach will not require the need for constant regeneration of F1 ewes. This study also suggests that selective *inter se* mating of F1 cross ewes would be a relatively minor economic impediment in a transition from purebred ewes to a highly prolific composite two-breed type. Notably, the relatively minor temporary loss in reproductive performance due to genetic recombination and loss of heterosis during early generation formation of the two-breed composite would not decrease performance below that of adapted western range breed purebreds.

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**Table 3. Least squares means for ewe fall body weight, fleece weight and wool grade by crossbred generation.**

| | *Inter se* generation[a] | | | |
|---|---|---|---|---|
| Trait and genotype[b] | 1 | 2 | 3 | 4 |
| Fall body weight, lb: | | | | |
| 1/2-FR | 153.4[d] | 141.4[e] | 147.7[f] | 152.0[d] |
| 1/2-FT | 154.2[d] | 148.8[e] | 153.5[d] | 156.8[d] |
| 1/4-FT | 165.2[d] | 157.9[e] | 160.5[e] | 166.5[d] |
| 1/4-FC | 162.1[d] | 157.2[e] | 159.3[d,e] | 158.0[d,e] |
| SE range | 0.8 to 1.0 | 1.5 to 1.9 | 1.2 to 1.6 | 1.3 to 2.5 |
| Fleece weight, lb: | | | | |
| 1/2-FR | 8.6[d] | 7.9[e] | 8.1[e] | 7.6[e] |
| 1/2-FT | 8.4[d] | 7.9[e] | 8.7[d] | 8.5[d] |
| 1/4-FT | 9.9[d] | 9.7[d,e] | 9.5[e] | 9.8[d,e] |
| 1/4-FC | 10.1[d,e] | 9.8[d] | 10.3[e] | 9.8[d,e] |
| SE range | 0.08 to 0.11 | 0.17 to 0.22 | 0.14 to 0.20 | 0.12 to 0.28 |
| Wool grade[g]: | | | | |
| 1/2-FR | 4.8 | 4.9 | 4.7 | 4.7 |
| 1/2-FT | 5.3[d] | 5.4[d,e] | 5.5[d,e] | 5.6[e] |
| 1/4-FT | 4.9 | 4.9 | 5.0 | 5.0 |
| 1/4-FC | 5.7[d] | 5.8[d,e] | 6.0[e] | 5.8[d,e] |
| SE range | 0.06 to .07 | 0.12 to 0.13 | 0.10 to 0.12 | 0.09 to 0.20 |

[a] *Inter se* generation evaluated in coded groupings according to ewe Fn value where: 1 = F1; 2 = F2; 3 > F2 and ≤ F3; 4 > F3.

[b] Purebreds used in breed crosses were: Finnsheep (F), Rambouillet (R), Targhee (T), Columbia (C).

[c,d,e,f] Row means with different superscripts differ ($P < 0.05$).

[g] Wool grade codes of spinning count range from 1 = 70s through 9 = 48s.


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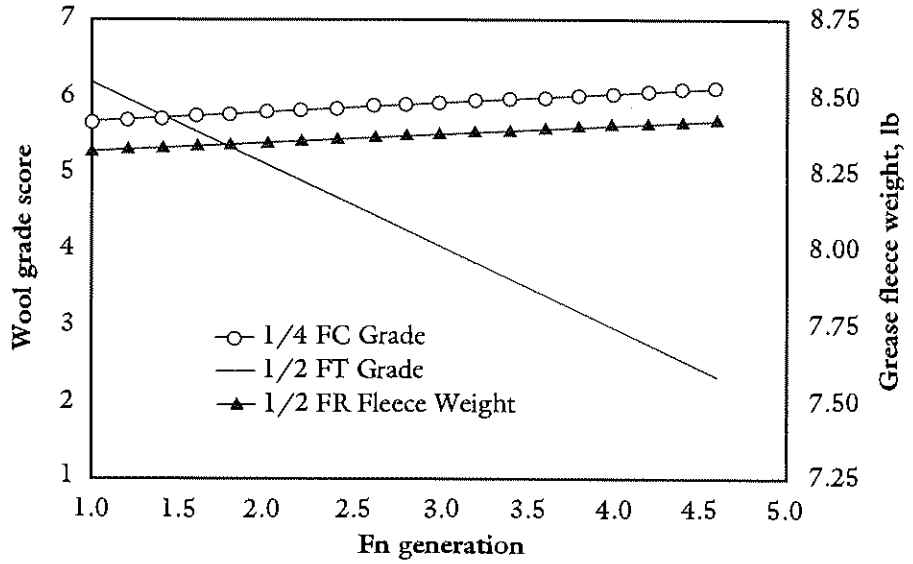
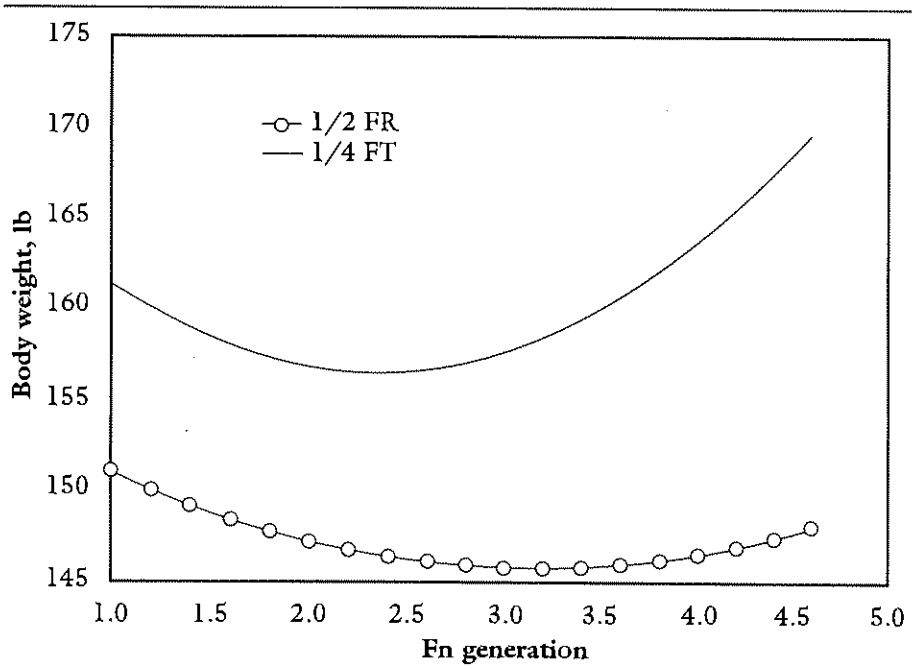
**Figure 5. Regression lines estimating changes in wool traits (grease fleece weight for 1/2-FR ewes, and wool grade score for 1/2-FT and 1/4-FC ewes) that occur as the average Fn generation value[a] increases for selected *inter se* mated ewes.[b]**




[a] $Fn = [(F^{sire} + F^{dam})/2] + 1$.

[b] Wool grade was expressed as a code of visually estimated spinning count and ranged from 1 = 70s through 9 = 48s.

**Figure 6. Regression lines estimating changes in fall body weight for 1/2-FR ewes and 1/4-FT ewes that occur as the average Fn generation value[a] increases for selected *inter se* mated ewes.**




[a] $Fn = [(F^{sire} + F^{dam})/2] + 1$.

# Use of a Rapid Progesterone Radioimmunoassay to Predict Pregnancy and Fetal Numbers in Ewes[1,2]

F.A. Schneider[3] and D.M. Hallford[3,4]

## Summary

The feasibility of quantifying progesterone ($P_4$) in a single serum sample for pregnancy determination and prediction of fetal numbers at 100 days of gestation was investigated. A total of 341 blood samples were collected from ewes (one to seven years of age) and were used for a three-year study. Each year, ewes were shorn in late January and blood was collected one week after shearing. Serum $P_4$ values were compared with lambing data to assess their accuracy for pregnancy diagnosis and for prediction of lamb numbers. Ewes with $P_4 \leq 2.4$ ng/mL were considered non-pregnant, while ewes with a $P_4$ concentration $\geq 2.5$ ng/mL were considered pregnant. Ewes with $P_4$ from 2.5 to 10.9 ng/mL had one lamb and ewes with more than 11 ng/mL had multiple lambs. Pregnancy was accurately diagnosed in 111 of 113 (98%) ewe lambs and in 224 of 227 (99%) mature ewes with an overall accuracy of 98% (335/340) when serum was collected at 100 ± 9 days of gestation. Fetal numbers were estimated with 88% accuracy in ewe lambs, with 74% accuracy in mature ewes and with 79% accuracy when all ages were combined. This method of pregnancy diagnosis provides comparable accuracy to ultrasound.

**Key words:** sheep, progesterone, pregnancy diagnosis, fetal numbers.

## Introduction

The importance of accurate pregnancy diagnosis has been recognized for many years and used for culling and altering feeding regimens. Nutritional status is particularly important during the last 50 days of pregnancy for both the ewe and feti (Holst et al., 1986; Hallford and Sanson, 1983).

Various methods of pregnancy diagnosis have been developed. Although many of these methods are practical and useful they all require training, equipment expense and labor involved in gathering and handling sheep. An experienced operator using rectal-abdominal palpation with a rod can detect pregnancy by 70 days after breeding with 100% accuracy (Hulet, 1972). Trapp and Slyter (1983), using the same method from 60 to 96 days of gestation, achieved 63% accuracy and experienced some death loss from peritonitis and abortions. Ultrasound imaging has yielded 77 to 99% accuracy in predicting fetal numbers in sheep (Fowler and Wilkins, 1984; Hallford et al., 1990; Veserat et al., 1993). Initial cost of equipment and operator experience are limiting factors to this method of pregnancy diagnosis (Goel and Agrawal, 1992; Veserat et al., 1993).

Hormone analysis also is a tool for pregnancy determination. Progesterone ($P_4$) and pregnancy-specific protein B have been investigated for use in pregnancy determination in sheep (Ruder et al., 1988; Hallford et al., 1990). Plasma $P_4$ has been shown to rise steadily between days 50 and 120 of gestation in sheep, with ewes carrying twins having about twice the concentration of $P_4$ as ewes carrying single lambs during the last 50 days (Bassett et al., 1969; Stabenfeldt et al., 1971). Various methods have been used to quantify serum $P_4$ including radioimmunoassay (RIA) and enzyme-linked immunoassay. Pregnancy diagnosis using these methods was about 90% accurate (Goel and Agrawal, 1992). Gadsby et al. (1972) predicted fetal numbers based on $P_4$ concentration with 69% accuracy. The purpose of this study

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was to determine whether serum $P_4$ measured at a convenient time for producers (i.e., at shearing) using a solid-phase direct serum RIA could be used to predict fetal numbers.

## Materials and Methods

A total of 341 blood samples were collected from Debouillet ewes during the three-year study. Ewe lambs were added each year while mature ewes were maintained within the herd. Ewes were grouped as ewe lambs (bred to lamb at one year of age) or mature (two to seven years of age) with distribution by year shown in Table 1. All ewes were maintained under ambient conditions on the campus of New Mexico State University. Ewes were fed pelleted alfalfa (17% crude protein [CP]) and cracked corn in amounts appropriate for stage of gestation and had free access to water, salt, mineral and shade. In mid-October of each year, ewes were joined with fertile rams fitted with marking harnesses for a 34-day breeding period. Breeding marks were used to calculate approximate stage of gestation at blood sampling and lambing dates. Ewes were shorn in late January and a single blood sample was collected from each ewe one week after shearing. Blood was collected into serum separator tubes via jugular venipuncture and was allowed to clot at room temperature for 30 minutes. Serum was harvested after centrifugation at 1,500 × g for 15 minutes at 4 °C and stored at -20 °C until analyzed for progesterone. At lambing, during March and April, the number of lambs was recorded.

Serum progesterone was quantified using a commercial RIA kit (Coat-A-Count; Diagnostic Products Corporation, Los Angeles, CA). The procedure is a solid-phase, antibody-coated tube assay using $^{125}I$-$P_4$ as the tracer and requires no extraction of serum (the tracer solution also liberates $P_4$ from its binding protein). The kit was modified for use with ovine serum by adding 50 µL of serum from a chronically ovariectomized ewe to each standard which was prepared in 0.01 M phosphate buffered saline plus 0.1% gelatin (PBS+gel). Duplicate 50 µL serum samples from pregnant and non-pregnant ewes were assayed and all tubes were normalized to 500 µL using PBS+gel. Tracer solution (500 µL) was then added to all tubes. Following a brief vortexing, tubes were incubated at room temperature for three hours after which the supernatant was decanted. Radioactivity in fractions bound to the tube was determined by counting each tube for one minute in a gamma counter (Packard Auto Gamma 500C; Packard Instrument Company, Downers Grove, IL). The detection limit of the assay was 0.01 ng/mL. Recovery of $P_4$ added to serum was 108%. Within and between assay coefficients of variation were 7.0% and 10.0%, respectively. As an additional step in validating this method, 23 ovine samples were assayed using both this procedure and the charcoal-dextran, benzene:hexane extraction assay previously described by Hallford et al. (1982). Means were 6.8 and 6.4 ng/mL for the extraction and antibody-coated tube methods, respectively, and the correlation coefficient for the two procedures was 0.96 ($P < 0.01$). These assay validation results are similar to those reported for this RIA kit by Hamra et al. (1986).

Serum $P_4$ values were initially examined by analysis of variance in which number of lambs, ewe age, year and all interactions were included in the model. This procedure revealed a ewe age-by-year interaction ($P < 0.05$) necessitating that year and age effects be examined cautiously. Therefore, data were summarized by year and age group using the frequency procedure of SAS (1989). Effects of fetal number on serum $P_4$ were evaluated within ewe age by analysis of variance (Snedecor and Cochran, 1967) computed by GLM procedures of SAS (1989).

## Results and Discussion

### *Model Formulation*

In 1993, 19 ewe lambs did not produce offspring, 20 had single lambs and 3 had multiple offspring; 8, 24 and 24 mature ewes had zero, one or two lambs, respectively. Serum was collected during the first week of February at 102 ± 10 (mean ± SD) days of gestation as calculated from marks recorded during breeding. After all ewes had lambed, $P_4$ values were analyzed according to the number of lambs born. Progesterone values (mean ± SE) pooled across age differed ($P < 0.01$) among ewes having zero, one or two lambs. Ewes not producing a lamb had a mean $P_4$ concentration of 0.4 ± 0.8 ng/mL and ranged from 0.1 to 2.4 ng/mL. Ewes that had one lamb ranged from 1.9 to 21.5 ng/mL with a mean concentration of 7.1 ± 0.6 ng/mL, while ewes that had two or more lambs ranged from 5.6 to 32.7 ng $P_4$/mL with a mean of 16.5 ± 0.8 ng/mL. When serum $P_4$ concentration for 1993 was used as the dependent variable in regression analysis with lamb number, the slope of the regression line was 7.9 ng/mL with a standard error of estimate of 4.7 ng/mL.

Using these values, a model was formulated to predict pregnancy and fetal numbers from a single $P_4$ value. The $P_4$ values that most consistently predicted pregnancy were: 1) ewes having a $P_4$ concentration ≤ 2.4 ng/mL were considered non-pregnant; and 2) ewes with a $P_4$ concentration ≥ 2.5 ng/mL were considered pregnant. In order to predict fetal

**Table 1. Distribution of ewes by age group and year used for determination of pregnancy and prediction of fetal numbers.**

| Year | Ewe lambs | Mature ewes[a] | Total |
|---|---|---|---|
| 1993 | 42 | 56 | 98 |
| 1994 | 40 | 88 | 128 |
| 1995 | 31 | 84 | 115 |
| Total | 113 | 228 | 341 |

[a] Mature ewes were from two to seven years of age.

numbers, the following criteria were used: 1) ewes having a $P_4$ concentration ≤ 2.4 ng/mL were considered to have no lambs; 2) ewes with a $P_4$ concentration ≥ 2.5 ng/mL but ≤ 10.9 ng/mL were estimated to have one lamb; and 3) ewes with a $P_4$ concentration ≥ 11.0 ng/mL were estimated to have two or more lambs. If the predicted value matched the actual number of lambs born, the prediction was considered accurate. If these values did not agree, the prediction was considered inaccurate.

### *Pregnancy Diagnosis*

In order to check the accuracy of the model, $P_4$ concentrations obtained in 1993 were fit to the model and checked against actual lamb numbers. Following the criteria of the model, pregnancy was correctly determined in 40 of 42 ewe lambs for 95% accuracy (Table 2). When mature ewes were considered, 8 ewes were considered to be open and 48 to be pregnant for 100% accuracy. When all ages were combined, pregnancy was predicted with 98% accuracy.

In 1994, pregnancy was accurately determined in 127 of 128 ewes when $P_4$ was quantified in serum obtained at 100 ± 8 days of gestation. Similar results were obtained in 1995, with an overall accuracy of pregnancy diagnosis of 98% (113 of 115) when ewes of all ages were considered. Pregnancy was accurately determined in 100% of ewe lambs, while pregnancy was accurately determined in 98% (82 of 84) mature ewes. The two ewes incorrectly diagnosed had been determined to be pregnant with $P_4$ concentrations of 4.1 and 6.5 ng/mL. These two ewes were later considered to be cycling at the time of blood sampling, but the possibility exists that fetal reabsorption could have occurred if the ewes were carrying a small single fetus. When the results from the three years were combined, pregnancy was accurately diagnosed in 335 of 340 ewes when $P_4$ was quantified in a single serum sample obtained at 100 ± 9 days of gestation.

Accuracy of pregnancy determination in the present study was greater than the 90% accuracy reported by Gadsby et al. (1972). The rate of accuracy was similar to the 95% achieved by Willard et al. (1994) who used $P_4$ for pregnancy determination in elk cows after 100 days of gestation. Similar results in pregnancy determination were obtained by Fowler and Wilkins (1984) at various stages between 40 and 96 days of gestation and Goel and Agrawal (1992) between 45 and 50 days of gestation, both using ultrasound.

### *Progesterone Concentration Related to Fetal Numbers*

Mean $P_4$ concentrations in ewes carrying twin lambs has been estimated to be twice that in ewes with a single lamb (Bassett et al., 1969). In 1993, $P_4$ values (Table 3) pooled across age differed ($P < 0.01$) among ewes having zero, one or multiple lambs (0.4, 7.1 and 16.5 ± 0.8 ng/mL, respectively). Similar differences ($P < 0.01$) were observed when ewes were divided by age. Throughout this study, mean $P_4$ concentration measured in ewes that had zero, one or two or more lambs differed consistently (Table 3). Ewes that produced multiple lambs consistently had approximately a two-fold greater concentration than ewes that had a single lamb. The increase in serum $P_4$ with fetal numbers and the wide range of variability among individual ewes are consistent with results reported by Basset et al. (1969). Very high $P_4$ values in individual ewes may be partially explained by fetal weight. The correlation coefficient for $P_4$ and lamb birth weight in this study was 0.55 ($P < 0.01$). With an increase in the total fetal weight, an increase in placental mass would be expected which could lead to an increase in placental $P_4$ production. Stabenfeldt et al. (1971) reported increased $P_4$ production from days 75 to 125 of gestation for ewes with single lambs and days 55 to 130 for ewes with twins. With increased fetal weights, ewes that are sampled at 100 days of gestation would likely be experiencing increased $P_4$ within these time limits.

### *Prediction of Fetal Numbers*

The $P_4$ ranges used in this model yielded 86% accuracy in predicting fetal numbers for all ages in 1993 (Table 4). Two ewe lambs that had produced a single lamb had been predicted to be open. Prediction of fetal numbers in lambs was 95% accurate. The prediction model yielded 80% accuracy in mature ewes. Of the 11 incorrect predictions, six ewes were predicted to have multiple lambs when they only produced single lambs. Additionally, five ewes that had produced multiple lambs had been predicted to have single lambs.

In 1994, fetal numbers were predicted prior to lambing. Once all ewes had lambed, accuracy of the model was determined. When all age groups were considered, fetal numbers were accurately predicted in 102 of 128 ewes (80%). Fetal numbers were accurately predicted in 33 of 40 ewe lambs

**Table 2. Accuracy (%) of serum progesterone in predicting pregnancy in sheep.[a,b,c]**

| | Age | | |
|---|---|---|---|
| Year | Ewe lambs | Mature ewes | Overall |
| 1993 | 95 | 100 | 98 |
| 1994 | 100 | 99 | 99 |
| 1995 | 100 | 98 | 98 |
| Combined years | 98 | 99 | 98 |

[a] Serum samples were collected one week after shearing each year. Shearing was accomplished in late January. Ewes were at approximately 100 days of gestation at the time of sampling (calculated from marks recorded during breeding season).

[b] Prediction model for pregnancy determination: progesterone ≤ 2.4 ng/mL = not pregnant; progesterone ≥ 2.5 ng/mL = pregnant.

[c] If predicted status for an individual ewe agreed with actual status at lambing, the prediction for that ewe was considered "accurate". The number of accurate predictions divided by total number of ewes in each group was percentage accuracy.

(82%). Two ewes, predicted to have single lambs, produced twins and five ewes predicted to have twins only produced single lambs. When mature ewes were analyzed, fetal numbers were accurately predicted in 69 of 88 ewes (78%). One ewe, with 3.9 ng $P_4$/mL, was predicted to have a single lamb and produced no lambs. Two additional ewes were projected to have single lambs and produced multiple lambs. Of the 67 ewes predicted to have multiple lambs, 51 produced twins while the remaining 16 produced single lambs.

In 1995, fetal numbers were predicted with 87% accuracy in ewe lambs. Of the 12 ewe lambs predicted to have single lambs, 10 produced single lambs and the remaining two produced twins. Two of the four ewe lambs predicted to have twins produced twins with the remaining two producing single lambs. Accuracy was decreased in mature ewes (69%) due to an over-estimation of twin-bearing ewes. A total of seven ewes were predicted to have single lambs with two being open and the remaining five correctly diagnosed. A total of 75 mature ewes were predicted to have twins. Fifty-one ewes produced twins while the remaining 24 produced single lambs. In 1995, the mean birthweight for single lambs was 5.2 ± 0.7 kg and the total birthweight for twin lambs was 8.3 ± 1.2 kg. With a birthweight for single lambs nearly matching total birthweight for twins, using serum $P_4$ to separate a heavy single lamb from twin lambs could be difficult.

When the three years were combined, fetal numbers were accurately predicted in 269 of 340 ewes (79%) of all ages. With fewer total numbers of ewe lambs, 88% accuracy may be somewhat inflated. However, with a pregnancy rate of 51% in yearling ewe lambs for three years and a greater number of single lambs born compared to twins, predicting fetal numbers for yearling ewes should be fairly accurate. Mature ewes displayed an increase in mean $P_4$ for zero, one or multiple lambs (Table 3). The decrease in accuracy of fetal number prediction was due in part to the increase in mean $P_4$ for ewes bearing single lambs. While this indicates increases in birthweights for single lambs, this model could still be used as a management tool to adjust the nutrition of ewes carrying large single lambs as well as for ewes carrying twins.

This method of estimating lamb number yielded a greater degree of accuracy over three years than the 63% accuracy reported by Gadsby et al. (1972). However, the large variability in serum $P_4$ among ewes producing the same number of lambs makes very high accuracy rates difficult to achieve. Over the three-year study, pregnancy was correctly determined in 335 of 340 (98%) ewes at 100 ± 10 days of gestation and fetal numbers were correctly determined in 269 (79%) ewes when all ages were considered. In a review presented by Goel and Agrawal (1992), pregnancy has been determined at 45 to 50 days of gestation with 90% accuracy in sheep using ultrasound. Veserat et al. (1993) reported 99% accuracy in pregnancy determination after 50 days gestation, with more than 85% accuracy in separation of single- and multiple-bearing ewes between 50 and 100 days of gestation. Likewise, Fowler and Wilkins (1984) achieved 99% accuracy in pregnancy determination from 46 to 100 days gestation. Fowler and Wilkins (1984) also achieved 97% accuracy in diagnosing fetal numbers using real-time imaging. However, when using ultrasound, all previous authors state that accuracy increases with technician experience. The current method being investigated allows for an alternative method of pregnancy diagnosis and prediction of fetal numbers. In certain situations this method would allow for a minimum of handling and gathering because sheep are typically shorn four to six weeks before lambing and a single blood sample could be taken at this time. With a properly equipped laboratory, 600 to 800 serum samples could be quantified in a day, thus yielding timely results that might aid producers who are considering supplementing energy supplies for ewes carrying multiple feti.

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**Table 3. Serum progesterone (ng/mL) in Debouillet ewes producing zero, one or two lambs.[a,b]**

| Year | Age[d] | Lambs per birth[c] 0 | 1 | Multiple | SE |
|---|---|---|---|---|---|
| 1993: | Ewe lambs | 0.2 | 4.8 | 14.5 | 0.8 |
| | Mature | 0.8 | 9.0 | 16.8 | 1.9 |
| | Overall | 0.4 | 7.1 | 16.5 | 0.8 |
| 1994: | Ewe lambs | 0.6 | 8.8 | 12.7 | 1.4 |
| | Mature | 1.5 | 11.6 | 17.5 | 1.9 |
| | Overall | 0.8 | 10.7 | 17.2 | 0.8 |
| 1995: | Ewe lambs | 0.3 | 6.6 | 10.9 | 1.2 |
| | Mature | 3.4 | 13.8 | 20.1 | 2.5 |
| | Overall | 1.0 | 11.7 | 19.4 | 1.2 |

[a] Serum samples were collected one week after shearing each year. Shearing was accomplished in late January of each year. Ewes were approximately at 100 days of gestation at the time of sampling (calculated from marks recorded during breeding season).
[b] Ewes were grouped according to actual number of lambs at parturition.
[c] Row values differ ($P < 0.01$).
[d] Mature ewes were from two to seven years old.

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**Table 4. Prediction of number of offspring using serum progesterone determined at shearing in late January at approximately 100 days of gestation.**

| | | Age[a] | | | | | |
|---|---|---|---|---|---|---|---|
| | | Ewe lambs | | Mature ewes | | Overall | |
| Year | Lambs per birth | Predicted[b] | Actual[c] | Predicted[b] | Actual[c] | Predicted[b] | Actual[c] |
| 1993: | 0 | 21 | 19 | 8 | 8 | 29 | 27 |
| | 1 | 18 | 20 | 23 | 24 | 41 | 44 |
| | 2 | 3 | 3 | 25 | 24 | 28 | 27 |
| Accuracy[d] | | 40/42 (95%) | | 45/56 (80%) | | 85/98 (86%) | |
| 1994: | 0 | 21 | 21 | 4 | 5 | 25 | 26 |
| | 1 | 13 | 16 | 17 | 30 | 30 | 46 |
| | 2 | 6 | 3 | 67 | 53 | 73 | 56 |
| Accuracy[d] | | 33/40 (82%) | | 69/88 (78%) | | 102/128 (80%) | |
| 1995: | 0 | 15 | 15 | 2 | 4 | 17 | 19 |
| | 1 | 12 | 12 | 7 | 29 | 19 | 41 |
| | 2 | 4 | 4 | 75 | 51 | 79 | 56 |
| Accuracy[d] | | 27/31 (87%) | | 58/84 (69%) | | 85/115 (74%) | |
| Combined years: | | | | | | | |
| | 0 | 57 | 55 | 14 | 17 | 71 | 72 |
| | 1 | 43 | 48 | 46 | 84 | 89 | 132 |
| | 2 | 13 | 10 | 167 | 126 | 180 | 136 |
| Accuracy[d] | | 100/113 (88%) | | 169/227 (74%) | | 269/340 (79%) | |

[a] Mature ewes were from two to seven years of age.
[b] Serum progesterone ($P_4$) in predicted lamb groups: zero lambs ≤ 2.4 ng/mL; one lamb ≥ 2.5 but ≤ 10.9 ng/mL; multiple lambs ≥ 11.0 ng/mL.
[c] Actual values are number of ewes which produced zero, one or two lambs at parturition.
[d] If the predicted number of lambs for an individual ewe agreed with the actual number of lambs at parturition, the prediction for that ewe was considered "accurate". The number of accurate predictions divided by total number of ewes in each group was percentage accuracy.

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# Out-of-Season Breeding of Ewes Using Transcervical Artificial Insemination[1,2]

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## Summary

An experiment was conducted to identify factors that affect pregnancy rate resulting from transcervical artificial insemination (T-AI) of ewes during the seasonal anestrous period. In April/May mature Finncross ewes (n = 30) were treated with a sponge or a controlled internal drug-release device-type G (CIDR-G). Half of the ewes were injected with an inhibin-neutralizing antibody (α-IF-Ab), a treatment known to increase ovulation rate. Ewes were exposed to teaser rams at the time progesterone-releasing pessaries were removed. Plasma progesterone concentrations were higher ($P < 0.02$) in CIDR-G-treated than in sponge-treated ewes during the latter portion of the 12-day treatment period. All other results were similar between sponge- and CIDR-G-treated ewes. Transcervical AI was conducted 8 to 28 hours following onset of estrus in 25 ewes, and at 57 hours post-pessary withdrawal in five ewes not expressing estrus. Ewes were inseminated with approximately $245 \times 10^6$ motile post-thaw spermatozoa. Fourteen ewes (47%) conceived based upon progesterone profiles and ultrasonography. Luteal progesterone concentrations were higher ($P < 0.01$) in α-IF-Ab-treated ewes than in controls, but otherwise α-IF-Ab produced no significant effects. Various factors were examined retrospectively for a relationship with pregnancy. No differences were found in duration of intervals, such as that from the preovulatory LH surge to T-AI. The magnitude of the LH surge was greater ($P < 0.01$) in ewes that became pregnant than in those that did not. In conclusion, T-AI using frozen-thawed semen can be used with reasonable success for out-of-season breeding of ewes. Timing of T-AI evidently does not need to be especially precise. Results point to follicular development and maturation as key factors underlying success of T-AI performed out-of-season.

**Key words:** transcervical artificial insemination, ewes, seasonal anestrus.

## Introduction

In previous experiments out-of-season breeding has been achieved by treating Finncross ewes with progesterone-releasing pessaries followed by sudden introduction of rams (Wheaton et al., 1992a; Wheaton and Windels, 1994). Addition of a single injection of inhibin-neutralizing antibody (α-IF-Ab) was shown to increase ovulation rate and number of lambs born (Kusina et al., 1995). An abundance of rams was used to minimize effects of decreased libido and sperm production that some rams experience in spring (Fitzgerald, 1992).

Breeding by artificial insemination (AI) would reduce the number of rams needed and it would allow the use of semen collected during the breeding season when quality is high. Storage of semen from fall to spring necessitates the use of frozen-thawed semen (Maxwell and Salamon, 1993). To realize even partial success using frozen-thawed semen it should be deposited directly into the uterine body (Evans and Maxwell, 1987). Intrauterine deposition can be accomplished via laparoscopic or transcervical techniques (T-AI). The latter is a low-cost non-surgical alternative to the former (Buckrell, 1993). However, pregnancy rates resulting

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from T-AI using frozen-thawed semen in progestogen-treated anestrous ewes have been low, typically below 30% (Buckrell et al., 1992; Buckrell et al., 1994).

Viability of frozen-thawed spermatozoa may be lower than that of fresh spermatozoa in the uterine body (Lightfoot and Salamon, 1970). Hence it may be especially important that AI be appropriately timed in relation to ovulation (Fukui et al., 1989). The main objective of the present study was to gain insight into the appropriate timing of T-AI in Finncross ewes induced to ovulate using progesterone-releasing pessaries and the ram effect. Secondary objectives were to determine whether type of progesterone-releasing pessary and passive immunization against inhibin altered temporal relationships.

## Materials and Methods

Twenty-two two- to five-year-old crossbred ewes (1/4 Finn-1/4 Targhee-1/2 Rambouillet; 67 ± 2 kg) and eight two- to three-year-old Polypays (61 ± 4 kg) were maintained in a 9 × 5 m pen in a barn and fed 2 kg of hay per day. Last lambing dates ranged from February 3 to March 10 and lambs had been weaned on or before April 15.

Ewes were assigned within genotype to four treatment groups in a two-by-two factorial arrangement. Factors were type of progesterone-releasing pessary: 1) sponge (containing 500 mg progesterone) versus controlled internal drug release device-type G (CIDR-G, 9% progesterone; InterAg, Private Bag, NZ); and 2) α-IF-Ab versus control solution. Pessaries were inserted on April 26 and withdrawn 12 days later at 0600 hours (day 0; hour 0). A single i.m. injection of 630-RP-2 kU α-IF-Ab or phosphate-buffered saline was administered 48 hours before pessary removal (Kusina et al., 1995). One vasectomized ram and three testosterone-treated wether lambs were transported from a distant shelter, fitted with marking harnesses and turned-in with the ewes at 0700 hours on day 0. Wether lambs had been injected i.m. with 4 ml of corn oil containing 25 mg testosterone propionate on alternate days for two weeks (Fulkerson et al., 1981). Ewes were checked for breeding marks at three-hour intervals for 54 hours. Onset of estrus was considered to have occurred an hour and a half before observation of a breeding mark. Blood samples were drawn via jugular vein puncture every other day from day 14 to 0; at six-hour intervals from 0 to 48 hours; and then on alternate days until day 19.

Cylindrical sponges measuring 3.5 cm in diameter and 4.5 cm in length (Identi-Plug plastic foam stoppers for 27-34 mm test tubes; Jaece Industries, Inc., North Tonawanda, NY) were sewn and tied with two 55-cm lengths of 13.6 kg-test monofilament fishing line. Progesterone was incorporated into the sponge by applying ten 1-ml aliquots of a methanolic solution containing 50 mg/ml progesterone. Each aliquot was evaporated using a fan before addition of the next.

Semen was collected from six yearling Hampshire rams during the breeding season. Rams were maintained under natural lighting and were trained to serve into an artificial vagina. Two ejaculates were obtained twice weekly from each ram. Ejaculates were screened immediately following collection and those with good motility (≥ 80%), sperm concentration ($\geq 3 \times 10^9$) and volume were further processed. One part semen was diluted with two parts Tris-glucose-egg yolk-glycerol (Salamon, 1976), drawn into 0.5 ml French straws (IMV, L'Aigle, France). These were frozen and then stored in liquid nitrogen. Procedures have been previously described (Salamon, 1976). Two days following freezing, one straw from each ejaculate was thawed and incubated in a water bath at 37 °C for one hour to evaluate post-thaw motility. Four ejaculates from the ram that gave the highest post-thaw motility (50 to 55%) were selected for use. Ewes were inseminated with $230 \times 10^6$ to $260 \times 10^6$ motile frozen-thawed spermatozoa.

Most ewes were inseminated from 24 to 28 hours after onset of estrus. Three ewes expressed estrus more than 36 hours following pessary removal and these ewes were inseminated 8 to 17 hours following onset of estrus. The five ewes that did not exhibit estrus were inseminated 56 to 59 hours following pessary removal. Ewes were placed into a turning cradle and, via a vaginoscope, a bent-tipped probe attached to a post-load handle was manipulated through the circular folds of the cervix. Equipment for T-AI was obtained from Laboratory Diagnostic (Fort Collins, CO). Additional probes were fabricated at Scientific Apparatus (St. Paul, MN). When the probe was through the cervix, a straw was placed into a Cito thaw unit (Nasco; Fort Atkinson, WI) at 37 °C for 40 seconds, after which the straw was inserted into the probe handle and semen expelled into the uterine body.

Plasma LH concentrations were measured using a double-Ab radioimmunoassay described previously (Niswender et al., 1969). Assay components were NIH-LH-S19 for reference, NIADDK-oLH-I-3 for radioiodination and NIADDK-anti-oLH-1 for antiserum. Sensitivity was 0.5 ng/ml and the intraassay CV was 8.1%. Plasma progesterone concentrations were measured using a solid-phase radioimmunoassay (Coat-A-Count; Diagnostic Products Corporation, Los Angeles, CA). Sensitivity was 0.1 ng/ml and the intraassay CV was 5.1%.

Pregnancy and number of fetuses were determined ultrasonically (Aloka 500V console and 7.5 MHz prostate probe; Corometrics Medical Systems, Inc., Wallingford, CT). The trans-rectal probe was covered with a sanitary sheath (IMV, L'Aigle, France). Carboxymethylcellulose sodium salt (1%; Sigma Chemical Company, St. Louis, MO) was used as a lubricate and coupling gel.

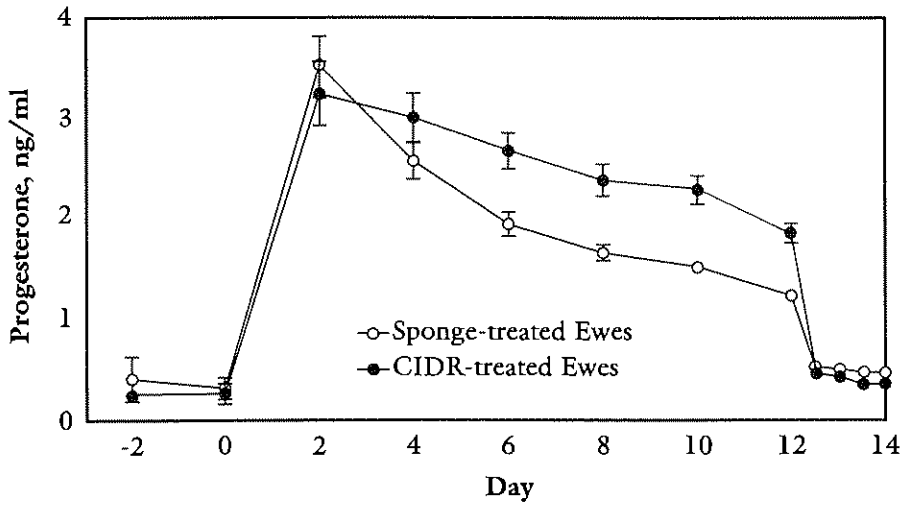
Means ± SE are presented in text and figures unless noted. Progesterone concentrations were analyzed for effects of type of pessary in a split-plot design for repeated measures; progesterone slopes from days 2 to 12 were compared using Student's t-test. Effects of type of pessary and α-IF-Ab treatment on intervals to onset of estrus and to the preovulatory LH surge, on number of fetuses and on luteal progesterone concentrations

were evaluated in a two-by-two factorial arrangement. Luteal progesterone concentrations were reduced to one value per animal by averaging levels on days 11, 13 and 15 following pessary withdrawal. Effects of type of pessary and α-IF-Ab treatment on incidence of estrus, preovulatory LH surge and pregnancy were analyzed using the categorical data procedures of SAS/STAT (SAS/STAT, 1985). Variables in pregnant and non-pregnant ewes were compared using Student's t-test (continuous data) and Chi-square (categorical data).

## Results and Discussion

No CIDR-G or sponges were expelled during the 12-day treatment period. Progesterone concentrations in plasma samples taken before insertion of progesterone-releasing pessaries were less than 0.5 ng/ml, with the exception of one ewe in which concentration was more than 3 ng/ml. Progesterone data from this ewe were excluded from further analysis. (This ewe did not become pregnant from subsequent T-AI). Progesterone concentrations differed by type of pessary ($P < 0.02$) and by day ($P < 0.001$) and there was a pessary-by-day interaction ($P < 0.001$). Progesterone concentrations increased following pessary insertion and highest values were detected in the first plasma sample collected after insertion (Figure 1). Highest values were similar in CIDR-G- and sponge-treated ewes. From days 2 to 12 progesterone concentrations decreased at a greater rate in sponge-treated than in CIDR-G-treated ewes ($P < 0.05$). Progesterone concentrations from days 2 to 12 averaged 2.6 ± 0.1 and 2.1 ± 0.1 ng/ml in CIDR-G- and sponge-treated ewes, respectively. Following removal of pessaries, progesterone concentrations fell to less than 0.5 ng/ml within 12 hours. The plasma pattern and concentrations of progesterone produced by CIDR-G were similar to those reported previously for CIDR-S, a prototype device which has been superseded by the CIDR-G (Hamra et al., 1986; Wheaton et al., 1993). Sponges, which were loaded with 500 mg progesterone, produced greater progesterone concentrations than those reported previously for 400 mg progesterone sponges (Hamra et al., 1986). Sponges and CIDR-G produced similar post-pessary treatment responses, such as incidence and intervals to estrus and timing and magnitude of the preovulatory LH surge. Thus sponges were as effective as CIDR-G even though they provided less progesterone during the latter portion of the 12-day treatment period. An advantage of CIDR-G is that they do not absorb fluid nor promote accumulation of vaginal fluid as sponges do, making them more aseptic than sponges.

**Figure 1. Plasma progesterone concentrations in ewes treated with sponges (n = 15) and CIDR-G (n = 14).[a]**




[a] Progesterone-releasing pessaries were inserted and removed on days 0 and 12, respectively.

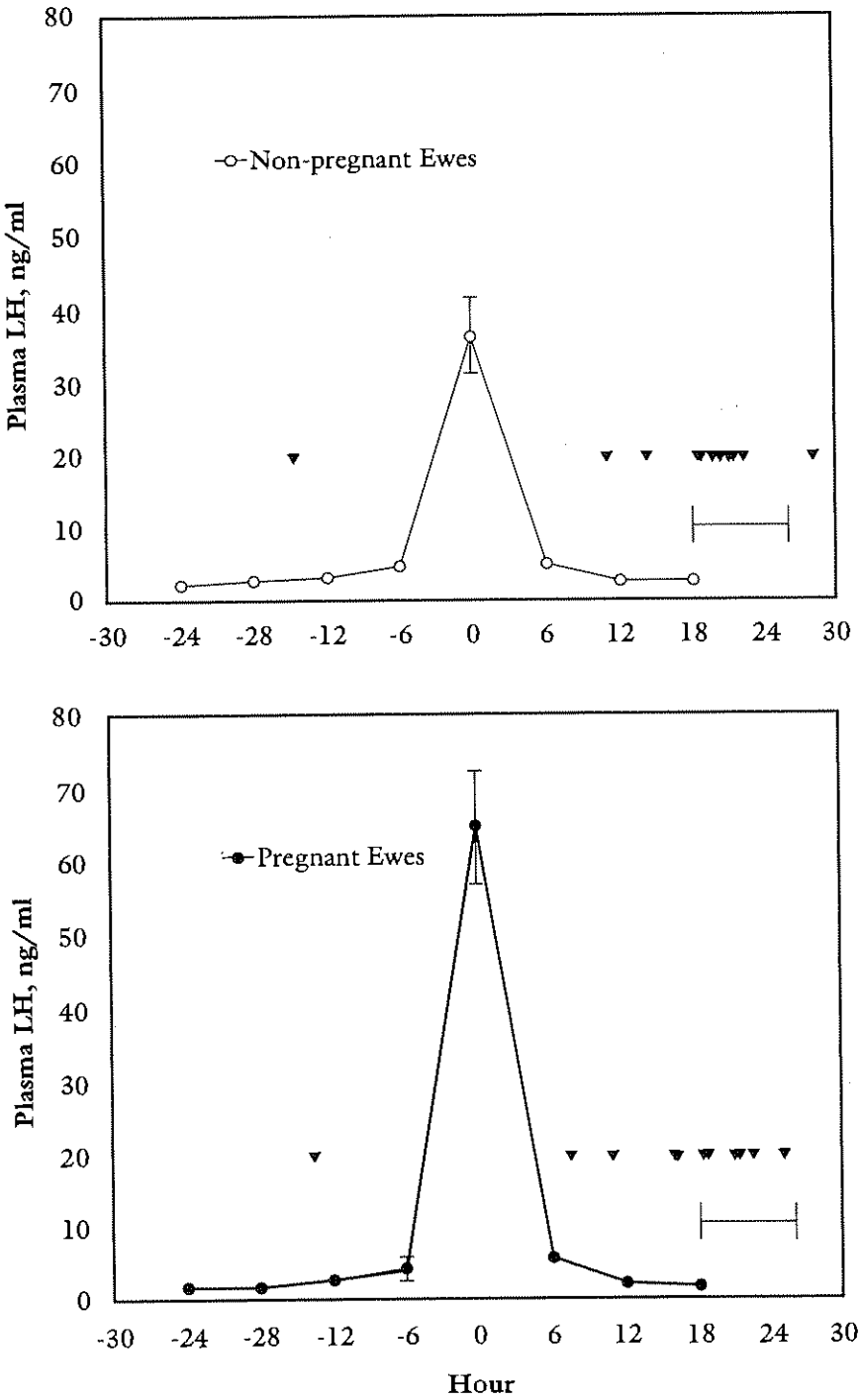
Estrus was observed in 25 out of 30 ewes and intervals from pessary withdrawal to onset of estrus averaged 31 ± 1 hours. Incidence of estrus was similar to that in previous studies in which Finncross ewes had been treated with progesterone-releasing pessaries and exposed to rams in April/May (Wheaton et al., 1992a). A preovulatory LH surge was detected in 25 out of 30 ewes. The mean interval from pessary removal to onset of the preovulatory LH surge was 32 ± 2 hours. Peak preovulatory LH surge values averaged 50 ± 5 ng/ml and were detected six hours after onset of the surge. Temporal relationships were similar to those reported for synchronization of estrus using CIDR-G during the breeding season (Shackell, 1991; Wheaton et al., 1992b).

Shackell (1991) monitored the time of ovulation in CIDR-G-synchronized ewes. Mean intervals from CIDR-G removal, estrus and onset of the preovulatory LH surge to ovulation were 59, 29 and 28 hours, respectively. The interval from onset of the preovulatory LH surge to ovulation had the least amount of variation associated with it. Extrapolating the 28-hour interval to the present study, the presumed time of ovulation was 60 ± 12 (SD) hours following pessary removal. Presumed time of ovulation would have followed onset of estrus by 30 ± 8 (SD) hours. Pregnancy rates following intrauterine deposition of frozen-thawed semen have been greatest when insemination has taken place before or close to the time of ovulation (Jabbour and Evans, 1991; Maxwell et al., 1993). Findlater et al. (1991) found little difference in conception rates when ewes had been inseminated from approximately 19 hours before to 4 hours after the predicted time of ovulation. Ewes in the present study were inseminated from 37 hours before to 6 hours after the presumed time of ovulation. Intervals from time of insemination to the presumed time of ovulation were similar in ewes subsequently diagnosed pregnant or non-pregnant

(Figure 2). In pregnant ewes the mean time of insemination was 6 hours before the presumed time of ovulation and ranged from 35 hours before to 3 hours after. The range indicates that a rather lengthy period exists in which conception is possible. The period appears to be centered approximately 10 hours before ovulation based upon present results and those of Findlater et al. (1991). Ten hours before ovulation corresponds to approximately 50 hours following pessary removal in the present experiment. This interval is close to the 48 hours recommended in New Zealand protocols for AI of CIDR-G-synchronized ewes (Shackell, 1991). Had a fixed-time interval of 48-hours from pessary removal been used in the present study, then ewes would have been inseminated on average 12 hours before the presumed time of ovulation. If in fact the range in which conception is possible extends from 35 hours before ovulation to 3 hours after ovulation as present data indicate, then a fixed-time interval of 48 hours from pessary removal, or a 24-hour interval from onset of estrus as was the case for most ewes in the present study, would be expected to yield similar conception rates. Either way, 90% of the ewes at the time of T-AI would have been within the range where conception was possible (Figure 3). Intervals of approximately 18 hours from onset of estrus to T-AI and approximately 42 hours from pessary removal to T-AI would tend to centralize the bulk of ewes within the range (Figure 3).

All but one ewe was transcervically inseminated. One ewe was inseminated at the first cervical ring due to failed attempts to maneuver the probe through the cervix. The 97% penetration rate achieved in the present study compares favorably to other studies in which penetration rates ranged from 43 to 98% (Halbert et al., 1990; Fukui and Roberts, 1978; Buckrell et al., 1994; Windsor et al., 1994). An important factor may have been that all ewes had lambed within three months of the date of T-AI. A penetration rate of 89% was reported for T-AI ewes within four months of last lambing date, after which the rate dropped to 66% (Buckrell et al., 1994). Experience gained from a previous experiment also may have contributed to the success rate (Husein et al., 1994; Buckrell, 1993). Time needed for manipulation of the probe through the cervix averaged 5.1 minutes and ranged from 1 to 13 minutes. Mean penetration times of 5 to 6 minutes have been reported by Fukui and Roberts (1978) and Buck-

**Figure 2. Temporal relationships among the preovulatory LH surge, T-AI and the presumed time of ovulation.[a]**



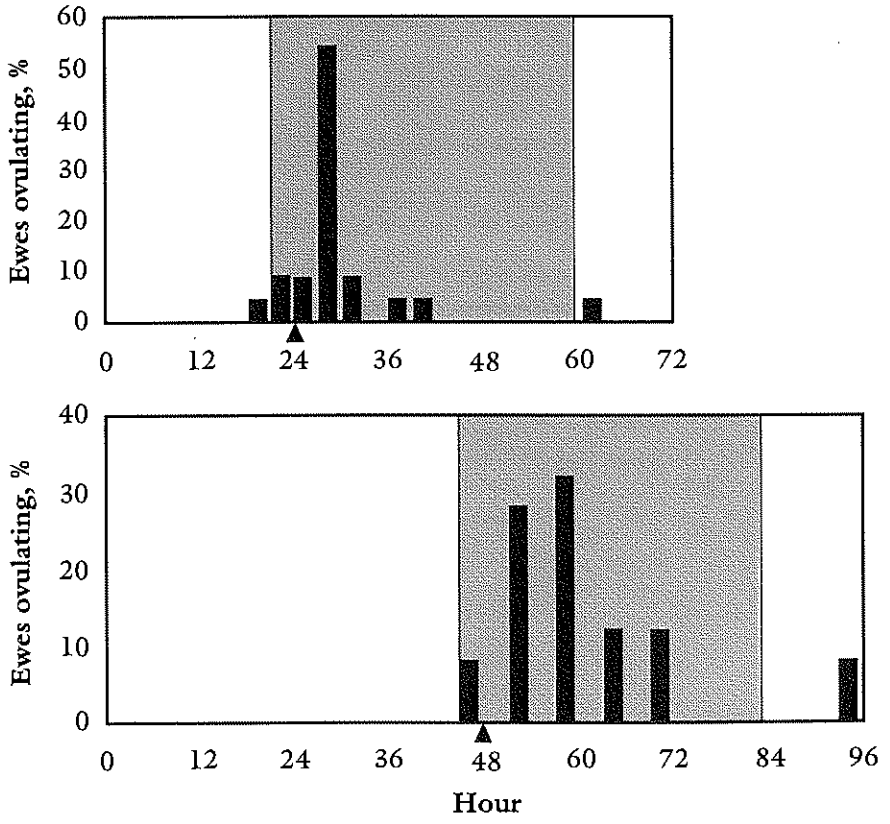

[a] Plasma LH levels were averaged and aligned to the peak value in ewes that did and did not become pregnant following T-AI. Also shown are the time of T-AI (▼) and the presumed time of ovulation (⊢⊣).

rell (1993). Anatomical differences among ewes in the structure of the cervical orifice and canal have been shown to affect penetration time (Fukui and Roberts, 1978).

Four days following pessary removal, progesterone concentrations increased in 27 out of 30 ewes and reached highest levels on days 11, 13 and 15 (Figure 4). These ewes were considered to have ovulated and developed fully formed corpora lutea. Progesterone levels on days 11, 13 and 15 were higher ($P < 0.01$) in α-IF-Ab (7.1 ± 0.6 ng/ml) than control (5.0 ± 0.3 ng/ml) ewes. Higher luteal-phase progesterone concentrations are consistent with α-IF-Ab-induced multiple ovulations (Wheaton et al., 1992b). Treatment with α-IF-Ab had no other significant effect. After day 15, progesterone levels remained high in 14 ewes and decreased in 13 ewes. Sustained progesterone concentrations on day 17 and thereafter reflect maintenance of corpora lutea and pregnancy. In three ewes progesterone concentrations either did not increase or increased only for a short duration. Follicular development, ovulation and/or luteinization was apparently dysfunctional in these ewes.

Fourteen ewes were diagnosed as pregnant using transrectal ultrasonography. These were the same 14 ewes deemed pregnant based upon progesterone profiles. The ewe that was inseminated cervically was not pregnant. Number of fetuses averaged 2.1 for α-IF-Ab-treated ewes and 1.8 for control ewes ($P > 0.1$). Pregnant ewes had one ($n = 2$), two ($n = 10$) or three ($n = 2$) fetuses. The two ewes that had three fetuses had been treated with α-IF-Ab and these two ewes also had the highest luteal phase progesterone concentrations. In a previous study, incorporation of α-IF-Ab treatment into the progesterone-ram effect method to stimulate reproductive activity during spring increased ovulation rate and numbers of lambs born (Kusina et al., 1995). In that study, control ewes had an ovulation rate of one and each ewe gave birth to a single lamb; α-IF-Ab-treated ewes had a mean ovulation rate of 2.5 and averaged 1.8 lambs born per ewe. It seems that α-IF-Ab treatment is effective in boosting prolificacy only when the control rate is near one.

**Figure 3. Temporal relationships among T-AI, the presumed time of ovulation and conception.[a]**




[a] The top panel depicts temporal relationships as they presumably existed in the experiment when T-AI was performed 24 hours following onset of estrus. The x-axis is referenced to onset of estrus (0 hour) and time of T-AI is shown (▲). Bars indicate presumed time of ovulation and the shaded area represents the period in which conception had occurred. The bottom panel extrapolates temporal relationships as they would have been had T-AI been performed 48 hours following removal of progesterone-releasing pessaries. The x-axis is referenced to time of pessary removal (0 hour), time of T-AI is shown (▲) and bars reflect presumed time of ovulation. The shaded area represents the period in which conception would be possible.

Although the authors consider a pregnancy rate of 47% to be reasonably successful for T-AI performed out-of-season using frozen-thawed semen, it nonetheless indicates that unfavorable conditions existed in a majority of ewes. There are apparent reasons for non-pregnancy in 6 of the 16 open ewes. These are site of insemination, ovarian dysfunction (as aforementioned) and lack of estrus. None of the five ewes that did not express estrus became pregnant even though two of them presumably ovulated and formed normal corpora lutea. A retrospective comparison of pregnant and non-pregnant ewes revealed no differences in intervals from pessary removal to estrus and to the preovulatory LH surge, in intervals from the preovulatory LH surge to T-AI, in cervical penetration times or in the particular ejaculate used for insemination. One significant difference was found. Highest preovulatory LH surge values were greater ($P < 0.01$) in ewes that became pregnant (65 ± 8 ng/ml) than in those that did not (36 ± 5 ng/ml). Glover et al. (1985) reported a similar finding for domestic cats. Peak LH values and the area under the curve were significantly greater for cats that became pregnant than for cats that did not. Glover and co-investigators speculated that a diminished LH surge may be

adequate to induce ovulation but insufficient to promote maturation of the oocyte and/or fertilization and subsequent development.

## Conclusions

Transcervical-AI using frozen-thawed semen can be used with reasonable success for out-of-season breeding of ewes. Based upon intervals from withdrawal of progesterone-releasing pessaries to onset of estrus and to the preovulatory LH surge, it is recommended that T-AI be performed approximately 42 hours after pessary removal or approximately 18 hours after onset of estrus. Although not tested, results suggest that the two intervals would yield similar pregnancy rates. For progesterone-priming of anestrous ewes, sponges containing 500 mg progesterone and CIDR-G are equally effective. Inclusion of α-IF-Ab treatment is of little if any value.

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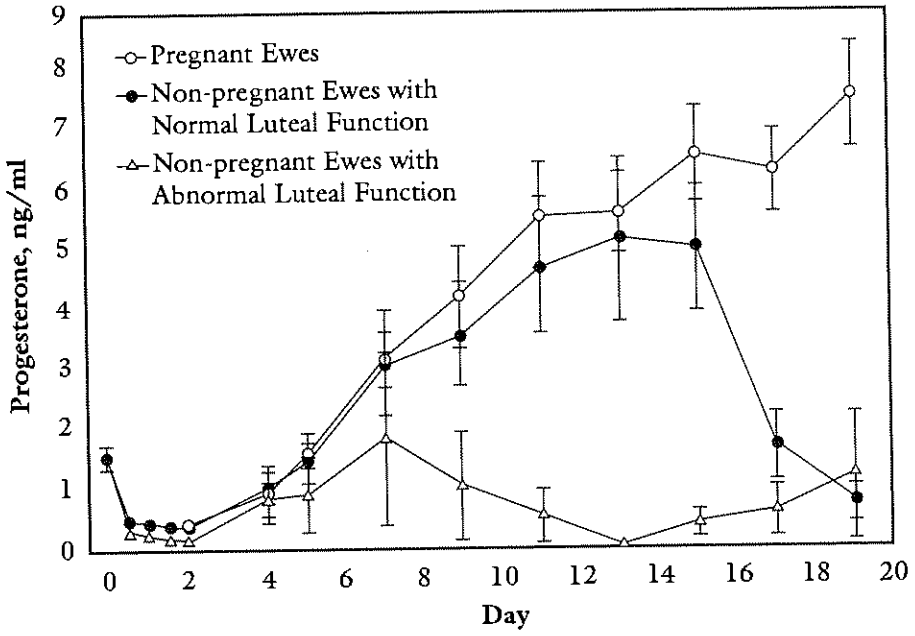
**Figure 4. Plasma progesterone profiles following withdrawal of progesterone-releasing pessaries on day 0.[a]**




[a] In pregnant ewes progesterone concentrations increased and remained elevated on days 17 and 19 (n = 14); in non-pregnant ewes progesterone concentrations either increased and then dropped after day 15 (n = 13), or did not increase or increased only for a short duration (n = 3).

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# Research Briefs

## Trends in the U.S. Textile Market – Wools Research and Development Response

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*Cited from: Wool Techn. Sheep Breed., 43 (3):229-243. 1995.*

The structure of the U.S. textile market and various trends within the market for the period of 1980 to 1990 are reviewed. The overall U.S. market for non-industrial (apparel, home-furnishings, floor coverings) textile fibers increased by 25% during this period during which man-made fibers and cotton dominated with wool occupying a static 2% market share. However, cotton's market share, particularly in apparel and home furnishings, increased steadily at the expense of man-made fibers. In contrast, man-made fibers continued to dominate the floor coverings market in which wool's share was less than 1%. Compared to other industries, U.S. textile manufacturers operate on very low margins, around 2.5% profit on sales (compared to 5 to 6% for U.S. manufacturing generally). Even with modern manufacturing and information technologies, it is still difficult for U.S. manufacturers to compete with imports from countries with lower labor costs. "Quick response" and "just-in-time" management techniques are being used to increase efficiency, profitability and competitiveness. The structure of the U.S. retail market for apparel is segmented into five main areas: 1) department stores, 2) national chains, 3) discount stores, 4) offprice stores, and 5) specialty stores. In 1992, their market shares were 24.2, 22.6, 19.4, 19.1 and 14.7%, respectively. Apparel growth projections between 1990 and 2002 are predicted to average 2.75% per annum for a period in which the U.S. population is expected to increase by 10%. Wool product needs identified by International Wool Secretariat (IWS) managers primarily for U.S. consumers included: lightweight, soft, bulky, warmth without weight, easy care, no prickle, skin comfortable, casual/relaxed, non-wrinkling and acceptable cost. The consumer also wants garments that have good performance, ease of use and reflect lifestyle (including awareness of "green" and "ethical" issues). Current CSIRO research projects are addressing the following U.S. and international needs: increased bulk of wool clothes; improved skin comfort; easy care fabrics including stable, lightweight knitwear; and improved comfort. These new initiatives in research and development have potential for providing market-led products to increase the demand for wool in this cost-driven, volume-production-oriented market. (30 references)

*– prepared by C.J. Lupton*

## The Effect of Reduced Feed Intake on the Efficacy of Oxfendazole against Benzimidazole-Resistant *Haemonchus contortus* and *Trichostrongylus colubriformis* in Sheep

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CSIRO Division of Animal Health, Geelong, Australia

*Cited from: International Journal for Parasitology, 25 (1):71-74. 1995.*

Two different experiments are reported in this paper. In one, marker techniques were used to demonstrate that the level of feed intake (800 vs. 400 g) influenced (reduced) the rate of digesta flow and the concentration (increased) of orally administered drugs or markers. This presumably could increase the effectiveness of certain anthelmintics. In the second experiment, crossbred wether sheep which had been previously treated with ivermectin were orally infected with 5,000 larvae of Benzimidazole-resistant *Haemonchus contortus* and 10,000 resistant *Trichostrongylus colubriformis*. Twenty-one days later, the animals were placed in three comparable groups based on fecal egg counts. At 28 days they were treated

as follows: Group 1 (control) was fed at a rate of 800 g daily; Group 2 was fed 800 g daily and treated with Oxfendazole at the rate of 5 mg/kg; and Group 3 was fed 400 g and treated with 5 mg Oxfendazole. Ten days later all animals were autopsied and the parasite numbers determined. In Group 2, the number of *H. contortus* was reduced 60% over the controls while those fed at a lower level (Group 3) had a 90% reduction. In the case of *T. colubriformis* the equivalent values were 19 and 60%, respectively. The authors interpret the results to mean that a reduced feed level improved the results through increased concentration of the anthelmintic and also increased transit time. Other studies are cited which report similar results. The authors concluded that reduced feed intake or a period of temporary food restriction prior to treatment may improve the effectiveness of anthelmintic treatments. They especially caution against treating animals receiving large intakes on lush pasture which promotes rapid gastric transit. Producers with large flocks which drench "out of the shearing pen" may have partially accomplished the desired effect due to gathering and holding in the process of shearing. Though not addressed in this study, it may also be beneficial to hold sheep for a period of time after treatment to allow them to pass some of the eggs still viable in the track, especially if they are being rotated to fresh pastures.

*–prepared by Maurice Shelton*

# News and Notes

## Verl M. Thomas (1950 – 1996)

Verl Thomas passed away on March 1, 1996, after a fight with cancer. Verl was born and raised in Oregon, graduating from Oregon State University in 1972 with a B.S. in Animal Science. He received his M.S. (1974) and Ph.D. (1976) in Animal Nutrition from Purdue. Verl taught at the University of Idaho from 1976 until 1984, when he joined the faculty of Montana State University where he had since conducted research and taught courses covering sheep production and beef cattle nutrition.

Verl served on the Nutrition Review Panel for the ASI Sheep & Goat Research Journal from 1986 until mid-1995. He also dedicated himself to many other Montana Wool Growers and American Sheep Industry activities. Scientist, fly fisherman and friend, we'll miss him.

Memorials in his name may be made to the Verl M. Thomas Memorial Scholarship Fund, Animal and Range Sciences Department, 119 Linfield Hall, Montana State University, Bozeman, MT 59717. The scholarship fund will help support graduate student research.

## National Sheep Referendum Passed

Dan Glickman, U.S. Secretary of Agriculture, announced on March 5 that the National Promotion, Research and Information Program for sheep and wool passed in a industry-wide referendum. Of the 19,801 valid ballots cast, 10,707 (54.1%) favored and 9,094 (45.9%) opposed the program. Funds generated under the new program would be used to finance promotion research, education and informational activities designed to strengthen the sheep and wool industry.

The program would assess a tax of 1¢/lb on the sale of lamb and 2¢/lb on the sale of wool. It was expected that approximately $13 to $14 million would be raised each year, including approximately $6 million from importer contributions.

The final order was published and assessments were to begin July 1, 1996. On May 17, the USDA announced that it will suspend the order due to inconsistencies and differences in voting procedures at the official polling places. A second referendum will be scheduled and announced by the USDA soon.

# Sheep & Goat Research Journal
# Guidelines for Authors

## Objective

The aim of the Sheep & Goat Research Journal is to provide a publication of sheep and goat research findings which can be used by scientists, educators, Extension agents and sheep and goat producers alike. The specific goal of the Journal is to gather and distribute current research information on all phases of sheep and goat production and to encourage producer use of research which has practical application. The Journal is published three times each year.

## Editorial Policy

We are most interested in publishing articles of research relating to all aspects of sheep and goat production and marketing. Articles should relate and contribute to the advancement of the American sheep and goat industries and/or their products. All research manuscripts must represent unpublished original research. The submission of review articles is encouraged but will require review as well as those reporting original research. Articles which promote commercial products or services will not be approved for publication. Conclusions reached must be supported by research results. An orientation to practical applied research which may be useful to the sheep and goat industries is encouraged. At least one author of each manuscript must subscribe to the Journal.

## Review Process

Manuscripts will be subject to critical review by an editorial board or others designated by the editor. Authors will be notified of acceptance or rejection of papers by mail. Manuscripts needing revision will be returned to authors and should be revised and returned by the deadline indicated. When papers are accepted for publication, the authors must send a floppy disk with the manuscript in the ASCII file format along with two hard copies. Papers not suitable for publication will be returned to the authors with a statement of reasons for rejection. Consult the Sheep & Goat Research Journal Editorial Policy and Procedures for details of the technical requirements for manuscripts submitted to the Journal.

## Guidelines

Several sources were consulted, including the Journal of Animal Science and the Council of Biology Editors, Inc., when preparing these guidelines. Though the nature of the Journal is such that relatively few regulations are needed on style and form, we have attempted to standardize the manner in which the material is published as a service to Journal subscribers. Following are general guidelines for style and form.

## Format

Manuscripts must be typed and double-spaced; five copies must be submitted. The lines on all pages including those pages for Literature Cited and Figure Legends mnst be numbered in the left margin beginning with the numeral one (1) at the top of the page. Tables should be as few and as simple as is feasible for presentation of the essential data; tables should be typed and double-spaced. Each table should be on a separate sheet. All figures used in the text must be camera-ready. The author will be billed at full cost if figure preparation is required.

Research manuscripts should follow the format of:

| | |
|---|---|
| 1st | Summary (250 words or less) |
| 2nd | Key Words (up to 6) |
| 3rd | Introduction |
| 4th | Materials and Methods |
| 5th | Results and Discussion |
| 6th | Conclusions |
| 7th | Literature Cited |

In citing literature in the text, use both authors if there are only two. If there are more than two, use the first author and "et al." Authors are asked to provide "interpretive summaries" for use by the sheep and goat industries in other media.

## Proofing

Primary authors will receive galley proofs of articles. Corrected proofs should be returned by the deadline indicated. Failure to do so will result in delay of article publication.

## Reprints

Fifty reprints of each article will be provided at no cost to the primary author. When galley proofs are sent, the author will be requested to complete a reprint order form requesting free and any additional reprints and provide the name of the institution, agency or individual responsible for the reprint charges.

## Charge

The publication charge for the Sheep & Goat Research Journal is $60.00 per page and position announcements are $30.00 per quarter-page or less. Contributors will be billed following publication. All manuscripts and correspondence should be addressed to: Sheep & Goat Research Journal, 6911 South Yosemite Street, Englewood, CO 80112-1414; unless noted otherwise on materials received from the editorial staff.

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American Sheep Industry Association

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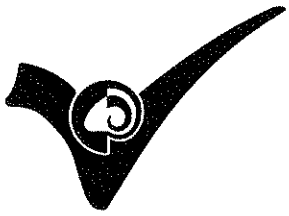

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# Effect of Selection for Lifetime Production of Lamb Weaned per Ewe on Feedlot Performance, Carcass Characteristics and Internal Organ Weight of Targhee Lambs[1]

W.A. Head, Jr.[2], P.G. Hatfield[3], J.A. Fitzgerald[4], M.K. Petersen[5], D.M. Hallford[5] and J.N. Stellflug[3]

## Summary

Eighty-eight lambs (51 ewes, 37 wethers; 120 ± 8 days of age) were used to determine the effects of selection for kilograms of lamb weaned per ewe on postweaning feedlot performance, carcass characteristics and internal organ weight. Treatments were: 1) lambs from a line of ewes selected for lifetime production of kilograms of lamb weaned per ewe (selected); and 2) lambs from a random-bred control line of ewes (control). Immediately after weaning, twin lamb pairs were placed in 5 m × 5 m pens and fed twice daily at 0730 and 1600 hours. Lambs received an initial diet of 30% whole barley and 70% chopped alfalfa hay. Barley was increased by 10% every third day until a finishing diet of 90% whole barley and 10% chopped alfalfa hay was achieved. Double-day shrunk body weights were recorded at the beginning and end of the study. Ultrasound measurements for backfat (BF) and loin-eye area (LEA) were made on all lambs. Carcass and internal organ weight data were collected on 36 lambs. Statistical models included fixed effects for line and sex, with lamb age tested as a covariable. Selected lambs were heavier ($P < 0.01$) at the beginning and end of the study. However, average daily gain and feed-to-gain (F:G) ratio did not differ ($P \geq 0.17$) between selected and control lambs. Dry matter intake (kg/lamb/day [DMI]) was greater ($P = 0.08$) by selected than by control lambs. No differences were detected ($P \geq 0.11$) for BF, LEA, dressing percent, carcass weight or internal organ weight between selected and control lambs. Selected lambs weighed more than controls and consumed more feed (kg/lamb/day), but did not differ in daily gain or DMI when expressed as percentage of body weight. These data suggest that selected lambs had greater nutrient intake but were no more efficient in feedlot performance than control lambs.

**Key words:** sheep, selection, post-weaning performance, carcass, organ weight.

## Introduction

Ercanbrack and Knight (1994) reported a marked difference for kilograms of lamb weaned per ewe between Targhee sheep selected for this trait and random-bred control ewes over a 12-year period (34.2 kg and 28.0 kg for selected and control ewes, respectively). This was verified by Head et al. (1995). Increased production per ewe in the selected group has been attributed to higher ovulation rate (Stellflug et al., 1994) and greater milk production and lamb forage intake (Head et al., 1995). Nonetheless, Head et al. (in press) demonstrated that no differences existed between selected and control lambs for growth hormone or insulin-like growth factor (IGF-I).

Thompson et al. (1985) stated that the effect of selection for weaning weight on efficiency of growth will depend not only on changes in growth rate to weaning, but also on post-weaning changes in food intake, feed efficiency, body weight and body composition of the animal. Lasslo et al. (1985) reported that Targhee

[1] The authors appreciate the technical assistance of J. Hopkins, E. Vadnais, K. Jensen, P. Wells and H. Wells.

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lambs selected for increased weaning weight were more efficient in postweaning growth than control lambs. With these factors in mind, this study investigated postweaning performance including body weight change, carcass composition and internal organ weight between lambs from a line of ewes selected for lifetime production of lamb weaned and lambs from a random-bred control line of ewes.

## Material and Methods

Eighty-eight lambs (51 ewes, 37 wethers; average body weight 28 ± 0.7 kg) were used in the study. Lambs were either from a line of ewes selected for lifetime production of kilograms of lamb weaned per ewe (selected; n = 44) or from a random-bred control line of ewes (control; n = 44). Preweaning management was described by Head et al. (1995). Briefly, ewes were shed-lambed in April and all male lambs were castrated two days postpartum. From birth until approximately 25 days postpartum, ewes and lambs were held in confinement and allowed ad libitum access to chopped alfalfa. From 26 days postpartum until weaning, ewes and lambs grazed fenced inter-mountain sagebrush-bunchgrass range at the U.S. Sheep Experiment Station near Dubois, ID.

Immediately after weaning on September 9, 1993, twin lamb pairs were confined in 5 m × 5 m pens. Lamb age was 120 ± 8 days. Lambs were fed twice daily at 0730 and 1600 hours. Amount of feed offered was recorded daily and refusals were collected and weight recorded when more than 500 g of refused feed accumulated in the feed bunk. When lambs entered the feedlot, they received a diet of 30% whole barley (10% crude protein [CP], dry matter [DM] basis), 70% chopped alfalfa hay (18% CP, DM basis) and 115 g per lamb daily of a commercially-prepared pelleted supplement (Table 1; 17.0% CP, DM basis). The amount of barley in the diet was increased by 10% every third day until a finishing diet of 90% whole barley, 10% chopped alfalfa hay, and 115 g per lamb per day of supplement was achieved.

Lambs were weighed (double day, overnight shrink without feed and water) at the beginning and end of the study. At the end of the feeding period, all lambs were scanned using realtime ultrasound for longissimus muscle area and backfat thickness. Thirty-six lambs, balanced by sex and line, were slaughtered for carcass and organ data. Carcass weight and dressing percentage were measured at a commercial abattoir. Internal organ weights (heart, lungs, kidneys, liver) were determined at time of slaughter. Organ weights were obtained by placing organs on a top-load balance and weights were recorded to the nearest gram.

Pen (n = 44) was the experimental unit for all feedlot performance data and individual lamb (n = 36) was the experimental unit for carcass data. Data were analyzed using the GLM procedure of SAS (1985). Models for feedlot data included fixed effects for line (selected or control) and sex, with age tested as a covariable. Models for carcass data included fixed effects for line and sex, with carcass weight and age tested as covariables. All possible two- and three-way interactions were also tested.

## Results and Discussion

No two-way (sex-by-line; sib-sex-by-line) or three-way (sex-by-line-by-sib-sex) interactions were detected ($P > 0.10$) for any of the data analyzed. Therefore, only main effects are reported.

Lambs from the selected ewes were heavier ($P \leq 0.02$) than control lambs at the beginning and end of the study (Table 2). However, daily gain, DMI expressed as a percentage of body weight and F:G ratio did not differ ($P \geq 0.17$) between selected and control lambs (Table 2). When DMI was expressed as kilograms per lamb per day, DMI was greater ($P = 0.08$) for selected than control lambs.

Our data conflict with those of Brown et al. (1987) who found that Targhee lambs from lines selected under range conditions for increased weaning weight exhibited a 16% greater ADG than control lambs. They also reported that selected lambs were more efficient at converting feed to gain. Brown et al. (1987) suggested that the selection criteria had decreased maintenance energy requirements in selected animals. Our data agree with the findings of Thompson et al. (1985), who found no differences in feed efficiency or daily gain in Merino sheep selected under range conditions for increased weaning weight. Our results suggest

**Table 1. Ingredient composition of commercial supplement fed at the rate of 115 g per lamb per day.**

| Ingredient | Percentage as fed |
|---|---|
| Wheat millfeed | 68.35 |
| Calcium carbonate | 6.58 |
| Meat and bone meal | 5.00 |
| Bentonite | 5.00 |
| Fish meal (60% CP) | 5.00 |
| Soybean meal (40% CP) | 4.54 |
| Magnesium oxide | 3.47 |
| Salt | 1.04 |
| Sodium bicarbonate | 0.34 |
| Bovatec (68 g/lb) | 0.21 |
| Farr sheep trace mineral | 0.15 |
| Vitamin A and D (100,000 IU) | 0.04 |
| Vitamin E (40,000 IU) | 0.01 |

**Table 2. Lamb postweaning feedlot performance, dry matter intake (DMI), feed-to-gain (F:G) ratio, standard error (SE) and observed significant level (OSL) for selected and random-bred control lambs.**

| Item[a] | Selected | Control | SE | OSL |
|---|---|---|---|---|
| Starting weight, kg | 29.3 | 26.9 | 0.77 | 0.02 |
| Ending weight, kg | 42.1 | 38.2 | 1.2 | 0.01 |
| Average daily gain, kg | 0.16 | 0.14 | 0.01 | 0.17 |
| DMI, kg/lamb/day | 1.3 | 1.2 | 0.05 | 0.08 |
| DMI, % of body weight | 3.2 | 3.2 | 0.07 | 0.65 |
| F:G ratio | 8.8 | 9.3 | 62.0 | 0.57 |

[a] All performance data were tested with pen (n = 44) as the experimental unit.

that a selection criteria based on increased weaning weight has not increased the efficiency of gain.

No differences ($P \geq 0.41$) in ultrasound measurements of backfat thickness or longissimus muscle area (n = 36; Table 3) were observed. Likewise, no differences ($P \geq 0.20$) were detected for dressing percentage or carcass weight between selected and control lambs. Brown et al. (1987) found that lambs from lines selected for weaning weight had heavier carcasses and tended to have leaner carcasses than control lambs. Thompson et al. (1985) also reported that Merino sheep selected for heavier weaning weight were leaner than control animals at the same weight. Perry et al. (1988) found that sheep from lines selected for increased weaning weight had increased total muscle weight compared with controls. Our data indicate no difference in body composition between selected and control lambs.

Internal organ weight, expressed as absolute values or as a percentage of carcass weight, did not differ ($P \geq 0.18$) between selected and control lambs (Table 4). Organ weights have been positively related to maintenance energy requirements of ruminants (Ferrell et al., 1986; DiCostanzo et al., 1990). Brown et al. (1987) found that rams selected for increased weaning weight had larger livers than control rams. This was not the case in our study. However, the findings of Brown et al. (1987) that selected sheep had greater liver weight and tended to have greater muscle mass than control sheep would appear to refute their conclusion that selection reduced energy cost for maintenance when selection resulted in an apparent increase in metabolically active tissue.

**Table 3. Ultrasound longissimus muscle area (LMA), backfat thickness (BF), dressing percentage, carcass weight, standard error (SE) and observed significance level (OSL) for selected and control lambs.**

| Item[a] | N[b] | Selected | Control | SE | OSL |
|---|---|---|---|---|---|
| Ultrasound LMA, $cm^2$ | 88 | 9.9 | 9.9 | 0.16 | 0.75 |
| Ultrasound BF, mm | 88 | 1.9 | 2.1 | 0.17 | 0.41 |
| Dressing percentage | 36 | 47.8 | 48.7 | 0.48 | 0.20 |
| Carcass weight, kg | 36 | 21.3 | 20.9 | 0.47 | 0.51 |

[a] All carcass data tested with animal as the experimental unit.
[b] N = number of animals included in analysis.

**Table 4. Internal organ weight expressed both as absolute weight and as a percentage of carcass weight, standard error (SE) and observed significant level (OSL) for selected and control lambs.**

| Item[a] | N[b] | Selected | Control | SE | OSL |
|---|---|---|---|---|---|
| Kidney weight, g | 36 | 122.7 | 107.6 | 7.8 | 18.0 |
| Percentage of carcass weight | 36 | 0.58 | 0.52 | 0.04 | 0.36 |
| Liver weight, g | 36 | 619.4 | 611.4 | 21.7 | 0.79 |
| Percentage of carcass weight | 36 | 2.9 | 3.0 | 0.11 | 0.64 |
| Heart weight, g | 36 | 212.7 | 210.1 | 10.9 | 0.86 |
| Percentage of carcass weight | 36 | 1.00 | 1.00 | 0.06 | 0.65 |
| Lung weight, g | 36 | 643.4 | 701.7 | 37.9 | 0.28 |
| Percentage of carcass weight | 36 | 3.0 | 3.39 | 0.19 | 0.18 |
| Kidney fat weight, g | 36 | 697.9 | 616.7 | 48.8 | 0.25 |
| Percentage of carcass weight | 36 | 3.2 | 2.9 | 0.22 | 0.30 |

[a] All carcass data was tested with animals as the experimental unit.
[b] N = number of animals included in the analysis.

# Conclusions

We previously reported that lambs from the line selected for kilograms of lamb weaned per ewe consume more energy preweaning than control lambs, both in the form of milk and forage. Present results indicate that within parity group, selected lambs had a greater dry matter intake than control lambs, but not when expressed as a percent of body weight. Moreover, daily gain and feed conversion did not differ between selected and control lambs. These findings indicate that selection based on kilograms of lamb weaned has increased body weight and nutrient intake as a percent of body weight during the pre- and post-weaning period, but has not affected efficiency of production.

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# Performance of Sheep Grazing California Annual Range[1,2]

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## Summary

A sheep grazing trial was conducted in coastal northern California on two subtypes of annual range. Grassland improved by fertilization and seeding to subterranean clover (*Trifolium subterraneum* L.; plant nomenclature is taken from Munz and Keck [1973] and Hickman [1993]) and grass-woodland were grazed continuously for five years by Targhee type ewes at 100%, 150% and 200% of moderate grazing intensity (stocking rates of 0.6, 1.8, 3.2 and 5.3, 8.0, 10.0 ewes/ha on woodland and grassland range, respectively). Sheep performance was compared among stocking rates and between range subtypes over years by evaluating responses in lamb weaning weight, ewe fleece weight, lamb crop percentage, ewe mortality and turnoff of feeder lambs and grease wool. Turnoff of lambs and wool was about six-fold greater on improved grassland (IG) than on grass-woodland (GW) range (164 vs. 29 kg of lambs/ha; 22.1 vs. 3.8 kg of wool/ha). Stocking rate had no significant effect on any performance variable, but weaning weights tended to decrease as stocking rate was increased on woodland and appeared heaviest under 200% moderate grazing on IG range. Lamb crops weaned from woodland ranges tended to decline at stocking rates above moderate grazing. There was a trend for increasing wool and feeder lamb yield/ha with rising stocking rates on IG range. On GW range, turnoff increased only at the highest stocking rate. Increasing turnoff from GW range by raising stocking rates required survival feeding. This prevented ewe mortality and reductions in lamb crop from exceeding those under moderate grazing. Moderate stocking of GW range (0.6 to 1.0 ewe/ha under year-long grazing) was suggested for sheep operations with less intensive management. Stocking at 200% of moderate (10.0 ewes/ha year-long) was recommended for annual grassland seeded to subterranean clover.

**Key words:** sheep, lambs, wool, annual range, stocking rate.

## Introduction

California ranks second in the United States in the production of sheep and lambs and third in the production of wool (USDA/NASS, 1994). Much of these commodities are produced from forage growing on annual range. This grazing type covers approximately 10 million hectares occurring as several subtypes (open grassland, grass-woodland [GW], improved grassland [IG]). Because annual range can be managed under year-long grazing (Heady, 1961) and improved by fertilization (Jones, 1974) and legume seeding (Murphy et al., 1973), it is the basis of many ewe-lamb operations.

For California to maintain a vigorous sheep industry in the face of land base shrinkage to urbanization, it is imperative that remaining land produce lambs and wool profitably at increasingly higher yields. Increasing turnoff (yield of animal products) from annual ranges by grazing management has been studied infrequently. There have been no investigations to appraise impacts of stocking rate on performance of sheep grazing annual range in California. The following trial was conducted to determine year-long stocking rates which optimize individual animal performance, lamb/wool turnoff and flock produc-

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tivity on GW and IG subtypes of annual range under ranching situations typical of coastal California.

## Materials and Methods

This study was one component of an integrated experiment which concurrently examined effects of grazing intensity on nutritive value of sheep diets (Rosiere and Torell, 1985) and botanical composition and production of range plant communities (Rosiere, 1987). It was conducted from 1979 to 1985 in coastal northern California on the University of California Hopland Field Station in Mendocino County (160 km north of San Francisco Bay; 64 km inland) within the series of hills comprising the Pacific Coast Mountain Range. Climate is humid mesothermal (Mediterranean) with mild moist winters and hot dry summers and a growing season of roughly six months (October or November to April or mid-May). Average annual rainfall is 90 cm but totaled 109, 68, 138, 172 and 102 cm for the respective five years of study.

Two subtypes of annual range were studied: 1) grass-woodland (GW), a mosaic of annual grassland and savanna of blue oak (*Quercus douglasii* H. & A.), interior live oak (*Q. wislizenii* A. DC.) and madrone (*Arbutus mensiesii* Pursh.) in the upperstory and sclerophyllus shrubs like manzanita (*Arctostaphylos* spp. Adans.) and chamise (*Adenostoma fasciculatum* H. & A.) and annual herbs in the understory; and 2) improved grassland (IG), swards of native and naturalized annual grasses and forbs overseeded to subterranean clover. Species composition of herbaceous communities as determined by step-point procedure (Evans and Love, 1957) at peak standing crop is given in Table 1.

IG was established in the fall of 1979 by overseeding Mount Barker and Woogenellup cultivars of subterranean clover (22.4 kg seed/ha) and applying elemental sulfur (112 kg/ha) and triple superphosphate (56 kg/ha; 11.3 kg P/ha). In the fall of 1980 and 1983, IG range was top-dressed with normal superphosphate (168 kg/ha; 14.8 kg P/ha). GW ranges were developed in 1961. They were managed since then at stocking rates similar to those used in the present experiment (Pitt and Heady, 1979).

Details of experimental pastures (soils, size, station designations, grazing history) were given by Rosiere and Torell (1985) and Rosiere (1987).

Both range subtypes were grazed continuously by flocks of Targhee type ewes in grazing treatments of three stocking rates that were 100%, 150% and 200% of moderate use (1×, 1.5×, 2× moderate, respectively) as established by past management and studies (Hooper and Heady, 1970; Pitt and Heady, 1979). Mean stocking rates of GW and IG ranges by respective grazing treatments were: 0.6, 1.8, 3.2 and 5.3, 8.0, 10.0 ewes per grazable hectare, plus their lambs for three months and one ram for two months. In all years but 1981, periodic addition of sheep to IG range was used in early portions of the growing season to reduce shading of subterranean clover by taller annual grasses. Put-and-take stocking was consistent with the three grazing treatments. Herbage productivity (recorded as peak standing crop), residue remaining prior to fall germination and degree of use in ranges are presented in Table 2.

Ewe flocks were primarily of Targhee breeding and of mixed ages. Over course of trial, ages of individual ewes varied from one to nine years. Mean flock age was five years. Mixed-age flocks were maintained to represent typical management by replacing ewes that died with ones of corresponding ages. In the third year of study, older ewes with unsound mouths and udders were replaced by long-yearling ewes from the second lamb crop. Hence, only a small proportion (7%)

**Table 1. Species composition (%) of two subtypes of annual range grazed continuously at three stocking rates over five years[a] in coastal northern California.**

| | Grazing intensity (moderate)[b] | | | | | |
|---|---|---|---|---|---|---|
| | 1× | | 1.5× | | 2× | |
| Species | GW[c] | IG[d] | GW[c] | IG[d] | GW[c] | IG[d] |
| *Aira caryophyllea* | 12 | – | 24 | – | 5 | – |
| *Avena barbata, A. fatua* | 10 | – | 2 | – | 2 | – |
| *Bromus mollis* | 33 | 41 | 33 | 34 | 53 | 25 |
| *Bromus rigidus* | 8 | – | 4 | – | 2 | – |
| *Bromus rubens* | 1 | – | 3 | – | T[e] | – |
| *Elymus caput-medusae* | 3 | – | 1 | – | T[e] | – |
| *Festuca* spp. | 3 | 4 | T[e] | 6 | 13 | 6 |
| *Hordeum* spp.[f] | T[e] | 11 | T[e] | 14 | 3 | 8 |
| Misc. annual *Gramineae*[g] | 3 | T[e] | 2 | Te | 3 | T[e] |
| Perennial *Gramineae* | T[e] | – | – | – | – | – |
| *Erodium* spp. | 9 | 2 | 9 | 4 | 1 | 6 |
| *Iris macrosiphon* | T[e] | – | T[e] | | T[e] | – |
| *Lupinus* spp. | 1 | – | T[e] | – | – | – |
| *Medicago hispida* | T[e] | – | T[e] | – | T[e] | – |
| *Trifolium subterraneum* | – | 40 | – | 41 | – | 53 |
| Other *Trifoium* spp. | 4 | T[e] | 8 | T[e] | 2 | T[e] |
| Misc. annual forbs[h] | 13 | 1 | 15 | 1 | 15 | 2 |

[a] Mean; determined by step point procedure.
[b] 1× moderate, 1.5× moderate, 2× moderate = 0.6, 1.8, 3.2 and 5.3, 8.0, 10.0 ewes/grazable ha for GW and IG range, respectively.
[c] GW = grass-woodland range.
[d] IG = improved grassland range.
[e] T = trace (less than 1%).
[f] Primarily *H. leporinum* and *H. hystrix.*
[g] *Briza minor, Bromus* spp. *Cynosurus echinatus, Gastridium ventricosum, Poa annua.*
[h] *Baeria chrysostoma, Brodiaea* spp., *Carduus pycnocephalus, Daucus pusillus, Geranium* spp., *Lepidium* spp., *Lotus* spp.

of ewes were present for the duration of the experiment. To insure replacement ewes, Targhee rams were used to sire the first three lamb crops. The last two crops were sired by Suffolk rams so that traditional "black-faced" lambs would be represented.

Ewes were pasture-exposed to rams beginning in late August. Lamb production was thus coordinated with period of most plentiful and nutritious feed supply (February through May). Lambs were born on range without artificial shelter. They were eartagged, docked and castrated four to six weeks after birth. Lambs were weaned and weighed at approximately 110 days of age. Ewes were weighed at weaning and just prior to the breeding period. They were dewormed (thiabendazole and levamisole in rotation) and were sheared at weaning and tagged (crutched) prior to lambing.

Survival or maintenance feeding, defined by Cook and Stubbendieck (1986) as temporary provision of a balanced ration when quantities of available forage are too low to meet dry matter (DM) requirements, of ewes grazing woodland ranges at 1.5× and 2× moderate use was necessary to prevent starvation. During the first two years, alfalfa hay was fed at a rate of 3.5 kg per ewe per week from mid-September to mid-November. The same feeding program was followed the third year except that ewes under 2× moderate grazing received 8 kg alfalfa per ewe per week during the last month. In the fourth year, rates of feeding for the September to November period were 2.5 kg and 4.25 kg alfalfa/ewe weekly at 1.5× and 2× moderate grazing treatments. In the final year, there was a drought in January and maintenance feeding of ewes on the 2× moderate treatment of woodland range was necessary. Weekly feeding rates per ewe were 8 kg from mid-February through March and 4.25 kg during April.

Maintenance feeding on woodland range was a practice inherent to this experiment because a DM deficiency during the low-feed season was unavoidable when year-long stocking rates were high enough to insure heavy utilization at peak of herbage production. Survival feeding was not required on IG range because the abundant fruit of subterranean clover furnished adequate feed during the critical season, probably serving as a natural protein and energy supplement. Feeding was done only to prevent death of ewes. It was not a flushing practice because range diets were amended only to the level of maintenance (NRC, 1985) and, during the last year under 2× moderate use, lactation (NRC, 1985). Lamb weaning weights, ewe grease fleece weights, turnoff of lambs and grease wool, lamb crop percentage and ewe mortality rates were analyzed in this factorial experiment by split-plot analysis of variance (Steel and Torrie, 1980). Range subtypes and stocking rates (fixed effects) were main plots and years (random effects) were subplots. The error term for testing significance of range subtype and stocking rate effects was the range subtype by stocking rate interaction. Significance of year effect and interaction with other main effects was tested using the three-way interaction as error term. Variation for fleece and weaning weights among sheep within pasture was tested for significance using year by animal within pasture variation. Treatment means were not tested further because there were only two treatments for range subtype and there were no significant F-values for stocking rate effects.

# Results and Discussion

Sheep performance and flock productivity are presented as lamb weaning weights and ewe fleece weights (Table 3), lamb crop and ewe mortality (Table 4) and lamb and wool turnoff (Table 5). Significance of stocking rate, range subtype, year and interactions on production variables is summarized in Table 6. Effects of these factors on sheep performance were not definitive in this trial.

Differences among individual sheep within treatments accounted for most of the variation in weaning and fleece weights (Table 6).

**Table 2. Peak standing crop[a], residue[b] and utilization[c] of herbaceous vegetation on two subtypes of annual range grazed continuously at three stocking rates for five years in coastal northern California.**

| | Grazing intensity (moderate)[d] | | | | | |
|---|---|---|---|---|---|---|
| | 1× | | 1.5× | | 2× | |
| Species | GW[e] | IG[f] | GW[e] | IG[f] | GW[e] | IG[f] |
| Peak standing crop, kg/ha[a,g] | 1,840 ± 303 | 4,619 ± 287 | 1,015 ± 168 | 5,041 ± 751 | 1,552 ± 204 | 3,627 ± 419 |
| Residue, kg/ha[b,g] | 979 ± 124 | 2,695 ± 148 | 510 ± 138 | 2,019 ± 123 | 598 ± 259 | 805 ± 118 |
| Utilization, %[c,g] | 44 ± 7 | 41 ± 5 | 49 ± 10 | 55 ± 8 | 63 ± 12 | 75 ± 7 |

[a] Determined by clipping 0.09 m² plots at ground level at time of seed-set.
[b] Prior to first fall germinating rain.
[c] Residue (100): peak standing crop; residue determined by clipping 0.09 m² plots (ground level) just prior to germinating fall rains.
[d] 100% moderate, 150% moderate and 200% moderate = 0.6, 1.8, 3.2 and 5.3, 8.0, 10.0 ewes/grazable ha for GW and IG range, respectively.
[e] GW = grass-woodland range.
[f] IG = improved grassland range.
[g] Mean ± standard error.

Stocking rate had no significant effect on any of the sheep performance variables. By contrast, there was a significant influence of years on all sheep attributes except grease fleece weight and wool yield. Turnoff of feeder lambs and grease wool was significantly greater on the more productive and heavier stocked IG range than on woodland range (164 vs. 29 kg of lambs/ha; 22.1 vs. 3.8 kg of wool/ha).

There were significant interactions between range subtype and stocking rate for weaning weight and wool turnoff. On woodland range weaning weight tended to decline with increasing rates of stocking while on grassland range average weaning weights tended to increase under highest stocking (Table 3). Wool and lamb turnoff increased non-significantly as stocking rate increased on grassland range while on woodland range turnoff of these commodities was four times greater under the heaviest grazing treatment (Table 5). Significant second-order interactions of range subtype, stocking rate and year occurred for weaning and fleece weights. Year effects did not interact with those of range subtype or stocking rate on a first-order level.

There were relatively few investigations of sheep responses to range stocking rates in North America with which to compare these results. A consensus of stocking rate studies indicated that performance of individual animals declined while total yield from animals per area of land rose as stocking rate increased (Heady and Child, 1994). Malechek et al.

**Table 3. Weaning weights (WW; kg) of single lambs[a] and fleece weights (FW; kg) of ewes grazing grass-woodland (GW) and improved grassland (IG) annual range at three stocking rates for five years in coastal northern California.**

| | GW range (moderate) | | | | | | IG range (moderate) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1×[b] | | 1.5×[b] | | 2×[b] | | 1×[b] | | 1.5×[b] | | 2×[b] | |
| Year | WW | FW | WW | FW | WW | FW | WW | FW | WW | FW | WW | FW |
| 1980 | 34 | 3.9 | 35 | 3.3 | 27 | 2.9 | 35 | 3.4 | 39 | 3.5 | 36 | 3.1 |
| 1981 | 33 | 3.0 | 25 | 2.3 | 22 | 2.2 | 31 | 3.2 | 36 | 3.4 | 32 | 2.6 |
| 1982 | 35 | 3.5 | 29 | 2.9 | 26 | 3.2 | 34 | 3.0 | 31 | 3.4 | 38 | 3.1 |
| 1983 | 33 | 2.6 | 34 | 2.5 | 29 | 2.3 | 41 | 2.9 | 36 | 3.2 | 46 | 3.4 |
| 1984 | 36 | 2.8 | 30 | 2.8 | 26 | 2.6 | 39 | 2.8 | 35 | 2.7 | 41 | 2.7 |
| Mean ±SE[c] | 34±1 | 3.2±0.2 | 31±2 | 2.8±0.2 | 26±1 | 2.6±0.2 | 36±2 | 3.1±0.1 | 35±1 | 3.2±0.1 | 39±2 | 3.0±0.1 |
| (CV)[d] | (4) | (17) | (13) | (14) | (10) | (16) | (11) | (8) | (8) | (10) | (14) | (11) |

[a] Approximately 110 days of age; Targhee in 1980, 1981 and 1982; Targhee × Suffolk in 1983 and 1984.
[b] 1× moderate, 1.5× moderate, 2× moderate = 0.6, 1.8, 3.2 and 5.3, 8.0, 10.0 ewes per grazable ha for GW and IG range, respectively.
[c] SE = standard error.
[d] CV = coefficient of variation.

**Table 4. Lamb crop[a] (LC; %) and ewe mortality (EM; %) in flocks of Targhee-type sheep grazing grass-woodland (GW) and improved grassland (IG) annual range at three stocking rates for five years in coastal northern California.**

| | GW range (moderate) | | | | | | IG[c] range (moderate) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1× | | 1.5× | | 2× | | 1× | | 1.5× | | 2× | |
| Year | LC | EM | LC | EM | LC | EM | LC | EM | LC | EM | LC | EM |
| 1980 | 92 | 0 | 92 | 17 | 90 | 0 | 67 | 11 | 100 | 0 | 88 | 0 |
| 1981 | 85 | 7 | 92 | 23 | 86 | 25 | 63 | 0 | 71 | 13 | 100 | 22 |
| 1982 | 92 | 8 | 71 | 30 | 60 | 17 | 86 | 13 | 13 | 13 | 29 | 13 |
| 1983 | 67 | 0 | 22 | 0 | 50 | 0 | 87 | 12 | 50 | 0 | 57 | 0 |
| 1984 | 100 | 0 | 100 | 33 | 100 | 12 | 87 | 12 | 87 | 0 | 100 | 0 |
| Mean ±SE[c] | 87±6 | 3±2 | 75±14 | 21±6 | 77±9 | 11±5 | 78±5 | 10±2 | 64±15 | 5±3 | 75±14 | 7±5 |
| (CV)[d] | (14) | (137) | (42) | (64) | (27) | (101) | (15) | (56) | (53) | (137) | (42) | (144) |

[a] Lambs weaned per ewe exposed to ram; Targhee in 1980, 1981 and 1982; Targhee × Suffolk in 1983 and 1984.
[b] 1× moderate, 1.5× moderate, 2× moderate = 0.6, 1.8, 3.2 and 5.3, 8.0, 10.0 ewes per grazable ha for GW and IG range, respectively.
[c] SE = standard error.
[d] CV = coefficient of variation.

(1978) reported that on Intermountain range, ewe and lamb weight gains were greater under moderate grazing while lamb production per unit of rangeland was higher with heavy stocking. On improved hill pasture in Oregon, which was similar to improved California annual grassland, Sharrow et al. (1981) found that lamb weaning weights were lighter at lowest rather than at the highest stocking rate evaluated. Turnoff of lambs/ha increased with increasing rates of stocking.

Trials involving seasonal grazing would likely have more pronounced differences in sheep performance than those like the present study using continuous grazing where stocking rates were low enough to furnish some feed during plant dormancy. Perhaps this was why current findings indicated trends rather than distinct differences. Robards et al. (1978) explained that the range in stocking rates capable of being tested on rangeland was so limited that production per animal was often not affected by grazing intensity.

The most substantive finding of this study was that stocking rate had little influence on performance of individual sheep grazing California annual range at intensities ranging from 1× moderate to 2× moderate year-long rates that assured intensities were reached at time of peak herbage yield. Inferences of stocking rates and related flock management were pertinent for conditions that were typical of ranching practices in coastal California. Stocking rates were not so extreme as to show basic mechanisms of sheep biology under a wide array of grazing intensities.

An obvious result of sheep performance on annual range was low lamb crop percentage weaned which averaged 76% (80% on woodland range; 72% on grassland range). This was less than three-fourths of the birth rate of lambs on Pacific hill pastures when flushing and shed lambing were practiced (Sharrow et al., 1981), but as these workers did not report weaned percentage it was unclear if lamb crops were higher under more intensive management. Lamb crop percentages on annual range were well above the 30% to 50% reported by Squires (1981) for Australia's arid zone and below those recorded for subterranean clover/annual grass pasture in Australia (Brown, 1977; White et al. 1980). Weaned lamb crop percentages in the current study corresponded to the Texas average of 75% (Texas Farm Bureau, 1987). Lamb crops of the current study were lower than the 89% reported by Thomas et al. (1990) and 88% reported by Burfening and Van Horn (1993) for Montana range and the 108% found by Walker et al. (1993) weaned off of Idaho desert range. They were the same as the 77% weaned on South Dakota range (Inman and Slyter, 1993). Ewes in the studies by Thomas et al. (1990) and Inman and Slyter (1993) were of Targhee and Targhee-fine wool breeding but shed lambing was practiced followed by penning of pairs and then group penning. Lambs in the Walker et al. (1993) trial were born on range, but the ewes were $^3/_4$-Targhee × $^1/_4$-Finnsheep.

Personal communications with commercial ewe-lamb operators in coastal California indicated that lamb crops of 70% to 80% were typical for range lambing and single-sire flocks. Low lamb crops were consequences of several factors (still-born lambs, neonatal death loss, poor ewe maternal ability, limited shelter from rain, coyote/dog predation).

Lack of significant effect of stocking rate on lamb crops was consistent with other findings of sheep grazing annual grass and subterranean clover pastures (Russell and Blackburn, 1973; Fitzgerald, 1976; Brown, 1977; Robards et al., 1978). It was not clear from the current investigation, or from cited studies, why there was no detectable response of lamb crop to stocking rate. Lamb crops may have been low enough that stocking rate effects could not be detected. It was

**Table 5. Turnoff of feeder lambs[a] (TFL; kg/ha) and grease wool (TGW; kg/ha) from grass-woodland (GW) and improved grassland (IG) annual range at three stocking rates for five years in coastal northern California.**

| | GW range (moderate) | | | | | | IG range (moderate) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1×[b] | | 1.5×[b] | | 2×[b] | | 1×[b] | | 1.5×[b] | | 2×[b] | |
| Year | TFL | TGW | TFL | TGW | TFL | TGW | TFL | TGW | TFL | TGW | TFL | TGW |
| 1980 | 17 | 2.5 | 24 | 2.4 | 94 | 10.3 | 138 | 18.0 | 290 | 28.1 | 192 | 17.1 |
| 1981 | 16 | 1.8 | 18 | 1.8 | 50 | 6.3 | 95 | 17.2 | 162 | 23.5 | 219 | 19.1 |
| 1982 | 14 | 1.9 | 9 | 1.7 | 31 | 7.7 | 68 | 14.0 | 31 | 24.1 | 96 | 31.4 |
| 1983 | 12 | 1.8 | 4 | 1.5 | 35 | 7.4 | 138 | 13.6 | 73 | 25.6 | 230 | 25.4 |
| 1984 | 17 | 1.8 | 14 | 1.1 | 73 | 7.2 | 180 | 15.1 | 242 | 21.6 | 306 | 27.5 |
| Mean ±SE[c] | 15±1 | 2.0±0.1 | 14±3 | 1.7±0.2 | 57±12 | 7.8±1.5 | 124±19 | 15.6±0.9 | 160±49 | 24.6±1.1 | 209±34 | 26.1±2 |
| (CV)[d] | (14) | (16) | (56) | (28) | (47) | (19) | (35) | (12) | (69) | (10) | (36) | (17) |

[a] Lambs were Targhee in 1980, 1981 and 1982; Targhee × Suffolk in 1983 and 1984.
[b] 1× moderate, 1.5× moderate, 2× moderate = 0.6, 1.8, 3.2 and 5.3, 8.0, 10.0 ewes per grazable ha for GW and IG range, respectively.
[c] SE = standard error.
[d] CV = coefficient of variation.

also likely that lamb crop was influenced by so many factors independent of the grazing treatments that any influence of stocking rate was masked.

Influence of stocking rate on ewe mortality varied with range subtype (significant interaction; Table 6). This indicated that maintenance feeding prevented death rates under 1.5× and 2× moderate grazing on woodland from exceeding those on grassland and moderately grazed woodland. While feeding was the major equalizer of mortality on woodland range it was probably not the only factor involved.

Death rates also did not differ among stocking rates on grassland range where survival feeding was not practiced. This showed that annual ranges with large populations of subterranean clover could be grazed heavily without reliance on survival feeding because DM and nutrients were not reduced below ewe maintenance requirements (Rosiere and Torell, 1985). It further suggested that dry ewes are well-adapted for survival on closely grazed range. Brown (1977) and White et al. (1980) also determined that stocking rate did not affect mortality of ewes grazing subterranean clover and annual grass.

Maintenance feeding of ewes did not increase lamb crop percentage above that of unfed ewes on moderately grazed woodland range. There was a trend for higher lamb crops under moderate grazing on woodland (mean of 87% with 1× moderate grazing vs. 75% and 77% for 1.5× and 2× moderate grazing, respectively; Table 4). Given this trend and an average fall feeding of 32.5 and 41.4 kg of alfalfa hay per ewe for 1.5× and 2× moderate grazing, respectively, stocking of sheep on unimproved annual range beyond moderate rates was an expensive practice that involved economic as well as biological considerations.

Effect of stocking rate was obviously confounded with that of survival feeding. Lane (1962) noted that this situation occurred frequently when stocking rates were constant over time. Cook and Stubbendieck (1986) discussed this as a frequent occurrence in management studies that incorporated heavy grazing and feeding based on need. They mentioned the desirability of some economic discussion in such cases. Robards (1981) explained that economic implications of total lamb and wool yield could be compared regardless of confounding results.

Although maintenance feeding did not increase performance of individual ewes, it did result in increased production of lamb and wool per hectare under 2× moderate grazing. Feeding and 2× moderate grazing increased turnoff about four-fold over moderate grazing and 1.5× moderate grazing plus feeding on woodland range (Table 5). Stocking woodland range at greater-than-moderate rates to increase total sheep production was possible only at high ewe concentrations (e.g., increasing production per hectare by increasing number of ewes per hectare became increasingly more likely as larger portions of ewe diets were provided by survival feeding). Based solely on hay expense incurred during the trial, feeding cost averaged $7.22/ha ($4.01/ewe) under 1.5× moderate grazing and $16.36/ha ($5.11/ewe) under 2× moderate grazing. Average cash receipts from combined sale of feeder lambs and grease wool were $100.36/ha under 2× moderate grazing and $25.00/ha under 1× moderate and 1.5× moderate grazing. By investing $16.36/ha in alfalfa plus additional costs, an extra $75.36/ha was received with 2× moderate grazing on woodland range. An expenditure of $7.22/ha resulted in no more cash return than with moderate grazing and no feeding.

Stocking woodland ranges beyond moderate rates not only increased risk of insufficient forage at the end of the growing season or during drought, but also included the possibility that grazing might not be heavy enough to offset cost of feed (for example, spending $7.22/ha or $4.01/ewe for hay and getting no increase in income).

In an economic analysis of grazing intensity for woodland range on Hopland Field Station in Mendocino County, CA (Hooper and Heady, 1970), it was determined that the optimum stocking rate left 560 kg of residue per hectare just prior to onset of the next growing season. This corresponded most closely to 2× moderate grazing in the present trial (Table 2). Hooper and Heady (1970)

**Table 6. Significance of main effects and interactions in sheep performance parameters on grass-woodland and improved grassland annual range at three stocking rates for five years in coastal northern California.**

| Source of variation | Performance variable | | | | | |
|---|---|---|---|---|---|---|
| | WW[a] | FW[b] | LC[c] | EM[d] | TFL[e] | TGW[f] |
| Range subtype (RS) | NS[g] | NS[g] | NS[g] | NS[g] | ***[h] | **[h] |
| Stocking rate (SR) | NS[g] | NS[g] | NS[g] | NS[g] | NS[g] | NS[g] |
| Year (Y) | **[h] | NS[g] | ****[h] | **[h] | **[h] | NS[g] |
| RS × SR[i] | ****[h] | NS[g] | NS[g] | **[h] | NS[g] | ***[h] |
| Y × RS[i] | NS[g] | NS[g] | NS[g] | NS[g] | NS[g] | NS[g] |
| Y × SR[i] | NS[g] | NS[g] | NS[g] | NS[g] | NS[g] | NS[g] |
| Y × RS × SR[i] | ****[h] | ****[h] | – | – | – | – |
| Sheep per pasture | ****[h] | ****[h] | – | – | – | – |

[a] WW = weaning weight of lambs.
[b] FW = fleece weight of ewes.
[c] LC = lamb crop percentage.
[d] EM = ewe mortality rate.
[e] TFL = turnoff of feeder lambs.
[f] TGW = turnoff of grease wool.
[g] NS = not significant.
[h] * = P < 0.05; ** = P < 0.025; *** = P < 0.01; **** = P < 0.005
[i] Error terms: RS × SR interaction for RS and SR effects; Y × RS × SR interaction for Y, Y × RS, Y × SR effects; year × flock mean within pasture for Y × RS × SR interaction; year × individual sheep within pasture for WW and FW variability.

based their determination on price of forage, not animal performance, and they did not consider maintenance feeding. They indicated that it was less costly to graze too lightly than to graze too heavily.

Forage shortage did not result from higher stocking rates on grassland range because residue of subterranean clover remained adequate for year-long grazing. Turnoff of wool and lambs apparently increased with successively increasing rates of stocking (Table 5) and, as production per animal did not differ or trend downward, there was an apparent advantage to heavy grazing on grassland range. Several grazing trials on subterranean clover documented greater total production of lambs and wool with heavier stocking rates while wool clip per sheep usually declined (White and McConchie, 1976; Brown, 1977) and lamb growth rate either decreased (Fitzgerald, 1976; Brown, 1977) or was unaffected (Robards et al., 1978; White et al., 1980). Robards et al. (1978) and Reeve and Sharkey (1980) noted that reductions in wool produced per sheep under heavy grazing on annual range and subterranean clover were so slight that wool produced per unit of land increased linearly with rising stocking rates. An approximate situation existed in the present experiment on grassland but not on woodland range.

Comparable levels of sheep performance between grassland and woodland range for parameters other than turnoff was probably not unusual. Major forage species except subterranean clover were common to both subtypes (Table 1) and, while sheep diets were more nutritious on grassland range, there was more difference between subtypes in amount of forage than in nutritional value of forage (Rosiere and Torell, 1985). Campbell et al. (1973) and Robards et al. (1978) learned that sheep performance did not differ between annual and perennial range, a greater contrast than comparison between two annual subtypes.

Significant year effects on sheep parameters except wool production may have indicated important management considerations. Most studies cited above revealed yearly variation in sheep performance. In the present trial some fluctuation in performance over years was expected because it was necessary to raise Targhee- and Suffolk-sired lambs in different years. This could have accounted for some of the yearly variability in weaning weight but probably not in lamb crop where environmental factors (winter storms, predation) and ewe mothering ability were more influential. Furthermore, influence of ram breed was not consistent. Weaning weights tended to be higher with Suffolk-sired lambs (1983 and 1984 crops) but mean weaning weight in some flocks was heavier in 1980, 1981 and 1982 with Targhee-sired lambs (Table 3). Although mixed-age flocks were kept throughout the trial, it was reasonable that yearly differences would also occur in wool production because many older ewes were replaced by yearling and two-year-old ewes in the fourth and fifth years. Comparison of grease fleece weights (Table 3) to weaned lamb crop percentage (Table 4) during the five years of study indicated that wool was a more stable commodity to produce than feeder lambs. As such, wool production would be critical to commercial sheep ranches on coastal annual range, especially those with less intensive management.

Another implication of year effects was the limited importance of stocking rate relative to fluctuations in weather and forage growing conditions. Yearly fluctuations in herbage production and botanical composition were documented for the annual type (Duncan and Woodmansee, 1975; Pitt and Heady, 1978) and were found on ranges used in the current study to exceed variations due to stocking rate (Pitt and Heady, 1979; Rosiere, 1987). A parallel existed in performance of sheep grazing annual range which, in conjunction with significant variation among individual sheep, largely negated influences of stocking rate across two kinds of annual range. Limited influence of grazing intensity on performance of individual sheep mirrored its slight impact on vegetation (Rosiere, 1987). Stocking rates were important primarily as long-term influences on sheep production per hectare rather than on performance of individual animals. This finding was consistent with numerous stocking rate studies of sheep on annual ranges, particularly those seeded to subterranean clover.

If stocking rates of sheep on annual ranges have effects so limited that they can be masked or countered by routine husbandry or yearly differences in growing conditions, sheepmen should place less emphasis on grazing intensity than on other management factors.

# Conclusions

Stocking rate is a notable management factor for sheep production on annual range in coastal northern California because it may affect yield of lamb and wool per unit of land area. However, at 1X moderate to 2X moderate stocking rates there is little influence on performance of individual sheep because: 1) on annual grassland overseeded to subterranean clover, there is adequate forage even with heavy grazing; and 2) on annual grass-woodland range, continuous heavy grazing is impossible without survival feeding which prevents sheep production from declining below that under moderate grazing. Within woodland and grassland subtypes of annual range, yearly fluctuations in environmental and managerial factors affect individual sheep performance more than do differences in range composition and production that result from stocking rate.

Improvement of annual grassland by fertilizing and seeding to subterranean clover is an effective way to increase turnoff of lambs and wool. To get full advantage of subterranean clover grassland it should be grazed heavily (10 ewes/ha with year-long use in northern California).

Moderate grazing of annual woodland range (0.6 to 1.0 ewe/ha with year-long use, depending on range site) is minimal, but economically and biologically sound, management. Sheep turnoff from woodland range can be increased by higher rates of stocking accompanied by increased

risk of forage shortage and maintenance feeding.

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# Effect of Pelleted Corn Diets during Pre- and Post-Weaning on Serum Hormone and Metabolite Profiles, Wool Characteristics and Performance in Early-Weaned Lambs[1,2,3]

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## Summary

The objective of this study was to examine the effect of three levels of corn fed during the pre- and post-weaning period on intake, serum insulin, growth hormone (GH), prolactin (PRL), insulin-like growth factor-I (IGF-I) and metabolite concentrations, wool growth and weight gains in lambs weaned at 28 ± 1 days (mean ± SD) of age. Eighteen lambs (nine sets of twins) were randomly allotted at two weeks of age to ad libitum feeding of a pelleted diet containing either 0, 30 or 60% corn (five ewe lambs and one wether lamb per group). Each animal (dam and two offspring) was housed individually in pens (1.5 m × 3 m) which consisted of raised expanded metal flooring. Lambs remained in these pens following weaning. Blood samples were collected from five ewe lambs per treatment at 20-minute intervals for six hours at 28, 35, 56 and 84 days of age. Weekly body weights (BW) and average daily gain (ADG) did not differ ($P > 0.12$) during the study. Post-weaning pen intake decreased (linear, $P < 0.04$) as level of corn increased; as a result, a linear ($P < 0.05$) decrease in crude protein (CP) intake was observed as the amount of corn increased. Feed-to-gain (F:G) ratio and metabolizable energy (ME) intake were not affected ($P > 0.19$) by dietary treatment. Serum insulin, insulin-to-GH (INS:GH) ratio and secretory characteristics of GH and PRL were not influenced ($P > 0.20$) by diet. Insulin-like growth factor-I was increased ($P = 0.03$) as the proportion of corn increased. At 28, 35 and 56 days of age, serum glucose concentrations increased (linear, $P < 0.10$) as corn in the diet increased. In contrast, serum urea-N (SUN) decreased ($P = 0.04$) as the amount of corn increased. Non-esterified fatty acids (NEFA) were not affected ($P > 0.30$) by diet. Staple length and pre-weaning wool fiber diameter did not differ ($P > 0.15$) among groups; at two months post-weaning, however, a decrease ($P = 0.03$) in fiber diameter was observed as the percentage of corn increased. Although differences in serum hormone and metabolite profiles were detected due to dietary treatment, the proportion of corn in the diet did not influence post-weaning growth performance.

**Key words:** lamb, diets, early weaning, hormones, wool.

## Introduction

Lambs born in the spring are routinely left with their dams for 60 to 120 days. After 40 days post-partum, milk production of the ewe declines rapidly; therefore, lambs are forced to compete with their dams for available forage. Early weaning could allow for more efficient use of pasture resources in situations of limited forage availability, heavy parasite infections or accelerated lambing systems (American Sheep Industry Association, 1992). Although early

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weaning may increase ewe productivity, it often is associated with less than optimum post-weaning gains in weaned lambs (Holcombe et al., 1992)

A prerequisite to a successful early weaning program is early consumption of a diet that promotes establishment of a ruminal microbial population capable of utilizing dry feed (Wardrop and Coombe, 1961; Warner, 1962). Concentrates enhance rumen development (Warner et al., 1956) but roughages are even more stimulatory (Brownlee, 1956; Poe et al., 1969). Nonetheless, a mixture of alfalfa meal and concentrates has been shown to be equally effective as roughage diets (Poe et al., 1971). Determining optimum composition of the pre- and early post-weaning feeding systems that will promote ruminal development and optimal body growth are essential for early weaning to be successful.

Early weaning may also affect hormonal and metabolic patterns; these patterns have been reported to remain altered for a longer period in lambs weaned at 30 days as compared with 60 days of age (Holcombe et al., 1994, 1995). Characterizing these responses in lambs fed different diets may provide important insights into their physiological status and help to identify alternative feeding strategies (Lane and Albrecht, 1991). The objectives of this study were to examine the effect of three diets fed pre- and early post-weaning on feed intake, serum hormones and metabolites, wool characteristics and growth in lambs weaned at 28 days of age.

# Materials and Methods

### *Animal Management*

Eighteen Polypay lambs (nine sets of twins) born within a three-day period (in March) were randomly allotted at two weeks of age to one of three dietary treatments with each treatment group consisting of three sets of twins (five ewe lambs and one wether lamb). The diets contained either 0%, 30% or 60% corn and were adjusted to contain approximately 15% CP. Ingredients and chemical composition of the diets are shown in Table 1. Lamb diets were assayed for percentages of dry matter (DM) and CP using standard procedures (Association of Official Analytical Chemists [AOAC], 1984). Metabolizable energy for lamb diets was estimated from ingredients of pelleted feed based on standards set by the National Research Council (NRC, 1985). Each animal unit (dam and two offspring) was housed in individual pens (1.5 m × 3 m) with raised expanded metal flooring and allowed free access to water and trace mineral salt (Leslie Salt Company, Newark, CA; guaranteed analysis: NaCl, 96 to 98%; Zn, 0.3%; Fe, 0.2%; Cu, 0.04%; Co, 0.002%; I, 0.002%). All animal care followed procedures outlined in the Consortium (1988). While maintained in individual pens, ewes were fed a chopped alfalfa hay (16% CP) and corn diet according to their NRC (1985) requirements on a BW basis. Lambs were not allowed access to their mother's diet. Beginning at 14 days of age, lambs were allowed ad libitum access to their designated diet using pen feeders. Fresh feed and water were provided for each set of twins (two lambs per pen) at 0700 hours daily and feed refusals from the previous day were obtained. Weekly pen intakes were then determined and recorded through 85 days of age. Lambs were weaned at 28 ± 1 days of age (mean ± SD). At weaning, ewes were moved to a separate facility and lambs continued to be housed in the 1.5 m × 3 m pens through 85 days of age. Weekly BW measurements were recorded from 13 to 83 days of age.

### *Pre- and Post-Weaning Blood Sampling*

All ewe lambs were subjected to jugular blood sampling at 28, 35, 56 and 84 days of age to examine the effects of milk intake (day 28 only) and dietary treatments on serum constituents pre- and post-weaning. Lambs were fitted with indwelling cannulae (18 g × 5.1 cm; Abbocath-T, Abbott Hospital, Inc., Chicago, IL) at 1200 hours the day before sampling. At 28 days of age, milk intake was determined by a weigh-suckle-weigh technique. Lambs were separated from their dams at 0400 hour and remained separated for three hours. At 0645 hours, a pre-feed blood sample (3 mL) was obtained, lambs were weighed and then allowed to suckle (0700 hours) until satisfied. At 0730 hours, lambs were separated from their dams, re-weighed and jugular blood samples were obtained at 20-minute intervals for six hours. During the sampling period at 28 days of age, lambs remained separated but had physical contact with their dams. Lambs were allowed free access to water throughout the sampling period. After blood sampling was completed, lambs were weaned and ewes were moved to a separate facility. At 35, 56 and 84 days of age, lambs were fasted for 12 hours, after which lambs were allowed access to their designated diet for 30 minutes (0700 to 0730 hours) on the day of

**Table 1. Ingredients and chemical composition[a] (%) of the pelleted diets containing 0%, 30% and 60% corn fed to early-weaned lambs.**

| | Concentrate, % | | |
|---|---|---|---|
| Item | 0 | 30 | 60 |
| Alfalfa hay | 97.5 | 65 | 25 |
| Ground corn | 0 | 30 | 60 |
| Soybean, 46% CP | 0 | 2.5 | 12.5 |
| Molasses | 2.47 | 2.47 | 2.47 |
| Decoquinate[b] | 0.03 | 0.03 | 0.03 |
| DM, % | 93.1 | 92.3 | 91.9 |
| CP, % | 15.5 | 14.6 | 15.1 |
| Metabolizable energy, Mcal/kg[c] | 1.93 | 2.17 | 2.56 |

[a] On DM basis.
[b] 15 mg/kg of pelleted feed; Rhone Poulenc, Inc., Atlanta, GA.
[c] Metabolizable energy estimated from ingredients of pelleted feed based on NRC (1985).

sampling. Following feed removal (0730 hours), blood samples were obtained as described earlier. In addition, blood samples were collected daily at 0700 hours for one week following weaning. Blood samples were allowed to clot at 4 °C overnight, after which serum was separated by centrifugation (2,300 g for 15 minutes at 4 °C). Serum was stored at -20 °C until analyzed.

*Laboratory Analysis*

Blood samples collected daily for one week after weaning were analyzed for serum glucose, urea nitrogen (SUN) and nonesterified fatty acid (NEFA) concentrations. Serum glucose and SUN were examined colorimetrically using the ortho-toluidine and diacetyl-monoxime assay procedures (Stanbio Laboratory, Inc., San Antonio, TX), respectively. NEFA concentrations were determined using a modified colorimetric technique (Wako Chemicals, Inc., Richmond, VA), as modified by McCutcheon and Bauman (1986). Interassay coefficient of variation (CV) for glucose (n = 20), SUN (n = 20) and NEFA (n = 10) were 7.0%, 10.0% and 6.7%, respectively. In samples collected hourly on the four bleeding days, serum glucose, SUN and insulin concentrations were determined. Serum insulin was quantified using a radioimmunoassay described by Sanson and Hallford (1984) with a within-assay CV of 10.0% (n = 20). Serum growth hormone (GH) and prolactin (PRL) concentrations were examined in all samples collected at 28, 35, 56 and 84 days of age. Serum GH and PRL were determined by radioimmunoassay as reported by Hoefler and Hallford (1987) and Spoon and Hallford (1989), respectively. Intra- and interassay CV for the GH assay were 9.6% (n = 8) and 10.3% (n = 10), respectively. Between- and within-assay CV for serum PRL were 9.8% (n = 7) and 7.2% (n = 10), respectively. Because of the pulsatile release of GH and PRL, mean and baseline concentrations, number of peaks, average peak amplitude and area under the curve for serum GH and PRL in blood samples collected at 28, 35, 56 and 84 days of age were determined by a microcomputer program that employed the algorithm as reported by Lunstra et al. (1989). Blood samples collected every hour of sampling were pooled and a single sample for IGF-I analysis was obtained. Serum IGF-I concentrations were examined using a radioimmunoassay procedure describe by Holland et al. (1988) with a within-assay CV of 4.6% (n = 8).

*Wool Sampling*

At 14 days of age, a dye-band was applied to the wool (mid-side) of all lambs as described by Williams and Chapman (1966). A second dye-band was applied at 84 days of age. After one week, the dye-banded area was clipped and staple length was determined. In addition, a 10-$cm^2$ mid-side sample was obtained at 14 days of age, after which this patch was clipped again at 85 days of age. Wool samples were sent to Montana State University Wool Laboratory for fiber diameter and variation determination and measured by microprojection (ASTM, 1986; designation D-2130).

*Statistical Analysis*

Pen feed intake, pen F:G ratio, pen ME and CP consumption were analyzed by analysis of variance for a completely random design (Steel and Torrie, 1980) using pen as the experimental unit. Body weight (BW), average daily gain (ADG) and wool characteristics were analyzed by analysis of variance for a completely random design using lamb as the experimental unit. Secretory characteristics for serum GH and PRL, serum IGF-I and serum metabolites in samples collected daily for one week post-weaning were analyzed as a split-plot design with the main effect, treatment (main plot), tested against ewe lamb within treatment (error a; Gill and Hafs, 1971). The main effect, day of age (subplot) and the interaction of day of age and treatment were tested against residual error (error b). Serum insulin, INS:GH ratio and metabolite concentrations were analyzed as a split-split-plot in a completely random design with time of sampling (sub-subplot) and the respective two- and three-way interactions with the other two main effects tested against residual error. The subplot effects were tested against ewe lamb within treatment by day of age as the error term (error b). When a significant F-test was detected ($P < 0.05$) for treatment differences, means were evaluated using linear and quadratic contrasts. Following a significant F-test ($P < 0.05$) of the interaction effects, the least significant difference procedure was used for mean separations (Steel and Torrie, 1980). All analyses were computed using the GLM procedure (SAS, 1988).

# Results and Discussion

*Feed Intake and Performance*

Before weaning (28 days of age), pelleted feed intake was unaffected ($P > 0.10$) by dietary treatment (Table 2). Likewise, milk intake determined by the weigh-suckle-weigh technique at 28 days of age did not differ ($P = 0.74$) in lambs receiving 0%, 30% and 60% corn diets (93, 108 and 102 ± 13.5 g, respectively). For the first two weeks following weaning, pen intake did not differ ($P > 0.20$) among dietary treatments. After this period, however, a linear decrease ($P < 0.04$) in intake was observed as the percentage of corn increased; this difference was observed throughout the experimental period. These data agree with Grovum (1988) who reported that sheep fed high-concentrate diets consume less feed than sheep on low-concentrate diets. Although intake decreased as the percentage of corn increased, calculated ME (Mcal/day) did not differ ($P > 0.19$) among the three treatments. Therefore, although lambs ate less as the proportion of corn increased, the consumption of ME was fairly constant. In studies with ewes (Donefer et al., 1963) and dairy heifers (Montgomery and Baumgardt, 1965), digestible energy intakes were relatively uniform when pelleted rations were varied in energy concentration by changing the proportion of alfalfa to barley or corn. When protein intake (g/day) was calculated, a linear decrease ($P < 0.05$) in protein consumption was observed as corn in the diet increased. Protein differences were detected beginning two weeks post-weaning (42 to 48 days of age). This decrease continued throughout the study and reflects lower dry matter intake (DMI). In addition, lambs receiving the 30% and 60% corn diet

did not meet NRC (1985) recommended protein requirement for moderate growth (0.20 to 0.25 kg/day) until four and five weeks post-weaning, respectively. In contrast, lambs receiving the 0% corn diet met their NRC (1985) recommended protein requirements by three weeks post-weaning. Although pen intake and protein consumption differed ($P < 0.04$) among treatments post-weaning, no differences ($P > 0.12$) were observed either pre- or post-weaning (Table 3) in BW or ADG, which were within ranges reported by others (Thomas et al., 1988; Lane and Albrecht, 1991; Holcombe et al., 1995) in early-weaned lambs. Likewise, pen F:G ratio was not influenced ($P > 0.28$) by dietary treatment during the duration of the trial (Table 3).

In this study, rate of gain was not affected by dietary treatments, which suggests that a pelleted diet that consist of either 0, 30 or 60% corn would provide gains expected for moderate growth in early-weaned lambs. It is also possible that lower protein intake and/or period of protein deficiency inhibited ADG, particularly in lambs receiving the 60% corn diet. Therefore, CP content may need to be higher than 15% in diets consisting of over 50% corn in order to meet requirements and provide optimum gains for early-weaned lambs.

**Table 2. Daily pen intake, metabolizable energy (ME) and crude protein (CP) consumption in early-weaned lambs fed 0%, 30% and 60% corn pelleted diet pre- and post-weaning.[a]**

| | Corn, % | | | |
|---|---|---|---|---|
| Days of age | 0 | 30 | 60 | SEM |
| **Pen pelleted feed intake, kg:** | | | | |
| 13 to 20 | 0.04 | 0.07 | 0.04 | 0.01 |
| 21 to 27 | 0.13 | 0.19 | 0.13 | 0.04 |
| 28 to 34 | 0.90 | 0.88 | 0.75 | 0.96 |
| 35 to 41 | 1.33 | 1.33 | 1.04 | 0.93 |
| 42 to 48[b] | 1.93 | 1.78 | 1.48 | 0.95 |
| 49 to 55[b] | 2.42 | 2.17 | 1.95 | 0.78 |
| 56 to 62[b] | 3.04 | 2.75 | 2.54 | 1.32 |
| 63 to 69[b] | 3.29 | 2.95 | 2.32 | 1.83 |
| 70 to 76[b] | 3.01 | 2.73 | 2.33 | 1.88 |
| 77 to 83[b] | 3.70 | 3.42 | 2.96 | 1.69 |
| **ME, Mcal/day:** | | | | |
| 28 to 34 | 1.74 | 1.92 | 1.92 | 0.19 |
| 35 to 41 | 2.56 | 2.90 | 2.67 | 0.18 |
| 42 to 48 | 3.72 | 3.87 | 3.79 | 0.20 |
| 49 to 55 | 4.67 | 4.71 | 5.00 | 0.18 |
| 56 to 62 | 5.87 | 5.97 | 6.49 | 0.29 |
| 63 to 60 | 6.35 | 6.39 | 5.94 | 0.41 |
| 70 to 76 | 5.81 | 5.92 | 5.95 | 0.42 |
| 77 to 83 | 7.14 | 7.42 | 7.57 | 0.39 |
| **CP, g/day:** | | | | |
| 28 to 34 | 139 | 129 | 113 | 14 |
| 35 to 41 | 205 | 195 | 157 | 14 |
| 42 to 48[b] | 299 | 260 | 223 | 14 |
| 49 to 55[b] | 375 | 317 | 295 | 11 |
| 56 to 62[b] | 471 | 401 | 383 | 20 |
| 63 to 69[b] | 509 | 429 | 350 | 28 |
| 70 to 76[b] | 467 | 399 | 351 | 28 |
| 77 to 83[b] | 574 | 499 | 447 | 25 |

[a] Lambs were pen fed (two lambs/pen; three pens/treatment); lambs were weaned at 28 ± 1 days of age (mean ± SD).
[b] Linear effect within row ($P < 0.05$).

### *Serum Hormone and Metabolite Profiles*

No significant three-way interactions were detected ($P > 0.15$) for any serum constituents. A split-split plot analysis revealed no treatment by day of age or treatment by time of sampling interactions ($P > 0.10$); however, a day of age by time of sampling interaction ($P < 0.05$) was detected for serum insulin and NEFA concentrations. Therefore, treatment main effect means are presented for serum insulin and NEFA concentrations and day of age effects on these constituents are discussed within time of sampling. No two-way interactions ($P > 0.15$) were detected for either INS:GH ratio or SUN concentrations; therefore, treatment and day of age main effects are presented. Serum GH and PRL secretory variables and IGF-I concentrations were not affected by treatment by day of age interactions ($P > 0.10$); therefore, main effects are discussed.

Serum insulin values across day of age and sampling times tended to differ ($P = 0.07$; Table 4) among treatments. Insulin concentrations have been associated with the amount of grain in the diet (Trenkle, 1972; Cole et al., 1988) and positively correlated with intestinal CP and ruminal organic matter digested by sheep (Bassett et al., 1971; Weston and Hogan, 1974). Serum insulin did not differ ($P = 0.15$) among days for the pre-feeding sampling (zero hour; Figure 1). After feeding and throughout the sampling period, however, lambs at 28 days of age had greater ($P < 0.01$) insulin concentrations than lambs at 35, 56 and 84 days of age. The rise in serum insulin associated with milk ingestion has also been reported by others (Porter and Bassett, 1979; Symonds et al., 1989; Holcombe et al., 1992, 1995).

No differences ($P > 0.50$) were observed in serum GH mean (GHmn), baseline (GHbl), area under the curve (GHauc), amplitude (GHam) and number of pulses per six hours (GHnp) in lambs receiving 0%, 30% and 60% corn diets (Table 5). Although no treatment effects were observed, serum GH characteristics were affected by day of age (Table 5).

At 35 and 56 days of age, lambs had greater ($P < 0.01$) serum GHmn, GHauc and GHbl than at 28 and 84 days of age. These GH characteristics were lowest at 84 days of age and differed from the other age groups. The increase in GH variables the first month after weaning may reflect a limitation in nutrient intake since nutrient restrictions have been associated with an increase in GH values (Turgeon et al., 1986; Onischuk and Kennedy, 1990). GHnp did not differ ($P = 0.36$) among days of age; however, GHam was greater ($P < 0.01$) at 28, 35 and 56 days of age compared to 84 days of age. In this regard, serum GH has been shown to decrease with lamb age (Bassett, 1974; Symonds et al., 1989).

Insulin-to-GH ratio did not differ ($P > 0.30$; Table 4) among treatments but numerically decreased as the concentrate in the diet increased. INS:GH ratio differed ($P < 0.05$) among ages and was the greatest at 28 days of age and the least at 35 days of age (0.072, 0.031, 0.041 and 0.058 ± 0.004 INS:GH ratio for 28, 35, 56 and 84 days of age, respectively). The INS:GH ratio is considered to be an indication of energy status of the animal. A high INS:GH ratio reflects a positive energy balance and a low INS:GH ratio is indicative of a negative energy balance (Cole et al., 1988). Therefore, the low values which occurred one week after weaning might be expected considering that was when the lowest ME intake occurred and indicate dietary treatments did not alleviate the stress associated with weaning.

Serum PRL mean (PRLmn), baseline (PRLbl), area under the curve (PRLauc), amplitude (PRLam) and number of pulses in six hours (PRLnp) were not affected ($P > 0.10$) by the percentage of concentrate in the diet (Table 5). Nonetheless, serum PRL characteristics were influenced by age of lamb (Table 5). At 35 days of age, PRLmn, PRLauc, PRLam and PRLbl were lower ($P < 0.05$) than at 28, 56 and 84 days of age; PRL values at 84 days of age were greater ($P < 0.05$) than the other three sampling days. Forbes et al. (1979) found PRL concentrations in

**Table 3. Body weights (BW), average daily gain (ADG) and pen feed-to-gain (F:G) ratio (kg of feed/kg of gain) of early-weaned lambs fed 0%, 30% and 60% corn diet pre- and post-weaning.[a]**

| | Corn, % | | | |
|---|---|---|---|---|
| Days of age | 0 | 30 | 60 | SEM |
| **BW, kg:** | | | | |
| 13 | 7.4 | 8.1 | 6.7 | 0.4 |
| 20 | 9.8 | 10.1 | 9.0 | 0.6 |
| 27 | 11.8 | 12.4 | 11.3 | 0.6 |
| 34 | 13.7 | 14.7 | 12.9 | 0.7 |
| 41 | 15.0 | 15.7 | 14.2 | 0.8 |
| 48 | 17.0 | 17.2 | 16.4 | 0.7 |
| 55 | 19.7 | 19.5 | 18.9 | 0.7 |
| 62 | 22.1 | 21.5 | 20.7 | 0.9 |
| 69 | 24.4 | 23.4 | 22.8 | 1.1 |
| 76 | 26.6 | 25.7 | 25.4 | 1.1 |
| 83 | 28.8 | 27.7 | 27.5 | 1.2 |
| **ADG, kg:** | | | | |
| 13 to 20 | 0.35 | 0.29 | 0.36 | 0.04 |
| 21 to 27 | 0.27 | 0.32 | 0.28 | 0.02 |
| 28 to 34 | 0.26 | 0.26 | 0.22 | 0.03 |
| 35 to 41 | 0.20 | 0.21 | 0.18 | 0.03 |
| 42 to 48 | 0.29 | 0.23 | 0.32 | 0.03 |
| 49 to 55 | 0.39 | 0.34 | 0.36 | 0.03 |
| 56 to 62 | 0.35 | 0.27 | 0.28 | 0.04 |
| 63 to 69 | 0.32 | 0.28 | 0.27 | 0.04 |
| 70 to 76 | 0.32 | 0.33 | 0.38 | 0.03 |
| 77 to 83 | 0.31 | 0.29 | 0.33 | 0.04 |
| **Pen F:G ratio:** | | | | |
| 28 to 34 | 1.7 | 2.2 | 1.5 | 0.3 |
| 35 to 41 | 3.5 | 3.5 | 2.6 | 0.4 |
| 42 to 48 | 3.5 | 3.6 | 2.8 | 0.6 |
| 49 to 55 | 3.3 | 3.0 | 3.0 | 0.2 |
| 56 to 62 | 5.3 | 5.5 | 3.5 | 0.8 |
| 63 to 69 | 6.5 | 5.1 | 4.1 | 0.9 |
| 70 to 76 | 4.1 | 4.1 | 3.9 | 0.5 |
| 77 to 83 | 5.7 | 5.0 | 6.7 | 1.1 |

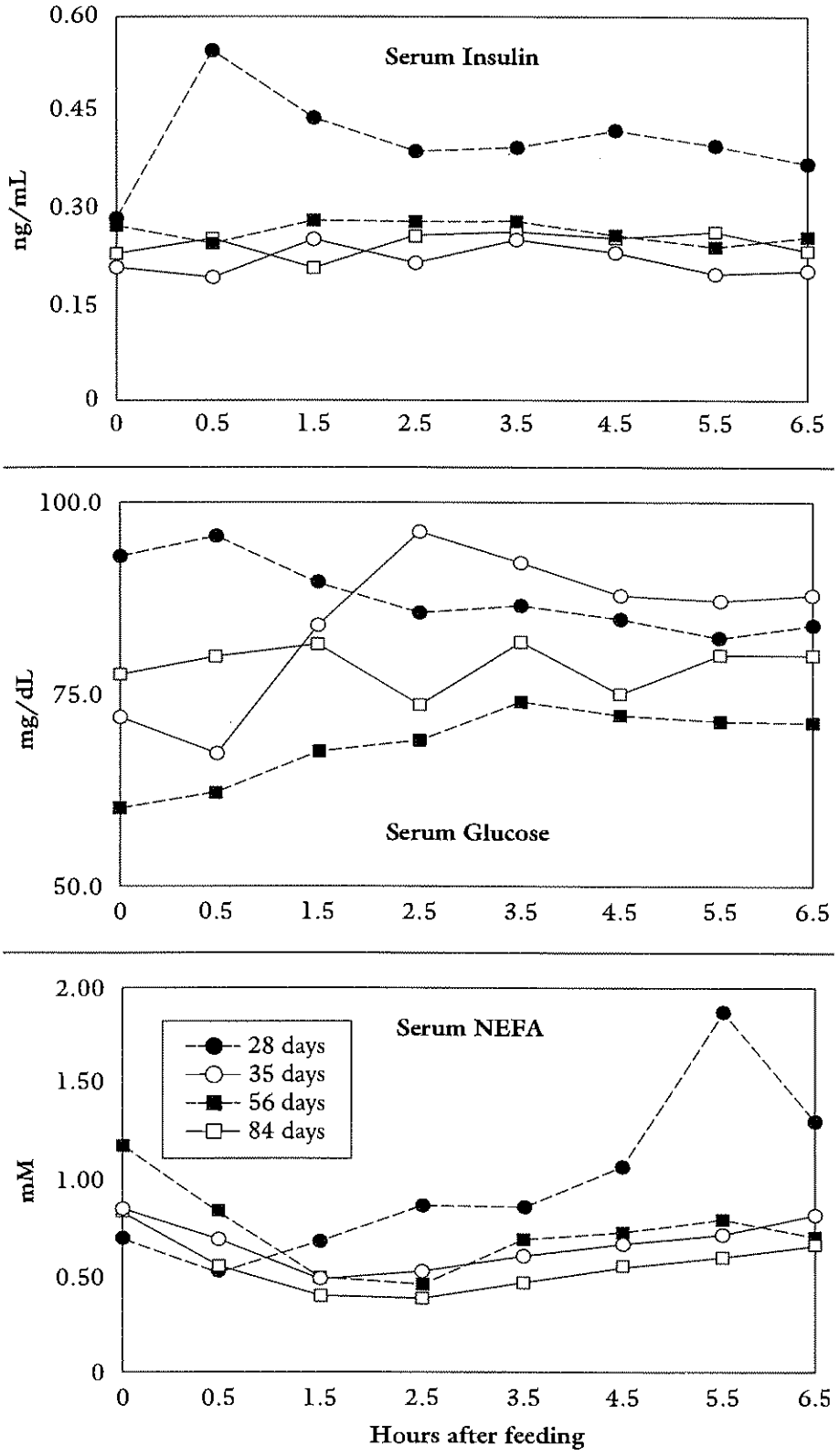
[a] Mean ± SE; six lambs per treatment group; lambs were weaned at 28 ± 1 days of age.

**Table 4. Effect of 0%, 30% and 60% corn diet on serum insulin, insulin-to-growth hormone (INS:GH) ratio, insulin-like growth factor-I (IGF-I), nonesterified fatty acids (NEFA) and serum urea nitrogen (SUN) in early-weaned lambs.**

| | Corn, %[a,b] | | | |
|---|---|---|---|---|
| Item | 0 | 30 | 60 | SEM |
| Insulin, ng/mL | 0.29 | 0.30 | 0.26 | 0.01 |
| INS:GH ratio | 0.058 | 0.051 | 0.042 | 0.007 |
| IGF-I, ng/mL[c] | 260.0 | 346.9 | 425.4 | 38.1 |
| NEFA, mM | 0.82 | 0.71 | 0.63 | 0.08 |
| SUN, mg/dL[c] | 15.5 | 13.0 | 11.4 | 1.0 |

[a] Five ewe lambs in each dietary treatment; lambs were weaned at 28 ± 1 days of age (mean ± SE).
[b] No treatment by day of age or treatment by sampling time interactions ($P > 0.10$) were detected; therefore overall means were tested.
[c] Linear effect within row ($P < 0.05$).

**Figure 1. Effect of day of age on serum insulin, glucose and nonesterified fatty acids (NEFA) in lambs weaned at 28 ± 1 day of age (mean ± SE).[a]**




[a] Samples were collected before (zero hour) and after milk (28 days of age) or feed (35, 56 and 84 days of age) consumption.

lambs decreased with restricted feeding compared with ad libitum feeding, suggesting that differences observed one week after weaning may be caused by changes in intake which occur immediately after weaning. PRLnp did not differ ($P = 0.36$) among days of age. Serum PRL values were highest at 84 days of age and reflect the increase in day length because PRL concentrations have been shown to be responsive to change in photoperiod (increasing as daylight increases; Pelletier, 1973; Ravault, 1976). The role PRL plays in ruminant growth is still not specifically defined. Prolactin has been implicated in a number of metabolic processes (Bauman and McCutcheon, 1986); these results would suggest PRL is affected by change in nutritional status.

Serum IGF-1 concentrations were affected ($P < 0.05$) by dietary treatment in a linear fashion; as the proportion of concentrate increased, serum IGF-I increased (Table 5). These data imply that the nature of nutrients absorbed may contribute to changes in IGF-I concentrations. In cattle, circulating concentrations of IGF-I have been shown to be affected by both energy (Breier et al., 1986; Houseknecht et al., 1988) and protein intake (Elsasser et al., 1989). A positive relationship has been observed between circulating IGF-I and nitrogen balance (Breier et al., 1986; Elsasser et al., 1989) as well. Holcombe et al. (1994) reported a positive correlation between serum SUN (which is reflective of CP intake and IGF-I in early-weaned lambs) suggesting a relationship between CP intake and IGF-I. These authors speculated that various dietary components such as CP and carbohydrate content may affect serum IGF-I concentrations in young lambs. Serum IGF-I has also been reported to be correlated with ADG in lambs (Holcombe et al., 1994). Although serum IGF-I was affected by treatment, no differences were observed in ADG among dietary treatments. Therefore, other factors such as tissue responsiveness to IGF-I must be considered in the relationship between IGF-I and growth (Kerr et al., 1991).

A day of age affect (P < 0.002) was observed across dietary treatments; serum IGF-I was lower at 35 days of age (237.7 ± 24.5 ng/mL) compared to 28, 56 and 84 days of age (394.4, 388.3 and 354.8 ± 24.5 ng/mL, respectively). Similarly, Holcombe et al. (1994) found a significant decline in IGF-I one week after weaning in lambs weaned at both 30 and 60 days of age; a much more pronounced decrease was observed in lambs weaned at 30 days of age. In addition, Breier et al. (1988) reported a decline in plasma IGF-I following weaning in calves and suggested this decline may result in part from inadequate nutrient absorption along with the transition to dependence on microbial fermentation. These IGF-I values are within ranges reported for 30-day-old lambs weaned onto a pelleted diet (Holcombe et al., 1994), but are higher than those observed in two- to three-month-old suckling lambs maintained on pasture with no access to creep feed (Medrano and Bradford, 1991). Differences among studies discussed are most likely due to nutritional status at the time of sampling.

A treatment by day of age interaction (P = 0.03) was detected for serum glucose so values were examined within day of age (Table 6). At 28 days of age, serum glucose tended to differ (linear, P = 0.10) among groups with glucose increasing as percentage of concentrate increased. At 35 and 56 days of age, a similar linear response (P < 0.04) was observed. These results may be reflective of differences in energy densities of the three diets since Cole et al. (1988) reported lambs receiving a high concentrate diet had elevated glucose values compared to lambs receiving a low concentrate diet. Interestingly, an increase in glucose concentrations did not correspond with an increase in insulin concentrations. At 84 days of age, serum glucose demonstrated a quadratic response (P = 0.04) with lambs receiving 30% corn having higher values than lambs receiving 0% or 60% corn.

A day of age by time of sampling interaction (P = 0.01) was detected for serum glucose concentrations so values were examined within sampling time and are shown in Figure 1. Prefeeding values differed (P = 0.03) among days; serum glucose was greatest at 28 days of age, intermediate at 35 and 84 days of age and lowest at 56 days of age. After feeding, serum glucose concentrations tended to be elevated in lambs at 28 and 35 days of age as compared to lambs at 56 and 84 days of age. Plasma glucose concentrations have been reported to decline with advancing age in calves (Quigley et al., 1991). Purser and Bergen (1969) suggested this change in glucose with advancing age is due to an age-dependent alteration in hepatic enzymes rather then changes associated with rumen development.

Serum urea-N decreased (P = 0.04) in a linear fashion as the amount of corn increased (Table 4). Serum urea-N concentrations have been shown to be highly correlated to protein intake (Preston et al., 1965); therefore, these results may reflect differences observed in the amount of CP consumed by lambs. Day of age also affected (P = 0.01) SUN concentrations; SUN values were lower at 28 and 35 days of age (12.4 and 11.9 mg/dL, respectively) than at 56 and 84 days of age (14.5 and 14.2 mg/dL, respectively). These results support the CP intake data in that older lambs consumed more protein per kilogram of BW than younger lambs.

Serum NEFA values were not affected (P = 0.14) by treatment (Table 5) but

**Table 5. Effect of 0%, 30% and 60% corn diet and day of age on secretory characteristics of prolactin and growth hormone in early-weaned lambs.[a,b]**

| | Corn, % | | | | Day of age | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Item | 0 | 30 | 60 | SEM | 28 | 35 | 56 | 84 | SEM |
| **Prolactin:** | | | | | | | | | |
| Mean, ng/mL | 136.4 | 130.7 | 122.8 | 15.0 | 114.8[c] | 69.7[d] | 141.8[c] | 193.6[b] | 10.9 |
| Area under the curve, ng/mL/min | 26,029 | 25,158 | 23,504 | 3,045 | 21,680[c] | 13,428[d] | 27,392[c] | 39,089[b] | 2,143 |
| Number of pulses per six hours | 2.0 | 1.7 | 1.5 | 1.3 | 1.5 | 1.6 | 1.7 | 2.1 | 0.3 |
| Amplitude, ng/mL | 230 | 227 | 181 | 30 | 203[c] | 107[d] | 221[c] | 321[b] | 25 |
| Baseline, ng/mL | 77.4 | 72.2 | 66.3 | 10.9 | 60.1[c] | 37.9[d] | 79.1[c] | 110.7[b] | 6.6 |
| **Growth hormone:** | | | | | | | | | |
| Mean, ng/mL | 8.3 | 7.4 | 8.1 | 1.1 | 7.9[c] | 9.5[b] | 9.3[b] | 5.1[d] | 0.4 |
| Area under the curve, ng/mL/min | 1,579 | 1,406 | 1,549 | 204 | 1,518[c] | 1,805[b] | 1,772[b] | 950d | 80 |
| Number of pulses per six hours | 2.4 | 1.7 | 1.8 | .2 | 2.2 | 1.9 | 2.3 | 1.6 | 0.3 |
| Amptitude, ng/mL | 12.6 | 10.2 | 10.7 | 1.7 | 12.2[b] | 13.5[b] | 12.9[b] | 5.9[c] | 1.3 |
| Baseline, ng/mL | 5.1 | 5.0 | 5.4 | 0.7 | 4.8[c] | 6.4[b] | 5.9[b] | 3.6[d] | 0.3 |

[a] Five ewe lambs in each dietary treatment and 15 ewe lambs in each day of age period; lambs were weaned at 28 ± 1 days of age (mean ± SE).
[b,c,d] Row means within days of age differ (P < 0.05).

were numerically decreased as corn in the diet increased. A day of age effect was detected (P = 0.03) for NEFA concentrations, which are presented in Figure 1. Before milk or feed intake, serum NEFA concentrations were lower (P = 0.04) in lambs at 28 days of age than at 35, 56 and 84 days of age. After consuming milk, serum NEFA decreased slightly and then increased above prefeeding values thereafter. In contrast, in lambs consuming only the pelleted diet, serum NEFA values decreased after feeding for one and a half hours, after which values increased but remained lower than pre-feeding values. Serum NEFA concentrations differed (P< 0.05) between pre- and post-weaning ages; values were greater in lambs at 28 days of age at 2.5, 4.5, 5.5 and 6.5 hours post-feeding. In agreement, Quigley et al. (1991) reported that calves fed milk and grain had higher NEFA concentrations than calves receiving only grain.

In serum samples collected daily for one week after weaning, no treatment by day of sampling interactions (P > 0.15) were observed for serum glucose, SUN and NEFA concentrations. Mean glucose concentrations differed (linear, P = 0.03) among the three groups (89.5, 91.6 and 99.2 ± 1.9 mg/dL for lambs consuming 0%, 30% and 60% corn, respectively). Daily values for all groups were highest two to three days following weaning and lower thereafter. In contrast, other researchers (Lane et al., 1986; Lane and Albrecht, 1991) reported a decline in serum glucose after weaning in early-weaned lambs and attributed it mainly to the stress of weaning and decrease in feed intake. Serum urea N also demonstrated a linear response (P = 0.02); however, lambs receiving no corn in their diet had the highest SUN values and lambs receiving 60% corn had the lowest values (14.6, 10.1 and 9.9 ± 0.7 mg/dL for the 0, 30 and 60% treatment groups, respectively). Serum NEFA values were similar (P = 0.25) among the three groups one week after weaning with values of 0.50, 0.52 and 0.67 ± 0.02 mM for lambs consuming 0%, 30% and 60% corn, respectively. Daily samples revealed that NEFA values were numerically highest one day after weaning for all groups and decreased after that period to pre-weaning values. Because peak NEFA concentration was not affected by diet, this response suggests that after weaning, body fat was mobilized in response to total nutrient intake changes which occurred immediately following weaning.

### *Wool Characteristics*

Wool staple length did not differ (P = 0.20) among lambs receiving 0%, 30% and 60% corn diets (16.8, 17.3 and 15.2 ± 0.9 cm, respectively) during the treatment period. Average fiber diameter at 28 days of age did not differ (P = 0.30) among treatments (21.9, 22.0 and 21.1 ± 0.5 mm for lambs receiving 0, 30 and 60% corn, respectively). However, average fiber diameter at 84 days of age decreased (linear, P = 0.03) as corn level in the diet increased (24.0, 23.6 and 22.2 ± 0.6 mm, respectively). Likewise, when the difference between average fiber diameter at 84 and 28 days of age was determined, a linear decrease (P = 0.09) was observed as corn in the diet increased (2.1, 1.6 and 1.0 mm, respectively). Fiber diameter variability standard deviation at 84 days of age did not differ (P = 0.20) for the 0%, 30% and 60% corn groups (6.5, 5.7 and 5.7 ± 0.5 mm, respectively).

Difference in fiber diameter among treatments may reflect actual protein intake and/or amount of dietary sulfur consumed by lambs. Sulfur is an important mineral needed for wool production (Qi and Lupton, 1994) and most grains are low in sulfur compared to alfalfa (NRC, 1985). When the percentage of sulfur for each diet was estimated, the 0%, 30% and 60% corn diets contained 0.225%, 0.202% and 0.191% (DM basis), respectively. Estimated sulfur intake was determined from DM consumption and was shown to differ (P < 0.04) among treatments beginning three weeks post-weaning and continuing throughout the experiment. As might be expected, as the corn in the diet increased, sulfur intake decreased (linear effect, P < 0.04; data not shown). Reis et al. (1992) reported increases in abomasal protein levels caused substantial increases in wool fiber diameter and length in mature Merino sheep. Fiber diameter was also increased with fish meal with no observed increase in wool length in crossbred lambs (Sun et al., 1990). Fishmeal is considered to be a high bypass protein, meaning greater than 60% can escape ruminal degradation where as dehydrated alfalfa meal is 40% to 60% bypassable (NRC, 1985). It is possible that more sulfur or sulfur-containing protein bypassed ruminal degradation and was digested post-ruminally in diets with a higher alfalfa content. Conversely, if total protein intake was increased, this may have allowed for an increase in the amount of microbial protein available for absorption by the small intestines.

**Table 6. Effect of 0%, 30% and 60% corn diet on serum glucose (mg/dL) in early-weaned lambs at 28, 35, 56 and 84 days of age.**

| | Corn, %[a,b] | | | |
|---|---|---|---|---|
| Days of age | 0 | 30 | 60 | SEM |
| 28[c] | 79.2 | 88.8 | 90.6 | 3.7 |
| 35[d] | 76.0 | 87.3 | 89.9 | 2.9 |
| 56[d] | 63.9 | 67.1 | 74.2 | 3.0 |
| 84[e] | 72.3 | 94.4 | 73.4 | 6.2 |

[a] Five ewe lambs in each dietary treatment; lambs were weaned at 28 ± 1 days of age (mean ± SE).
[b] No treatment by sampling time interactions (P > 0.10) were detected; however, a treatment hy day of sampling interaction (P = 0.03) was observed.
[c] Linear effect within row (P = 0.10).
[d] Linear effect within row (P < 0.04).
[e] Quadratic effect within row (P = 0.04).

# Conclusions

Satisfactory growth of early-weaned lambs can be achieved on diets containing either 0%, 30% or 60%

corn. These data suggest, however, that CP content may need to be increased with more concentrated grain diets in order to compensate for the decrease in intake and meet protein requirements. Therefore, producers that use early weaning as a management tool would have considerable flexibility in formulating rations for lambs and could adjust the diet according to the most economical return. These data also indicate that appreciable metabolic changes occur one week after weaning. Attenuation or correction of these metabolic changes shortly after weaning through different feeding strategies could possibly lead to improved performance in early-weaned lambs.

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# Performance of Nursing Lambs Receiving Vitamin E at Birth or from Dams that Received Vitamin E[1]

J.K. Williamson[2], M.L. Riley[2], A.N. Taylor[2] and D.W. Sanson[3]

## Summary

Three hundred and thirty-nine ewes were randomly allotted within breed and age to four groups to evaluate the effects of vitamin E injections on lamb performance. Five breeds (45 Columbia, 49 Rambouillet, 39 Suffolk, 42 Hampshire, 164 white-face Columbia × Rambouillet) were represented. Six hundred and four lambs (88 Columbia, 93 Rambouillet, 72 Suffolk, 70 Hampshire, 281 white-face Columbia × Rambouillet) were born and 502 lambs (79 Columbia, 83 Rambouillet, 70 Suffolk, 60 Hampshire, 210 white-face Columbia × Rambouillet) were weaned. Purebred ewes began lambing on January 19 (43-day lambing period) while crossbred ewes began lambing on April 6 (42-day lambing period). Treatments were arranged in a two-by-two factorial treatment arrangement with half of the ewes receiving one injection of vitamin E (1,200 IU) approximately two weeks before lambing and another injection (1,200 IU) of vitamin E at lambing. The remaining ewes served as controls. Lambs from half of the ewes that received vitamin E injections and lambs from half of the control ewes received 600 IU of vitamin E at birth, while the remainder of the lambs served as controls. There were no interactions present ($P > 0.1$). Vitamin E injections to ewes had no effect ($P = 0.85$) on lamb birth weight. However, lambs from ewes that received vitamin E had higher vigor scores (3.2 vs. 3.0 ± 0.1; $P = 0.05$) than lambs whose dams did not receive vitamin E. Neither weaning weight nor 60-day adjusted weaning weight were affected ($P > 0.49$) by ewe treatment; however, lambs from ewes that received vitamin E gained 17 g more weight ($P = 0.04$) per day than lambs from control ewes. Lamb treatment had no effect ($P > 0.23$) on lamb performance.

**Key words:** sheep, vitamin E, performance, vigor.

## Introduction

Vitamin E has been implicated as being important in the immune system. Tengerdy et al. reported that high levels of vitamin E stimulated serum antibody syntheses, particularly IgG antibodies. Improved disease resistance in lambs given vitamin E and inoculated with chlamydia (Stephens et al., 1979) and chicks infected with *E. coli* (Heinzerling et al., 1974) has also been reported. Droke and Loerch (1989) observed a large enhancement of serum IgG titers in response to *P. haemolytica* vaccinations with steers given an injection of a combination of selenium (Se) and vitamin E. Nemec et al. (1990) reported that supplemental vitamin E enhanced the production of antibody to *S. typhimurium*. Reffett et al. (1988) found dietary supplementation of Se and vitamin E enhanced the immune response with lambs challenged with parainfluenza virus.

Vitamin E levels of newborn lambs appear to be influenced by placental and mammary gland transfer of tocopherol (Hidiroglou et al., 1972). Njeru et al. (1994) reported that vitamin E supplementation of pregnant ewes in late gestation and early lactation increased serum tocopherol concentration in their lambs via mammary gland transfer, but placental transfer was inefficient. This finding would indicate that an injection of vitamin E prior to or at lambing might be sufficient to improve vitamin E status of the lamb. The objective of the current study was to determine the effects of vitamin E injection to the ewe or to the newborn lamb of different breeds on vigor, survival and performance of the lambs.

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## Materials and Methods

Three hundred and thirty-nine ewes were randomly allotted within breed and age to four groups to evaluate the effects of vitamin E injections on lamb performance. Five breeds (45 Columbia, 49 Rambouillet, 39 Suffolk, 42 Hampshire, 164 white-face Columbia x Rambouillet) were used. Six hundred and four lambs (88 Columbia, 93 Rambouillet, 72 Suffolk, 70 Hampshire, 281 Columbia x Rambouillet) were born and 502 lambs (79 Columbia, 83 Rambouillet, 70 Suffolk, 60 Hampshire, 210 white-face Columbia x Rambouillet) were weaned. Treatments were arranged in a two-by-two factorial treatment arrangement with half of the ewes receiving one injection of vitamin E (1,200 IU) two weeks before lambing and another injection (1,200 IU) of vitamin E at lambing. The remaining ewes served as controls. Lambs from half of the ewes that received vitamin E injections and half of the lambs from control ewes received 600 IU of vitamin E at birth. The remainder of the lambs served as controls. Vitamin E (Vital E-300; Schering, Dallas, TX) was delivered as a non-aqueous solution containing 300 IU/ml.

Purebred ewes lambed from January 19 to March 3, while crossbred ewes lambed from April 6 to May 18. Ewes were penned 30 days prior to lambing and fed 0.45 kg/ewe of corn each day and free-choice alfalfa hay. Within one hour of birth, lambs were weighed and assigned a vigor score (1 = low vigor, 5 = high vigor; Hunnicutt, 1993). The vigor score was a subjective estimate of the length of time required for the lamb to get up and nurse. Ewe and lamb(s) were moved to a 1.2 m x 1.5 m lambing jug for two to three days. Upon removal from jugs, purebred ewes and lambs were maintained as one flock in a drylot and fed 0.91 kg of corn and free-choice alfalfa hay until weaning. Crossbred ewes were also maintained as one flock after removal from lambing jugs. These ewes received 0.68 kg of corn and free-choice alfalfa hay until June 4, then they grazed native range until weaning. Purebred lambs had access to a creep feed (30% corn, 30% oats, 40% dehydrated alfalfa; 13% CP) starting 30 days post-lambing. Crossbred lambs did not receive any creep. Purebred lambs were weaned on April 11, at an average age of 66 days. Crossbred lambs were weaned on July 21, at an average age of 65 days. Non-shrunk weights of lambs were recorded at weaning. Weaning weights were adjusted for age (60 days), sex, type of birth, type of rearing and age of dam (SID, 1988).

Date of death was recorded for all purebred and all crossbred lambs prior to turnout on native range. These data were grouped into five-day increments post-lambing through day 20, with the remainder classified as those dying more than 20 days post-lambing. These data and total mortality were analyzed using CATMOD (SAS, 1995). Birth weight and vigor score data were analyzed with a model that contained ewe treatment, breed, lamb sex and the associated interactions since lamb treatment was not imposed until after these variables were measured. Lamb weaning weight, average daily gain (ADG) to weaning and adjusted 60-day weaning weight were analyzed with a model that contained ewe treatment, lamb treatment, breed, sex and the associated interactions. Breed means were separated using least significant difference procedures. These data were analyzed using GLM procedures (SAS, 1995).

## Results and Discussion

No interactions were present for any of the variables analyzed. Vitamin E injections to ewes had no effect (P = 0.85) on lamb birth weight (Table 1). This would be expected since treatment was imposed in the last two weeks of gestation and most of the development of the fetus had occurred by this time. Lambs from ewes that received vitamin E had higher vigor scores (P = 0.05) than lambs whose dams did not receive vitamin E.

Weaning weight was not affected (P > 0.49) by either ewe or lamb treatment (Table 2). However, lambs from ewes that received vitamin E gained 17 g more weight (P = 0.04) per day than lambs from control ewes. Norton and McCarthy (1986) reported that ram lambs from ewes injected with vitamin E and Se three weeks before lambing had higher daily gains until weaning than ram lambs whose dams had not received Vitamin E and Se. These authors did not observe a difference in the daily gain among ewe lambs in response to ewe treatments. In addition, Bohn et al. (1995) reported a trend for heavier weaning weights in Targhee lambs whose dams had been supplemented with vitamin E. There was no effect of lamb treatment on ADG in the current study and adjusted weaning weight was not different (P > 0.18) due to either ewe treatment or lamb treatment.

There was no effect (P > 0.1) of either ewe or lamb treatment on death loss (Table 3). This finding contrasts research by Kott et al. (1983) who reported that ewes given monthly injections of vitamin E during pregnancy had a higher percentage of lambs weaned than control ewes. Seventeen lambs died in the first five days post-lambing across treatments, with only five deaths during the next 15 days. The majority (80 of 102) of the lamb deaths occurred after 20

**Table 1. Effect of vitamin E injection to purebred and crossbred ewes approximately two weeks before birth and at parturition on lamb birth weight and vigor score.**

| Item | Number | CON[a] | VITE[b] | SE[c] | P value |
|---|---|---|---|---|---|
| Birth weight, kg | 597 | 6.0 | 6.0 | 0.1 | 0.85 |
| Lamb vigor[d] | 597 | 3.0 | 3.2 | 0.06 | 0.05 |

[a] CON = ewes that received no vitamin E.
[b] VITE = ewes that received 1,200 IU of vitamin E two weeks before lambing and 1,200 IU of vitamin E at parturition.
[c] SE = standard error.
[d] 1 = lowest vigor and 5 = most vigor (Hunnicutt, 1993).

days post-lambing. Of these 80 lambs, 70 were in the crossbred flock that were grazing native range, compared to only 10 lambs that were maintained in drylot.

Ram lambs had higher ($P < 0.001$) birth weights than ewe lambs. However, lamb vigor tended to be higher ($P = 0.13$) for ewe lambs compared to ram lambs (Table 4). The higher birth weight for ram lambs agrees with Smith (1977) who reported that ram lambs had higher birth weights than ewe lambs and a higher percentage of ram lambs were classified as weak lambs than were ewe lambs across several breeds of sheep. Ram lambs were 1.7 kg heavier at weaning ($P = 0.002$) and gained 18 g more ($P = 0.01$) weight per day from birth to weaning. Ram lambs also had a higher ($P = 0.09$) 60-day adjusted weaning weight, indicating that the adjustment factor used to adjust for sex did not adequately correct ewe weaning weights.

Effect of breed on lamb performance is presented in Table 5. Data from crossbred lambs are presented with data from purebred lambs only as a reference since they lambed earlier and were managed different than purebred lambs. Therefore, statistical comparison of means from purebred lambs to crossbred lambs is not valid.

Columbia lambs had the lowest ($P < 0.001$) birth weights of the different breeds, followed by Rambouillet, with no difference between Suffolk and Hampshire lambs. In contrast, Sidwell and Miller (1971) reported higher birth weights for Suffolk lambs compared to Hampshire lambs. Lamb vigor score at birth was also lowest ($P < 0.001$) for Columbia lambs, followed by Suffolk, and highest for Rambouillet and Hampshire lambs. Smith (1977) reported no effect of breed on lamb vigor at birth using data from 3,535 purebred lambs (Suffolk, Hampshire, Rambouillet, Dorset, Targhee, Corriedale and Coarse Wool breeds).

Rambouillet lambs had the lowest ($P < 0.001$) weaning weights, ADG and 60-day adjusted weaning weights of the four breeds. Columbia lambs weighed 2.5 kg heavier at weaning and gained 27 g more weight per day than Rambouillet, while Suffolk and Hampshire lambs averaged 5 kg heavier at weaning and gained 66 g more weight per day than Rambouillet. Sixty-day adjusted weaning weights followed similar trends as weaning weights and ADG. Other researchers have reported differences in lamb data due to breed. Sidwell and Miller (1971) reported that Suffolk lambs had heavier weaning weights and higher preweaning gain than Hampshire lambs.

# Conclusions

Injection of vitamin E at birth to lambs used in this study did not improve vigor or weight gain or decrease death loss. Lambs from ewes given vitamin E two weeks prior to lambing and again at parturition had higher vigor scores and higher rates of preweaning gain but did not weigh more at weaning or have lower death loss. These data suggest that under the conditions of this study vitamin E injections did not improve the amount of salable product. Therefore, use of vitamin E injections can not be expected to offer an economic incentive. However, vitamin E or Se deficiency has not been a major problem with these sheep under the management regimen used in this study and results might be different if sheep were on diets deficient in vitamin E and/or Se.

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**Table 2. Effect of vitamin E injection to purebred and crossbred ewes approximately two weeks before birth and at parturition or to purebred and crossbred lambs at birth on weight gain of lambs.**

| | | Ewe treatment[a] | | | | Lamb treatment[b] | | | |
|---|---|---|---|---|---|---|---|---|---|
| Item | Number | CON[c] | VITE[d] | SE[e] | P value | CON[c] | VITE[d] | SE[e] | P value |
| Weaning weight, kg | 502 | 25.7 | 26.1 | 0.4 | 0.50 | 25.9 | 25.9 | 0.4 | 0.91 |
| Average daily gain, g | 502 | 293 | 309 | 5 | 0.04 | 298 | 304 | 5 | 0.24 |
| Adjusted wean weight, kg[f] | 502 | 27.6 | 28.3 | 0.4 | 0.19 | 27.7 | 28.2 | 0.4 | 0.29 |

[a] Treated ewes received 1,200 IU of vitamin E two weeks before lambing and 1,200 IU of vitamin E at parturition.
[b] Treated lambs received 600 IU of vitamin E at birth.
[c] CON = ewes that received no vitamin E.
[d] VITE = ewes that received vitamin E.
[e] SE = standard error.
[f] Weights adjusted to 60-day (SID, 1988).

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**Table 3. Effect of vitamin E injection to purebred and crossbred ewes approximately two weeks before birth and at parturition or to purebred and crossbred lambs at birth on lamb mortality.**

| Treatment[a] | Lambs born | Days post-lambing | | | | | Total mortality[b] |
|---|---|---|---|---|---|---|---|
| | | 0-5[b] | 6-10[b] | 11-15[b] | 16-20[b] | > 20[b] | |
| **Ewe effect:** | | | | | | | |
| CONT[b] | 302 | 7 | 0 | 1 | 2 | 37 | 47 |
| VITE[c] | 302 | 10 | 0 | 1 | 1 | 43 | 55 |
| **Lamb effect:** | | | | | | | |
| CONT[b] | 304 | 4 | 0 | 0 | 3 | 43 | 50 |
| VITE[c] | 300 | 13 | 0 | 2 | 0 | 37 | 52 |

[a] Treatment means within main effect do not differ (P > 0.1).
[b] CONT = ewes that received no vitamin E.
[c] VITE = ewes that received 1,200 IU of vitamin E two weeks before lambing and 1,200 IU of vitamin E at parturition.

**Table 4. Effect of sex of purebred and crossbred lambs on lamb birth weight, vigor score and pre-weaning performance.**

| Item | Number | Male | Female | SE[a] | P value |
|---|---|---|---|---|---|
| Birth weight, kg | 597 | 6.1 | 5.9 | 0.1 | 0.003 |
| Lamb vigor[b] | 597 | 3.1 | 3.2 | 0.04 | 0.13 |
| Wean weight, kg | 502 | 26.7 | 25.0 | 0.4 | 0.002 |
| Average daily gain, g | 502 | 306 | 292 | 0.4 | 0.01 |
| Adjusted wean weight, kg[c] | 502 | 28.3 | 27.6 | 0.3 | 0.09 |

[a] SE = standard error.
[b] 1 = lowest vigor and 5 = most vigor (Hunnicutt, 1993).
[c] Weights adjusted to 60-day (SID, 1988).

**Table 5. Effect of breed of ewe on birth weight, lamb vigor at birth and pre-weaning performance of lambs.**

| Item | Breed | | | | | | |
|---|---|---|---|---|---|---|---|
| | Columbia | Rambouillet | Suffolk | Hampshire | Crossbred[a] | SE[b] | P value |
| Birth weight, kg | 5.3[c] | 5.7[d] | 6.3[e] | 6.3[e] | 5.9 | 0.1 | < 0.001 |
| Vigor[f] | 2.8[c] | 3.3[d] | 3.0[e] | 3.2[d] | 3.1 | 0.07 | < 0.001 |
| Weaning weight, kg | 24.9[c] | 22.4[d] | 26.8[e] | 27.9[e] | 27.4 | 0.8 | < 0.001 |
| Average daily gain, g | 275[c] | 254[d] | 315[e] | 333[e] | 322 | 9 | < 0.001 |
| Adjusted wean weight, kg[g] | 26.4[c] | 24.2[d] | 29.4[e] | 30.3[e] | 29.4 | 0.6 | < 0.001 |

[a] Columbia × Rambouillet ewes; mean comparisons are not presented for these data because lambs were born later in the year and were managed differently than purebred lambs.
[b] SE = standard error.
[c,d,e] Row means with different superscripts differ (P < 0.05).
[f] 1 = lowest vigor and 5 = most vigor (Hunnicutt, 1993).
[g] Weights adjusted to 60-day (SID, 1988).

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# Prescribed Sheep Grazing to Suppress Cheatgrass: A Review[1,2]

Jeffrey C. Mosley[3]

## Summary

Prescribed sheep grazing is a promising tool for suppressing cheatgrass *(Bromus tectorum)*. Sheep foraging behavior can be manipulated to suppress cheatgrass growth, seed production and mulch accumulations, and thereby improve biological diversity, growth and vigor of perennial plants. Fire-free intervals can be lengthened by using prescribed sheep grazing to disrupt fine-fuel continuity and reduce fine-fuel loads. Cheatgrass suppression can be achieved rather easily in areas devoid of desirable perennial herbs, but more care must be exercised in plant communities where remnant desirable perennial herbs are present. Prescribed sheep grazing can also be integrated with prescribed fires, herbicides, disking and broadcast seeding when cheatgrass sites are artificially seeded with desirable herbs and shrubs.

**Key words:** downy brome, *Bromus tectorum*, weed control, range management.

## Introduction

Cheatgrass, or "downy brome" *(Bromus tectorum)*, is an annual grass that was introduced to North America from southern Europe in the late 1800s. Cheatgrass is now widely distributed in the United States and occurs throughout the West from the sagebrush semi-desert biome in the southern Great Basin into the coniferous forest zone. Cheatgrass is a major herbaceous species particularly in the sagebrush steppe and Pacific Northwest bunchgrass regions where it dominates more than 6.4 million acres (Tisdale and Hironaka, 1981; Young et al., 1987; Miller et al., 1994).

Cultivation and subsequent land abandonment, excessive livestock grazing and repeated fires have all interacted to aid the proliferation of cheatgrass in many areas (Hull and Pechanec, 1947). But cheatgrass also thrives in areas that have never been cultivated or grazed by domestic livestock (West, 1991; Svejcar and Tausch, 1991; Kindschy, 1994; Tausch et al., 1994b). Cheatgrass is very persistent across its range of habitats (Daubenmire, 1940 and 1975; Cline et al., 1977) and in some places is so dense that few perennial grasses or sagebrush plants are present. In these situations, cheatgrass reduces biological diversity (Rosentreter, 1994). Plant production on cheatgrass-infested rangeland is substantially less and much more variable from year to year than the native bunchgrass vegetation (Murray et al., 1978). Cheatgrass also has a shorter green period than the native vegetation. Although the range livestock industry has adapted to the presence of cheatgrass, range livestock production probably would be enhanced if cheatgrass could be replaced with perennial grasses. Any attempts to control undesirable plants, however, should be approached cautiously. The idea of suppressing cheatgrass to enhance desirable perennials assumes that desirable perennials will fill the temporary void left by cheatgrass. But in many areas desirable perennials may be outcompeted for site resources by plant species often considered more undesirable than cheatgrass, such as medusahead *(Taeniatherum asperum)* or yellow starthistle *(Centaurea solstitialis)*. A thorough reconnaissance and site evaluation should be completed before initiating any form of plant control (J.A. Young, 1983).

Tools commonly used to control cheatgrass include disking, prescribed burning and herbicides, but these methods have proven unsuccessful for cheatgrass control unless the treatments were followed by artificial seeding. Vallentine and Stevens (1994) recently discussed the possibility of using livestock grazing as a biological tool for controlling cheatgrass. These authors concluded that: 1) grazing in early spring may

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suppress cheatgrass growth, seed production and excessive mulch build-up; and 2) heavy grazing might help prepare sites for artificial seeding of desirable perennials.

The concept of using livestock grazing to suppress cheatgrass is not new. In fact, the advantages of prescribed livestock grazing for this purpose first appeared in the scientific literature almost sixty years ago (Megee, 1938; Daubenmire, 1940). But this tool has gone largely untapped during the past several decades. Before this method of cheatgrass control can be more widely used and investigated in the future, scientists, land managers and others need to become more aware of how, when and where it can be applied. This paper assimilates the existing knowledge about using domestic sheep grazing to suppress cheatgrass and, based on this review, suggests appropriate management guidelines.

Prescriptions to suppress cheatgrass via sheep grazing must be tailored to each site's unique combination of soil, plant and animal variables. Therefore, successful prescribed sheep grazing programs require the artful application of one's knowledge of plant ecology and sheep foraging behavior. The guidelines discussed in this paper are not a substitute for experience nor are they intended to be cookbook recipes for management plans, but these guidelines should help resource managers develop better strategies and increase the likelihood of achieving their objectives.

## Sheep Diet Selection

Domestic sheep are well-suited to prescribed grazing programs. Sheep can meet their nutritive requirements when prescribed to graze with either high or low selectivity. Their small body size and dextrous mouth parts enable sheep to sustain themselves with small amounts of highly digestible forage, yet their comparatively large digestive tract capacity also enables sheep to perform well on large amounts of less digestible forage. Timing, frequency, intensity and distribution of grazing can be closely controlled because sheep can be herded or easily confined with portable electric fence. Whether prescribed sheep grazing achieves its objectives depends upon the manager's ability to control diet selection by the sheep.

Sheep normally select foods that minimize unpleasant sensory stimuli. Plant parts that are tender, succulent, readily visible and pleasant smelling and/or tasting are selected over those that are coarse, dry, obscure and obnoxious smelling and/or tasting (Arnold, 1981). Sheep selection of cheatgrass depends greatly on its moisture content and the attractiveness of the alternative forages on a site. Sheep readily select cheatgrass when it is in its early growth stages in early and late spring (Cook and Harris, 1952). Because sheep are much more likely to consume forages with which they are familiar (Arnold and Maller, 1977; Curll and Davidson, 1983; Provenza and Balph, 1988), sheep should ideally have been reared on cheatgrass rangeland if they are expected to consume cheatgrass. Sheep will graze more selectively within plant communities and across landscapes that have heterogenous vegetation and topography. Dense stands of cheatgrass without perennial herbs will be grazed relatively uniformly. Some control can be exerted over the degree of diet selectivity exhibited by sheep. For example, grazing selectivity can be altered by controlling the hunger level of sheep when they enter an area to be grazed and the time of day when sheep graze an area. Hungry sheep are usually less selective (Arnold et al., 1964) which may help explain why sheep grazing in the morning tend to be less selective than sheep grazing in the evening (Doran, 1943; Van Dyne and Heady, 1965; Kothmann, 1966). The type of forage that the sheep have been grazing immediately before their arrival in a cheatgrass treatment area also affects their diet selectivity. If sheep have been grazing on very palatable vegetation they will be more selective when foraging, whereas sheep that have been grazing on less attractive vegetation are usually less selective (Senft et al., 1987). Close herding or high stock densities decrease grazing selectivity (Doran, 1943). Fast herding further decreases selectivity. Finally, the breed of sheep used for prescribed grazing can also affect diet selectivity. Intraspecific relationships within bands or flocks of highly gregarious breeds such as Rambouillet or Merino may cause these sheep to graze less selectively than sheep within less cohesive breeds such as Suffolk or Dorset.

## Cheatgrass Ecology

Cheatgrass is a prolific seed producer. Even during years with unfavorable growing conditions it produces enough seed to perpetuate itself (Tisdale and Hironaka, 1981). Cheatgrass throughout western North America is usually a "winter annual." Its seed germinates in the early fall when moisture becomes sufficient and then cheatgrass plants grow rapidly until cold temperatures arrive. Above-ground growth sometimes continues during winter if the weather is warm and rainy (Klemmedson and Smith, 1964). The root system of cheatgrass often continues to develop during winter even when above-ground growth is dormant (Harris, 1967; 1970). Plants from seeds that germinated in the fall break dormancy in late winter or early spring when ambient temperatures become warm. Plants grow and develop rapidly in the spring, usually flower in early May, ripen seeds by early June and the plants are fully dried one to two weeks later (Stewart and Hull, 1949; Hulbert, 1955; Klemmedson and Smith, 1964). Corresponding stages are about six weeks later in bluebunch wheatgrass *(Agropyron spicatum)*. Cheatgrass seeds can also germinate in the spring, but spring-germinated plants are often less numerous and vigorous and seedling emergence is slow (Stewart and Hull, 1949; Hull and Hansen, 1974). Spring-germinated plants produce fewer inflorescences (groups of flowers borne on a single stem); if the seed germinates late in the spring no inflorescences are produced (Hulbert, 1955).

Cheatgrass seeds become viable soon after seeds mature. Seeds are viable when the fruits have barely started to turn purple and are still mostly green. However, some viable seed is produced even if the inflorescences are clipped before any purple coloration

appears (Hulbert, 1955). Cheatgrass seeds germinate quickly and at very high rates (up to 95%) as soon as moisture conditions are favorable (Hulbert, 1955; Hull and Hansen, 1974). Ungerminated cheatgrass seeds do not usually remain viable for longer than one year under natural conditions (Hulbert, 1955).

Cheatgrass adds considerable organic matter to the soil surface (Stewart and Hull, 1949). This facilitates the establishment of cheatgrass seedlings because they are favored by large amounts of plant mulch (Evans and Young, 1970; Young et al., 1987). The amount of seed mass produced by cheatgrass is often sufficient litter for some of its seeds to germinate (Young et al., 1987). Mulch also results in less cryptogamic cover of lichens and mosses on the soil surface and substantial mulch cover may inhibit establishment of perennial bunchgrasses (Svjecar and Tausch, 1991; Tausch et al., 1994b).

## Cheatgrass-Fire Relationships

Cheatgrass can dramatically influence plant community composition by its effect on fire regimes. This effect is most evident in the sagebrush steppe where, prior to European settlement, fire-free intervals probably varied from about 20 to 25 years in higher-elevation mountain big sagebrush *(Artemisia tridentata vaseyana)* habitat types to 50 or 100 years in the drier Wyoming big sagebrush *(Artemisia tridentata wyomingensis)* habitat types that dominated the Snake River Plain (Burkhardt and Tisdale, 1976; Wright and Bailey, 1982). Much of the Snake River Plain today burns at intervals of five years or less because cheatgrass increases the continuity of fine-textured fuels that result in more frequent and larger fires. Although fine-fuel continuity influences fire frequency more so than the amount of fine fuel (Whisenant, 1990), the amount of fine fuel is also important (Boltz, 1994).

The cheatgrass-fire cycle is self-promoting (Peters and Bunting, 1994). Increased fire frequency quickly removes nonsprouting shrubs such as Wyoming big sagebrush. More fire-tolerant, sprouting shrubs may persist for a while but they also cannot tolerate the short fire-free intervals common today. Continued increases in fire frequency eventually remove and exclude all perennial shrubs and herbs from the landscape. These altered fire regimes and subsequent changes in botanical composition can occur without any influence from livestock grazing (Cottam and Evans, 1945).

## Steady States versus Seral Stages

As mentioned earlier, cheatgrass is very persistent wherever it becomes established, and thus eradication of cheatgrass is not a reasonable goal in most situations. But the extent to which cheatgrass dominates a plant community greatly determines the ways that prescribed sheep grazing can be applied to suppress cheatgrass. Large areas that are mostly devoid of perennials and have fire-free intervals of five or less years have probably crossed a threshold and the cheatgrass community probably represents a relatively stable "steady state" (Laycock, 1994). This situation is common today in many sites within the Wyoming big sagebrush habitat types in western Idaho. Prescribed sheep grazing in these areas can be implemented without concern for perennial herbs. In these plant communities, prescribed sheep grazing can be used to: 1) diminish the fire hazard; 2) protect from fire adjacent areas where shrubs and other perennials still persist; and 3) improve the efficacy of artificial seedings of desirable perennials. In contrast to those areas where cheatgrass rangeland represents a steady state, there are also large areas in the West where cheatgrass is present but native perennials still dominate the herbaceous layer. Prescribed sheep grazing strategies in these "seral stage" plant communities must consider the needs of the perennial herbs. Prescribed sheep grazing on these sites can: 1) decrease cheatgrass abundance to enhance the competitiveness of the perennial herbs; 2) diminish the fire hazard; and 3) improve the efficacy of artificial seedings of desirable perennials. Finally, there are also areas in the West where sagebrush and other shrub densities have increased significantly and cheatgrass dominates the understory. Prescribed sheep grazing in these areas can be used to: 1) diminish the fire hazard; 2) decrease cheatgrass abundance to enhance the competitiveness of the perennial herbs; and 3) decrease shrub cover to enhance the competitiveness of perennial herbs.

## Prescribed Grazing Strategies

Timing is the most important variable for success in using prescribed sheep grazing to suppress cheatgrass. Sandberg bluegrass *(Poa sandbergii)* and bottlebrush squirreltail *(Sitanion hystrix)* are two species often found in association with cheatgrass. Both of these perennial grasses can initiate spring growth and become green and accessible to sheep before the winter rosettes of cheatgrass (Tipton, 1994). If sheep are allowed access to such a site too early in the spring, they may graze almost exclusively on these other grasses instead of cheatgrass (Murray, 1971). Sheep in northwestern Utah began grazing cheatgrass during its boot stage (May 2) and readily selected cheatgrass until May 28 when cheatgrass was in the dough stage and the plants were turning purple (Cook and Harris, 1952).

To keep cheatgrass seeds from becoming viable the inflorescences should be grazed off when they are still green and anthesis is incomplete. The goal is to graze cheatgrass plants before they begin to turn purple (Hulbert, 1955). The seeds must be prevented from reaching the dough stage. In Michigan alfalfa fields, Megee (1938) successfully controlled cheatgrass by grazing in late April and early May, but control was unsuccessful if grazing was delayed until after May 15. In a similar fashion, mowing cheatgrass about one week after inflorescences emerged controlled cheatgrass in native grass pastures in Nebraska (Finnerty and Klingman, 1962). Likewise, offset-disk plowing in southern Idaho reduced live plant densities and seed

reserves of cheatgrass when disking occurred in spring before cheatgrass seeds ripened (Pellant, 1990).

Daubenmire (1940) observed that after a few years where sheep grazing prevented cheatgrass seeds from maturing, cheatgrass populations suddenly crashed and only a scattered, thin population remained. He further stated that to keep cheatgrass from dominating, seed maturity must be prevented by grazing every year or every other year. Finnerty and Klingman (1962) later demonstrated that practical control of cheatgrass could be obtained after two successive years of preventing cheatgrass seed production.

Tausch et al. (1994a) evaluated three simulated grazing treatments on cheatgrass and perennial grass in western Nevada. Clipping twice in late spring (from the end of April to mid-May) reduced cheatgrass biomass and density compared with the unclipped control. A heavy defoliation rate was used and clipping coincided with the early boot stage of cheatgrass. Clipping in early spring (end of March to end of April) also reduced cheatgrass biomass compared with the control, but did not reduce cheatgrass density. Neither clipping in early spring or late spring affected perennial grass plant density, but the heavy defoliation in either season of clipping reduced perennial grass biomass compared with the control. Clipping twice in spring is necessary because new inflorescences emerge on cheatgrass plants about three to four weeks after the first clipping (Hulbert, 1955). Haferkamp et al. (1994) evaluated clipping effects on a similar annual brome grass, Japanese brome *(Bromus japonicus)*, in a greenhouse experiment. In their study, Japanese brome was clipped to a three-inch stubble height every week or every other week, or clipped to a six-inch stubble every week or every other week. All clipping treatments reduced production of roots, herbage and total biomass compared with the unclipped controls. Finnerty and Klingman (1962) found that clipping to a height of two to three inches successfully controlled cheatgrass in Nebraska pastureland.

Grazing intensity can be high (residual stubble height less than three inches) if the site is in a cheatgrass-dominated steady state. In seral plant communities, brief late-spring defoliation to a three-inch stubble can be sustained every year by the desirable cool-season perennial grasses of the Great Basin, Pacific Northwest and Northern Great Plains. These species include bluebunch wheatgrass, bottlebrush squirreltail, Sandberg bluegrass, Idaho fescue *(Festuca idahoensis)*, rough fescue *(Festuca scabrella)*, prairie junegrass *(Koeleria cristata)*, needle-and-thread *(Stipa comata)*, Thurber needlegrass *(Stipa thurberiana)* and sand dropseed *(Sporobolus cryptandrus)*. Pechanec and Stewart (1949) determined that bluebunch wheatgrass could tolerate spring grazing by sheep when its leaves averaged two and a half inches and soil was firm. The key factor was that the sheep only grazed for a week or two before being moved to a new unit. This strategy allowed the perennial bunchgrass to recover in the weeks that followed.

When sheep are grazing in late spring they should be observed closely to ascertain whether they are selectively consuming cheatgrass plants, selectively consuming desirable perennial herbs or readily grazing both cheatgrass and desirable perennials. Brief grazing periods in late spring should limit preferential grazing of desirable perennial grasses. However, if sheep are grazing desirable perennials more than cheatgrass, managers should use the behavior strategies presented above to encourage sheep to graze more uniformly.

Prescribed sheep grazing can enhance seed production and vigor of perennial plants by reducing the amount of soil water consumed by cheatgrass. Soil water depletion by cheatgrass is one of its principal mechanisms for successfully competing with perennial grasses (Melgoza et al., 1990; Melgoza and Nowak, 1991). Grazing sheep on dry cheatgrass in winter (Hull and Pechanec, 1947) will reduce mulch accumulations and enhance seedling establishment of perennials. Grazing during winter dormancy will have little or no effect on perennial herbs as long as sufficient residue remains to insulate perennial plant crowns from severe cold. Winter browsing of shrubs will also have minimal impact on shrub vigor, especially if browse utilization in winter does not exceed 50% to 60% (Julander, 1937; Hormay, 1943; Garrison, 1953).

In some areas, sagebrush densities may need to be reduced to enhance the ability of perennial herbs to compete with cheatgrass and sagebrush. This can be accomplished with heavy sheep grazing in late autumn (November and December) at stocking rates between 30 to 60 sheep days per acre (Mueggler, 1950; Laycock, 1967).

Prescribed sheep grazing can help diminish the fire hazard of cheatgrass by disrupting fine-fuel continuity and reducing fine-fuel loads. This will extend fire-free intervals and enhance the competitiveness of perennial plants. Using prescribed sheep grazing to protect existing stands of shrubs or perennial grasses from fire should be a high priority because it is easier and less expensive to prevent cheatgrass from dominating than it is to restore or rehabilitate depleted plant communities (Whisenant, 1990). These grazed firelines should be at least 250 feet wide (Wright et al., 1979; Wright and Bailey, 1982).

Artificial seeding of depleted sites is usually unsuccessful unless the cheatgrass is first suppressed by some method. Evans (1961) found that cheatgrass at densities of 64 and 256 plants per square foot competed strongly with crested wheatgrass *(Agropyron desertorum)* seedlings, whereas moderate competition was exerted when cheatgrass densities were 4 and 16 plants per square foot. Prescribed sheep grazing alone can be used to suppress cheatgrass before artificial seeding, especially on steep or rocky terrain or where predicted economic returns are low. Cheatgrass can be practically eliminated by uniformly heavy sheep grazing in spring (Daubenmire, 1940) and sheep can be used following broadcast seeding to help trample desired seed into the ground (Havstad, 1994). Usually a high stock density for a brief

period on moist ground works best. If soils are too wet soil compaction will exceed acceptable levels.

Prescribed sheep grazing also may be integrated with prescribed fire, herbicides or disking treatments to improve their efficacy before artificial seeding. For example, prescribed fire is used before seeding to lessen competition between cheatgrass and new seedlings of the seeded species (R.P. Young, 1983; Bunting et al., 1987; Rasmussen, 1994). Fire removes excessive mulch accumulations and reduces the number of cheatgrass seeds in the soil. This in turn greatly reduces the density of cheatgrass plants the next growing season, but those plants that do establish may produce so much more seed per plant that total seed production for the site may actually increase by a factor of 100 (J.A. Young, 1983). Unless the artificially seeded species become established and outcompete cheatgrass, density of cheatgrass plants may exceed pre-burn levels within one to five years (Wright et al., 1979). Prescribed sheep grazing can be applied in late spring following a prescribed burn that was conducted during the previous fall. The few cheatgrass plants that establish can be reduced in vigor and be prevented from producing mature seeds. Drilling the site with seed can be delayed until after the grazing treatment, or the site can be broadcast-seeded just before the grazing treatment in order to use sheep to trample in the seed. Grazing intensity can be high and grazing selectivity only needs to ensure that cheatgrass plants are prevented from developing mature seeds. Ideally the site should be regrazed soon after new cheatgrass inflorescences develop on plants that were grazed earlier in spring. Prescribed sheep grazing can similarly be used to suppress cheatgrass on sites that have been treated with herbicides prior to artificial seeding (Evans et al., 1983; Ogg, 1994) or sites treated with disking (Pellant, 1990). Following any artificial seeding, sheep should generally be excluded from a site for at least one-and-a-half to two growing seasons.

## Sheep Performance on Cheatgrass

Although livestock performance is a secondary objective in any prescribed sheep grazing program, few producers will agree to graze their sheep to suppress cheatgrass if lamb or wool production suffers greatly or variable costs increase significantly. If sheep performance declines or production costs rise, sheep producers may need to be granted free access to forage, or they may need to be compensated from budgets for weed control, watershed management or wildlife habitat. These types of lease arrangements currently exist in the northwestern United States and western Canada where silvicultural budgets pay sheep producers to use prescribed sheep grazing to enhance tree growth.

Grazing sheep in spring to suppress cheatgrass, however, should not materially hinder sheep performance. Murray (1971) found that sheep weight gain in spring on cheatgrass-dominated diets compared favorably with sheep performance on bunchgrass rangeland. These sheep gained 0.32 lb/head/day from early April to mid-May in southern Idaho (Murray, 1971). Wethers grazing cheatgrass in northwestern Utah gained 0.3 lb/head/day during early May, but gained only 0.01 lb/head/day during mid-June (Cook and Harris, 1952). These weight gains predictably followed changes in the nutritive content in cheatgrass as the stage of growth advanced. Crude protein content declined from 15.4% in early May to 8.2% at the end of May. Over the same time period, dry matter intake decreased from 3.3 lb/head/day during early May to 2.3 lb/head/day at the end of May (Cook and Harris, 1952). Sheep that are grazing dry cheatgrass in winter will need energy and protein supplements to meet nutrient requirements. Finally, caution is needed whenever sheep are grazing within plant communities where needle-and-thread is a major component. This grass species produces inflorescences with long awns that mature and become injurious to the eyes and mouths of sheep. These awns also degrade wool quality.

## Conclusions

Prescribed sheep grazing can be used to suppress cheatgrass density, growth and seed production. Prescribed sheep grazing can also help extend fire-free intervals by disrupting fine-fuel continuity and reducing fine fuel loads. Finally, prescribed sheep grazing can improve the efficacy of artificial seedings.

Optimal cheatgrass suppression will be obtained when sheep graze cheatgrass plants twice in late spring after the winter rosettes of cheatgrass have greened up and grown tall enough to be readily accessible to sheep. Grazing to a three-inch stubble height each time is desired, although residual stubble heights can be lower if the site is in a cheatgrass-dominated steady state. In most cases a one-week grazing period followed by a one- to three-week deferment and then another one-week grazing period should work best. The goal is to graze the cheatgrass each time before it begins to turn purple and thus prevent the seeds from reaching the soft dough stage. This will prevent most cheatgrass seeds from becoming viable. If a site is grazed in this manner every year or every other year for a few years in succession, the cheatgrass population will be reduced dramatically.

Sheep grazing at rates of 30 to 60 sheep days per acre in late autumn (when herbaceous plants are dormant) will decrease sagebrush cover and favor perennial herbs. This treatment can be applied to those sites where sagebrush density needs reducing to enhance the ability of perennial herbs to compete with cheatgrass and sagebrush.

Grazing of dried cheatgrass during winter dormancy will help reduce mulch accumulations and enhance seedling establishment of perennials. Grazing intensity in winter can be moderately heavy without damaging desirable perennial herbs and shrubs.

Prescribed sheep grazing to suppress cheatgrass is probably best suited to localized areas, either for protecting existing stands of perennial plants

from fire or for aiding the artificial seeding of severely depleted sites.

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# Research Briefs

## Shedding of Ovine Lentivirus in Semen of Infected Rams

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Venereal shedding plays a very important role in the epidemiology and transmission of several viral diseases of humans and domestic animals. Although venereal transmission of the human immunodeficiency viruses (HIV), the human lentiviruses, is known to be an important route of transmission, the factors that determine frequency and amount of lentivirus shedding in semen remain largely undefined. Inflammatory lesions of the reproductive tract have been reported in rams infected with ovine lentivirus (OvLV). However, there is no information on venereal shedding and transmission of OvLV.

In this paper, seven rams were used to determine if epididymitis increased the risk of shedding infectious OvLV in semen of infected rams. Rams 1 and 2 were naturally infected with OvLV. Rams 3, 4, 5 and 6 were inoculated intravenously with $1 \times 10^6$ $TCID_{50}$ of OvLV. Ram 7 was inoculated with a cell culture supernatant and used as OvLV negative control. Fourteen weeks after OvLV inoculation, rams 1, 2, 3, 6 and 7 were inoculated with $8 \times 10^8$ CFU of *Brucella ovis* into the left epididymis. Ram 4 was a natural case of *B. ovis* epididymitis; ram 5 was left non-inoculated and used as a *B. ovis* negative control.

Ovine lentivirus was demonstrated in the semen of rams 3 and 6, but only after *B. ovis* inoculation. Ovine lentivirus was isolated consistently, starting eight weeks after virus inoculation through the end of the experiment, from blood mononuclear cells (BMNC) of rams 3 and 6, but only occasionally from rams 1, 2, 4 and 5. Semiquantitative determination of OvLV-DNA amplified by Polymerase Chain Reaction (PCR) from alveolar macrophages showed a higher OvLV-DNA load in rams 3 and 6 than in the other OvLV-infected rams. Collectively these results suggest that the presence of inflammatory cells in the ejaculate and a high virus load in infected animals are important factors that determine the shedding of ovine lentivirus in semen. Dissemination of OvLV through contaminated semen could have important implications in the epidemiology and control of this infection.

*– compiled by A. de la Concha-Bermejillo*

## Lifetime Lamb and Wool Production of Targhee or Finn-Dorset-Targhee Ewes Managed as Farm or Range Flocks

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*Cited from: Journal of Animal Science. 1996. 74:1757-1764 and 74:1765-1769.*

Improvement in the reproductive rate of the ewe flock offers one of the greatest single opportunities for increasing the efficiency of lamb meat production. With the recent phase-out of the wool incentive program, increasing production efficiency is even more significant to the economic survival of the sheep industry.

In these studies, the authors evaluated lifetime (five-year) lamb and wool production of $^1/_4$-Finn–$^1/_4$-Dorset–$^1/_2$-Targhee (FDT) and straight-bred Targhee (T) ewes managed in either a farm or range production system. Ewe fertility rates were similar for FDT (92.2%) and T (91.0%) ewes. The FDT ewes had higher prolificacy and weaned more lambs per ewe exposed than T ewes, while T ewes produced heavier fleeces expressed as mean annual values. Range flock ewes had higher fertility rates and weaned more lamb per ewe exposed. Farm flock ewes gave birth to more lambs and produced heavier fleeces than range flock ewes. Incorporation of Finn-sheep and Dorset breeding increased the reproductive

performance in both management systems but decreased wool production on an average annual ewe performance basis.

Cumulative data reported indicate that for every 100 T ewes brought into the breeding flock, 11,050 kg of weaned lamb and 1,610 kg of wool were produced; whereas for every 100 FDT ewes, 13,170 kg of weaned lamb and 1,361 kg of wool were produced during the five years of production. Because of the higher value of lamb compared with wool, FDT ewes had a higher gross return than T ewes during their lifetime.

The authors conclude that the use of FDT ewes offers a potential for increased returns over straight-bred Targhees ewes in both management situations. Data presented should provide information for individual producers to use in making informed decisions on whether incorporation of a similar breeding program would provide economic advantage to their own operation.

*– prepared by Lowell Slyter*

## Selection for Lean Growth in Terminal Sire Sheep to Produce Leaner Crossbred Progeny

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*Cited from: Animal Science. 63:133-142. 1996.*

In the mid-1980s a selection index was designed at the Scottish Agricultural College (SAC) to improve the rate of lean growth in terminal sires and was applied in one line of the SAC Suffolk flock. The index combined ultrasonic measures of muscle depth, fat depth and live weight as predictors of carcass composition. Rams were chosen on index score calculated from their performance in an indoor intensive performance test at 150 days of age. Such intensive husbandry is typical of the United Kingdom in pedigree flocks. In commercial flocks, where terminal sires are used for crossbreeding, lambs are instead usually reared on grass. A progeny test was designed to test whether genetic superiority for lean growth in terminal sires is expressed in their crossbred progeny when reared in a different environment.

In each of the three years (1986, 1987, 1988), 11 rams with high index scores and 11 rams with low index scores were chosen at the end of their performance test from the SAC Suffolk flock. Around 400 crossbred ewes were mated in each year and the resulting lambs were finished on grass to one of three target live weights (35.5, 41.5, 47.0 kg). Shoulder joints of 1,505 lambs were dissected; half carcasses of 372 lambs were dissected. Information from the shoulder joints and half carcasses were then combined to more precisely predict the lean, fat and bone weight and the content of the carcass.

With each increment increase in target live weight, the carcasses became heavier and proportionally fatter. The progeny of high index rams consistently had 142 (s.e.d. 32) g more lean, 66 (s.e.d. 12) g more bone and 186 (s.e.d. 32) g less fat in a 19.7 (s.e. 0.5) kg carcass than progeny of low index rams. This improved composition reflected a correlated response to ram selection on the index. One standard deviation increase in ram index score corresponded to 51 g more lean and 64 g less fat in the 20 kg carcass of their crossbred offspring. These results show that the use of rams with high lean index scores in a crossbreeding system will produce lambs with leaner carcasses.

Visual appraisals of fat and conformation both increased as the weight and consequently the fatness of the carcass increased. Offspring of high index rams were consistently scored as less fat than offspring of low index rams. But at the lighter weights (35.5 and 41.5 kg), they were also scored lower in conformation – in effect a penalty for their higher genetic merit for lean growth. An unfortunate consequence of this coupling of conformation with fat score is that progress in reducing fat in market lambs may be slowed by the carcass assessment system in place.

*– prepared by R.M. Lewis*

# Sheep & Goat Research Journal
# Guidelines for Authors

## Objective

The aim of the Sheep & Goat Research Journal is to provide a publication of sheep and goat research findings which can be used by scientists, educators, Extension agents and sheep and goat producers alike. The specific goal of the Journal is to gather and distribute current research information on all phases of sheep and goat production and to encourage producer use of research which has practical application. The Journal is published three times each year.

## Editorial Policy

We are most interested in publishing articles of research relating to all aspects of sheep and goat production and marketing. Articles should relate and contribute to the advancement of the American sheep and goat industries and/or their products. All research manuscripts must represent unpublished original research. The submission of review articles is encouraged but will require review as well as those reporting original research. Articles which promote commercial products or services will not be approved for publication. Conclusions reached must be supported by research results. An orientation to practical applied research which may be useful to the sheep and goat industries is encouraged. At least one author of each manuscript must subscribe to the Journal.

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Manuscripts will be subject to critical review by an editorial board or others designated by the editor. Authors will be notified of acceptance or rejection of papers by mail. Manuscripts needing revision will be returned to authors and should be revised and returned by the deadline indicated. When papers are accepted for publication, the authors must send a floppy disk with the manuscript in the ASCII file format along with two hard copies. Papers not suitable for publication will be returned to the authors with a statement of reasons for rejection. Consult the Sheep & Goat Research Journal Editorial Policy and Procedures for details of the technical requirements for manuscripts submitted to the Journal.

## Guidelines

Several sources were consulted, including the Journal of Animal Science and the Council of Biology Editors, Inc., when preparing these guidelines. Though the nature of the Journal is such that relatively few regulations are needed on style and form, we have attempted to standardize the manner in which the material is published as a service to Journal subscribers. Following are general guidelines for style and form.

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Manuscripts must be typed and double-spaced; five copies must be submitted. The lines on all pages including those pages for Literature Cited and Figure Legends must be numbered in the left margin beginning with the numeral one (1) at the top of the page. Tables should be as few and as simple as is feasible for presentation of the essential data; tables should be typed and double-spaced. Each table should be on a separate sheet. All figures used in the text must be camera-ready. The author will be billed at full cost if figure preparation is required.

Research manuscripts should follow the format of:

| | |
|---|---|
| 1st | Summary (250 words or less) |
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| 5th | Results and Discussion |
| 6th | Conclusions |
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In citing literature in the text, use both authors if there are only two. If there are more than two, use the first author and "et al." Authors are asked to provide "interpretive summaries" for use by the sheep and goat industries in other media.

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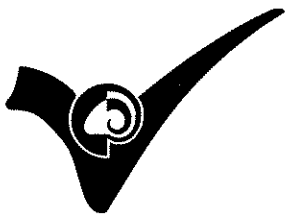


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# The Relationships of Lambs' Growth Traits to the Production Test Performance of their Sires

F.J. Schwulst[1], L.C. Martin[2], L.A. Arehart[3] and C.W. Spaeth[2]

## Summary

This study evaluated the growth performance of lambs sired by Suffolk rams that ranked high or low in a ram-lamb growth performance trial. Four rams (12 total) were obtained each year (1990 to 1992) from Colby Community College. The rams used were as close as possible to the two top-ranking and the two bottom-ranking ram lambs of that year's test and were bred to four genetically similar groups of ewes. The 30-day breeding season occurred during September and lambing took place during late January and February of the next year. Thus the 1990 rams sired lambs born during the late winter of 1991 and so forth. Data analyses of weights of lambs born, weaned and marketed were done on the basis of ewes exposed to breeding, ewes that actually lambed and individual lambs. Reproductive data were analyzed on the basis of ewes exposed. Ram ranking did not have a statistically significant effect on the weight of lambs born, weaned and marketed per ewe exposed or per ewe lambed. Lambs sired by high-ranking rams gained faster from weaning (50 ± 3 days) to market and were heavier when marketed than lambs sired by low-ranking rams. However, no difference occurred in backfat thickness at market weight. Ram ranking did not affect the conception rate of exposed ewes. Ewe breed significantly affected the total weight of lambs born per ewe lambed and all lamb traits except backfat thickness. Ewe age affected all ewe production traits and all lamb traits except backfat thickness. Ewe age had a greater effect on conception rate than either ram ranking or ewe breed. Type of birth affected all lamb weight and growth traits including backfat thickness. Male lambs (wethers) weighed more at birth, gained faster from weaning to market and were leaner than female lambs.

**Key words:** ram test, lambs, progeny performance.

## Introduction

Central ram testing programs have existed since at least 1948 when the Texas Agricultural Experiment Station initiated a test at Sonora, TX (Shelton, 1979). Rams in the Texas test were fed for specific periods of time that decreased over the years down to 140 days by 1972. About 90% of all rams tested were of the Rambouillet breed. Waldron et al. (1989) described central ram tests in five midwestern states. Most of the tests were time-constant. However, in one case, the test endpoint was determined when a ram reached 0.76 cm of fat covering over the rib-eye muscle. Most rams reached that point by 98 days on test. In another case, the date of reaching 0.76 cm of fat cover was recorded, although all rams remained on test to a time-constant end. About 80% of all rams evaluated were of the Suffolk breed. Waldron et al. (1990) reported weight and gain differences found among Suffolk ram lambs on a central growth test (63 days, starting at two months of age) were not reliable as predictors of growth differences among their progeny.

The objectives of this study included the evaluation of productivity, in terms of weight of lamb produced, by ewes exposed to rams that ranked high or low in a ram-lamb growth performance trial. We also evaluated growth traits of lambs sired by high- or low-ranking rams and the effect of ram rank on the conception rates of exposed ewes.

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## Materials and Methods

Four Suffolk rams were obtained each year (1990 to 1992) from the Colby Community College ram lamb growth performance test. The rams entered the trial as 60- to 90-day-old lambs and were full-fed a ground ration of 25% roughage (alfalfa) and 75% concentrate (corn and soybean meal). The rams were fed to an endpoint of 0.64 cm of backfat as measured by "hands-on" evaluation. About 40 Suffolk rams from four or five flocks were evaluated each year. Rams were ranked by an index that gave equal emphasis to rate of gain and weight per day of age. Each year, two top-ranking and two bottom-ranking rams were bred to four genetically similar groups of 27 to 34 ewes from the Northwest Research Extension Center (NWREC) flock. Rams were 9 or 10 months old when the 30-day (September) breeding season began each year. Lambing took place during the last week of January and the month of February of the next year. Thus, 1990 ram-test rams sired lambs born during January and February of 1991 and so forth.

The ewes used in this trial were from a flock that began with a base of Rambouillet ewes. Suffolk, Dorset and Finn × Rambouillet rams were used in a rotational crossbreeding system to produce the ewes. The ewes ranged in age from 2 to 9 years during the course of the study.

Male lambs were castrated using elastrator bands at about 7 to 10 days of age, and all lambs were docked at that time using an emasculator. All lambs were weighed at birth and were weaned and weighed at 50 ± 3 days. As the lambs approached market size, they were weighed at two-week intervals and were marketed after reaching 50 kg of weight. Backfat thickness was estimated by human evaluation just before the lambs were sold at auction in a local sale barn.

Data analyses of weights of lambs born, weaned and marketed were done on the basis of ewes exposed to breeding, ewes that actually lambed and individual lambs. Parameters measured to determine their effects on those weights and gains included ram rank, ewe breed, ewe age, type of birth and sex. Chi-square comparisons were used to determine deviation from the expected in conception rate of ewes exposed.

## Results and Discussion

Table 1 displays ram breeding performance data based on the number of ewes exposed to breeding. Conception rates were very nearly equal for ewes bred to high-growth-rate and low-growth-rate rams (90.9% and 89.2%, respectively). Suffolk-sired ewes had a conception rate of 95.0% compared with 88.2% for Finn × Rambouillet-sired ewes and 87.2% for Dorset-sired ewes. A Chi-square test showed that the observed conception rates did not differ significantly from expected rates for breed of ewe.

To evaluate the effect of ewe age on conception rate and growth traits, data from the few two-year-old ewes that lambed in the first year were included with the data for three-year-old ewes and the data for nine-year-old ewes that lambed in the last year were included with the data for eight-year-old ewes.

Chi-square tests showed that conception rates were higher than expected for the three- and four-year-old ewes and lower than expected for the eight-year-old ewes. The three- and four-year-olds had only one open ewe per group, resulting in a 97.7% conception rate for each group. Conception rate then declined to 93.1% for the five-year-old ewes. It continued to decline as age increased until it reached 83.9% for the eight-year-old ewes. Thus ewe age appeared to have more effect on conception rate than the growth performances of the rams to which the ewes were mated. Flock history at the NWREC indicates that the conception rates of ewes in this study were generally consistent with long-term means for fall-bred, spring-lambing ewes.

Ram rank did not have a significant effect on the weight of lamb born, weaned or marketed per ewe exposed to breeding (Table 2). However, the high-ranked rams did have an advantage at each point: 2.6% at birth, 6.8% at weaning and 11.3% by the time the lambs were marketed. The advantage in weight of lamb marketed by ewes bred to high-ranking rams was 6.6 kg per ewe exposed.

There were no significant ($P > 0.05$) differences among ewe breed groups in terms of kilograms of lamb born, weaned and marketed on a per-ewe-exposed basis. Four-year-old ewes gave birth to more ($P < 0.05$) kilo-

**Table 1. Conception rates for ewes bred to high- or low-ranking rams from a ram growth trial.**

| | Number of pregnant ewes | Number of open ewes | Percent pregnant |
|---|---|---|---|
| **Ram rank:** | | | |
| High | 149 | 15 | 90.9 |
| Low | 148 | 18 | 89.2 |
| **Ewe breed:** | | | |
| Suffolk-sired | 95 | 5 | 95.0 |
| Dorset-sired | 82 | 12 | 87.2 |
| F × R-sired[a] | 120 | 16 | 88.2 |
| **Ewe age:** | | | |
| 3 years | 42 | 1 | 97.7[b] |
| 4 years | 43 | 1 | 97.7[b] |
| 5 years | 54 | 4 | 93.1 |
| 6 years | 60 | 9 | 87.0 |
| 7 years | 51 | 9 | 85.0 |
| 8 years | 47 | 9 | 83.9[b] |

[a] F × R = Finn × Rambouillet rams.
[b] Significant deviation from expected (Chi-square = 0.05).

grams of lamb per ewe exposed than all other age groups except the five-year-old ewes; the five-year-old ewes produced more ($P < 0.05$) kilograms of lamb weaned and marketed than did the seven- and eight-year-old ewes. No significant ($P > 0.05$) differences existed among the three- to six-year-old ewe groups. The advantage in kilograms of lamb produced for five-year-old ewes over the oldest ewes was 8.9 kg at weaning and 23.2 kg at market.

Data per ewe lambed (Table 3) follow an almost identical pattern as that of data expressed on a per-ewe-exposed basis. However, one difference occurred in the effect of ewe breed on the total weights of lambs born. Finn × Rambouillet-sired ewes produced 8.8 kg of lamb born per ewe lambed compared with 8.4 kg for Suffolk-sired ewes and 8.2 kg for Dorset-sired ewes. The advantage of 0.6 kg of the Finn × Rambouillet-sired ewes over the Dorset-sired ewes was significant ($P < 0.05$).

**Table 2. Total weights of lambs born, weaned and marketed per ewe exposed.**

| | Lambs born, kg | Lambs weaned, kg | Lambs marketed, kg |
|---|---|---|---|
| **Ram rank:** | | | |
| High | 7.7 | 23.4 | 65.0 |
| Low | 7.5 | 21.9 | 58.4 |
| **Ewe breed:** | | | |
| Suffolk-sired | 7.9 | 23.4 | 62.5 |
| Dorset-sired | 7.1 | 22.0 | 58.0 |
| F × R-sired[a] | 7.8 | 22.5 | 64.9 |
| **Ewe age:** | | | |
| 3 years | 7.5[b] | 23.4[b,c] | 65.4[b,c] |
| 4 years | 8.9[c] | 25.5[b] | 65.5[b,c] |
| 5 years | 8.0[b,c] | 27.0[b] | 74.2[b] |
| 6 years | 7.5[b] | 22.7[b,c] | 61.7[b,c] |
| 7 years | 6.9[b] | 19.1[c,d] | 52.9[c] |
| 8 years | 7.0[b] | 18.1[d] | 51.0[c] |

[a] F × R = Finn × Rambouillet rams.
[b,c,d] Means in the same column within main effects with different superscripts differ ($P < 0.05$).

**Table 3. Total weights of lambs born, weaned and marketed per ewe lambed.**

| | Lambs born, kg | Lambs weaned, kg | Lambs marketed, kg |
|---|---|---|---|
| **Ram rank:** | | | |
| High | 8.5 | 25.6 | 71.6 |
| Low | 8.4 | 24.6 | 66.0 |
| **Ewe breed:** | | | |
| Suffolk-sired | 8.4[a,b] | 24.7 | 66.5 |
| Dorset-sired | 8.2[a] | 25.4 | 67.4 |
| F × R[d]-sired | 8.8[b] | 25.2 | 72.5 |
| **Ewe age:** | | | |
| 3 years | 8.0[a] | 25.2[a,b,c] | 70.6[a,b] |
| 4 years | 9.2[b] | 26.6[a,b] | 68.5[a,b] |
| 5 years | 8.7[a,b] | 29.3[a] | 81.2[a] |
| 6 years | 8.6[a,b] | 26.3[a,b] | 71.3[a,b] |
| 7 years | 8.1[a] | 22.5[b,c] | 62.6[b] |
| 8 years | 8.0[a] | 20.7[c] | 58.5[b] |

[a,b,c] Means in the same column within main effects with different superscripts differ ($P < 0.05$).
[d] F × R = Finn × Rambouillet rams.

The lamb data presented in Tables 4 and 5 are in general agreement with the work of Shelton et al. (1954) who noted that highly heritable differences existed among the performances of offspring of different sires. Shelton (1959) also found a positive correlation of 0.18 between the test gains of sires and the weaning weights of their progeny. In our evaluation of central test sires, lambs sired by high-ranking rams gained faster ($P < 0.05$) from weaning (50 ± 3 days) to market and were heavier ($P < 0.05$) when marketed than lambs sired by low-ranking rams. However, no difference occurred in backfat thickness at market. Ram rank did not affect birth weight, weaning weight or average daily gain from birth to weaning, which all are traits that are much affected by the maternal environment provided by the ewe.

Ewe breed significantly ($P < 0.05$) affected all lamb traits except backfat thickness. Lambs born to Suffolk-sired and Dorset-sired ewes were heavier at birth than lambs born to the more prolific Finn × Rambouillet-sired ewes. Lambs born to Suffolk-sired ewes were heavier at weaning and grew more rapidly from birth to weaning than did lambs born to either of the other ewe groups. Lambs from Suffolk-sired ewes were heavier at market and made greater gains from weaning to market than lambs born to Finn × Rambouillet-sired ewes. Lambs from Dorset-sired ewes were intermediate for both traits and did not differ from either of the other groups.

Ewe age significantly ($P < 0.05$) affected all lamb traits except backfat thickness. Generally, four-year-old ewes produced the heaviest and fastest-growing lambs. Though some differences among age groups were significant ($P < 0.05$), most differences were very small. For most traits, the three-year-old ewes produced lambs that were the lightest or slowest growing.

Type of birth affected ($P < 0.05$) all lamb weight and growth traits including backfat thickness. At birth, single lambs were 1.3 kg and 2.0 kg heavier than twins and triplets, respectively. By weaning, the advantages of the singles were 5.7 kg and 7.1 kg over the twins and triplets, respectively. Single lambs were 2.3 kg and 4.5 kg heavier when marketed than twins and triplets, respectively. Thus single-born lambs began life heavier than multiple-birth lambs and maintained that advantage throughout their lives.

Birth-to-weaning growth rate was greatest for single lambs, with no difference being expressed between twins and triplets. Postweaning growth rate also was greater for single lambs; however, twins then were intermediate to singles and triplets and did not differ from either group in terms of growth rate. Single lambs also had significantly ($P < 0.05$) more backfat cover when marketed: 0.06 cm more fat than twins and 0.08 cm more than triplets. The difference between twins and triplets was not significant. Backfat thickness was determined by a "hands-on" examination of the live lamb just before sale.

Male lambs were 0.2 kg heavier ($P < 0.05$) at birth than females and were castrated using elastrator rings at 7 to 10 days of age. No significant differences occurred in weaning weight or market weight between male and female lambs. Males did gain faster (0.03 kg per day) from weaning to market and, though castrated early, were leaner (0.03 cm of backfat) when marketed.

# Conclusions

When Suffolk rams that were high-ranking or low-ranking in a ram-lamb growth trial were bred to genetically similar sets of ewes, no significant differences occurred in total kilograms of lamb produced at birth, weaning and market per ewe exposed or per ewe lambed. However, lambs sired by high-ranking rams had a higher ($P < 0.05$) rate of gain from weaning to market and were significantly ($P < 0.05$) heavier at market than were lambs sired by low-ranking rams.

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**Table 4. Lamb weights and average daily gain through weaning (50 ± 3 days).**

| | Birth weight, kg | Weaning weight, kg | ADG[a], kg (birth to weaning) |
|---|---|---|---|
| **Ram rank:** | | | |
| High | 4.8 | 17.9 | 0.26 |
| Low | 4.8 | 17.8 | 0.26 |
| **Ewe breed:** | | | |
| Suffolk-sired | 4.9[b] | 18.7[b] | 0.27[b] |
| Dorset-sired | 4.9[b] | 17.7[c] | 0.25[c] |
| F × R-sired[e] | 4.7[c] | 17.1[c] | 0.25[c] |
| **Ewe age:** | | | |
| 3 years | 4.8[b,c] | 16.8[b] | 0.24[b] |
| 4 years | 5.0[b] | 19.5[c] | 0.29[c] |
| 5 years | 4.8[b,c] | 18.3[c,d] | 0.27[c,d] |
| 6 years | 4.9[b,c] | 18.0[b,d] | 0.26[b,d] |
| 7 years | 4.6[c] | 17.2[b,d] | 0.25[b,d] |
| 8 years | 4.7[c] | 17.2[b,d] | 0.25[b,d] |
| **Type of birth:** | | | |
| Single | 5.9[b] | 22.1[b] | 0.33[b] |
| Twin | 4.6[c] | 16.4[c] | 0.23[c] |
| Triplet | 3.9[d] | 15.0[d] | 0.22[c] |
| **Sex:** | | | |
| Male | 4.9[b] | 18.0 | 0.26 |
| Female | 4.7[c] | 17.7 | 0.26 |

[a] ADG = average daily gain.
[b,c,d] Means in the same column within main effects with different superscripts differ ($P < 0.05$).
[e] F × R = Finn × Rambouillet rams.

**Table 5. Lamb market weights, average daily gain from weaning (50 ± 3 days) and backfat thickness.**

| | Lamb market weight, kg | ADG[a], kg (birth to weaning) | Backfat thickness, cm |
|---|---|---|---|
| **Ram rank:** | | | |
| High | 52.5[b] | 0.28[b] | 0.58 |
| Low | 50.8[c] | 0.26[c] | 0.58 |
| **Ewe breed:** | | | |
| Suffolk-sired | 52.5[b] | 0.28[b] | 0.58 |
| Dorset-sired | 51.3[b,c] | 0.27[b,c] | 0.61 |
| F × R-sired[e] | 51.0[c] | 0.27[c] | 0.58 |
| **Ewe age:** | | | |
| 3 years | 49.5[b] | 0.26[b] | 0.58 |
| 4 years | 53.0[c] | 0.29[c] | 0.61 |
| 5 years | 51.3[b,c] | 0.27[b,c] | 0.61 |
| 6 years | 51.8[c] | 0.27[b,c] | 0.58 |
| 7 years | 52.2[c] | 0.27[b,c] | 0.61 |
| 8 years | 52.0[c] | 0.26[b] | 0.61 |
| **Type of birth:** | | | |
| Single | 53.9[b] | 0.29[b] | 0.64[b] |
| Twin | 51.6[c] | 0.27[b,c] | 0.58[c] |
| Triplet | 49.4[d] | 0.26[c] | 0.56[c] |
| **Sex:** | | | |
| Male | 52.1 | 0.29[b] | 0.58[b] |
| Female | 51.1 | 0.26[c] | 0.61[c] |

[a] ADG = average daily gain.
[b,c,d] Means in the same column within main effects with different superscripts differ ($P < 0.05$).
[e] F × R = Finn × Rambouillet rams.

# Effect of Service Sire on Ewe Reproductive Rate and Estimated Breeding Values for Reproductive Rate in Rambouillet Sheep[1]

Peter J. Burfening[2,3] and K.C. Davis[2]

## Summary

The objective of this study was to evaluate the effect of ewe's service sire on number of lambs born per ewe exposed for breeding and per ewe lambing and to evaluate the effect of service sire on the estimated additive genetic variance component and estimated breeding values for number of lambs born per ewe exposed and per ewe lambing. Service sire was a significant ($P < 0.01$) source of variation for number of lambs born per ewe exposed but not on a per-ewe-lambing basis. The smallest difference in the ranges in the least-squares means for lambs born per ewe exposed within line-year was 0.12 lambs and the largest difference in the ranges was 0.66 lambs. Effect of service sire on variance components and breed-ing values were estimated using MTDFREML procedures (Boldman et al., 1993) with two models. The first model contained the fixed effects of age of ewe selection line, year of mating, additive genetic effect and non-random permanent environmental effect of the ewe. The second model had the additional non-genetic random effect of service sire. Service sire had no effect on the estimated additive genetic variance for number of lambs born per ewe exposed or per ewe lambing and accounted for less than 1% of the total variation. Pearson correlations and Spearman rank correlations between the breeding values from the two models approached one. These results indicate that although service sire had a significant effect on number of lambs born per ewe exposed, it had no effect on the additive genetic variance or the breeding values for number of lambs born per ewe exposed. Therefore service sire does not need to be included in models used to estimate breeding values for reproductive traits in sheep.

**Key words:** sheep, service sire, estimated breeding values, reproductive rate.

## Introduction

Estimated breeding values (EBV) for reproductive rate in sheep are based on the number of lambs born per ewe and is an important component of the National Sheep Improvement Program (NSIP). Service sire (the male to which the female is mated or exposed) has been shown to affect reproductive rate. This effect is not only due to fertilization failure but also to differential rates of embryonic mortality (Courot and Colas, 1986). If service sire affects reproductive rate then service sire could potentially affect estimated breeding values for measures of reproductive rate. Work with swine indicates that service sire accounts for a small percentage (0.3% to 3%) of the total variation in number of pigs born alive (Strang and Smith, 1980; Mabry et al., 1988; Buytels and Long, 1991; See et al., 1993). However, in a simulation study, Woodward et al. (1993) found that including service sire increased the correlation between the true and predicted breeding values for number of pigs born alive. In a review of literature, no studies in sheep on the effect of service sire on EBV or on the percentage of total variation accounted for by service sire could be found.

The objective of this study was to determine if there are differences in number of lambs born per ewe exposed for breeding or per ewe

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lambing as influenced by service sires and if service sire affects the EBV for these reproductive traits.

# Materials and Methods

*Management of Sheep*

Records used in this study were obtained from the sheep flock maintained at the Montana Agricultural Experiment Station's Red Bluff Research Ranch (Norris, MT). Rambouillet sheep used in this study were from lines selected for low (LL) and high (HL) reproductive rate (based on an index of lambs born per ewe exposed) and a randomly selected control line (CL). Each line was maintained at approximately 100 ewes ranging in age from two to six years old. Details of the selection procedures, management of the sheep and response to selection were presented by Burfening et al. (1992). Ewes were herded on unfenced areas of the ranch through-out the grazing season and fed hay only when snow cover was too deep to permit grazing. Just prior to breeding, approximately November 10, ewes were moved to the ranch headquarters, sorted by line and randomly assigned within line and age of ewe to individual sire breeding pens. Four rams were used each year in LL and HL and eight rams were used each year in CL. Rams were used for only one year. Rams in LL and HL were selected within selection line on the basis of a simple index (Burfening et al., 1992) until 1990, when selection was based on estimated breeding values for number of lambs born per ewe exposed. Rams in CL were selected at random within line. All rams were 18 to 19 months old when exposed to the ewes and were not fertility checked prior to breeding. A total of 210 service sires (56 LL, 56 HL, 98 CL) were used during this 14-year period. Each LL and HL ram was exposed to approximately 25 ewes; CL rams were exposed to approximately 12 to 13 ewes. Ewes were exposed to the rams for 28 days, then removed from the breeding pens and mass-mated to blackface rams for another 15 days, after which they were returned to the range for the remainder of the gestation period. At lambing, ewes were moved to a large drop pen during the daylight hours and placed in a large lambing shed at night. They were under continual observation for lambing. When a ewe was observed to have lambed, the ewe and her lamb(s) were placed in a small individual pen. Lambs were eartagged within 12 to 24 hours of birth. Each lamb's eartag number, birth weight, sex, type of birth, birth date and dam number was recorded. A few days after lambing, ewes and their lambs were returned to the range for grazing.

*Data Analysis*

Records on the number of lambs born per ewe exposed and per ewe lambing from 1981 through 1995 were used in this study (with the exception of the data from 1990, when the ewes were artificially inseminated). Ewes failing to lamb to their service sire (i.e., those giving birth to blackface lambs) were considered not to have lambed for the purposes of this study.

To determine the importance of service sire on ewe reproductive performance, data were analyzed using the generalized linear models procedure using a fixed effect model (SAS, 1994). Dependent variables were number of lambs born per ewe exposed (0 through 4) and per ewe lambing (1 through 4). Independent variables were year of mating, age of ewe (2 through 6 years of age), selection line, selection line-by-year of mating interaction and service sire within line-by-year of mating.

Effect of service sire on estimated variance components and breeding values were evaluated using the MTDFREML procedures (Boldman et al., 1993) with two different models. Model 1 estimated the breeding values for number of lambs born per ewe exposed and per ewe lambing with the fixed effects of year of mating, age of ewe and selection line and the random effects of additive genetic variance ($\sigma^2_a$) and the ewe common environmental effect ($\sigma^2_c$). Model 2 was the same as model 1 with the addition of the non-genetic random effect of service sire ($\sigma^2_s$). Variance components were estimated for the additive genetic effect ($\sigma^2_a$), common environmental effect among records within ewe ($\sigma^2_c$), service sire ($\sigma^2_s$) and random error ($\sigma^2_e$). Estimated breeding values (EBVs) were calculated for each animal using both models.

To determine the importance of adding service sire to the model, Rao (1973), Mood et al. (1974) and Ferraz and Johnson (1993) describe a method to compare the ratios of likelihoods from different models. One property of REML methods is that the larger the likelihood function the better the model explains the variation in the data. The ratio

$$-2\,[\log \Lambda_i - \log \Lambda_j]$$

is asymptotically distributed as Chi-square with degrees of freedom equal to the difference in the number of parameters in the models i and j, where $\Lambda$ is the value of the likelihood function for the model, after the convergence criterion was reached. Differences between the likelihood functions for models 1 and 2 was a Chi-square value that tested for the effect of adding service sire to the model. To determine if adding service sire to the mixed model equations affected the EBV for number of lambs born per ewe exposed and per ewe lambing, Pearson and Spearman rank correlations were calculated among the EBV from models 1 and 2.

# Results and Discussion

The GLM fixed effect model (Table 1) showed that year of mating, age of ewe, selection line and selection line-by-year of mating affected number of lambs born per ewe exposed and per ewe lambing ($P < 0.05$). Service sire affected number of lambs born per ewe exposed ($P < 0.01$), but had no significant effect ($P = 0.80$) on lambs born per ewe lambing (Table 1). Eighty-seven percent of the ewes lambed and had 1.22 and 1.40 lambs born per ewe exposed and lambing, respectively. None of the rams used were sterile, but some had only a few progeny. The smallest difference in the ranges in the least-squares means for service sire for lambs born per ewe exposed within line-year was 0.12 lambs and the largest difference in the ranges for service sire was 0.66 lambs. Figure 1 shows the least-squares means for lambs born per ewe

exposed and per ewe lambing for each service sire within year-by-selection line. The figure shows the large range in lambs born as affected by service sire. In 1995, for example, the ewes exposed to the HL rams had an average of 2.07, 1.73, 1.72 and 1.59 lambs per ewe exposed. Since ewes were assigned randomly within selection line to one of the four rams, the relatively large differences for the four rams are due to the affect of service sire on number of lambs born. Yet when comparing 1995 with 1993, the differences between HL rams is very small.

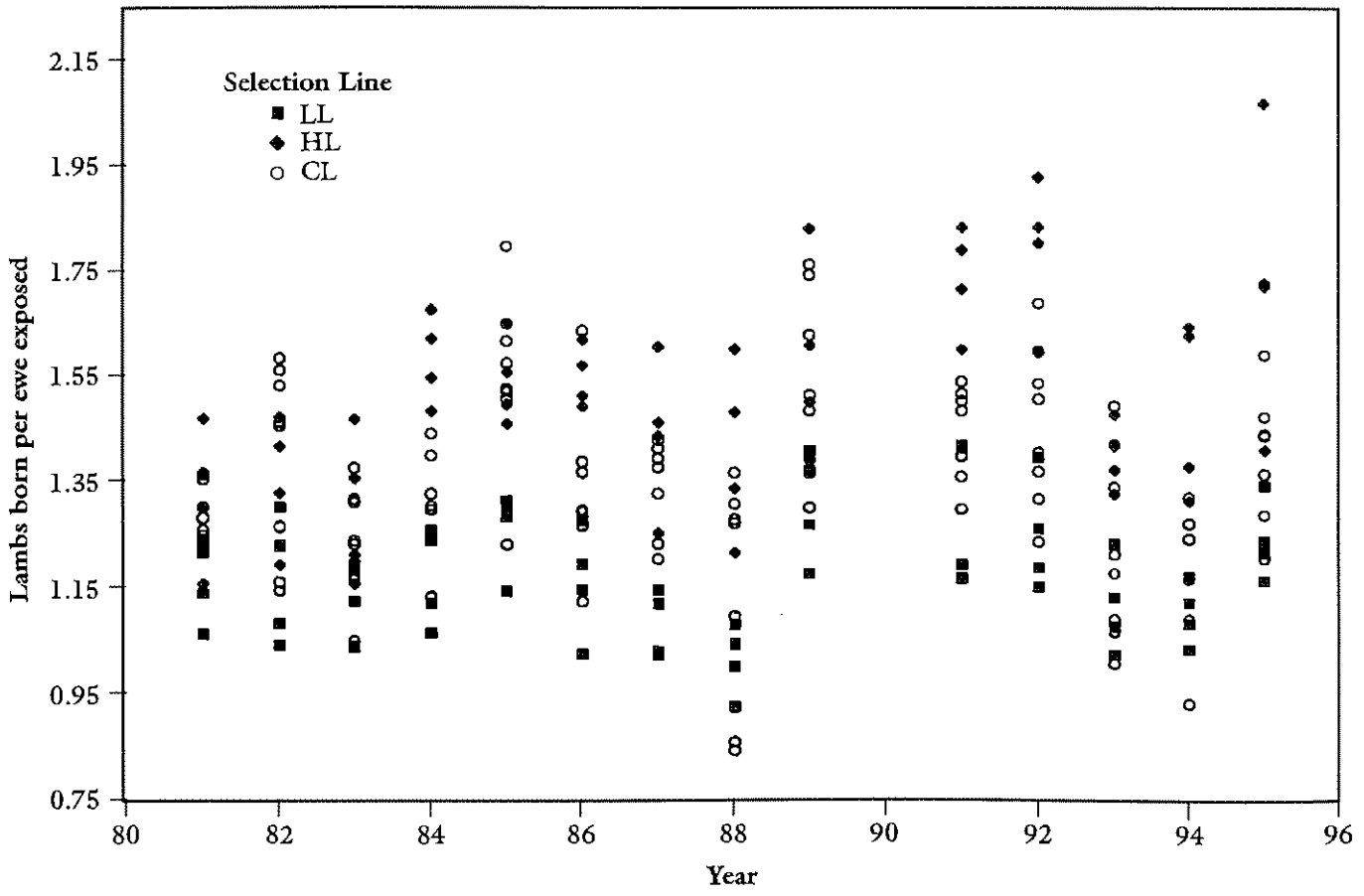
No significant differences were observed in the log likelihood functions between models 1 and 2. This means that when service sire was added to the model, service sire did not account for significant variation ($P > 0.20$). The estimated variance components and percentage of the variation from both models are presented in Table 2. Pearson or Spearman rank correlations of the breeding values between the two models were 0.98 for lambs born per ewe exposed and lambs born per ewe lambing, regardless of whether the model included service sire or not. Further visual observation of the breeding values from both models indicated no important changes in rank. Selection and culling decisions based on EBV for number born per ewe exposed or per ewe lambing would have been essentially the same

**Table 1. Least-squares analysis of variance of the number of lambs born per ewe exposed for breeding and per ewe lambing.**

| | | MS[a] lambs born | |
|---|---|---|---|
| Source of variation | df[b] | Per ewe exposed | Per ewe lambing |
| Year of breeding | 13 | 7.39[c] | 3.65[c] |
| Age of ewe | 4 | 19.56[c] | 14.67[c] |
| Selection line | 2 | 34.81[c] | 25.27[c] |
| Year-by-selection line (Y × L) | 26 | 1.87[c] | 0.41[c] |
| Service sire within (Y × L) | 181 | 0.75[c] | 0.20 |
| Residual | 3,573 | 0.38 | 0.22 |

[a] MS = means-squared.
[b] df = degrees of freedom.
[c] ($P < 0.01$).

**Figure 1. Least squares means of service sire within year-line (low line [LL], high line [HL] or control line [CL]) on the number of lambs born per ewe exposed for breeding.**



regardless of which model was used to obtain the EBV.

## Conclusions

Service sire accounted for significant variation in the fixed effect model for number of lambs born per ewe exposed. This could be the result of failure of the ram to mate ewes while they were in estrus, differences in fertilization rates of individual oocytes attributed to the service sire, differences in survival rates of fertilized embryos or a combination of all three. Although we do not know the causes, differences in lambs born per ewe expose did exist. When reviewing the literature on this subject, Courot and Colas (1986) noted that "one is surprised to note that most work has been devoted to the role of the female, rarely to that of the male." The same holds true still. Furthermore, fertilization failure and early embryonic mortality are often not separated but are lumped together as "fertilization failure." Ulberg and Burfening (1967) showed that the spermatozoa fertilizing the oocyte could have been damaged but it had no affect on the percentage of oocytes fertilized. However, the resulting embryo dies later in development but with the death generally occurring prior to the time that maternal recognition of pregnancy occurs, thus causing the animal to return to estrus at the expected time. This type of early embryonic mortality is often referred to as fertilization failure when in fact fertilization occurred but the embryo died later in development. Moore and Whyman (1980) and Moore (1981) reported that rams from high- and low-prolificacy flocks had different fertilization rates when mated to a random group of ewes. Burfening et al. (1977) observed that while there was no difference in fertilization rates among rams that had been selected for high and low reproductive rate, there was a significant difference in embryonic survival rate between oocytes fertilized by the two types of rams. Barker and Land (1970) found no differences between rams in their effect on embryonic survival rates even though they were from breeds that differed greatly in litter size. Although there were large differences in the effect of service sire on lambs born per ewe exposed, service sire had no effect on the additive genetic variance components or the ranking of the estimated breeding values.

In conclusion, these results show that the service sire does not need to be included in the mixed model equations for the estimated breeding values for lambs born per ewe exposed or per ewe lambing.

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**Table 2. Estimates of sire, common environmental, service sire and error variance components and percentage of the total variation in number of lambs born per ewe exposed and per ewe lambing.**

| | | Variance component[a] | | | | Percentage of variation[a] | | |
|---|---|---|---|---|---|---|---|---|
| Trait | Model | $\sigma^2_a$ | $\sigma^2_c$ | $\sigma^2_s$ | $\sigma^2_e$ | $\sigma^2_a$ | $\sigma^2_c$ | $\sigma^2_s$ |
| Lambs born per ewe exposed | 1 | 0.0342 | 0.0079 | – | 0.2738 | 10.826 | 2.501 | – |
| Lambs born per ewe lambing | 1 | 0.0350 | 0.0000 | – | 0.1900 | 15.556 | 0.000 | – |
| Lambs born per ewe exposed | 2 | 0.0449 | 0.0022 | 0.0008 | 0.2728 | 13.992 | 0.689 | 0.240 |
| Lambs born per ewe lambing | 2 | 0.0350 | 0.0000 | 0.0002 | 0.1899 | 15.534 | 0.000 | 0.076 |

[a] $\sigma^2_a$ = random effects of additive genetic variance; $\sigma^2_c$ = ewe common environmental effects; $\sigma^2_s$ = non-genetic random effect of service sire; and $\sigma^2_e$ = random error.

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# Performance and Carcass Components of Lambs in a Negative Energy Balance Fed Soybean Meal or Fish Meal[1]

C.E. Aimone[2], D.W. Sanson[2,3], M.L. Riley[2] and D.C. Rule[2]

## Summary

Thirty-eight fine wool wether lambs (body weight [BW] = 60.8 ± 1.4 kg) were used to determine the effect of protein sources on weight change and carcass components of lambs previously fed a finishing diet (60% corn; 40% dehydrated alfalfa pellets). Lambs were randomly assigned to one of four treatments: 1) initial slaughter (IS); 2) energy control (corn plus wheat straw; CWS); 3) soybean meal plus wheat straw (SBM); or 4) fish meal plus wheat straw (FM). On day 1 of the experiment, IS lambs (n = 9) were slaughtered. Remaining lambs were housed in a temperature-controlled building in 1.2 m × 2.4 m pens with wire mesh floors and fed their respective diets for 42 days. Diets provided 63% of estimated net energy for maintenance ($NE_m$) requirements. Lambs fed FM and SBM received 1.93 g of crude protein (CP) per kilogram BW and the CWS diet provided 0.59 g of CP/kg BW. Weights were recorded weekly prior to feeding. Kidney, pelvic and heart fat (KPH), intestinal fat (IF), subcutaneous fat (SCF), streaking, maturity and conformation were determined at slaughter. The rack from each lamb was separated into bone, muscle, seam fat (SF) and SCF. Lambs receiving FM lost less weight (P = 0.006) during the 42-day period than lambs fed either CWS or SBM (5.0, 8.2 and 8.0 ± 0.5 kg for FM, CWS and SBM, respectively). Slaughter weights were not different among lambs fed 42 days, but were lower than with lambs slaughtered initially (P < 0.001). Lambs slaughtered initially had higher (P < 0.03) KPH and IF (g/kg BW) than lambs fed for 42 days. Maturity scores were higher (P < 0.001) for IS lambs than for others. No differences (P = 0.46) were observed in conformation scores among treatments. Streaking scores were lower (P = 0.036) for lambs fed FM than either IS lambs or lambs fed the other diets. Rack muscle content (g/kg rack) was not different (P = 0.419) among the four treatments. Rack bone and SF (g/kg rack) contents were lower (P < 0.001) for IS lambs than FM, CWS and SBM lambs. In this trial, FM fed to lambs at 63% of maintenance energy decreased weight loss compared to CWS or SBM, but had only slightly altered carcass composition.

**Key words:** lambs, fish meal, carcass, protein, fat.

## Introduction

Diets containing feed sources high in rumen-undegradable protein may improve performance by altering the amino acids available for metabolism. Hovel et al. (1983) reported that lambs fed straw and supplemented with rumen-undegradable protein gained more body weight than lambs fed only straw and urea. Fattet et al. (1984) reported that lambs given a submaintenance energy diet with fish meal supplementation could continue lean muscle growth within a negative energy balance. Vipond et al. (1989) reported that fat lambs fed ad libitum straw plus fish meal lost less weight than lambs fed only straw ad libitum. Although these studies indicate a change in fat metabolism when a feed high in rumen-undegradable protein is fed, these diets were not formulated to supply equal amounts of dietary energy. They also did not evaluate possibilities that straw diets supplemented with rumen-degradable protein may increase microbial protein syntheses resulting in greater amino acid flow to the small intestine. This study was designed to evaluate the effects of feeding iso-caloric diets containing either a rumen-degradable protein source or a rumen-undegrad-

[1] Appreciation is expressed to Zapata Protein (USA), Inc., (P.O. Box 2868, Hammond, LA 70404) for providing fish meal.

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able protein source to lambs in a negative energy balance on performance and carcass composition.

## Materials and Methods

Thirty-eight fine wool wether lambs previously fed a diet consisting of 60% corn and 40% alfalfa pellets were randomly assigned to one of four treatments: 1) initial slaughter (IS); 2) energy control (corn plus wheat straw; CWS); 3) wheat straw plus soybean meal (SBM); or 4) wheat straw plus fish meal (FM). Supplements were formulated and fed to provide equal amounts of estimated $NE_m$ (Table 1). Dried molasses was used in formulating the supplements to equalize energy content and to aid in palatability. A mineral/vitamin premix was also added to each supplement. All lambs were fed 63% of their net energy requirements (NRC, 1985) for maintenance (straw plus supplement). Lambs fed FM and SBM meal received 1.93 g of CP/kg BW and the CWS diet provided 0.59 g of CP/kg BW.

On day 1 of the experiment, lambs assigned to IS were slaughtered. The remaining lambs were individually confined in a temperature-controlled barn in 2.9 m × 2.9 m pens with wire mesh floors and fed their respective diets for 42 days. Body weights were recorded prior to feeding on two consecutive days at the beginning and end of the trial; intermediate weights were taken every seven days. Lambs were fed their respective supplement at 0800 hours followed by their allotment of straw. During the first week some lambs refused the FM supplement. By the second week, however, all lambs were consuming their allotted feed.

Lambs were bled hourly starting at 0700 hours on day 42 for six hours. Blood was allowed to clot for one hour at room temperature, centrifuged at 2000 × g for 15 minutes and serum was harvested and stored frozen at -20 °C until analyzed. Lambs were slaughtered on day 43. Immediately after slaughter, fat tissue was removed from the tail head of each lamb, quick-frozen in liquid nitrogen and stored at -80 °C until analyzed for glycerophosphate acyltransferase (GPAT) activity. Subsequently, hot carcass weights were recorded and KPH and IF were separated and weighed. Viscera (including esophagus, rumen, reticulum, omasum, abomasum, small intestine, cecum, large intestine) were weighed, emptied of feed and fecal material, flushed with water and re-weighed. Fill was calculated as the difference between the full and empty viscera weights. Liver and kidneys were also separated and weighed. Carcasses were then scored for maturity, conformation and streaking. Fat depth at the 12th rib was measured. The rack from each carcass was removed and separated into muscle, bone, SF and SCF. The components were weighed. After weighing, the soft tissue from each rack was combined, ground through a 3.2-mm plate, thoroughly mixed, finely pulverized using a vertical chopper (model number 428; Hely-Joly, Tassin, France) and sampled for analysis. Samples were stored at -20 °C in sealed polyethylene bags until analyzed.

Rack samples were thawed overnight at room temperature and were analyzed for dry matter (DM), ash, protein and lipid in duplicate by procedures outlined by AOAC (1980). Lipid was determined with a Goldfisch extractor using hexane instead of petroleum ether. Protein was determined as Kjeldahl N × 6.25 using a Tecator digestion and distillation unit (Perstorp Analytical, Silver Springs, MD). Serum samples were thawed, pooled within animal and analyzed for non-esterified fatty acids (NEFA C kit; Wako Chemicals USA, Inc., Richmond, VA), β-hydroxybutyrate (procedure number 310-UV; Sigma Diagnostics, St. Louis, MO) and urea nitrogen (Fawcett and Scott, 1960) using colormetric procedures. GPAT activity was determined on in vitro homogenate of adipose tissue dissected from each lamb at slaughter (Rule, 1992).

Statistical analysis was conducted with SAS (1985) GLM procedures for a one-way ANOVA. Significant treatment effects were separated with least-significant difference mean separation procedures.

**Table 1. Formulation and composition of supplements and wheat straw fed to lambs.**

| | FM[a] | CWS[b] | SBM[c] | Straw |
|---|---|---|---|---|
| **Ingredients, %:** | | | | |
| Corn | 27.1 | 87.5 | – | – |
| SBM[c] | – | – | 89.3 | – |
| FM[a] | 56.9 | – | – | – |
| Dried molasses | 13.3 | 9.5 | 7.7 | – |
| Minerals premix[d] | 2.7 | 3.0 | 3.0 | – |
| **Nutrient composition, % DM[e]:** | | | | |
| CP[f] | 45.2 | 10.2 | 46.4 | 4.0 |
| $NE_m$[g], Mcal/kg[h] | 1.88 | 2.06 | 1.93 | 0.75 |
| **Daily intake:** | | | | |
| DM[e], g/kg BW[i] | 4.23 | 3.87 | 4.13 | 6.33 |
| CP[f], g/kg BW[i] | 1.91 | 0.40 | 1.91 | 0.25 |
| $NE_m$[g], Kcal/kg BW[i] | 7.96 | 7.96 | 7.96 | 4.75 |

[a] FM = fish meal.
[b] CWS = corn plus wheat straw.
[c] SBM = soybean meal.
[d] 2.7% NaCl, 20% Ca, 6% P, 0.007% I, 0.0012% Se and 90,000 IU of Vitamin A, 45,000 IU of Vitamin D and 160 IU of vitamin E per kg.
[e] DM = dry matter.
[f] CP = crude protein.
[g] $NE_m$ = net energy for maintenance.
[h] Estimated from table values (NRC, 1987).
[i] BW = body weight.

## Results and Discussion

Weight loss over the 42-day period was lower (P = 0.007) for lambs supplemented with FM compared to lambs receiving CWS or SBM (Table 2). Vipond et al. (1989) reported significantly less weight loss when fat lambs consuming straw were supplemented with 100 g/day of fish meal compared to those receiving only straw; also lambs receiving supplements actually gained weight during the first 28 days. In the current study, lambs consuming FM lost an average of 140 g/day, while lambs consuming CWS and SBM lost 194 and 189 g/day, respectively.

Empty BW and chilled carcass weight of lambs fed the experimental diets were lower (P < 0.001) compared to IS lambs (Table 3), with no differences among lambs fed FM, SBM and CWS. Empty gastrointestinal tract (GIT) weight of lambs slaughtered initially were higher (P < 0.01) than lambs fed the experimental diets, whereas GIT fill weights were lower (P < 0.001) for IS lambs and lambs fed SBM as compared to lambs fed CWS or FM. Although GIT fill weights were different among lambs, there were no differences (P = 0.208) in dressing percentage among these lambs.

Lambs fed FM, CWS or SBM had smaller (P = 0.075) rib-eye areas than lambs slaughtered at the start of the study. This would agree with the lower carcass weights and empty BW of these lambs. Fat depth at the 5th and 12th ribs of lambs slaughtered initially was greater (P < 0.024) than lambs fed the experimental diets, but no differences in fat depth were observed among lambs fed FM, CWS and SBM. Lambs fed the experimental diets had lower (P < 0.001) maturity scores than lambs slaughtered at the start of the trial; however, there were no differences (P = 0.46) in conformation scores among the four treatments. Lambs fed FM had lower (P = 0.04) streaking scores than lambs from the other treatments, with no differences among lambs slaughtered at the start of the trial and lambs fed either CWS or SBM. Intestinal and KPH fat weights were greater (P < 0.001) for IS lambs than lambs fed the experimental diets, with no differences among lambs fed either FM, CWS or SBM. No differences were

**Table 2. Performance of lambs fed wheat straw and supplemented with either fish meal, corn or soybean meal.**

| | IS[a] | FM[b] | CWS[c] | SBM[d] | SE[e] | P |
|---|---|---|---|---|---|---|
| Number | 9 | 10 | 9 | 10 | – | – |
| Initial BW[f], kg | 60.2 | 62.0 | 60.2 | 61.1 | 1.4 | 0.726 |
| Final BW[f], kg | – | 56.1 | 52.1 | 53.2 | 1.3 | 0.397 |
| Daily weight loss, kg | – | 139.8[g] | 193.9[h] | 189.2[h] | 12.6 | 0.007 |

[a] IS = initial slaughter.
[b] FM = fish meal.
[c] CWS = corn plus wheat straw.
[d] SBM = soybean meal.
[d] SE = standard error.
[f] BW = body weight.
[g,h] Row means with different superscripts differ.

**Table 3. Composition data of lambs fed wheat straw and supplemented with either fish meal, corn or soybean meal.**

| | IS[a] | FM[b] | CWS[c] | SBM[d] | SE[e] | P |
|---|---|---|---|---|---|---|
| Number | 9 | 10 | 9 | 10 | - | - |
| Empty BW[i], kg | 53.0[f] | 44.4[g] | 43.4[g] | 44.7[g] | 1.0 | < 0.001 |
| Carcass weight, kg | 30.2[f] | 26.3[g] | 25.5[g] | 26.6[g] | 0.7 | < 0.001 |
| Empty GIT[j] weight, kg | 4.6b[f] | 3.1[g] | 3.3[g] | 3.3[g] | 0.2 | < 0.001 |
| GIT[j] fill weight, kg | 5.1[f] | 7.9[g] | 6.3[g] | 6.1[f] | 0.4 | < 0.001 |
| Dressing percent | 52.1 | 50.5 | 51.5 | 52.2 | 0.7 | 0.208 |
| Rib-eye area, $cm^2$ | 14.4[f] | 12.8[g] | 13.0[g] | 13.3[g] | 0.4 | 0.075 |
| Fat depth at 5th rib, cm | 0.95[f] | 0.56[g] | 0.70[g] | 0.71[g] | 0.08 | 0.010 |
| Fat depth at 12th rib, cm | 0.50[f] | 0.28[g] | 0.34[g] | 0.30[g] | 0.05 | 0.023 |
| Maturity[k] | 1.78[f] | 1.18[g] | 1.39[g] | 1.32[g] | 0.11 | < 0.001 |
| Conformation[l] | 2.44 | 2.00 | 2.11 | 2.20 | 0.20 | 0.456 |
| Streaking[m] | 1.84[f] | 1.44[g] | 1.98[f] | 1.77[f] | 0.13 | 0.036 |
| KPH[n] weight, kg | 1.06[f] | 0.34[g] | 0.36[g] | 0.43[g] | 0.05 | < 0.001 |
| Intestinal fat weight, kg | 1.51[f] | 0.95[g] | 1.01[g] | 1.05[g] | 0.08 | < 0.001 |
| Liver weight, kg | 1.12[f] | 0.60[g] | 0.56[g] | 0.60[g] | 0.03 | < 0.001 |
| Kidney weight, g | 156.2[f] | 116.4[g] | 99.9[h] | 106.6[g,h] | 5.2 | < 0.001 |
| Heart weight, g | 312.5[f] | 233.9[g] | 228.3[g] | 244.9[g] | 12.0 | < 0.001 |
| Spleen weight, g | 115.9 | 94.0 | 104.0 | 99.6 | 8.2 | 0.276 |

[a] IS = initial slaughter.
[b] FM = fish meal.
[c] CWS = corn plus wheat straw.
[d] SBM = soybean meal.
[e] SE = standard error.
[f,g,h] Row means with different superscripts differ.
[i] BW = body weight.
[j] GIT = gastrointestinal tract.
[k] $A^0$ = 1; $A^{50}$ = 1.5; $B^0$ = 2.0.
[l] Choice$^-$ = 1.0; Choice$^0$ = 2.0; Choice$^+$ = 3.0.
[m] Slight$^0$ = 1.0; Slight$^{50}$ = 1.5; Small$^0$ = 2.0.
[n] KPH = kidney, pelvic and heart fat.

observed in liver weights among lambs fed FM, CWS or SBM, although these lambs had ($P < 0.001$) lighter livers than IS lambs. Kidneys from IS lambs were heavier ($P < 0.001$) than lambs fed the experimental diets and lambs consuming FM had heavier kidneys than lambs fed CWS. Kidney weights of lambs consuming SBM were not different from kidney weights of lambs fed either FM or CWS.

Berg et al. (1993) reported decreases in carcass fat and meat tenderness in steers finished on diets with supplemental protein from a protected soybean/rapeseed meal compared to steers fed supplemental protein coming from urea. They concluded that the lower tenderness scores were due to the lower intramuscular fat content of the carcasses. Although these steers were in a positive energy balance, the data would support the hypothesis that higher levels of dietary rumen-undegradable protein may alter fat metabolism of intramuscular fat. This is supported in the current study by the lower streaking scores in lambs fed FM, with no differences among lambs fed SBM or CWS and IS lambs.

Lambs slaughtered initially had higher ($P = 0.037$) fresh rack weights (grams of rack per kilogram of carcass) than lambs fed FM, while fresh rack weights from lambs fed CWS or SBM were not different than fresh rack weights of either IS or FM lambs. Bone weights ($P = 0.059$) were lower with IS lambs than with lambs fed the experimental diets (Table 4). Loin weight and muscle weight excluding the loin were not different ($P > 0.390$) among the four treatments. Separable SF was greater ($P < 0.009$) in IS lambs compared to lambs fed the experimental diets, with similar levels of separable SF for the lambs fed the experimental diets. Lambs slaughtered initially had more SCF ($P < 0.003$) than lambs fed the experimental diets, while lambs fed SBM and CWS had more SCF than lambs fed FM.

Dry, soft tissue rack weight (Table 4) from IS lambs was higher ($P = 0.001$) than from lambs fed either CWS or SBM, which were higher than that of lambs fed FM. Lipid content of the rack was different ($P < 0.003$) with lambs fed FM having the lowest amount of rack lipid. No differences ($P > 0.450$) were observed in rack ash or protein content among the four treatments. The decrease in carcass fat in this trial agrees with Fattet et al. (1984) who fed sodium hydroxide-treated straw with no protein supplementation or with FM supplementation. These researchers reported that all animals lost body fat, but lambs receiving FM lost less fat than the controls. Berg et al. (1993) found similar results feeding equal energy levels and different protein levels to steers in a positive energy balance.

Lambs fed SBM had higher ($P = 0.001$) β-Hydroxybutyrate than lambs fed either FM or CWS, while serum urea-N was higher ($P < 0.001$) with lambs fed CWS than lambs fed either FM or SBM (Table 5). No differences were observed ($P = 0.36$) in non-esterified fatty acids. Increased β-hydroxybutyrate has been reported during fasting with cattle, in which non-esterified fatty acids were concomitantly increased (Rule et al., 1986). In the present study, greater β-hydroxybutyrate in lambs fed SBM cannot be explained by greater lipolysis because serum non-esterified fatty acids, fat depth and SCF mass were not affected by treatment. Moreover, extracted lipid weight from racks of lambs fed SBM was higher than

**Table 4. Rack composition of lambs fed wheat straw and supplemented with either fish meal, corn or soybean meal.**

| | Rack composition, g/kg of empty BW[a] | | | | | |
|---|---|---|---|---|---|---|
| | IS[b] | FM[c] | CWS[d] | SBM[e] | SE[f] | P |
| Number | 9 | 10 | 9 | 10 | – | – |
| Rack weight | 22.4[g] | 19.6[h] | 20.8[g,h] | 21.0[g,h] | 0.6 | 0.037 |
| Bone weight | 4.0[g] | 4.8[h] | 5.1[h] | 4.8[h] | 0.3 | 0.059 |
| Muscle weight[j] | 5.4 | 5.0 | 4.8 | 5.4 | 0.3 | 0.391 |
| Loin weight | 4.8 | 4.5 | 4.9 | 4.3 | 0.2 | 0.395 |
| SF[k] weight | 3.9[g] | 2.8[h] | 2.9[h] | 2.8[h] | 0.2 | 0.008 |
| SCF[l] weight | 3.8[g] | 2.1[h] | 2.9[h] | 3.2[i] | 0.3 | 0.002 |
| | Rack soft tissue composition, g/kg of empty BW[a] | | | | | |
| | IS[b] | FM[c] | CWS[d] | SBM[e] | SE[f] | P |
| Number | 9 | 10 | 9 | 10 | – | – |
| Dry weight | 12.2[g] | 9.3[h] | 10.7[i] | 10.6[i] | 0.5 | 0.001 |
| Ash weight | 0.3 | 0.3 | 0.3 | 0.3 | 0.03 | 0.726 |
| Lipid weight | 9.1[g] | 6.2[h] | 7.5[i] | 7.4[i] | 0.4 | 0.002 |
| Protein weight | 3.0 | 2.8 | 2.6 | 3.1 | 0.2 | 0.856 |

[a] BW = body weight.
[b] IS = initial slaughter.
[c] FM = fish meal.
[d] CWS = corn plus wheat straw.
[e] SBM = soybean meal.
[f] SE = standard error.
[g,h,i] Row means with different superscripts differ.
[j] Excluding the loin.
[k] SF = Seam fat.
[l] SCF = subcutaneous fat.

lambs fed FM and similar to lambs fed CSW. It is possible that utilization of ketones in SBM-fed lambs may have been slower, resulting in greater steady-state concentrations of β-hydroxybutyrate.

Activity of GPAT was not different (P = 0.80) among treatments. West et al. (1994) reported changes in activity of GPAT that occurred in association with fat deposition in growing lambs. Glycerophosphate acyltransferase was measured in this study to determine if activity was altered in lambs in a negative energy balance when fed protein sources with different rumen degradability. Mechanisms responsible for glycerolipid biosynthesis were not affected by treatment because no differences in adipose tissue GPAT activity were observed. Bouyekhf et al. (1992) observed decreased palmitate esterification rates in vitro with slices of adipose tissue from steers in a negative energy balance, but activity of GPAT was not affected. They concluded that transport of substrates into the cell for glycerolipid biosynthesis was decreased in steers in a negative energy balance. This is also likely in the present study.

## Conclusions

Feeding a diet high in rumen-undegradable protein to lambs at 63% of maintenance energy decreased weight loss over 42 days compared to lambs fed diets containing similar levels of energy but either low in protein or at a similar level of a rumen-degradable protein. Lower streaking scores, lower SCF levels in the rack and lower lipid content in the rack from lambs fed FM may indicate a selective catabolism of fat from the body. However, differences were not as great as those reported by other researchers.

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**Table 5. Serum metabolites and tissue glycerophosphate acyltransferase activity of lambs fed wheat straw and supplemented with either fish meal, corn or soybean meal.**

| | FM[a] | CWS[b] | SBM[c] | SE[d] | P |
|---|---|---|---|---|---|
| Number | 10 | 9 | 10 | – | – |
| β-hydroxybutyrate, mg/dl | 4.20[e] | 4.02[e] | 5.32[f] | 0.25 | 0.001 |
| Non-esterified fatty acids, mg/dl | 93.2 | 88.2 | 83.6 | 4.9 | 0.360 |
| Urea nitrogen, mg/dl | 33.0[e] | 79.8[f] | 28.2[g] | 2.4 | < 0.001 |
| GPAT[h] | 108.0 | 105.5 | 122.8 | 21.5 | 0.802 |

[a] FM = fish meal.
[b] CWS = corn plus wheat straw.
[c] SBM = soybean meal.
[d] SE = standard error.
[e,f,g] Row means with different superscripts differ.
[h] GPAT = glycerophosphate acyltransferase; mmol glycerolipid$^{-1}$·g fat$^{-1}$·min.

# A Review of Factors Leading to High Fleece Production in Angora Compared to Down-Producing Goats[1]

A.J. Litherland[2] and T. Sahlu[2,3]

## Summary

This paper describes the possible factors which lead to high fleece production in Angora (mohair-producing) goats compared to down-producing goats. In comparison to down-producing goats, Angora goats have a reduced seasonality of fiber growth; a three- to four-fold greater fiber output per unit area of skin during active growth; and a two-fold greater mean follicular fiber output during active growth. This may be associated with an improvement in the follicular efficiency for keratin production. Angora goats, in comparison to down goats, have similar feed intakes (on a metabolic liveweight basis) and efficiencies of feed digestion. Angora goats partition more nutrients to fiber growth and less to muscle than down goats. Angora goats also retain more nitrogen, have lower plasma urea concentrations, recycle urea more effectively and excrete less urea than down goats. High fleece production in Angoras may be associated with a reduced gluconeogenic capability and lower blood glucose concentrations.

**Key words:** goat, angora, down, fleece, efficiency, metabolism.

## Introduction

The United States Angora goat produces an annual fleece weight of 3.6 to 8.1 kg compared to only 0.5 to 1.4 kg of total fiber from a down-producing goat of similar liveweight. The U.S. and South African Angoras, on a body weight basis, are two of the highest fiber-producing ruminants (Cronje, 1992). However, the physiological basis by which such a heavy fleece is produced is unknown. An understanding of the factors which lead to high fleece weight in the Angora compared to the down goat may permit further advances in mohair production and down production through improved selection methods or physiological manipulation. In addition, an understanding of the physiology for high fleece production opens up the opportunity for skin-specific modification of keratin production through the use of transgenics. This review explores the possible skin structure and physiological avenues by which selection may have increased fleece production in the Angora compared to the down goat and occasionally draws on comparisons of high and low wool-producing sheep.

## Fiber-Producing Area

The area of the body over which the fleece is grown differs only slightly between down and mohair goats. Down is not normally produced on the belly of the down goat while fleece growth extends further on the extremities of the Angora goat (personal observation).

## Follicle Seasonality

The length of the active fiber-producing phase differs between Angora and down goats. In the down-producing goat, both primary and secondary follicles have a biannual cycle of activity during which follicles are inactive for two to three months in late winter (Nixon et al., 1991a). In New Zealand Angora goats, secondary follicles are nearly all active throughout the year but primary follicles are inactive for one to two months in the latter half of winter (Nixon et al., 1991b). The seasonality of fiber growth in U.S. Angora goats has yet to be studied; however it is likely that some vestige of the seasonal growth pattern has been retained. In Romney sheep, which like the Angora produce fibers perennially, wool growth produced under constant

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nutrition is lower in winter compared to summer due to a seasonal depression in follicle bulb cell division rate (Holle, 1993). Selection for higher fleece production in the Romney, however, has led to higher winter wool growth rates (Hawker et al., 1988). Fleece weight differences between down and mohair goats can partially be explained by a reduced sensitivity of either the Angora seasonal endocrine system or the follicle to circannual photoperiod changes.

Pineal melatonin secretion, during the hours of darkness relative to dawn and dusk sensitivity windows, is the endocrinological translation of the photoperiod message (Bittman, 1984). In down goats, primary and secondary follicles are responsive to continuous melatonin treatment during spring (O'Neill et al., 1992). Photoperiod, and hence melatonin, regulates the seasonal secretion of prolactin from the pituitary of goats (Maeda et al., 1988). Prolactin has a causal role in regulating the molting and growth of the pelage in mink (Rose et al., 1987) and increasing circumstantial evidence is becoming available which suggests a regulatory role for prolactin on seasonal fiber growth of both sheep (Pearson et al., 1996) and down-producing goats (Dicks, 1994). Therefore, the effects of melatonin on fiber growth may be mediated via its effects on plasma prolactin secretion. However, both down- and mohair-isolated cultured follicles have an increased length growth rate following the inclusion of both melatonin and prolactin to the culture media (Ibraheem et al., 1993; Galbraith, 1994). In a study of modern and shedding sheep breeds and their crosses, it was found that high winter plasma prolactin concentrations are associated with greater wool growth during winter (Lincoln, 1990; Pearson et al., 1996). Provisional data indicate that the amplitude in seasonal prolactin concentrations is reduced in high, compared to low, fleece weight lines of Romney sheep (Clarke et al., 1993). In one study using down-producing goats, no evidence was found that seasonal plasma prolactin concentrations differed in goats with genotypically different patterns of down growth (Litherland, 1997). However, another study found that early-shedding down goat genotypes also had earlier increases in plasma prolactin concentrations compared to late-shedding genotypes (Rhind, 1994). It is not known whether seasonal plasma prolactin concentrations differ in Angora compared to down goats.

In conclusion, the duration of active growth clearly provides a partial explanation for the high fleece weight of Angora compared to down goats. A further understanding of the physiology of seasonality of fiber growth has a clear potential for improving fiber quantity in down (and possibly Angora) goats.

# Skin Area Fiber Output

The skin of down goats, with fully active follicles, produces 0.3 to 0.5 mg/cm$^2$/day of clean fiber (Nixon et al., 1991a) compared to 1.0 to 2.8 mg/cm$^2$/day for U.S. Angora goats (Sahlu et al., 1992). Therefore, skin area fiber output of the Angora goat is three- to four-fold greater than in down-producing goats.

### *Follicle Arrangement in the Skin*

The fleece and follicle structure of the Angora differs from that of the down goat and may be associated with breed differences in skin area fiber output. The down goat has a double coat with coarse medullated guard hair and fine down (fiber diameter: 80 to 150 µm and 6 to 25 µm, respectively; McDonald et al., 1987). In Angora goats, the mean fiber diameter of fibers derived from primary and secondary follicles only differs by 5 µm and ranges between 25 and 45 µm (Eppleston and Moore, 1990). The proportion of medullated fibers is normally less than 1% to 5% in U.S. Angoras and these fibers are predominantly produced by primary follicles.

The secondary-to-primary follicle ratio (S:P) is 5:7 for down goats (Millar, 1986; Restall and Pattie, 1989; Parry et al., 1992) and 6:10 for Angora goats (Dreyer and Marincowitz, 1967; Shelton, 1968; Wentzel and Vosloo, 1975; Winklmaier, 1983; Eppleston and Moore, 1990; Henderson and Sabine, 1991; Nixon et al., 1991b). Therefore, the Angora goat has approximately three or more secondary follicles per primary follicle than the down goat. High S:P ratios within breeds are usually associated with higher follicle densities in Angora goats (Eppleston and Moore, 1990), cashmere goats (Restall and Pattie, 1989) and sheep (Scobie and Woods, 1992). But high S:P ratios and follicle densities are not necessarily associated with higher fleece weights across different breeds (Scobie and Woods, 1992). Reported follicle densities for down goats are 17 to 46 follicles/mm$^2$ (Millar, 1986; Restall and Pattie, 1989; Parry et al., 1992) and 16 to 33 follicles/mm$^2$ for Angora goats (Eppleston and Moore, 1990; Parry et al., 1993). This information does not suggest that the Angora goat has more follicles per area of skin. Rather, it implies that the greater output of fiber per area of skin in the Angora compared to the down goat is due to a greater output of fiber per follicle.

# Follicular Fiber Output

The author calculated that the mean fiber volumes produced by single active follicles were 0.39 and 0.77 × $10^{-3}$ mm$^3$/day/follicle for down-producing and Angora goats, respectively. Equivalent values for sheep range from 0.33 to 0.53 × $10^{-3}$ mm$^3$/day/follicle for Merino (high density, low fiber diameter fleece) and Lincoln (low density, high fiber diameter fleece) sheep, respectively (Scobie and Woods, 1992). The mean specific gravity of the fiber produced from a single goat follicle was calculated as 0.90 and 1.29 g/cm$^3$ for the down-producing and Angora goat fleeces, respectively (The actual measured value for mohair is 1.3 g/cm$^3$; Lupton, 1992). The high degree of medullation in primary follicles of the cashmere goat contributes to the high mean follicular fiber volume and low specific gravity of the fiber produced. In summary, the active follicles of the Angora, in comparison with the down goat, produce two-fold the weight and three-fold the volume of fiber per follicle.

*Follicular Efficiency*

In Merino sheep, 96% of the variation in fiber output per follicle was accounted for by mitotic rate of the follicle bulb and the proportion of dividing bulb cells committed to fiber production (cellular efficiency; Hynd, 1989). In Merino and Romney sheep selected for higher fleece weight, follicle bulb (the proliferative zone) dimensions increased (Holle, 1993; Kelly et al., 1993). As fiber volume output per area of skin increases (2.89 to $5.71 \times 10^{-3}$ $mm^3/mm^2/day$) across sheep breeds, cellular efficiency also increases within the follicle (30% to 40%, Scobie and Woods, 1992; 44% to 55%, Kelly et al., 1993). There are no comparisons of follicle bulb dimensions and cellular efficiency for Angora compared to down goats. It is possible that in comparison to the down goat, the Angora goat may have a greater follicle proliferative area for a given area of skin and it may commit a greater number of dividing follicle cells towards fiber production.

For a given fiber diameter, the Angora goat has approximately a 50% greater fiber length growth rate than sheep (Reis and Sahlu, 1992). In addition, for a given width, cuticle scale structure is twice as long in the Angora compared to the down goat (Tucker et al., 1988). The cortical cell structure of mohair is predominantly cylindrical asymmetric ortho-cortex (Tucker et al., 1988). Both wool (Orwin et al., 1984) and down cortex (Couchman, 1984; Millar, 1986; Tucker et al., 1988; Wang, 1990, 1991) contain varying proportions of ortho-, para- and meso-cortex plus intermediatory types. These cortical cells are arranged in various ways ranging from bilateral to asymmetrical patterns. In sheep, cortical cell structure varies with season, nutrition, fiber diameter and genetic factors (Orwin et al., 1984). In comparison to paracortical cells in wool, orthocortical cells are larger, more prevalent in high fiber diameter and longer length wool, contain lower proportions of cystine and tyrosine and prevail under nutritional stress (Bradbury, 1973; Orwin et al., 1984; Scobie and Woods, 1992). During keratin deficiency in sheep, such as during the formation of thicker fibers or nutritional stress, the proportions of orthocortex increase relative to the other cortical cell types. Speculatively, orthocortical cells may be produced more efficiently in terms of rate-limiting amino acids than other cell types. There is no evidence that amino acid (Tucker et al., 1988, 1989; Wang, 1990) or high (Gillespie, 1965) or low sulfur protein composition (Crewther et al., 1966) of mohair differs compared to that of wool or down keratin. However, no studies have been conducted comparing the two species under comparable environment and nutrition regimes. In summary, the Angora goat has a two-fold greater mean follicular fiber output than the down goat but it is not known whether this is associated with an improvement in follicular efficiency for keratin production.

# Follicle Nutrient Supply

If it is assumed that keratin is produced with similar efficiencies within the follicles of Angora and down goats, then the higher follicle fiber output in the Angora must be associated with a greater nutrient flux to the follicle.

*Digestive Efficiency*

Compared to the down goat, the Angora goat, on a similar feed intake for liveweight, was equally efficient at digesting both energy and protein (Jia et al., 1995). In contrast, Cronje (1992) found nitrogen and organic matter digestibility to be 5% and 2% lower, respectively, in Angora than in Boer goats (another low fiber-producing goat). Angora goats, compared to down-producing goats, had a 17% advantage in acid detergent fiber digestibility in one study (Jia et al., 1995), but similar levels in another study (Sahlu et al., 1993). Angora goats have been shown to have lower ruminal total volatile fatty acids (Hart et al., 1993) and lower propionate molar percentage (Sahlu et al., 1993) than dairy goats. In summary, a greater nutrient flux to the follicle is not the result of either a greater feed intake on a metabolic liveweight basis or consistent improvements in the efficiency of feed digestion.

It has been demonstrated in sheep that 70% to 80% of the histidine and methionine (an essential rate-limiting sulfur amino acid required for fiber growth) disappears between the intestine and the portal blood supply (Harris and Lobley, 1990). No studies have been conducted to determine whether the Angora goat has an improved efficiency in provision of essential sulphur amino acids from the intestine to the blood supply.

*General Metabolism*

Angora goats appear to retain more nitrogen, recycle urea more effectively, excrete less urea (Cronje, 1992) and have lower plasma urea concentrations (Sahlu et al., 1993) than other goat breeds. However, other studies failed to detect differences among Angora and other goat breeds in nitrogen retention (Sahlu et al., 1993; Jia et al., 1995). An improvement in the efficiency of use of sulfur amino acids for mohair growth may reduce amino acid imbalances (Harris and Lobley, 1990; Qi et al., 1995), thereby leading to an increased apparent utilization of dietary nitrogen. In many ruminants, lower blood urea concentrations are normally associated with improved genetic merit for both liveweight gain and fiber production (Harris and Lobley, 1990).

Plasma creatinine concentration, a product of muscle catabolism, tended to be lower in Angora than in down-producing goats (Jia et al., 1995). Cronje (1992 and 1995) postulated that Angora goats have a reduced capability to mobilize labile body protein reserves for gluconeogenic pathways. In fact, high fleece weight Angora goats have lower blood glucose concentrations than Boer or Angora goats with low fleece weights (Cronje, 1992 and 1995). In addition, high fleece weight Angora goats take longer to restore blood glucose concentrations following an insulin challenge than do those with low fleece weights (Cronje, 1995) despite similar glucose clearance rates (Cronje, 1992). However, Angora and down goats had similar blood glucose concentrations in a different study (Jia et al., 1995).

Angora goats have lower cortisol concentrations than down goats (Jia et al., 1995) but have similar levels to Alpine and Nubian goats (Sahlu et al., 1993). However, infusion of cortisol directly to the skin had no effect on mohair growth (Pierzynowski et al., 1996). Differences do not exist between Angora and down goats in plasma concentrations of thyroxine, triiodothyronine and glucagon.

***Nutrient Partitioning***

Assuming equivalent amounts of essential amino acids enter the blood supply of Angora and down goats, then either partitioning or efficiency of use must differ between the two goat breeds. At comparable feed intakes and liveweights, down- and low-producing mohair and Alpine goats have higher liveweight gains and lower fiber growth rates than high-producing Angora goats (Hart et al., 1993; Cronje, 1995; Jia et al., 1995). The data of Jia et al. (1995), in conjunction with the theoretical requirements for liveweight gain and fiber growth for goats (NRC, 1981), was used to calculate the feed efficiency of energy (intake/MJME gain+fiber) and protein (DP intake/DP gain+fiber) for the down and Angora goats. The feed efficiency for energy was theoretically 38% versus 43% and protein was 37% versus 24% in Angora and down goats, respectively. In theory, it appears that Angora goats are more efficient users of feed protein and slightly less efficient users of energy than down goats. Compared with muscle, skin has a lower energy and increased protein requirement on a weight basis (Harris and Lobley, 1990). Therefore, such whole-body changes in energy and protein efficiency and partitioning could be accounted for by a shift in blood flow from muscle to skin. Sheep with higher genetic potentials for wool growth have higher blood flow rates to the skin but these differences are relatively minor (Hales and Fawcett, 1993). Low and high wool-producing sheep have similar cyst(e)ine fluxes to the skin, but higher net uptake of cyst(e)ine, indicating that genetic differences in wool growth may be due to improved transport of cyst(e)ine into the follicles (Harris et al., 1994). Similar measurements are not available for Angora and down-producing goats.

# Conclusions

High annual fleece weight in Angora compared to down goats is associated with a reduction in the seasonality of the Angora follicles, an increase in number and size of secondary follicles and an increase in fiber output per follicle. In comparison to the down goat, it appears that nutrients are partitioned away from muscle growth and towards fiber growth in the Angora. However, the physiology by which this occurs is unknown and thus warrants further research.

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# Comparing Performance of Pen- and Range-Mated Ewe Lambs from Different Lines of Targhee Sheep[1]

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## Summary

Ewe lambs from three Targhee lines were used to investigate effects of synchronization and mating systems on reproductive performance. Line 41 was selected for lifetime production of kilograms of lamb weaned, line 42 was a random-bred control and line 48 was a visually selected group, outcrossed to reflect an industry mating system. In November, 195 April-born ewe lambs were allocated by age and body weight to synchronized (synchronization followed by pregnant mare serum gonadotrophin injection; S) or non-synchronized treatments (NS) within range-mating or pen-mating systems. Pen-mated ewe lambs were fed 1.4 kg of alfalfa and 0.9 kg/lamb/day of barley. Range-mated ewe lambs were fed 0.2 $kg \cdot lamb^{-1} \cdot d^{-1}$ of a 32% crude protein (CP) supplement and alfalfa hay as required depending on snow cover. Pregnancy in ewe lambs was determined using real-time ultrasound 45 days after the end of the 40-day breeding period. Pregnancy rate was 74%, 40% and 48% for lines 41, 42 and 48, respectively ($P < 0.08$). Although line had no effect ($P = 0.15$) on birth weight, body weight of line 48 ewe lambs was 6% greater than line 41 ewe lamb body weight which was 12% greater than line 42 ewe lambs from 77 to 263 days of age ($P < 0.01$). Synchronization had no effect on pregnancy within line ($P > 0.42$). Although pregnancy was greater ($P = 0.01$) in S pen-mated (63%) than S range-mated (39%) ewe lambs, no difference ($P = 0.99$) was noted in the NS pen-mated (56%) and NS range-mated (54%) treatments. Pen-mated ewe lambs ate $5.04/ewe lamb more in feed, weighed 11% more ($P = 0.01$) after breeding and gave birth to 50% more ($P = 0.04$) live lambs than range-mated ewe lambs. Ewe lambs that became pregnant were heavier ($P < 0.09$) than non-pregnant ewe lambs from birth to the end of breeding. However, no difference ($P = 0.36$) was observed in average daily gain (ADG) from weaning until breeding and non-pregnant ewe lambs gained more ($P = 0.05$) body weight during breeding than ewe lambs that became pregnant. Feed inputs post-weaning must be judged in accordance with the potential increased output. In addition, body weight of the ewe lamb early in life may be a better indicator of reproductive maturity than body weight after weaning.

**Key words:** sheep, fertility, reproduction, management, synchronization.

## Introduction

Ewes bred first as lambs produce more kilograms of lamb during their lifetime than ewes bred first at 18 months of age (Spencer et al., 1942). However, ewe lamb reproductive performance is almost always reduced when compared with mature ewes. Both breed and nutrition are important factors influencing ewe lamb reproductive performance. The onset of ewe lamb puberty can be advanced or delayed by manipulating the nutritional status of the animal (Allen and Lamming, 1961; Burfening et al., 1971). Ercanbrack and Knight (1994) reported a marked difference for kilograms of lamb weaned per mature ewe between Targhee sheep selected for this trait and random-bred control ewes. These researchers did not investigate ewe lamb reproductive performance. Our analyses of these Targhee ewe lambs from 1984 to 1987 indicated that selection pressure on mature ewes for lifetime production of kilograms of lamb weaned per ewe resulted in greater reproductive performance in the ewe lambs. We noted a 40% (21 percentage units) increase in reproductive performance for ewe lambs from ewes selected for lifetime production of kilograms of

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lamb weaned (line 41) compared to ewe lambs from the random bred control group (line 42). During this period, 73% of the Targhee ewe lambs from line 41 became pregnant in their first breeding season compared with 52% of the ewe lambs from line 42. During these years, line 41 ewe lambs averaged 4.5 kg (14%) heavier body weight on (approximately) September 1 than line 42 ewe lambs. From weaning until breeding, weight gain did not differ between the two lines. The objective of this study was to investigate changes in body weight and fertility in ewe lambs from different lines of Targhee ewes selected for lifetime reproductive merit. In addition, we were interested in comparing the effects of high-input pen-mating with low-input range-mating. We also investigated the effects of synchronization.

# Material and Methods

In November of 1992, 195 April-born Targhee ewe lambs were randomly assigned to either pen- or range-mating programs. A mix of single- and twin-born ewe lambs were from one of three genetic lines of Targhee sheep. Line 41 (n = 52) had been selected for lifetime production of kilograms of lambs weaned. Line 42 (n = 43) was a random-bred control line of ewes used to evaluate the selection progress in the line 41 ewes. Line 48 (n = 100) was visually selected on size and soundness and out-crossed to reflect an industry mating system. These specific ewe lambs were sired by Targhee rams purchased from a Montana producer. Selection for line 41 Targhee ewes began in 1977 and continues at the present time. The numbers of ewe lambs from each line used in this study represent all of the ewe lambs that were selected as replacements given the selection criteria outlined by Ercanbrack and Knight (1994). Ewe lambs were allocated to either range- or pen- mating for a 40-day breeding in such a manner that age and body weight were similar for the two systems. Pen-mated ewe lambs (n = 97) were confined in one pen and fed 1.4 kg of alfalfa and 0.9 kg/lamb/day of barley. Range-mated ewe lambs (n = 98) were confined in a 35 ha pasture and fed 0.2 kg/lamb/day of a 32% CP supplement and alfalfa hay as required depending on snow cover. Ewe lambs were allotted to either synchronized (S; n = 98) or non-synchronized (NS; n = 97) groups such that age and body weight were similar for the two treatments. Synchronized ewe lambs were given 60 mg medroxy-progesterone acetate pessaries (Upjohn Company, Kalamazoo, MI). Pregnant mare serum gonadotrophin (500 IU i.m.; Intervet, Holland) was given 10 days later at time of pessary removal. All ewe lambs were placed in breeding at this time. Ram-to-ewe lamb ratio was 1:33 in both range- and pen-mating systems. Rams were 18 months of age and had been tested for semen quality and libido prior to breeding. After breeding, all ewe lambs were managed as one group. Pregnancy was determined using real-time ultrasound 45 days after the end of breeding. The model for ewe lamb body weight and ADG included the effects of line (41, 42, 48), mating system (range, pen) and synchronization treatment (S, NS). Ewe lamb age was included as a co-variable. Chi-square analysis (SAS, 1988) was used to analyze the pregnancy data. In the final analysis, pregnant and non-pregnant ewes were considered fixed effects to compare body weight differences between pregnant and non-pregnant ewe lambs.

# Results and Discussion

No two- or three-way interactions for line, mating system and synchronization treatment were detected ($P > 0.15$) for body weight data. Interaction for synchronization and line and synchronization and mating system were observed for pregnancy data. Therefore, simple effects are presented where appropriate.

### *Lines 41, 42 and 48*

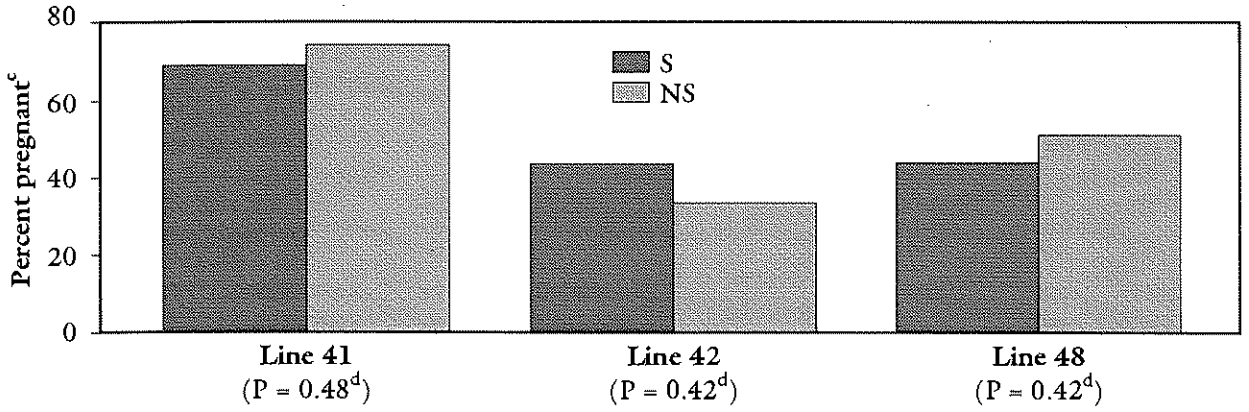
Percentage pregnant from line 41 was 60% and 124% greater ($P < 0.10$) than line 42 ewe lambs in the S and NS treatments, respectively (Figure 1). Non-synchronized line 48 ewe lambs had a 58% greater ($P = 0.02$) pregnancy rate than NS line 42 ewe lambs. Except at birth, line 41 ewe lamb body weight was 10% to 13% greater ($P = 0.01$) than line 42 ewe lambs (Table 1). Line 48 ewe lambs were heavier ($P \leq 0.08$) than line 41 ewe lambs on all dates weighed except July 2. Head et al. (1995), working with line 41 and 42 ewes, also reported a body weight advantage for both wether lambs and ewe lambs from line 41 ewes compared with line 42 ewes. From birth until November 13 (the beginning of breeding), ADG was greater ($P = 0.01$) for line 41 than line 42 ewe lambs (Table 1). The ADG did not differ ($P = 0.44$) between lines 41 and 42 during breeding. Line 48 ewe lambs consistently had a greater ADG than the line 42 ewe lambs. Although line 48 ewe lambs had a strong tendency to be heavier than the line 41 ewe lambs, line 41 ewe lambs had 42% and 57% greater percentage pregnancy for the S and NS treatments, respectively (Figure 1).

### *Range-Mating versus Pen-Mating*

Synchronization of pen-mated ewe lambs resulted in more ($P = 0.01$) pregnant ewe lambs than when S was used in the range-mating treatment (Figure 2). In the range-mating system, the large number of S ewe lambs exhibiting estrus in a short period of time were scattered over a large area. Ewe lambs in estrus typically do not seek out the ram and they may miss being bred (Edey et al., 1978). In comparing NS range- and pen-mating systems (information more pertinent to production operations), no difference ($P = 0.99$) was detected in fertility. During breeding, ADG was almost three times greater ($P = 0.01$) for pen- than range-mated ewe lambs, resulting in pen-mated ewe lambs weighing 4.5 kg more than range-mated ewe lambs at the end of breeding (Table 2). Although feed costs on range were 50% less than in the pen-mating system, snow depth limited forage availability resulting in an increasing amount (0 to 1.1 kg/ewe) of alfalfa hay being fed as the breeding season progressed. These results indicated that greater inputs in the form of harvested feeds may not be warranted as long as ewe lambs in the range-mating system are at some minimal, yet positive, nutritional plane. Pen-mated ewe lambs were heavier ($P = 0.01$) at the end of

lambing in May than range-mated ewe lambs (Table 2). No difference (P = 0.64) in body weight was noted in September of 1993 when ewe lambs were approximately 16 months of age. However, pen-mated ewe lambs had 50% more (P = 0.04) lambs born live than range-mated ewe lambs. This is due in part to the greater number of S ewe lambs that became pregnant in the pen- versus range-mating systems. However, more lambs were born dead in the range-mating system than in the pen-mating system. Average daily feed cost (actual 1992 prices) for pen-mated ewe lambs was $0.24/ewe lamb (1.4 kg of alfalfa hay at $78/ton; 0.9 kg of barley at $120/ton). Feed cost for range-mated ewe lambs averaged $0.12/ewe lamb (0.2 kg of supplement at $236/ton; 0.68 kg of alfalfa hay at $78/ton). With 97 ewe lambs in each treatment for 40 days, a $489 harvested feed cost saving for range-mated ewe lambs was realized. Assuming $0.25/kg price for a 36 kg feeder lamb, the pen-mating system would have to produce 11 more lambs than the range-mating system to pay for the higher feed cost. At current market lamb prices of $2/kg, the pen-mating system would still

**Figure 1. Fertility of synchronized (S) and non-synchronized (NS) treatments of line 41, 42 and 48 ewe lambs.[a,b]**




[a] Chi-square probability, line difference within S treatment = 0.08.
[b] Chi-square probability, line difference within NS treatment = 0.02.
[c] Percentage pregnant 45 days after rams were removed.
[d] Chi-square probability, S versus NS treatment within line.

**Table 1. Body weight and average daily gain of ewe lambs selected for kilograms of lamb weaned (line 41), a random-bred control (line 42) and a production-mated group (line 48).**

| Body weight, kg | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Line | | | | | 41 | 41 | 42 |
| Date | Age, days | 41 | 42 | 48 | SE | All over P | versus 42 | versus 48 | versus 48 |
| Birth | 1 | 4.7 | 4.7 | 5.0 | 0.11 | 0.15 | 0.80 | 0.08 | 0.12 |
| 07/02/92 | 77 | 25.4 | 22.5 | 26.4 | 0.54 | 0.01 | 0.01 | 0.18 | 0.01 |
| 08/06/92 | 112 | 33.3 | 29.4 | 35.0 | 0.58 | 0.01 | 0.01 | 0.04 | 0.01 |
| 09/18/92 | 155 | 37.7 | 34.1 | 40.6 | 0.60 | 0.01 | 0.01 | 0.01 | 0.01 |
| 11/13/92 | 211 | 40.4 | 35.7 | 42.6 | 0.58 | 0.01 | 0.01 | 0.01 | 0.01 |
| 01/04/93 | 263 | 44.6 | 39.6 | 47.5 | 0.63 | 0.01 | 0.01 | 0.01 | 0.01 |
| **Average daily gain, kg** | | | | | | | | | |
| | | Line | | | | | 41 | 41 | 42 |
| Dates | | 41 | 42 | 48 | SE | All over P | versus 42 | versus 48 | versus 48 |
| Birth to 09/18/92 | | 0.21 | 0.19 | 0.23 | 0.004 | 0.01 | 0.01 | 0.01 | 0.01 |
| 09/18/92 to 11/13/92[a] | | 0.05 | 0.03 | 0.04 | 0.005 | 0.03 | 0.01 | 0.01 | 0.01 |
| 11/13/92 to 01/04/92[b] | | 0.08 | 0.07 | 0.09 | 0.006 | 0.06 | 0.44 | 0.14 | 0.02 |

[a] All ewe lambs grazed dormant forage.
[b] Breeding period, ewe lambs either bred in pens or on range.

have to produce almost seven more lambs to pay for the higher feed cost. Note that facility, equipment and higher labor costs associated with confinement management of sheep has not been factored into the cost differential.

### *Pregnant versus Non-Pregnant Ewe Lambs*

When all lines of ewe lambs were combined to investigate weight change associated with ewe lambs that became pregnant in their first year, two striking details were noted: 1) weight gain from weaning to breeding and during the breeding period did not affect fertility; and 2) ewe lambs that became pregnant were heavier as early as 77 days (our earliest weight) after birth (Table 3). This weight characteristic is also noted for line 41 versus line 42 in Table 1. These same details are noted when pre- and post-weaning weight change of ewe lambs that became pregnant in their first year were investigated. The observation that weight from weaning to breeding and during breeding had little effect on fertility is in contrast to reports of a positive association between live-weight gain during the mating period and the incidence of pregnancy (Keane, 1975). The importance of early weight gain is supported by Baker et al. (1978) and by Boulanouar et al. (1995). These authors conclude that prepubertal body weight gain is a good indicator of age and weight at puberty. In addition, Jordan et al. (1970) concluded that although energy levels provided to ewe lambs post-weaning affected body and fleece weights, percentage of ewes conceiving and lambing at 13 months of age was not affected by energy levels. Hafez (1952) suggested that a minimum body weight was critical for first ovulation to occur in ewe lambs. This concept of a threshold body weight for puberty does not address body composition, metabolic processes or hormonal processes of the ewe lamb. Different factors (body fat, insulin, non-esterified fatty acids, amino acids or availability of metabolic fuel such as glucose) may interact to regulate secretion of hormones that modulate age at puberty (Schillo, 1992). Frisch and Vercoe (1991) suggest that a minimum amount of body fat may be necessary in females before they can exhibit estrus. Because body weight can remain constant despite large changes in body tissue reserves (Crooker et al., 1991), the concept of threshold body weight should not be interpreted as a cause of reproductive problems. Body weight should be used as a management tool that is correlated with reproductive performance and interpreted within the confines of environment and nutritional management.

## Conclusions

Selection for kilograms of lamb weaned per ewe has a profound effect on ewe lamb reproductive performance. Feed and other inputs post-weaning must be judged in accordance with potential increased output. In addition, advantages of synchronized treatments are dependent upon management (pen versus range). Weight gain from weaning to breeding and during the breeding period has little effect on fertility in ewe lambs that are in a positive nutritional plane. Ewe lambs that became pregnant were heavier early in life compared to ewe lambs that did not become pregnant. These factors demonstrate that body weight early in life may be a better indicator of reproductive maturity than body weight after weaning.

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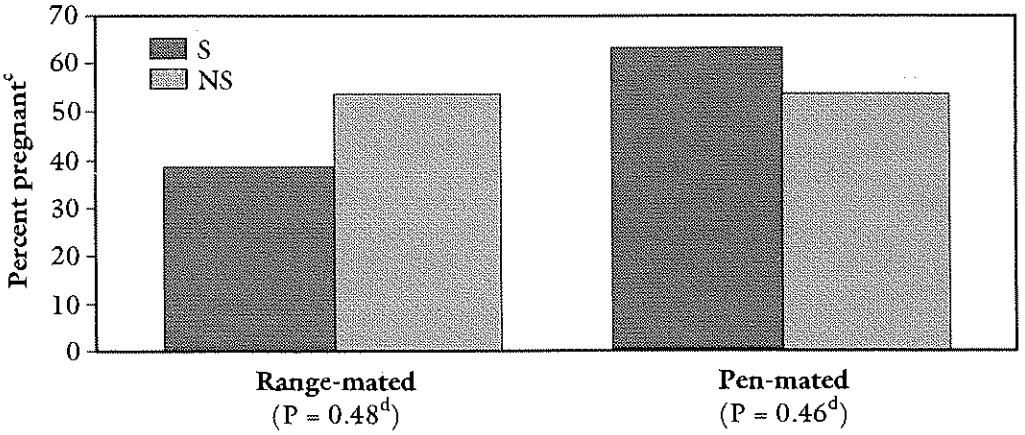
**Figure 2. Fertility of synchronized (S) and non-synchronized (NS) treatments of pen-mated and range-mated ewe lambs.[a,b]**




[a] Chi-square probability, site difference within S treatment = 0.01.
[b] Chi-square probability, site difference within NS treatment = 0.99.
[c] Percentage pregnant 45 days after rams were removed.
[d] Chi-square probability, S versus NS treatment within site.

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**Table 2. Body weight and average daily gain of ewe lambs mated in pens or on range.**

| Body weight, kg | | | | | |
|---|---|---|---|---|---|
| Date | Age, days | Range | Pen | SE | P |
| 11/13/92[a] | 211 | 39.8 | 39.4 | 0.40 | 0.51 |
| 01/04/93[b] | 263 | 41.6 | 46.1 | 0.43 | 0.01 |
| 05/24/93[c] | 403 | 44.0 | 48.0 | 0.79 | 0.01 |
| 09/04/93[d] | 506 | 60.9 | 60.4 | 0.69 | 0.64 |
| **Average daily gain, kg** | | | | | |
| Date | | Range | Pen | SE | P |
| Birth to 09/18/92 | | 0.21 | 0.21 | 0.002 | 0.29 |
| 09/18/92 to 11/13/92[e] | | 0.04 | 0.04 | 0.004 | 0.44 |
| 11/13/92 to 01/04/93[f] | | 0.04 | 0.13 | 0.005 | 0.01 |

[a] Beginning of breeding.
[b] End of breeding.
[c] Weight after shearing.
[d] Weight at end of 1993 summer grazing.
[e] All ewe lambs grazed dormant forage.
[f] Breeding period.

**Table 3. Body weight and average daily gain open and pregnant ewe lambs across study treatments.**

| Body weight, kg | | | | | |
|---|---|---|---|---|---|
| | | Pregnant | | | |
| Date | Age, days | No | Yes | SE | P |
| Birth | – | 4.7 | 4.9 | 0.07 | 0.09 |
| 07/02/92 | 77 | 23.8 | 25.7 | 0.37 | 0.01 |
| 08/06/92 | 112 | 31.6 | 33.5 | 0.40 | 0.01 |
| 09/18/92 | 155 | 36.3 | 38.6 | 0.42 | 0.01 |
| 11/13/92[a] | 211 | 38.3 | 40.9 | 0.40 | 0.01 |
| 01/04/93[b] | 263 | 42.9 | 44.9 | 0.44 | 0.01 |
| **Average daily gain, kg** | | | | | |
| | | Pregnant | | | |
| Date | | No | Yes | SE | P |
| Birth to 09/18/92 | | 0.20 | 0.22 | 0.002 | 0.01 |
| 09/18/92 to 11/13/92[c] | | 0.04 | 0.04 | 0.004 | 0.36 |
| 11/13/92 to 01/04/93[d] | | 0.09 | 0.08 | 0.004 | 0.05 |

[a] Beginning of breeding.
[b] End of breeding.
[c] All ewe lambs grazed dormant forage.
[d] Breeding period.

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# Scrapie: A Review[1]

L.A. Detwiler[2], A.L. Jenny[3], R. Rubenstein[4] and N.E. Wineland[5]

## Introduction

Scrapie is an insidious, degenerative disease affecting the central nervous system of sheep and goats. The disease is also called *La tremblante* (French for "trembling") or *Traberkrankheit* (German for "trotting disease") or *Rida* (Icelandic for "ataxia" or "tremor"). It was first recognized as a disease of sheep in Great Britain and other countries of western Europe over 250 years ago.

Scrapie is the prototype of a group of diseases known as transmissible spongiform encephalopathies (TSE). These diseases are caused by a transmissible agent which is yet to be fully characterized.

They share the following common traits:

- Prolonged incubation period of months or years.
- Progressive debilitating neurological illness which is always fatal.
- When examined by electron microscopy, detergent-treated extracts of brain tissue from animals or humans affected by these diseases reveal the presence of scrapie-associated fibrils (SAF; see Figure 1).
- Pathological changes are confined to the CNS and include vacuolation, astrocytosis and gliosis; amyloid plaques may be seen, especially in mice and hamsters.
- Transmissible agent elicits no detectable specific immune response in the host, inhibiting development of a live animal diagnostic test.

While both sheep and goats are susceptible to natural scrapie, the clinical disease occurs primarily in sheep of breeding age.

Other transmissible spongiform encephalopathies include the following:

**Creutzfeldt-Jakob Disease** (CJD) – This is a presenile dementia which affects humans. It occurs at an annual incidence of about one in a million of the population. Approximately 90% of the cases are sporadic with no known source of exposure. Between 5% to 10% of the cases are familial in nature and are associated with certain inherited gene mutations. An extremely small number of cases are the result of iatrogenic transmission such as corneal transplants, contaminated pituitary growth hormone injections or inadequately disinfected brain electrodes (Brown, 1988a,b).

**Kuru** – This is a disease of the Fore tribe in the Eastern Highlands of Papua, New Guinea. The disease is characterized by loss of coordination followed by dementia. The infection was thought to spread through the practice of cannibalism and exposure to high-risk tissues such as brain. Since this practice was discontinued the disease has essentially disappeared.

**Gerstmann-Straussler-Scheinker Disease** – A rare familial disease of humans caused by an inherited mutation in the PrP gene, approximately 50 extended families have been identified with this disease. It is characterized by loss of coordination and dementia (Prusiner, 1995).

**Fatal Familial Insomnia** – An extremely rare human disorder characterized by trouble sleeping and disturbances of the autonomic nervous system. An inherited mutation in the PrP gene has been identified as the precipitating factor of this disease (Lugaresi et al., 1986; Tateishi et al., 1995).

**Variant Creutzfeldt-Jakob** (vCJD) – Fifteen cases of vCJD have been identified in the United Kingdom (U.K.) and France between 1994 and 1996. Unlike sporadic CJD, the cases were unique in that the

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patients were younger than the usual age, the clinical manifestation was different and the cases displayed a new neuropathological profile. The Spongiform Encephalopathy Advisory Committee (SEAC) in the U.K. concluded that although there was no direct scientific evidence of a link between Bovine spongiform encephalopathy (BSE) and CJD, the most likely explanation at present, based on current data and in the absence of any credible alternative, is that these cases are linked to exposure to BSE before the introduction of the specified bovine offal ban in 1989 (Will et al., 1996).

**Transmissible Mink Encephalopathy** (TME) – TME is an uncommon disease of ranch-raised mink first described in 1965 by Hartsough and Burger (Hartsough and Burger, 1965). The disease has been reported in Canada, Finland, Germany, Russia and the United States (U.S.). The last case reported in the U.S. was in Wisconsin in 1985 (Marsh and Hadlow, 1992). It has been suggested that TME is a result of feeding either scrapie-infected sheep or scrapie-infected cattle to mink.

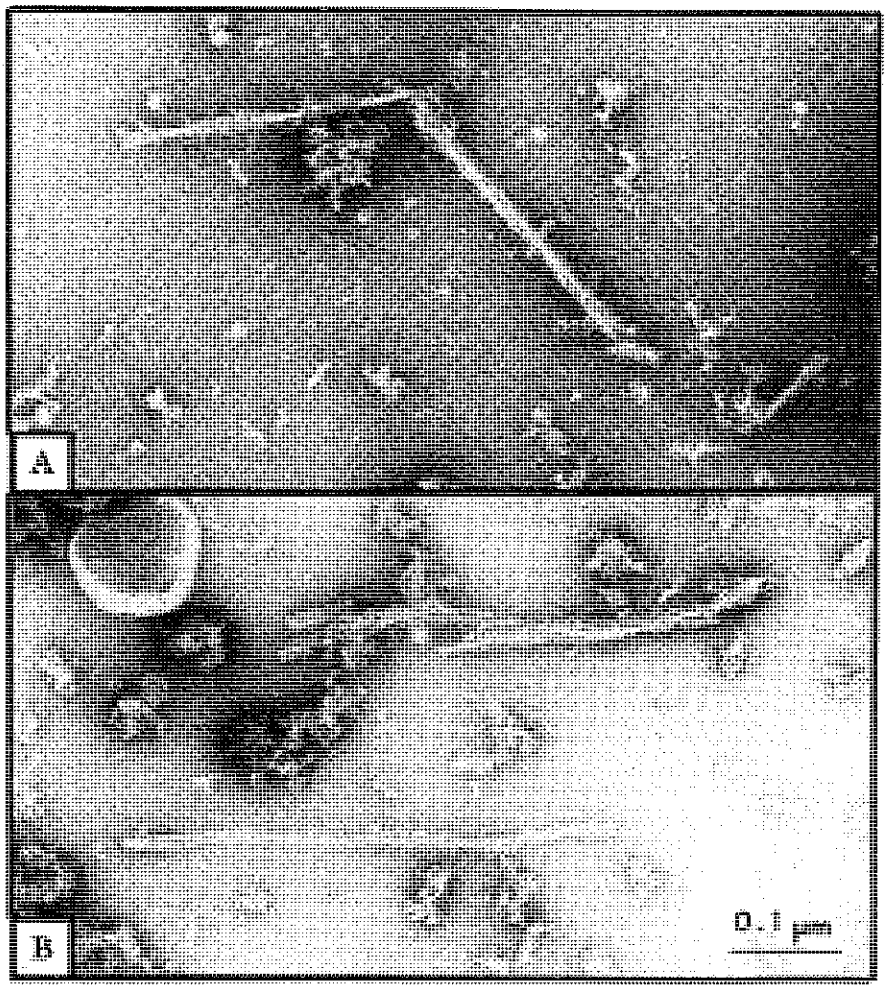
**Chronic Wasting Disease** (CWD) – CWD was first reported in 1980 by Williams and Young (Williams and Young, 1980) and originally was confined to mule deer and Rocky Mountain elk held in captivity in Colorado and Wyoming (Williams and Young, 1982). More recently the disease has been confirmed in free-ranging cervids in Colorado and Wyoming and has not been limited to mule deer and elk. The disease is characterized by emaciation, changes in behavior and excessive salivation.

**Bovine Spongiform Encephalopathy** (BSE) – BSE was first reported in Great Britain in 1986 (Wells et al., 1987). Since that time over 165,000 animals have been affected with this disease. The syndrome is characterized by changes in temperament, loss of body condition despite appetite retention and incoordination. The cause is thought to be incorporation of infectious TSE material into rations for cattle. BSE is hypothesized to have originated from feeding rendered material containing scrapie-infected sheep or previously-undetected BSE in cattle to cattle. Countries which have reported cases of BSE in domestic cattle include Great Britain, Northern Ireland, the Republic of Ireland, France, Switzerland and Portugal. BSE is not known to exist in the U.S.

**Feline Spongiform Encephalopathy** (FSE) – FSE is a naturally-occurring TSE first reported in domestic cats in 1990 (Wyatt et al., 1990). Over 70 cases of the disease have been diagnosed in the U.K. since 1990. In addition, one case of FSE has been identified in Norway (Bratberg et al., 1995) and one in Liechtenstein. Cats with the disease display locomotor disturbances, behavioral changes and a hypersensitivity to sudden movements or noises (Wyatt et al., 1991). Current evidence suggests that the disease in cats may be linked to BSE through the consumption of contaminated feed.

Other cases of spongiform encephalopathy have been reported in kudu, eland, nyala, gemsbok and a few exotic cats. These too are thought to be linked to BSE-contaminated feed.

**Figure 1. Electron micrographs of negatively stained SAF from brains of: A) sheep with experimentally transmitted scrapie; and B) mice affected with scrapie strain ME7 (3% phosphotungstic acid, pH 7.2).[a]**




[a] Micrographs reproduced with the kind permission of Dr. R. Rubenstein et al. (1987).

# Incidence

### *Worldwide*

Scrapie has been reported worldwide and affects most sheep-producing regions with a few notable exceptions. Australia and New Zealand are commonly accepted to be scrapie-free. The disease has been recognized for over two centuries in England, Wales and Germany (Parry, 1983).

The first reports of scrapie in existence appear in eighteenth and nineteenth century literature from England and Germany. According to McGowan (1922), the earliest definite record of occurrence of the disease in Britain was in 1732. Between 1750 and the early 1800s, a scrapie-like disease occurred in the Dorset Horn, Wiltshire Horn and Norfolk Horn breeds in England. Although reports of a scrapie-like condition on the continent of Europe at this time primarily link scrapie to imported Spanish Merino sheep (Parry, 1983), Greig (1940) maintained that it probably was endemic prior to introduction of the Merinos.

Later in England and Scotland, reports are found of scrapie in the Border Leicester, Blue-Faced Leicester, Cheviot, Scottish Blackface and Oxford Down breeds. Between 1920 and 1950, scrapie became a major problem in the English Suffolk breed, causing considerable financial loss in some flocks. Concern about the disease in the 1930s led to development of research at the Moredun Institute in Edinburgh (Parry, 1983). Since 1950, numerous field outbreaks have been reported. In the U.K., it is believed that the disease has affected most breeds. Anecdotal evidence suggests that the occurrence of scrapie in different breeds is a result of increased sheep movements, particularly in the post-World War II era.

Importation of sheep from countries where the disease was endemic has led to the occurrence of scrapie in many countries, as shown in Table 1.

Due to the nature of the disease it is difficult to develop all-inclusive guidelines which would establish scrapie-free status for a country. Currently, the Office of International Epizooties (OIE) is establishing criteria to use for this purpose.

The lack of a preclinical screening test which definitively detects all scrapie infection adds to the complexity of ascertaining freedom from the disease. For the same reason, it is virtually impossible to obtain a true picture of disease prevalence in a country where scrapie is endemic. Since many outside factors influence reporting, actual prevalence continues to remain obscure in most countries. It is rarely possible to justify freedom from scrapie on the basis of passive surveillance alone.

Although there are currently no definitive tests for the live animal infected with scrapie, recent developments with postmortem diagnostic techniques such as immunohistochemistry, western blot and a possible cerebrospinal fluid (CSF) test may allow countries to have an enhanced surveillance and trace-back program by testing mature sheep sold for slaughter.

### *United States*

Scrapie was first described in the U.S. in 1947 in animals imported from Canada which originated in the U.K. Scrapie subsequently became a nationally-reportable disease in 1952 with the development of the Scrapie Eradication Program. As part of the eradication program, records were kept on each positive animal; it is through these records that much of what we know about the epidemiology of natural scrapie has been ascertained.

Between 1947 and 1992, 1,117 cases of natural sheep scrapie were found in 657 flocks. Of these cases, 949 were ewes and 168 were rams. The breed distribution was as follows: 972 (87%) Suffolk, 68 (6%) Hampshire, 35 (3%) white-faced breeds (Cheviot, North Country Cheviot, Corriedale, Cotswold, Dorset, Finn, Merino, Montadale, Rambouillet, Southdown) and 42 (4 %) other breeds (Shropshire, mixed breed, unknown). The average age at death or destruction for diagnostic purposes was 43.9 months. The average within-flock mortality rate was 5.7% (Wineland et al., to be submitted for publication).

Between 1947 and July 31, 1996, 850 flocks were found to be infected in the U.S. A map showing a breakdown of infected flocks by state is included (see Figure 2).

The geographic distribution of positive flocks shows heavier concentrations in certain states; much of this is

**Table 1. Occurrence of scrapie following importation of infected sheep.[a]**

| Country | Date | Reference |
|---|---|---|
| Iceland | 1878 | Sigurdarson, 1991 |
| Canada | 1938 | Schofield, 1938 |
| United States | 1947 | Thorp et al., 1952 |
| New Zealand | 1952 | Brash, 1952 |
| Australia | 1952 | Bull and Murnane, 1958 |
| Norway | 1958 | Parry, 1983 |
| India | 1961 | Zlotnik and Katiyar, 1961 |
| Hungary | 1964 | Aldasy and Suveges, 1964 |
| South Africa | 1966 | Van der Merwe, 1966 |
| Kenya | 1970 | Cooper, 1973 |
| Germany | 1973 | Heipe and Jungman, 1973 |
| Italy | 1976 | Cravero et al., 1977 |
| Brazil | 1978 | OIE, 1985 |
| Yemen | 1979 | Hourrigan et al., 1979 |
| Sweden | 1986 | Elvander et al., 1988 |
| Cyprus | 1989 | Toumazos, 1988; Toumazos and Alley, 1989 |
| Japan | 1990 | Onodera et al., 1990a,b |

[a] Scrapie has also been reported in Austria, Belarus, Belgium, Colombia, Czechoslovakia, France, Ghana, Ireland, the Isle of Man, Israel, Lebanon, the Netherlands, Northern Ireland, Somalia, Switzerland and United Arab Emirates (OIE, 1995).

attributed to the level of tracing activity and education conducted within a particular state. Distribution of positive flocks varied over time but exhibited no seasonality in occurrence either at the flock level or the animal level.

Five cases of natural scrapie have been diagnosed in goats in the U.S. All of the cases were sheep-associated; none occured in herds containing only goats (USDA/APHIS/VS records).

## Agent/Host Relationship

Theories on the cause of scrapie have been debated for many years and the debates continue today. Initially, arguments over cause centered around a genetic versus infectious origin.

Parry (1964) felt that scrapie was an autosomal recessive genetic disease which was not naturally infectious. He did concede that affected animals harbored a transmissible agent which was infectious by artificial routes. Data accumulated from 1,400 cases appeared to support his theory.

Evidence of transmissibility went on record when Cuille and Chelle (1936) were successful in transmitting the disease from affected sheep to healthy sheep via intraocular injection. Chandler (1961, 1962, 1963) added to this discovery by transmitting scrapie to mice. Later information suggested that scrapie was a naturally-occurring contagious disease caused by an infectious agent (Brotherson et al., 1968; Dickinson et al., 1974; Hourrigan et al., 1979). However, the precise mechanism of natural transmission is still not well understood.

Current information indicates that both a host genotype and an agent play a role in the occurrence and transmissibility of scrapie.

### *Nature of the Agent*

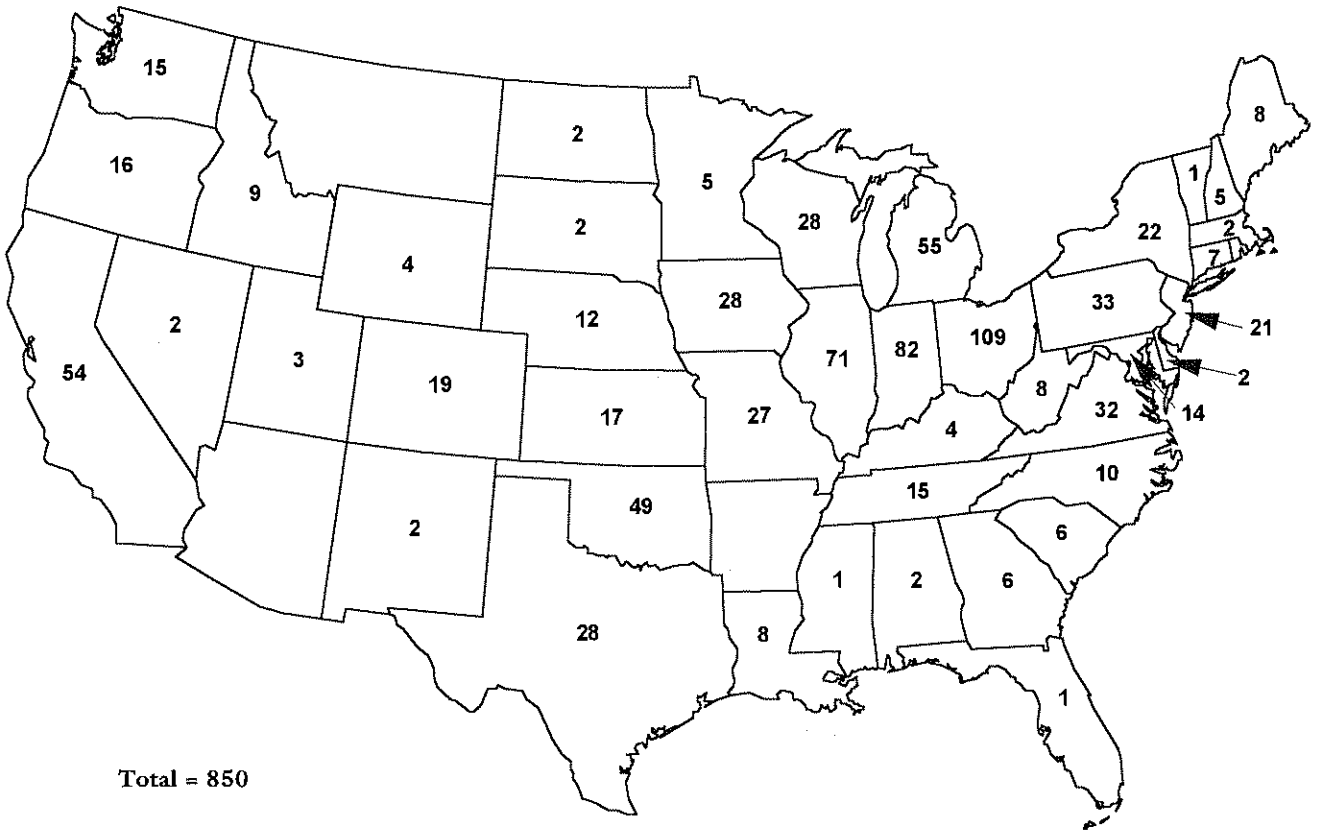
The variety of clinical, pathological and molecular genetic features of scrapie, as well as other transmissible spongiform encephalopathies, has led to speculation on the nature of the etiologic agent and the pathogenetic mechanisms of the disease. Although the cause of these biological differences among scrapie strains has not been resolved, several explanations have been suggested based upon theories related to the nature of the agent.

The main theories are as follows:

**The Virus Theory** – the virus would have to have unusual biochemical and biophysical characteristics in order to help explain the remarkable physicochemical properties (Rohwer, 1984; Czub et al., 1988; Manuelidis et al., 1988).

**The Prion Theory** – the agent is composed exclusively of the host-

**Figure 2. A breakdown by state of confirmed scrapie-infected flocks in the continental United States (1947 through July 31, 1996).**



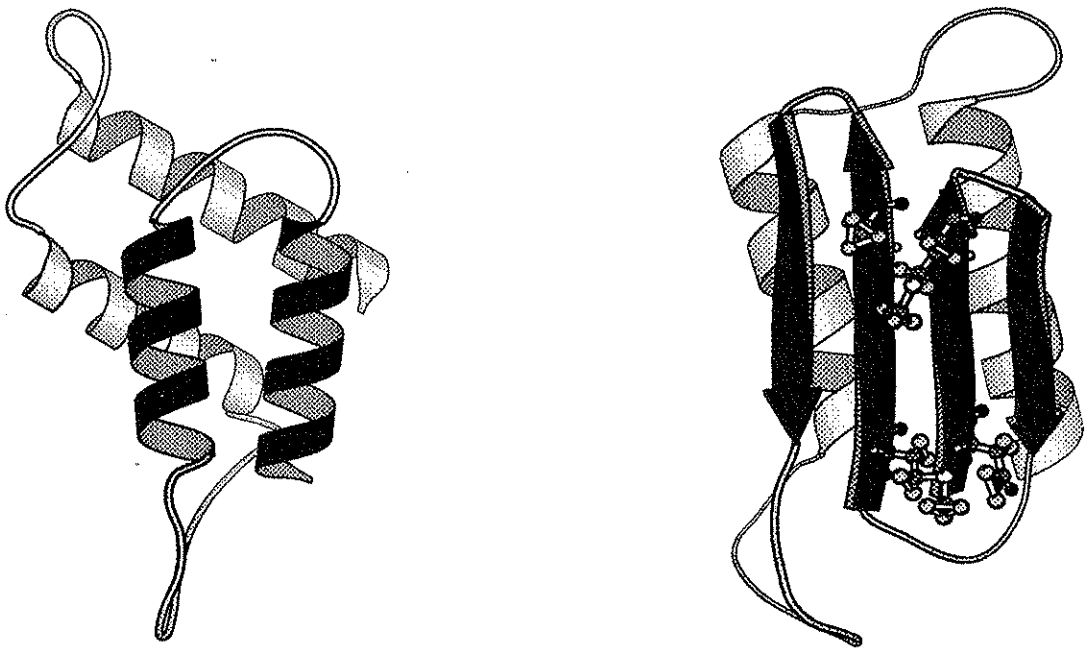
coded protein ($PrP^c$) that becomes partially protease-resistant ($PrP^{Sc}$), most likely through a post-translational conformation change after scrapie infection. In this theory there are no non-host components of the agent. That is, a scrapie-specific informational molecule (nucleic acid; i.e., RNA or DNA) is not present (Prusiner, 1982; Bolton and Bendheim, 1988).

**The Virino Theory** – the agent consists of a host-derived protein coat, with PrP being one of the candidates for this protective protein, and a small noncoding regulatory nucleic acid (Dickinson and Outram, 1979; Kimberlin, 1982).

All of the proposed theories have some degree of validity. Proponents of the virus and virino theories conclude that the existence of different scrapie strains unequivocally proves the existence of a nucleic acid component of the infectious agent which, as in conventional viruses, may undergo mutations responsible for phenotypic variations. The problem with these theories is that no agent-specific nucleic acid has been convincingly identified to copurify with infectivity (Manuelidis and Manuelidis, 1981; Duguid et al., 1988; Oesch et al., 1988; Meyer et al., 1991; Sklaviadis et al., 1993). Moreover, chemical, enzymatic or physical treatments which usually inactivate or degrade nucleic acids have no effect on the transmissible properties of the infectious agent (McKinley et al., 1983; Bellinger-Kawahara et al., 1987a,b; Neary et al., 1991). Possible reasons for this are that the amount of nucleic acid of the putative agent is too small to be detected with available techniques and that its tight bond to the protein protects it from chemical or physical inactivation. Weakening the validity of the virus and virino theories is also the inability to identify any virus particles under the electron microscope (Bots et al., 1971; Cho and Greig, 1975) and the failure of an infected host to generate an immune response. However, small particles resembling virus structures have been observed recently by electron microscopy (Ozel and Diringer, 1994).

The prion model involves propagation of a protein-only agent ($PrP^{Sc}$) whereby PrP can assume various tertiary structures caused by a combination of host genetics and the introduction of altered (infectious) PrP. Hence the structure of the infecting $PrP^{Sc}$ imprints upon the normal cellular precursor ($PrP^c$) resulting in a change of shape from an α-helix to a β-pleated conformation (Figure 3). This conformational change is presumably responsible for the protease resistance of $PrP^{Sc}$. It is suspected that mutations in the PrP gene may render resulting proteins

**Figure 3. Different forms of prion protein.**[a]



**$PrP^c$**

**The normal protein consists primarily of α-helices, regions in which the protein backbone twists into a specific kind of spiral.**

**$PrP^{Sc}$**

**The scrapie form contains β-strands, regions in which the protein backbone is fully extended.**

[a] Diagrams reproduced with the kind permission of Dr. S. Prusiner.

susceptible to "flipping," and the shape changes account for what is commonly referred to as "strain" differences. Several explanations for scrapie strain genetics in the context of the prion theory have been suggested but none has been proven (Prusiner, 1991; Weissman, 1991).

It should be pointed out that the prion theory fails to explain: 1) how the PrP of the infecting agent originally assumed the aberrant structure associated with infectivity; and 2) how the different structures originated as a function of the different strains. Although numerous scrapie strains can be differentiated in a single host (i.e., sheep), the PrP associated with these strains have not shown any biochemical and molecular differences.

Regardless of whether the prion ($PrP^{Sc}$) is or is not the agent, the partially protease resistant form is a marker of infection. There are currently a number of tests which may be used to detect the presence of the $PrP^{Sc}$.

*Host Genetics*

Wide variation may exist in the clinical manifestations as well as the pattern and intensity of histopathological lesions associated with scrapie and related transmissible spongiform encephalopathies. It is now well established that the phenotypic expression of disease is a direct result of host-agent interaction. Some aspects of pathogenesis can differ, depending upon the interaction of agent strain, host genotype, route of injection and dose of agent. If any one of these parameters is altered, so are some of the phenotypic appearances of disease. These distinct phenotypes must result from an interaction at the molecular level between host and scrapie strain.

Scrapie strains can be distinguished by such biological parameters as incubation period between infection and clinical appearance of the disease, spongiform changes in the brain (lesion profile) and amyloid plaque production (Dickinson and Meikle, 1971; Bruce and Fraser, 1982; Dickinson and Outram, 1988; Bruce et al., 1991). The strains are differentiated via the previously mentioned parameters as detected in bioassay systems using specifically-bred mice. The vast amount of research to characterize strains has been done using scrapie from British sheep. To date, research has not been done to determine which strain(s) of scrapie is(are) present in the U.S. The various scrapie strains show differences in their thermostability (i.e., resistance to heat) and their susceptibility to chemical treatments (Kimberlin et al., 1983).

Characteristic of these diseases is control of the incubation period through host gene loci such as Sip (scrapie incubation period) in sheep and Sinc (scrapie incubation) in mice. It is likely that the PrP gene and the genes controlling scrapie incubation periods (Sip and Sinc) are the same (Carlson et al., 1986; Hunter et al., 1987; Hunter et al., 1989; Westaway et al., 1987).

The Sinc gene has two alleles, designated s7 and p7, which correspond to two amino acid differences at codon 108 (Leucine → Phenylalanine) and codon 189 (Threonine → Valine) in the PrP sequence (Westaway et al., 1987). Experimental infection of mice with the ME7 strain of scrapie produces a short incubation period in s7 homozygous mice, a prolonged incubation period in p7 homozygous mice and an intermediate one in heterozygous mice, (s7p7). Furthermore, each of the strains of murine scrapie has a characteristic and reproducible incubation period in the three Sinc genotypes of mice supporting the view that this time period is under the control of both the host and the agent.

In sheep, two phenotypes of the Sip gene corresponding to the PrP gene, were identified in an experimental flock of Cheviot sheep. Phenotypes sA (short incubation allele) and pA (prolonged incubation allele) are associated with amino acid changes at codon 136 (Hunter et al., 1989) Sheep carrying either the 136 Valine/Valine (sA/sA) or 136 Valine/Alanine (sA/pA) genotypes develop clinical disease with strain A group scrapie isolate. Amino acid changes at codons 154 and 171 modulate the incubation time in the susceptible sheep. Cheviot sheep with the genotype 136 Alanine/Alanine (pA/pA) do not exhibit evidence of clinical disease after exposure to strain A scrapie (Hunter et al., 1996, Maciulus et al., 1992, Goldmann et al., 1991, Goldmann et al., 1990). However, Cheviot sheep with 136 Alanine/Alanine genotype develop clinical scrapie after exposure to strain C group scrapie if they are homozygous for the amino acid glutamine (QQ171) at codon 171 (Foster and Dickinson, 1988; Goldmann et al., 1994a,b).

Suffolk sheep rarely carry the 136 Valine allele. In this breed, natural and experimental scrapie is associated with 171 Glutamine/Glutamine (Westaway et al., 1994, O'Rourke et al., 1996). With very few exceptions, naturally-infected sheep of a number of breeds in the U.S., U.K., Europe and Japan carry either 136 Valine (136 Valine/Valine or 136 Valine/Alanine) or 171 Glutamine/Glutamine (QQ; Belt et al., 1995; Clouscard et al., 1995; Hunter et al., 1993; Hunter et al., 1994; Hunter et al., 1997; Ikeda et al., 1995; Laplanche et al., 1993a,b; Westaway et al., 1994; O'Rourke et al., 1996). There has been only one report of a scrapie-affected Suffolk carrying 171 Arginine/Arginine (RR; Ikeda et al., 1995) and three reports of scrapie-affected Suffolks with 171 Glutamine/Arginine (QR; Hunter et al., 1997; Ikeda et al., 1995). In other PrP gene polymorphisms have been identified in sheep; however, it appears that the ones identified at codons 136, 154 and 171 play the largest role in scrapie (Hunter et al., 1996). The clinical and pathological heterogeneity observed following infection appears to be controlled by both the particular scrapie strain and the host PrP genotype.

Many questions must be answered before the role of genetics in relationship to scrapie susceptibility is fully understood. Some of these are:

1. Do certain genotypes fully prevent scrapie infection or merely protect against the clinical manifestation of the disease?

2. Is there a carrier state wherein infected but clinically normal animals are shedding the agent and are a risk to other susceptible sheep?
3. If a flock was bred to be "resistant" to a certain strain of scrapie and another strain was introduced, would a vast majority of the animals succumb to the disease?

The PrP may be responsible for directing the infectious agent to specific target sites both within and outside of the central nervous system (Bruce et al., 1991; Scott et al., 1992).

# Transmission

Although it has been generally accepted that scrapie is an infectious, contagious disease, the means of natural transmission are not well understood. To avoid semantic confusion with terminology the following will be used as defined below:

**Lateral Transmission** – the spread of infection from one animal to another via direct and/or indirect contact.

**Vertical Transmission** – the spread of infection from parent to offspring from germplasm at the time of fertilization through embryonic and fetal development in utero.

**Maternal Transmission** – the spread of infection from a dam to its offspring either vertically or laterally by close post-parturient association.

### *Lateral Transmission*

It has been well established that scrapie can be transmitted laterally between unrelated sheep (Brotherson et al., 1968; Dickinson et al., 1974; Hourrigan et al., 1979). Hourrigan and associates (1979) exposed 140 sheep and goats to natural scrapie. The unexposed animals were introduced to the affected flock at three to nine months of age. Scrapie occurred in five of the 140 sheep. These were at 64, 80, 82, 85 and 93 months following initial exposure. Scrapie occurred in 27% of the progeny of these previously unexposed 140 animals. The average age for development of scrapie in the progeny was 41 months.

Evidence of lateral transmission is also displayed by goats contracting the disease after being reared with scrapie-infected sheep flocks (Hourrigan et al., 1979). Five goats have been diagnosed with natural scrapie in the U.S. All have been associated with sheep. In order for the disease to be considered infectious and contagious the agent must be able to enter the host and in turn be shed from the host to infect others. Work done by Hadlow et al. (1982) indicates that the alimentary tract is a likely portal of entry in natural scrapie. This study showed the agent was first detected in lymphoreticular tissue along the alimentary tract. This is substantiated by experimental transmission of scrapie to sheep and goats by the oral route (Pattison and Millson, 1961; Pattison et al., 1972, 1974). Other potential routes of natural infection which have been shown to be effective experimentally are scarification (Stamp et al., 1959) and via the conjunctiva (Haralambiev et al., 1973). A recent paper by Taylor and associates showed skin scarification to be as efficient and effective a route of scrapie infectivity in immunocompetent mice as intraperitoneal, intravenous or perivenous inoculation (Taylor et al., 1996).

Detection of the agent in the placenta (Pattison et al., 1972, 1974; Hourrigan, 1990) in combination with a failure to detect agent in feces, saliva, urine, colostrum or milk (Pattison and Millson, 1961; Hourrigan et al., 1979; Hadlow et al., 1980, 1982) has led to a fairly wide acceptance that the placenta and fetal fluids play a significant role in the spread of scrapie. Hence transmission would most likely occur from an infected mother to her progeny and other lambs who are in close association around the time of parturition. Whether this spread would be from direct contact with the infected tissues/fluids, from a contaminated environment or possibly from both is unknown. Additional evidence supports this theory of transmission. Race and associates (personal communication) have detected the partially protease-resistant form of the prion protein ($PrP^{Sc}$) in placenta.

One must be cautious on two points when expounding the above stated material as doctrine. First, shedding of the agent by means of the placenta may not be a constant occurrence. Hadlow et al. (1982) were unable to detect the agent in the placenta of two Suffolk ewes affected with scrapie. Second, both Pattison and Hadlow point out that not detecting agent in the feces or other excretions or secretions may not necessarily indicate their absence – it may just suggest inadequate examination (Pattison and Millson, 1961; Hadlow et al., 1982, 1991).

Certain data have shown that the longer offspring have contact with their infected dams postnatally the more likely they are to develop scrapie (Dickinson et al., 1966, 1974; Hourrigan et al., 1979). This would be indicative of lateral transmission. Hourrigan et al. (1979) reported that the incidence of scrapie in lambs from infected dams removed at birth was 10% compared to 16% for those removed at four months, 29% when removed at nine months and 41% when removed at 20 months. This also held true for goats. None of 10 goats removed at birth to an isolated environment developed scrapie although counterparts removed at six months had an incidence of 57% and all seven (100%) of those removed at eight to 10 months contracted scrapie (Hourrigan et al., 1979). Age of the animal when exposed to the agent may also be significant in development of clinical scrapie. Work at Mission, TX, revealed that sheep exposed to scrapie after nine months of age developed scrapie at a much lower rate than those exposed before nine months of age (Hourrigan et al., 1979).

The ram is thought to play a less significant role in the spread of scrapie than the ewe. With the exception of breeding season, most flock management practices do not allow the ram to have continuous contact with the ewes and their lambs. If scrapie is spread by feces or nasal discharge this minimal contact would explain a lower risk from the ram. Even if the ram proved not to be a source of infection, one would still have to

consider the function of genetics in incubation time and possibly resistance/susceptibility.

The extent to which scrapie is transmitted by a contaminated environment, including pens, barns, feed, water, bedding and other fomites (i.e., inanimate objects), is unknown. The remarkable resistance of the agent to inactivation would lead one to believe it may survive for a number of years. Results of an experiment by Brown and Gajdusek (1991) provide some justification for this theory. Scrapie-infected hamster brain was buried in soil. After three years the soil in which it was buried still contained infectivity. In a real-life situation the agent is probably dispersed throughout a premise. Hence, infectivity could depend on the amount of contamination required to provide a sufficient dose.

In Iceland, pastures were left vacant for several years before being restocked with sheep from flocks thought to be scrapie-free. Some of these new sheep developed scrapie (Palsson and Sigurdsson, 1958). Because this was not a controlled research situation, it is difficult to draw firm conclusions about it.

Other sources of infection have been explored to explain the reinfection of sheep in Iceland. These possible sources include transmission by vectors or fomites. Preliminary findings from Iceland and the Institute of Basic Research at Staten Island, NY, suggest that hay mites play a role in spread of scrapie (Wisniewski et al., 1996).

***Vertical Transmission***

Three research projects to study the possibility of scrapie transmission in sheep by embryo transfer have had conflicting results. Two studies in Scotland (Foster et al., 1992, 1996) showed that offspring derived from both washed and unwashed embryos developed scrapie. In the earlier study, six of 26 lambs were diagnosed with scrapie. These lambs were derived from unwashed embryos. The study completed in 1996 suggests that there is no obvious difference between the incidence of scrapie in groups of lambs from washed embryos (five of seven) and unwashed embryos (five of six). The results of the 1996 study are difficult to interpret as offspring from uninoculated ewes also developed scrapie. This research project was conducted in such a manner as to take great precautions to prevent external contamination, yet by the authors' own admission it remains a possibility. Other possibilities for transmission in this study are: 1) a carrier state in which the ewe does not exhibit signs of scrapie but is still capable of spreading the agent; or 2) scrapie was transmitted via the seminal fluids or the spermatozoa. Both rams used for the 1996 research work developed scrapie eight months after collection.

Another study involving embryo transfer was done in the U.S. by Foote et al. (1993). This study, which involved only washed embryos, did not result in the transmission of scrapie to progeny via the embryo or uterus. Due to the protocol followed in this study it was not possible to determine the dams of the resulting embryo transfer progeny. Since only 30% to 61% of the inoculated donors developed scrapie, it raises questions about actual exposure to the agent. In addition, there was a question about whether or not the length of time between inoculation and collection was adequate to allow exposure to the agent. Based on the conflicting results of current research, embryo transfer should not be considered a completely safe method of preventing the transmission of scrapie.

As stated previously, the ram is thought to play little if any role in the actual transmission of scrapie. Failure to detect the agent in semen, testes and seminal vesicles appears to indicate a lack of infectivity in the semen (Hadlow et al., 1982; Hourrigan, 1990; Palmer, 1959). Unpublished work by Foote and colleagues (Foote, personal communication) supports the position that rams do not spread scrapie through semen. However, this work involved experimental scrapie and a very small number of progeny. Anecdotal evidence also supports lack of lateral transmission from a ram (Sutton, personal communication). The primary role of the ram in scrapie transmission may be in determining the PrP/Sip genotype of his offspring but not in actual spread of the agent.

The natural transmission of scrapie is like an unfinished puzzle. We have a number of unconnected pieces, but no full picture in sight. In addition to the questions posed above, other unknowns regarding transmission include:

- What is the infective dose for sheep and goats?
- At what point in the incubation period does the host shed the agent and by what route(s)?
- Is shedding continuous or intermittent?
- Is there a carrier state?

Without a better understanding of natural transmission it will be very difficult to eradicate scrapie.

Scrapie was first shown to be experimentally transmissible from sheep to sheep in 1936. In 1961, Chandler was successful in transmitting scrapie to laboratory mice (Chandler, 1961). The utilization of mice as a disease model has been extremely useful in providing information on pathogenesis and genetic influences as well as serving as an alternative means of diagnosis.

Scrapie has also been experimentally transmitted to hamsters, rats, voles, gerbils, mink, monkeys and cattle (Cutlip et al., 1994).

# Pathogenesis

Significant study has been done on the pathogenesis of scrapie, but most of these projects have used the mouse as a model. Limited research has been done using sheep and goats, the natural hosts. An even smaller amount of information is available on the pathogenesis of the natural disease in breeds other than the Suffolk. These studies are time-consuming and expensive. Since cell culture has not been an effective method to assay the scrapie agent, mouse or other animal inoculation studies are the only alternative. Also, no serologic test is available to identify which animals are infected with the natural disease until they show clinical signs. Hence one or

more subjects for bioassay may not even be infected (Hadlow, 1991).

Hadlow et al. examined the first appearance and temporal distribution of the scrapie agent in clinically normal Suffolks of various ages, clinically affected adult Suffolks, a few clinically affected sheep of other breeds and clinically normal sheep over 54 months of age (Hadlow et al., 1979, 1982). In the natural disease in Suffolk sheep, presence of the scrapie agent was first identified in eight out of 15 preclinical lambs 10 to 14 months of age. Infectivity titers were measured in mice which were inoculated intracerebrally. Infectivity was not detected in lambs younger than 10 months of age in this study (Hadlow et al., 1982).

Scrapie infectivity was consistently detected in lymphoreticular and central nervous system tissue. Table 2 lists the tissues and relative amounts of infectivity as identified in clinically ill Suffolk sheep infected with natural scrapie. It is important to note that the above levels of infectivity reflect titers at the clinical stage of disease. In the preclinical stage of the disease the titers in the lymphoreticular tissue are actually higher than those in the central nervous system (CNS).

Scrapie infectivity has also been repeatedly found in the salivary glands of mice (Eklund et al., 1967). This prompted the suggestion that saliva may play a role in the lateral transmission of scrapie in mice (Outram, 1976). There has been only one report of agent presence in the salivary gland of experimentally-infected goats (Pattison and Millson, 1962) despite other attempts at isolation (Hadlow, et al., 1980, 1982). Also infectivity has never been found in saliva of sheep and goats (Hourrigan et al., 1979; Hadlow et al., 1980, 1982). Detection of agent presence in the placenta (Pattison et al., 1972, 1974; Hourrigan, 1990) in combination with a failure to detect infectivity in feces, saliva, urine, colostrum or milk (Pattison and Millson, 1961a; Hourrigan et al., 1979; Hadlow et al., 1980, 1982) has led to a fairly wide acceptance that the placenta and fetal fluids may play a significant role in the spread of scrapie.

Infectivity has been detected in low levels in concentrated samples of blood from infected hamsters (Diringer, 1984). Except for the initial few hours after infection, agent presence has not been identified in mouse blood (Eklund et al., 1967; Diringer, 1984). Numerous attempts to identify the agent in whole blood and serum of sheep and goats have also been unsuccessful (Pattison and Millson, 1962; Hadlow et al., 1980, 1982).

In summary, the findings of this study suggest an oral route of infection and early replication/propagation of the agent in intestinal and lymphoreticular tissues which include spleen, retropharyngeal and mesenteric lymph nodes. Over time the agent appears to spread to most lymph nodes and some other nonneural tissues. Replication/propagation continues in the lymphoreticular system (LRS) for a number of months before it can be found in the brain. Research using the severe combined immunodeficiency (SCID) mouse model also appears to indicate that the lymphoreticular system is essential in the manifestation of scrapie infection (O'Rourke et al., 1994; Taylor et al., 1996). A recent publication by Lasmezas et al. suggests that the LRS may trap the scrapie agent, allowing continuous amplification, hence higher exposure to the nervous tissue targets such as visceral autonomic fibers (Lasmezas et al., 1996).

The means by which the agent moves from the LRS to the brain has not been fully established. Blood and nerve fibers have both been suggested. Once the agent enters the CNS it continues to replicate/propagate to significant amounts. In Suffolk sheep and some other breeds, the agent remains in the extraneural tissues throughout the infection (Hadlow et al., 1979, 1982). A pathogenesis study in experimentally-inoculated goats has revealed similar findings (Hadlow et al., 1980).

It is important to note that failure to detect the agent in certain tissues, secretions or excretions of sheep and goats doesn't necessarily indicate its absence. It may exist in such low amounts that current methods of detection are not adequate.

# Epidemiology

Scrapie occurs most frequently in sheep of either sex between two and five years of age (Dickinson, 1976; Sigurdarson, 1991). Cases of the disease before 18 months of age are rare (Dickinson and Stamp, 1969; Sigurdarson, 1991; USDA/APHIS/VS, unpublished statistics), although a few cases of natural scrapie have been reported in sheep as early as 10 to 12 months of age (Zlotnik and Katiyar, 1961; Joubert et al., 1972). One

**Table 2. Relative infectivity tissues references.**

| Relative infectivity | Tissues | Reference |
|---|---|---|
| High levels | Brain, spinal cord | Hadlow et al., 1982 |
| Moderate levels | Lymph nodes (retropharyngeal, mesenteric-portal, prescapular, prefemoral, etc.) spleen, tonsil, ileum, proximal colon | Hadlow et al., 1982 |
| Small levels | Cerebrospinal fluid (CSF), sciatic nerve, pituitary gland, nasal mucosa, adrenal gland, distal colon, pancreas, liver, bone marrow, thymus, supramammary gland | Hadlow et al., 1982 |
| No detectable infectivity | Blood clot, mandibular and parotid salivary glands, thyroid, heart, lung, kidney, skeletal muscle, mammary gland, testis | Hadlow et al., 1982 |

report from Iceland states that scrapie was diagnosed in a seven-month-old animal (Sigurdarson, 1991). Since it is thought that most animals are infected at birth or shortly thereafter, age at onset of clinical signs and incubation period would be roughly the same.

Several observers have noted that once scrapie becomes endemic in a flock, age at death will decrease over time. The initial cases will usually be in four- to five-year-old sheep. Age of occurrence progressively declines to 18 to 24 months of age (Kimberlin, 1979; Foster and Dickinson, 1989; Sigurdarson, 1991; Detwiler, unpublished observations). Foster and Dickinson, (1989) stated that the most plausible reason for this result was an increase in exposure to the agent.

Incidence within a flock is variable. Some flocks may experience a 3% to 5% annual mortality (Sigurdarson, 1991). Reports of 10% to 20% annual losses are not uncommon (Pattison, 1965; Young et al., 1964; Sigurdarson, 1991). One commercial flock in Iceland reported an annual mortality rate of 50% (Sigurdarson, 1991).

With no diagnostic test available for live preclinical sheep, we must rely on the owner's ability to recognize the disease and his/her willingness to have it diagnosed. It can be difficult to obtain the true incidence within a flock, especially when there are outside economic factors which influence reporting. Many times it is higher than the limited available data indicate (Dickinson, 1976; Detwiler, unpublished observations).

Most of the cases of natural scrapie in goats have involved close association with scrapie-infected sheep. Many of the affected goats have been reared with the sheep (Chelle, 1942; Brotherson et al., 1968; Stemshorn, 1975; Hourrigan et al., 1979). Hourrigan et al. (1979) also showed that scrapie could be spread from goat to goat with no sheep contact. All five cases of natural scrapie in goats in the U.S. have been sheep-associated cases (USDA/APHIS/VS, unpublished statistics).

**Figure 4. Seven-year-old Suffolk ewe showing weight loss, pruritus and incoordination.**

## Clinical Signs

Scrapie is a nonfebrile, insidious disease in sheep and goats. Due to the damage to nerve cells, affected animals will usually show behavioral changes, tremor (especially of the head and neck), pruritus and locomotor incoordination which progresses to recumbency and death (see Figure 4). The clinical course of scrapie is usually of significant duration (one to six months). The onset of clinical signs often occurs with a slight change in behavior, wherein the animal becomes more nervous or aggressive and may separate itself from the rest of the flock. In many instances this goes unnoticed. Some sheep appear to be demented and have been observed head pressing or "star gazing."

Hypersensitivity is another characteristic sign of scrapie. An affected animal may appear normal if left undisturbed at rest, but when stimulated by a sudden noise, excessive movement or the stress of handling, tremors may become excessive or the animal may even fall down in a convulsive-like state. Scrapie-affected sheep (but not goats) may also have a tendency to lose much weight, despite retaining a normal appetite.

Scrapie acquired its name from the feature of sheep rubbing themselves against fixed objects. Pruritus may be so subtle as to go undetected or so dramatic that an animal will rub off most of its wool. The areas of wool loss may sometimes be rubbed raw. Some sheep will pull wool from their sides or bite at their legs. Affected goats are less likely to rub against fixed objects, but scratch vigorously with hind feet and horns (Hadlow, personal communication). Some sheep may exhibit a "nibble reflex" when rubbing themselves or when scratched by hand over the lumbar area.

Motor abnormalities often include a high-stepping (trotting) gait of the forelimbs and a "bunny hop" movement of the back legs. This gait is especially exaggerated when the animal is forced to run. As the disease progresses, there can be severe ataxia of the hind limbs causing the animal to sway. An affected animal will

support its hindquarters against a fence when standing and has difficulty rising.

Not all affected animals exhibit all signs of the disease. Extreme variations can exist in the clinical signs of individual animals. One showing severe pruritus may show little if any incoordination and vice versa. There also may be differences among breeds.

The clinical signs in most cases of scrapie are quite distinct and can be easily recognized upon observation. However, several other conditions should be considered as differentials, especially in the early stages of the disease. These include:

1. **Ectoparasites** (lice and mites) – can be eliminated by insecticide treatment.
2. **Pseudorabies** – ruled out by an extremely short clinical course in ruminants (36 to 48 hours), finding of a high fever and exposure to swine.
3. **Rabies** – not a problem in rabies-free countries; can be lower on list in rabies-endemic areas or by clinical course of greater than 10 days; due to the human health risk, should be eliminated only on postmortem examination and testing in endemic areas.
4. **Listeriosis** – febrile condition and usual short clinical course in sheep and goats.
5. **Ovine progressive pneumonia** (OPP; maedi-visna) – can be ruled out with a serologic test. However, a sheep may be infected with both scrapie and OPP.
6. **Pregnancy toxemia** (ovine ketosis) – if the shepherd misses all early signs it may be difficult to totally eliminate except by postmortem examination and by detection of ketones in the urine.
7. **Chemical and plant toxins** – also may be difficult to eliminate on antemortem exam if no source of toxin has been positively identified and no history of scrapie exposure exists.

# Diagnosis

Diagnosis of scrapie is based on occurrence of clinical signs of the disease and must be confirmed by laboratory testing. Histopathological examination of brain tissue collected after the animal dies or is euthanized is the initial step in the diagnostic process. Several areas of the brain are examined under a microscope to see if changes associated with scrapie are present. Histopathological examination may be done at a state diagnostic laboratory or the samples may be sent directly to the USDA National Veterinary Services Laboratories (NVSL) in Ames, IA. Due to the subtle nature of the lesions in some animals, it may not be possible to confirm the diagnosis by microscopic examination alone. In the past, mouse inoculation had been used to test some cases, but this has been discontinued due to duration (up to two years) and cost.

Research has shown that a partially protease-resistant form of a host coded glycoprotein, called prion protein ($PrP^{Sc}$), is a marker of subacute spongiform encephalopathies. $PrP^{Sc}$ is found in the central nervous system and lymphoreticular tissue of scrapie-infected animals, including sheep and goats. There are two tests which may currently be used to detect the $PrP^{Sc}$. The one which is being used routinely at NVSL is the immunohistochemistry test (Figure 5). Western-blotting is used only in very specific circumstances and is also performed at the NVSL. These techniques have expanded the diagnostic capability for scrapie. In the past, if the brain tissue was not harvested shortly after the animal's death autolysis might make it very difficult to confirm a diagnosis. The tests now allow for the possibility of confirming a diagnosis of scrapie even if the brain has been frozen or autolyzed.

One of the goals of scrapie research has been to develop a test that can be used to detect the presence of the scrapie agent or a marker of infection in the living animal. The scrapie agent does not induce a detectable antibody response, which is usually seen with infectious agents, hence a simple serum test is not available.

Studies have shown that the scrapie agent can be detected in tissues by mouse inoculation before an infected lamb is a year of age. Other work has shown that the $PrP^{Sc}$ can be found in extraneural tissues of clinically and preclinically scrapie-infected sheep (Ikegami et al., 1991; Muramatsu et al., 1993; Rubenstein et al., 1987). A newly-published study conducted in the Netherlands indicates that immunohistochemistry may be useful in detecting scrapie in the preclinical sheep. This analysis revealed the presence of $PrP^{Sc}$ in the tonsils of preclinical sheep (Schreuder et al., 1996). The USDA Animal and Plant Health Inspection Service is conducting a pilot study in 1996 and 1997. The purpose of the study is to harvest various tissues from mature sheep at slaughter and then test them using immunohistochemistry to ascertain if $PrP^{Sc}$ may be routinely detected in the preclinical animal.

The National Institutes of Health, in conjunction with the California Institute of Technology, has developed a test to detect a protein (other than $PrP^{Sc}$) in the cerebrospinal fluid of human patients exhibiting signs of CJD. At present, work has not been completed to evaluate the use of the test preclinically or to ascertain the extent of its use in animals (Hsich et al., 1996).

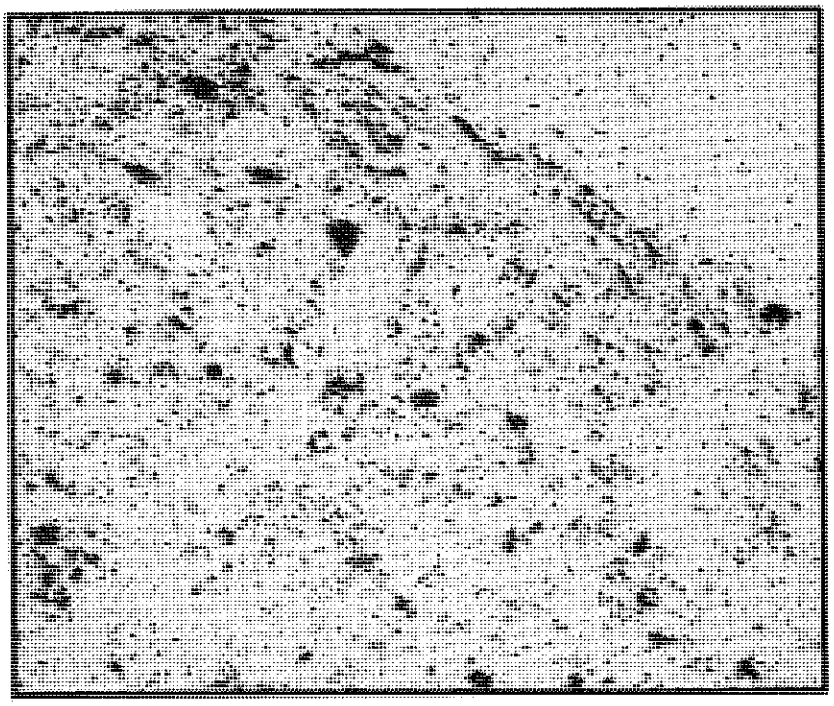
# Treatment

There is no known treatment for scrapie.

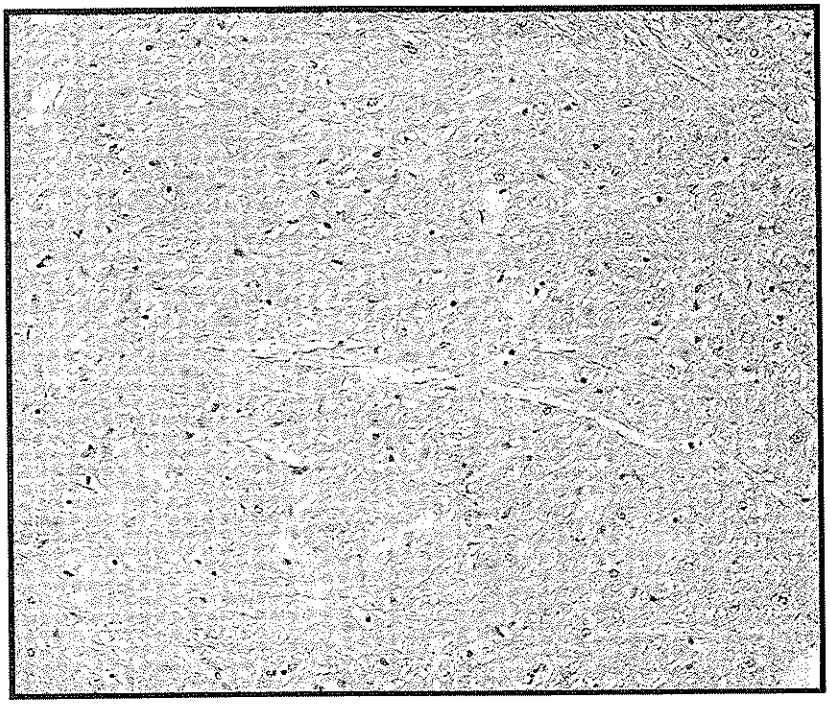
# Prevention

Routine methods of preventing a disease that is laterally transmitted are vaccination, quarantine, test and removal and/or prohibition of animal and animal product movements. Since the scrapie agent elicits no detectable immune response in the host, vaccines and serological tests are not possible at present. Current diagnostic tests for sheep and goats are not yet known to be effective or practical for the preclinical live animal. This prohibits one from ascertaining which animals are incubating the disease and may potentially be shedding the agent. Presently it is not possible to identify apparently normal sheep that may be

**Figure 5. Brain tissue sections from a scrapie-infected and a normal sheep. Both have been tested with the immunohistochemistry technique to reveal prion protein (PrP).[a]**



**Brain tissue from a sheep infected with scrapie. The abnormal PrP appears as large dark accumulations distributed randomly throughout the tissue.**



**Brain tissue from a normal sheep. Note the absence of prion protein; the small dark spots seen in this section are nuclei of normal brain cells.**

[a] Reproduced with the kind permission of Dr. J. Miller et al. (1994).

shedding the agent; therefore, the only absolute way to prevent an introduction of scrapie is to prohibit all movements of sheep and goats into an area.

Hence, the ideal means for preventing the introduction of scrapie is to maintain a closed flock. Any replacement ewes or breeding rams should originate from flocks known not to be affected and which have management practices precluding the introduction of scrapie. In reality, this is difficult to do since there is no definitive prepurchase test to assure freedom from the disease. A buyer must rely on the knowledge, integrity and honesty of the seller.

Despite the lack of a definitive live animal diagnostic test, there are some preventive steps a potential purchaser or new owner of purchased animals may take. These include:

1. Knowing the health status of the flocks in which an animal has been reared. USDA/APHIS/VS maintains a list of flocks enrolled in the voluntary scrapie flock certification program as well as a list of scrapie-infected and source flocks. Animals bought from flocks in Class B, Class A and Certified Class are likely to have a much lower risk of developing scrapie since these flocks are animals from their same level or higher and are monitored for the presence of scrapie by the owner and a veterinarian on a regular basis.
2. Testing for scrapie susceptibility. If research eventually proves that there is definitive evidence to show certain genotypes are resistant to scrapie infection, genetic testing would prove very useful to a flock owner.
3. If a ewe of unknown or questionable disease status is present in the flock, spread to other animals can be minimized by keeping her separate from the rest of the flock at lambing time and for a period of three months following lambing. Her offspring should also be segregated from the other lambs. If these animals show no abnormalities by the time they are four-and-one-half years old, they can safely

be included with the rest of the flock at lambing time provided that their opportunity for exposure occurred within the first six months of life. Ideally, all offspring of these animals of questionable disease status should be kept separate at lambing time until such time as the dam is believed to be very low risk (i.e., has attained four-and-one-half years of age and remains clinically normal). The role of sires in spreading scrapie is not sufficiently understood to develop recommendations for minimizing risks to the rest of the flock.

4. If the flock develops scrapie, the risk of further spread and/or reintroduction of the disease can be minimized through removal of high-risk animals, careful cleaning and disinfection of facilities and improved management of animals at lambing time, paying particular attention to segregating animals into small groups and keeping the risk classification of animals in each group at the same level.

# Public Health Concerns

Scrapie has been known to exist for over 250 years and there is yet to be any evidence that it is a human health risk, although there has been much speculation. Concern has prompted numerous intensive studies of the relationship between scrapie and the human spongiform encephalopathies and their transmission. There is no epidemiological evidence that scrapie of sheep and goats is transmitted to humans (Kondo and Kuroiiwa, 1982; Harries Jones et al., 1988). Furthermore, there is no epidemiological evidence indicating any preferential association of affected humans with farm animals, slaughterhouses or butchershops (Brown et al., 1987).

# Regulatory Review

***History in the United States***

**1947.** The first case of scrapie was diagnosed in a Michigan flock: The sheep were of British origin imported from Canada over a period of years.

**1952.** Scrapie was diagnosed in a California flock: Insistence from the United States Animal Health Association (USAHA) prompted the United States Secretary of Agriculture to declare a state of emergency to handle the disease. The eradication program included laboratory confirmation, quarantine and depopulation of infected flocks as well as tracing and slaughter of exposed animals sold from infected flocks. The federal indemnity paid at this time was 50% of the difference between the appraised value of the animal and salvage, but not to exceed $25 per head for grade animals and $75 for purebreds.

**1953.** The Act of 1884 was amended to include scrapie, and the emergency order was rescinded.

**1954.** Title 9 Code of Federal Regulations Part 54 was promulgated: These regulations covered "Animals Destroyed Because of Scrapie."

**1955.** Regulations were amended to include goats.

**1957.** The program was broadened to include source flocks: Source flocks were defined as flocks from which an affected animal was removed within 18 months before showing signs of scrapie. The source flock was also quarantined and depopulated. Exposed animals sold from the source flocks were traced and slaughtered.

**1964.** Scrapie Field Trials began at Mission, TX.

**1965.** The widespread eradication program was modified to allow a provision for bloodline slaughter: In the event the disease was limited to one bloodline, slaughter could be confined to that genetic line. The non-bloodline animals were placed under a two-year quarantine with sale to slaughter only. After the quarantine period, the animals were subject to an 18-month surveillance. In lieu of the bloodline option, the owner could choose to depopulate the entire flock. (Although the bloodline program was in effect for 10 years, the bloodline option was used in only four of some 71 cases.)

**1975.** Bloodline option was eliminated. Exposed animals could no longer be slaughtered for human consumption due to a perceived public health risk.

Federal indemnity was increased to $40 for grades and $90 for purebreds.

**1978.** Federal indemnity was paid in the amount of two-thirds of the appraised value of the animal not to exceed $300. This formula was used for both grades and purebreds.

**1980.** Canada adopts a bloodline program.

**1982.** On recommendations by USAHA and the National Woolgrowers Association, the Cooperative Scrapie Eradication Program was reviewed.

**1983.** The Scrapie Eradication Program as outlined in Veterinary Services Memorandum 557.1 (April 8, 1983) went into effect: The program involved diagnosing infected animals, tracing and euthanizing bloodline animals and maintaining infected and bloodline flocks under surveillance. The program concentrated primarily on elimination of bloodline animals on the maternal side. The rationale for this change was to reduce indemnity payments and preserve valuable bloodlines, supposedly without reducing the effectiveness of the program.

**1987/88.** Scrapie review meetings were held: These reviews involved representatives from industry, researchers, state regulators and USDA/APHIS.

Advance notice was given in the "Federal Register" of proposed rulemaking, soliciting comments on whether to discontinue the Scrapie Eradication Program.

Comments received in response to this rulemaking overwhelmingly asked APHIS not to discontinue efforts to control scrapie: The commentors did request that government officials in cooperation with industry groups devise a new program for control of scrapie.

**1990.** Scrapie Negotiated Rulemaking Committee established. The

following organizations were represented on the rulemaking committee:

- American Association of Small Ruminant Practitioners
- American Farm Bureau
- American Hampshire Association
- American Meat Institute
- American Polypay Association
- American Sheep Industry Association
- American Suffolk Society
- Animal and Plant Health Inspection Service
- Continental Dorset Club
- National Assembly of Chief Livestock Health Officials
- National Renderers Association
- National Suffolk Sheep Association
- United States Animal Health Association

**1991.** The Rulemaking Committee agreed upon a core program for the control of scrapie. This program consists of the following facets:

- A voluntary scrapie flock certification program.
- One time indemnification for infected and source flocks.
- Regulations to establish identification of sheep from scrapie-infected and source flocks moving interstate.

**1992.** Voluntary Scrapie Flock Certification Program was established.

Interstate regulations to identify sheep from scrapie-infected and source flocks were established.

Efforts to eradicate scrapie in the U.S. have been in effect since 1952 when the Secretary of Agriculture declared a state of emergency to deal with the disease. At this time, once the disease was confirmed the flock was quarantined and then depopulated. All exposed sheep sold from the flock were traced and slaughtered. In 1957, the regulations were amended to include locating and the subsequent depopulation of source flocks and those animals sold from source flocks. Modifications of this approach were made throughout the years; however, the main focus remained on total flock depopulation.

With the adoption of the bloodline/surveillance program in 1983, emphasis was shifted away from the total flock depopulation approach. The bloodline surveillance program required that the maternal bloodlines of a scrapie-infected sheep or goat be removed from the flock/herd. The remaining animals were then placed under 42-month surveillance by government veterinarians to observe for further evidence of scrapie. The change was made for a number of reasons:

1. Indemnity funds for total depopulation were costly and adequate funding was not always available.
2. It was felt that the drastic measure of total depopulation inhibited owners from reporting the disease and in actuality there was much more scrapie than was reported.
3. A portion of the research community argued against the significance of lateral transmission and stated that most cases of disease spread could be attributed to maternal transmission.
4. After 31 years of a total depopulation effort, scrapie still existed in the U.S.

A 1985 United States Animal Health Association resolution prompted a review of the bloodline/surveillance program. The review (which included representatives from the USDA/APHIS, the research community, State Animal Health Officials and industry) resulted in the conclusion that the present bloodline/surveillance should be abolished because it was not effective. Lateral transmission within flocks was significant, and scientific knowledge was inadequate to effectively eradicate the disease. The review also concluded that the USDA should redirect its efforts and funding toward education and research.

During the 1980s, the number of newly-reported infected flocks per year increased in the U.S. Numerous people commented that scrapie was running rampant in the U.S. because of the less restrictive bloodline/surveillance program. Since there was no knowledge of prevalence prior to the change, no one can say with certainty that there was indeed a real increase in the incidence of disease. The bloodline/surveillance program changed a number of outside factors. Indemnity increased from a maximum of $90 to $300. If scrapie was diagnosed the producer did not lose the entire genetic base of his flock which may have influenced the willingness to report. During this time education was stressed throughout the industry making producers aware of the disease and knowledgeable of what to report. On the other hand, this may have been a real increase of infected flocks.

In replacing the bloodline/surveillance program, the process of "negotiated rulemaking" was used. Due to the fact that we cannot test for the disease in the asymptomatic animal, regulatory officials rely heavily on the industry's support. Effective scrapie control relies upon the cooperation of all involved.

The negotiated rulemaking process brought together sheep producers, allied industry representatives, state veterinarians, scientific advisors and officials of USDA/APHIS to negotiate the text of a new program. This process was utilized to resolve conflicts between diverse factions and to focus on finding constructive and creative solutions that the industry could support. A committee was established in 1990 and met eight times over nine months to develop the new scrapie control efforts. In January of 1991, the Scrapie Negotiated Rulemaking Committee passed by consensus a core program for scrapie. The program became official in 1992 and is outlined below.

### *Current Federal Scrapie Program*

**Voluntary Scrapie Flock Certification Program (VSFCP).** The intent of the Voluntary Scrapie Flock Certification Program is to monitor flocks over a period of five years or more and to identify flocks that are free of scrapie. Since there is no live-animal test and scrapie has a long incubation period, a flock is considered free of the disease if no sheep have been diagnosed with scrapie and there is no

clinical evidence over an extended period of time (minimum of 5 years).

The program provides participating owners with the opportunity not only to protect their sheep from scrapie but also to enhance the marketability of their animals. The control effort focuses on risk reduction and sound husbandry practices. Since each advancing phase represents a lower risk of scrapie in the flock, the economic value of the animals is increased, especially after completing the five-year program and attaining "certified" status. This program may also have implications for exporting breeding stock to other countries.

Oversight of the program is conducted on both a national and a state level. The group at the national level is called the National Scrapie Oversight Committee. This group is responsible for advising APHIS of improvements and other changes which should be made in the program. Each state should have a scrapie certification board which reviews applications for enrollment and advancement, makes recommendations to the national committee and makes recommendations on the implementation of flock plans. Members of the National Oversight Committee and the state certification board are producers, allied industry representatives, state animal health officials and APHIS officials.

Any owner of a flock may apply to enter the Voluntary Scrapie Flock Certification Program by sending a written request to the state scrapie certification board. When participating in the program, the owner must:

- Agree to report scrapie-suspect animals to the proper animal health official immediately. Such animals must not be sold for breeding or slaughter.
- Officially identify all animals within a flock that are one year of age or older. Animals less than one year old must be identified whenever a change of ownership occurs, except for those in slaughter channels.
- Maintain required records as specified by the program. Records must be kept a minimum of five years after an animal dies or is removed from the flock.
- Allow breed associations and registries, livestock markets and packers to disclose records to APHIS and/or state animal health officials.
- After reasonable prior notice, allow inspection of animals and records by APHIS, state animal health officials and state scrapie certification board members.
- Provide necessary facilities and personnel to assist in inspections, including: 1) checking animals for official identification and signs of scrapie; and 2) checking records for completeness and accuracy.
- Account for all acquisitions, departures, births and deaths.
- Submit to an official laboratory tissues from scrapie-suspect animals and from animals suspected of other neurologic and chronic debilitation illnesses.

Requirements of the individual phases are as follows:

*Phase 1 - Certifiable Class C*

Animals must be officially identified.

Each animal must have a record containing:

- Official identification number and any secondary identification.
- Sex.
- Breed.
- Date of acquisition and source (if animal was not born in flock).
- Disposition – date and cause of death if known; date of removal and destination.

There will be annual inspections.

Suspect animals must be submitted for diagnostic purposes.

Minimum time requirement one year.

*Phase 2 - Certifiable Class B*

The flock owner has:

- Met requirements of Certifiable Class C.
- Agreed to follow provisions for Certifiable Class B.
- Official flock identification.
- Records that also include sire, dam and progeny of each animal.

The flock has:

- No evidence of scrapie for one year.
- Not been found to be a source flock in the last year.

There will be inspections every six months.

Suspect animals must be reported.

Minimum time requirement two years.

*Phase 3 - Certifiable Class A*

The flock owner has:

- Met requirements of Certifiable Class B.
- Agreed to provisions of Certifiable Class A.

The flock has:

- No evidence of scrapie in the last three years.
- Not been found to be a source flock in the last three years.

The requirements in this phase are the same as in Certifiable Class B.

Minimum time requirement two years.

*Phase 4 - Certified*

To enter the certified phase a flock must not have been found to be infected or to be a source flock in the last five years. The owner must have followed all the provisions of Certifiable Class A and agree to follow the provisions of the Certified Class.

In this phase, official identification and records will be the same as Class A; inspections will be performed annually and a flock may maintain this status indefinitely as long as all provisions are met.

There is also a commercial class status with less stringent requirements than the phases listed above.

All animal acquisitions must be from the same or higher class status. If an acquisition is made from a flock a lower status, the higher level flock will return to the lowest status of acquisition. Flock status will be jeopardized

if animals commingle with animals from a flock in a lower class. Semen from rams in the program may be used at any level.

If infection is found in a flock, an epidemiological investigation will be conducted. This investigation will identify trace and source flocks and exposed animals. A flock plan will be developed and implemented. Flock plans are designed to rid an infected or source flock of scrapie. They are developed by the flock owner or manager, regulatory personnel and an accredited veterinarian. Flock plans may include:

- Thorough epidemiological investigation.
- Identification and removal of "high-risk" animals.
- Cleaning and disinfection of the premises.
- Identification of the breeding flock.
- Record keeping.
- Periodic inspections.

Animals considered to be high risk are: 1) progeny of an infected ewe/doe; 2) those born during that lambing/kidding season when an infected ewe/doe gives birth; and 3) those born during the same season and in the same flock/herd as an infected animal. It is suggested that those "high-risk" animals be removed from the flock as soon as possible after they are identified.

After infected and high-risk animals are removed, the premises should be disinfected. The facilities and equipment should be thoroughly cleaned of organic matter. It is then recommended that they be exposed to 2% available chlorine at room temperature (Cooke, 1989) or a 1 molar solution of sodium hydroxide at room temperature for at least 30 minutes (Taylor, 1989b). These recommendations are based on work in the laboratory. We cannot say with any certainty that they will be 100% effective in the field. More research needs to be done in this area.

When more is learned about the roles of the Sip and PrP genes in the sheep, genetics may be found to play a significant role in the effort to control scrapie within a flock.

If one or more animals in a flock is diagnosed with scrapie or if the flock is identified as a source flock, the flock status will be "pending." After the flock plan has been developed and completed, the flock will return to Certifiable Class C.

**Interstate Regulations.** A permanent, highly-visible form of identification is required for interstate movement of sheep that are of high risk to perpetuate scrapie. These high-risk sheep include: 1) all animals from non-participating scrapie-infected or scrapie source flocks; and 2) high-risk animals from flocks participating in the voluntary certification program, except for animals less than one year of age moving in slaughter channels.

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# Research Briefs

## Crimp and the Handle of Fine Merino Wool

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Staple crimp and fiber diameter have always been regarded as primary indicators of raw wool quality. Traditionally, growers of fine Merino wool have strived to produce fiber with minimal diameter mean and variation and with maximum crimp frequency (and definition). For this study, the authors hypothesized that the softness of Merino lamb's wool is a consequence of its unique crimp properties compared to wool harvested from adult sheep. Specifically, the presence of less crimp in the tip (distal) portion of the staples produces a softer handle. To investigate the hypothesis, Merino lamb, ewe and wether fleeces varying in average fiber diameter and crimp frequency were harvested and processed in small batches (10 kg each) through woolen and worsted equipment. The yarns were further processed into knitted (30) and woven (6) fabrics. Physical characteristics of the raw materials, intermediate products, yarns and fabrics were determined objectively. For individual fleeces, staple crimp ranged from 3 to 9 crimps per cm, mean fiber diameter varied from 15 to 22 μm and resistance to compression ranged from 6 to 14 kPa. Tactile appraisals and objective measurements of compression and bending parameters were made on all fabrics.

Results from this study confirmed that there is only a poor correlation between average fiber diameter and staple crimp frequency for fine Merino wool and lamb's wool. Similarly, the correlation between average fiber diameter and resistance to compression was poor. However, there was a significant, direct correlation ($r = 0.68$) between staple crimp frequency and loose fiber resistance to compression. For wools processed on the woolen system, batches having lower crimp frequency exhibited relatively low resistance to compression that resulted in loftier sliver, more uniform slubbing, hairier yarns and softer, bulkier finished knitted fabrics. Lower than normal staple crimp also produced softer, sleeker worsted fabrics with no reduction in fullness. These results contradict the traditional view that higher crimp is necessary for fullness. This research indicates that decreasing the crimp in fine wools will improve loose fiber handle, processing performance and finished fabric softness. The observation that minimal rather than maximum crimp in fine Merino wool is capable of producing superior textiles has very important implications for processors and breeders alike.

*– prepared by C.J. Lupton*

## Flavour- and Tenderness-Related Quality Characteristics of Goat and Sheep Meat

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Twenty seven (27) carcasses representing each breed and species group of Angora goats, Boer goats, and sheep were selected to represent balance with respect to age, fat codes and gender (females and castrates). The carcasses were selected from commercial abattoirs. They were electrically stimulated to prevent toughening caused by cold-shortening and aged for seven days. Carcasses were transported in a frozen state to the research laboratory for this study. Rib and loin (m. longissimus) and leg samples were taken for sensory evaluation by a 10-member trained panel. Shear force values were also obtained. Collagen determinations were performed on rib samples. Only relatively minor differences could be attributed to age within the range of age involved in the study (one to four years). Meat from younger animals tended to be more tender and contained less fibrous residue. Characteristic species flavor was less typical in younger animals. With the increasing fatness, the tenderness and species

flavor of cooked cuts increased significantly. Significant differences were found between the quality characteristics of sheep, Angora and Boer goats. Sheep meat tended to receive high scores relative to aroma, flavor and tenderness and to have less tissue residue. Angora values were more closely related to sheep than were Boer goats. This suggests that when comparable in respect to age, fatness, etc., Angoras do not produce less desirable meat than Boer goats. The characteristic species flavor was more intense for sheep. Thus, if the characteristic species flavor was considered as undesirable, then this might be a cause for low consumption. It is suggested that South African consumers are prepared to pay a premium for lamb as contrasted to other red meats.

*– prepared by Maurice Shelton*

# News and Notes

The SID Sheep and Goat Research Journal has been published for 12 years by the American Sheep Industry Association (ASI). Originally, the funding for this organization was by "check off" from the Incentive Program, which has been discontinued. As most readers will be aware, a sheep industry referendum designed to replace the previous source of funding has (unofficially) been declared to have been defeated. As a result, the ASI staff and programs are being greatly reduced. However, since the journal is largely self-supporting, financial authorization has been obtained to continue its publication for the foreseeable future.

Correspondence pertaining to finance should continue to be sent to the ASI office. Questions concerning content or status of manuscripts may be sent to the editor at the following address:

Maurice Shelton, Editor
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Your continued support in the form of manuscripts, subscriptions, reviews, etc., is encouraged, appreciated and necessary to assure the continuation of the journal.

# Sheep & Goat Research Journal
# Guidelines for Authors

## Objective

The aim of the Sheep & Goat Research Journal is to provide a publication of sheep and goat research findings which can be used by scientists, educators, Extension agents and sheep and goat producers alike. The specific goal of the Journal is to gather and distribute current research information on all phases of sheep and goat production and to encourage producer use of research which has practical application. The Journal is published three times each year.

## Editorial Policy

We are most interested in publishing articles of research relating to all aspects of sheep and goat production and marketing. Articles should relate and contribute to the advancement of the American sheep and goat industries and/or their products. All research manuscripts must represent unpublished original research. The submission of review articles is encouraged but will require review as well as those reporting original research. Articles which promote commercial products or services will not be approved for publication. Conclusions reached must be supported by research results. An orientation to practical applied research which may be useful to the sheep and goat industries is encouraged. At least one author of each manuscript must subscribe to the Journal.

## Review Process

Manuscripts will be subject to critical review by an editorial board or others designated by the editor. Authors will be notified of acceptance or rejection of papers by mail. Manuscripts needing revision will be returned to authors and should be revised and returned by the deadline indicated. When papers are accepted for publication, the authors must send a floppy disk with the manuscript in the ASCII file format along with two hard copies. Papers not suitable for publication will be returned to the authors with a statement of reasons for rejection. Consult the Sheep & Goat Research Journal Editorial Policy and Procedures for details of the technical requirements for manuscripts submitted to the Journal.

## Guidelines

Several sources were consulted, including the Journal of Animal Science and the Council of Biology Editors, Inc., when preparing these guidelines. Though the nature of the Journal is such that relatively few regulations are needed on style and form, we have attempted to standardize the manner in which the material is published as a service to Journal subscribers. Following are general guidelines for style and form.

## Format

Manuscripts must be typed and double-spaced; five copies must be submitted. The lines on all pages including those pages for Literature Cited and Figure Legends must be numbered in the left margin beginning with the numeral one (1) at the top of the page. Tables should be as few and as simple as is feasible for presentation of the essential data; tables should be typed and double-spaced. Each table should be on a separate sheet. All figures used in the text must be camera-ready. The author will be billed at full cost if figure preparation is required.

Research manuscripts should follow the format of:

| | |
|---|---|
| 1st | **Summary** (250 words or less) |
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| 5th | **Results and Discussion** |
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In citing literature in the text, use both authors if there are only two. If there are more than two, use the first author and "et al." Authors are asked to provide "interpretive summaries" for use by the sheep and goat industries in other media.

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