ABSTRACT

PALA, AKIN. Effects of Three Twice-a-Year Breeding Schedules in Four Breeds of Sheep. (Under the direction of ODIS WAYNE ROBISON and ROGER LEE McCRAW).

Straightbred populations of Dorset, Finnsheep, Composite I (50% Finnsheep, 25% Dorset, and 25% Rambouillet), and Composite II (50% Finnsheep, 25% Suffolk, and 25% Targhee) sheep were evaluated under three different twice-a-year breeding schedules. Ewes were exposed for 32 d starting on August 13 and February 5 for schedule I, on September 15 and March 10 for schedule II, and on October 22 and April 11 for schedule III. Approximately 100 ewes of each breed were exposed to rams during each breeding season. The experiment was conducted for five complete cycles starting with matings in the fall of 1984 and ending with matings in the spring of 1989. Data were obtained on 9419 lambs produced from 2334 ewes and 257 rams. Traits of primary interest were conception rate, litter size at birth, weaning weight, weaning weight adjusted for conception rate, litter weaning weight and litter weaning weight per ewe exposed. Lactation status had a significant effect on conception rate and litter size while number of lambs suckling did not have a significant effect on

conception rate. Composite I ewes had the highest conception rates and litter size ($P < 0.01$) while Composite II had the heaviest litters, highest weaning weight adjusted for conception rate and greatest litter weaning weight per ewe exposed ($P < 0.01$). Dorset and Composite II lambs had similar weights at weaning ($P > 0.10$). However, they were heavier than Finnsheep and Composite I lambs ($P < 0.01$). While there was no difference between straightbred Finnsheep and Composite I ($P > 0.10$), both had larger litters ($P < 0.01$) than the other two breeds. Ewes giving birth in spring had the highest conception rate and heaviest lambs ($P < 0.01$). Animals bred in schedule I had the heaviest and largest litters, highest conception rate, heaviest lambs and highest litter weaning weight per ewe exposed ($P < 0.01$). Efficiency of twice-a-year lambing systems is greatly affected by breeds, breeding schedules and seasons. Twice-a-year lambing programs must use the correct breeding schedule. Further, using composite breeds can be of great benefit.

Genetic parameters for conception rate, litter size at birth, weaning weight, weaning weight adjusted for conception rate, litter weaning weight and litter weaning weight per ewe exposed were estimated using REML with animal models. Heritability estimates for conception rate were adjusted to a normal scale. Standard errors of heritabilities for conception rate were calculated using three methods, including bootstrapping. Heritabilities were estimated overall and within breed. Estimates of heritability for conception rate ranged from 0.17 ± 0.01 (Dorset) to 0.27 ± 0.01 (Composite I). Heritability estimates for litter size were 0.08 ± 0.01, 0.19 ± 0.01, 0.14 ± 0.01 and 0.13 ± 0.01 for Dorset, Finnsheep, Composite I and Composite II, respectively. Heritabilities for litter weaning weight and litter weaning weight per ewe exposed were similar across breeds and ranged from 0.31 ± 0.01 to 0.36 ± 0.01. Heritability for weaning weight was higher for Dorset (0.65 ± 0.01) than for Composite I (0.57 ± 0.01). Finnsheep and Composite II had similar heritabilities (0.41 ± 0.01). Overall heritabilities for litter weaning weight, litter weaning weight per ewe exposed, weaning weight, weaning weight adjusted for conception rate, conception rate and litter size were 0.33 ± 0.02, 0.35 ± 0.01, 0.64 ± 0.01, 0.64 ± 0.01, 0.24 ± 0.01 and 0.16 ± 0.01, respectively. Overall Spearman rank-order correlations of litter weight traits with conception rate or litter size ranged from 0.81 to 0.88. Correlations within breed were generally high and positive. Genetic correlations between dry and lactating ewes for conception rate and litter size were small (0.009 and 0.108, respectively), indicating that rank of sires was inconsistent under different environments (lactation status). Selection should be practiced among lactating animals for conception rate and litter size in twice-a-year lambing systems.

Heritability estimates were moderate to high for weight traits and low to moderate for reproduction traits, indicating that selection in twice-a-year lambing programs is feasible. There was no substantial evidence that heritabilities and rank correlations were different among the four breeds. Litter weaning weight may be increased along with conception rate and litter size in a selection program based on twice-a-year lambing. Small genetic correlation between dry and lactating ewes indicated that grouping sires according to the lactation status of the ewes is necessary in a selection program.

EFFECTS OF THREE TWICE-A-YEAR BREEDING SCHEDULES IN FOUR BREEDS OF SHEEP

by

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INTRODUCTION

This experiment was conducted to evaluate performance of four genetic groups in three twice-a-year lambing schedules. The study was carried out for a period of five cycles to measure long-term effects of the system. Dorset and Finnsheep breeds were included for their superiority for reproductive and weight traits. Fogarty et al. (1984) reported that Dorset and Finnsheep ewes produced more weight of lamb per ewe exposed than Rambouillet, Suffolk or Targhee ewes because of higher Dorset and Finnsheep conception rate, higher Dorset lamb survival and larger Finnsheep litters.

Genetic improvement of reproductive efficiency has been attempted by many. Results of these attempts have been variable, mainly due to the low heritabilities of reproductive traits. Matos et al. (1997) worked with Finnsheep and reported an adjusted heritability of 0.17 for fertility. Lee et al. (2000) reported that the heritability for number of lambs born was 0.06. Composite breeds may provide increased genetic variance in low heritability traits (Smith et al., 1979).

With a gestation of 5 mo and an interval of 1 to 2 mo from parturition to the resumption of estrous activity (in the breeding season), sheep have the potential to lamb every 6 mo. Accelerated lambing methods attempt to provide a lamb crop in addition to the regular spring-born lambs. A twice-a-year schedule is simpler and easier to manage than 8-mo lambing schedules (Hogue, 1986) because the breeding seasons are consistent across years and there is more synchrony among ewes in stage of production. Twice yearly breeding of ewes has been attempted, but results have been variable (Duncan and Black, 1978; Goot and Maijala, 1977; Whiteman et al., 1972). Breed, location and timing of breeding seasons could influence the effectiveness of twice yearly breeding programs. Effectiveness of various accelerated lambing schemes is dependent upon annual estrous activity of the breed utilized (Dzakuma and Harris, 1985). None of the above studies have attempted to determine which twice-yearly lambing schedule gives maximum lamb production for a given breed.

This research provides estimates of productivity of four breeds under three different twice-a-year schedules and of the ability of ewes of these breeds to conceive during lactation.

Genetic parameters are necessary for construction of selection indexes and for understanding of the complex associations among important traits. Objectives of this study were to obtain estimates of overall and within breed heritabilities, overall and within breed correlations and their standard errors. Further, conception rate for dry and lactating ewes may be viewed as two separate traits. Hence, the genetic correlation between conception rates in dry and lactating ewes was obtained.

LITERATURE REVIEW

With a gestation of five months and an interval of one to two months from parturition to the resumption of estrous activity (in the breeding season), sheep have the potential to lamb every six months. This system is simpler and easier to manage than the eight-month lambing schedule since there are fewer breeding seasons and more synchrony among ewes in stage of production. Twice yearly breeding of ewes has been attempted, but the success of these studies have been variable (Duncan and Black, 1978; Goot and Maijala, 1977; Whiteman et al., 1972). Choice of breed, the location and timing of breeding seasons would be expected to influence the effectiveness of twice yearly breeding programs. The effectiveness of various accelerated lambing schemes is dependent upon the shape of the annual estrous activity curve of the breed utilized (Dzakuma and Harris, 1985b). None of the above studies have attempted to determine which twice-yearly lambing schedule gives maximum lamb production for a given breed. The Dorset, Finnsheep, Synthetic I and Synthetic II have been the most productive breeds evaluated at this location and appear to be the most adaptable to systems of intensive lamb production under accelerated lambing programs.

Results of this research provide a basis for predicting the productivity of these breeds under different six-month breeding schedules and the ability of ewes of these breeds to conceive during lactation. The experiment includes four breeds, Finnsheep, Dorset, Synthetic I and Synthetic II.

Finnsheep is a prolific breed with litter size greater than 2 lambs (mean=2.6, Fogarty et al. 1984, Goot, 1973). Finnsheep were introduced into the U.S. via Canada during the late 1960's and numerous research organizations began evaluating Finnsheep as a component of a crossbred ewe for use in lamb production. Results of that research were summarized by Dickerson (1977). Use of ½ Finnsheep crosses with such breeds as Dorset, Suffolk, Targhee or Rambouillet as commercial ewes mated with meat breed sires can reduce ewe costs per pound of lamb marketed by 20 to 25% compared with use of ½ Rambouillet x domestic U.S. breed crossbred ewes. The ½ Finnsheep crossbred ewe lambs begin lambing at 1 year of age and produce at least 50 more live lambs per 100 ewes per year. More of the lambs from ½ Finnsheep ewes are twins or triplets and they average 5 to 6 pounds lighter at 10 weeks, but livability, postweaning gain, carcass yield and carcass grade closely approach that of lambs from ½ Rambouillet ewes when slaughtered at equal weights. Ercanbrack and Knight (1985) compared lifetime lamb and wool production of ¼ and ½ Finnsheep crossbred ewes with purebred Rambouillet, Targhee and Columbia dams under range conditions. For prolificacy, Finnsheep crosses were superior to purebreds; ¼ and ½ Finnsheep averaged 24 and 48% higher, respectively, than purebreds. Further, Finnsheep crossbred ewes surpassed purebreds ($P < .05$) for net reproductive rate and weight of lamb weaned. The superiority was consistent through all ages and averaged (over ages 2 through 7 yr) 29 and 49% for net reproductive rate and 24 and 41% for weight weaned, for ¼ and ½ Finns, respectively. Although purebreds were consistently superior for wool weight, the authors concluded that the loss in value of wool production associated with Finnsheep breeding was economically of much less importance than the gains made in weight of lamb weaned. They calculated that use of ¼ and ½ Finnsheep crosses involving Rambouillet, Targhee and Columbia increased the net value of lifetime production by approximately 18 and 29%, respectively. Ercanbrack and Knight (1989) reported that ¼ and ½ Finnsheep crossbred ewes from Rambouillet, Targhee and Columbia dams had 34 and 46% higher numbers of lambs weaned and 30 and 38% higher total weight of lamb weaned than purebred Rambouillet, Targhee and Columbia ewes. Cochran et al. (1984) found that litter size was higher (P < .01) for ½ Finnsheep (1.97) than ¼ Finnsheep (1.74). It is easy to see that as Finnsheep contribution increases (from ¼ to ½), number of lambs and weight of lambs weaned increase. Lewis and Burfening (1988) compared reproductive efficiency of ¼ Finnsheep crossbred ewes (Finnsheep x Rambouillet) with straightbred Columbia, Rambouillet and Targhee ewes. At 1 yr of age, ¼ Finnsheep crosses had 14.0 kg more lamb weaned per ewe exposed to breeding (P < .01) than Columbia, Rambouillet and Targhee crossbred ewes. Oltenacu and Boylan (1981b) wrote that Finnsheep produced the heaviest total weight of weaned lamb among Targhee, Suffolk and Minnesota 100. The authors calculated a ewe index as the total adjusted (male, 70-day equivalent) weight of weaned lamb plus three times the grease fleece weight. Purebreds ranked as Finnsheep, Targhee, Suffolk and Minnesota 100. Oltenacu and Boylan (1981a) noted Finnsheep lambs had moderate prenatal mortality, but lambs born alive had an superior survival rate to weaning (97.5%) compared to that of Targhee (85.2%), Minnesota 100 (78.9%) or Suffolk (76.8%) lambs. Based on all the advantages mentioned above, Finnsheep is fit to be used in an experiment targeting reproduction.

Dorset is a breed noted for much superiority on many different traits. Fogarty et al. (1984) noted that Dorset and Finnsheep ewes produced more weight of lamb per ewe exposed than Rambouillet, Suffolk and Targhee ewes because of higher Dorset and Finnsheep fertility, higher Dorset lamb survival and larger Finnsheep litters. This shows that Dorset and Finnsheep are suitable breeds to be used in a study investigating ways to increase reproductive traits. Nugent et al. (1988) compared Dorsets and Hampshires to study effects of ewe breed and ram exposure on ovulation and estrus. They used serum progesterone assays biweekly to observe ovulation and crayon marks to detect estrus. The authors wrote that more Dorsets ovulated (96%) than did Hampshires (72%), and of ewes that ovulated, more Dorsets mated (83 vs 28%). Vesely and Swierstra (1985) compared year-round breeding of crossbred Dorset and Finnsheep ewes using a synthetic light regimen. Although prolificacy of crossbred Finnsheep ewes was higher ($P < .05$) than Dorset ewes, mortality of lambs from the crossbred Dorset ewes (12%) was lower ($P < .01$) than that from the crossbred Finnsheep ewes (27%). Cochran et al. (1984) reported that lambs from Dorset dams were heavier at birth (3.88 kg) than lambs from ¼ Finnsheep (3.24 kg) or ½ Finnsheep (3.08 kg) dams ($P < .001$). In addition, lambs from Dorset dams had higher preweaning average daily gains and adjusted 90-d weights (.26 kg/d and 28.3 kg) than lambs from ¼ Finnsheep (.24 kg/d and 25.4 kg) or ½ Finnsheep (.24 kg/d and 25.1 kg) dams ($P < .001$).

Synthetic I and Synthetic II are breeds produced in the MARC center, Nebraska. A project initiated at the MARC in 1975 and terminated in 1984, was designed to determine the performance of maternal Synthetic populations relative to the contributing pure breeds as female parents in market lamb production and to develop selection criteria and procedures for improving maternal populations. Analysis established that the Synthetic I (50% Finnsheep, 25% Dorset and 25% Rambouillet) and Synthetic II (50% Finnsheep, 25% Suffolk and 25% Targhee) were 30-40% above the weighted mean of the contributing pure breeds and also superior to the best purebred (Finnsheep) for number of lambs and weight of lambs weaned per ewe exposed. In addition, these results indicate development of Synthetic dam populations with predictable levels of heterosis appears to be a feasible approach for utilizing heterosis and optimizing additive genetic breed composition without the expense of maintaining purebred lines for continuous production of Fl ewes or rotational crossing.

During the first two years of this project, flocks of Finnsheep, Dorset, Rambouillet, Targhee, first generation Synthetic I and Synthetic II ewes were managed under an eight-month accelerated lambing program with breeding occurring in April, August and December. Thereafter, flocks of Finnsheep, Dorset, Rambouillet and Synthetic I ewes continued under this program, while flocks of Finnsheep, Suffolk, Targhee and Synthetic II ewes were moved to the annual fall breeding program. Consequently, the only direct comparison of Synthetic I and Synthetic II occurred during the early generations of development. Results indicate that the flock of Rambouillet did not perform satisfactorily in any of the accelerated-lambing breeding seasons. Productivity of the Targhee and Suffolk under annual lambing was not satisfactory and it was difficult to maintain population size. Results also indicated that flocks under the annual program had a higher rate of lamb production per ewe per year than flocks under the accelerated program. This later result is a consequence of choosing breeding seasons in the accelerated program that coincided with periods of marginal estrous activity. This is generally a problem with eight-month accelerated lambing programs. Eight-month accelerated lambing programs have concomitant management problems as well. With breeding three times in two years, individual ewes are in a variety of stages of production which makes it difficult to impose proper feeding and health programs.

There are several reports in the literature that describe the annual estrous activity curves of a variety of breeds at different locations. Dzakuma and Harris (1985a) analyzed data from several reports to determine the effects of breeds, location and years. They used an algorithm which obtained a mathematical description of the annual estrous activity curves. Parameters that describe these curves have biological interpretations and allow for a more succinct description of the differences. Considerable variation in annual estrous activity curves existed within a breed from one location to another, or from one year to the next and between breeds during the same year and at the same location. Location effects were not only due to differences in latitude, but also differences in altitude and factors other than latitude and altitude. Factors other than latitude and altitude may be temperature or sampling.

The estrous activity curves described by this algorithm were used in a computer simulation program to simulate the biological aspects involved in alternative systems of lambing (Dzakuma and Harris, 1985b). Once-a-year, three-times-in-two-years, twice-a-year and continuous mating schemes were evaluated. The only variables in the simulation, other than mating times, were the parameters that described the estrous activity curves for the breeds at a given location. Parameters with important effects in the simulation were the average spread of the estrous season (SA), the measure of asymmetry (SD), and the maximum proportion of ewes exhibiting estrus (MX). It was demonstrated that breeds with large SA values (i.e., longer estrous and shorter anestrous seasons) were more adaptable to frequent lambing schemes. Breeds with low MX were not as productive as those with high MX. In breeds with high SD values (more asymmetry), it was difficult to bracket the period of high estrous activity by a short interval between lambings. This simulation assumed the time from parturition to first estrus was 45 days for all breeds.

In order for a ewe to conceive within 40 days after lambing, she must still be in her estrous season and uterine involution, ovulation and behavioral estrous must occur.

In general and as expected, ewes lambing toward the end of their estrous season have longer intervals to first estrus than ewes lambing at the beginning or middle of their estrous season (Smith, 1964; Mallampati et al., 1971; Whiteman et al., 1972; Hunter and Van Aarde, 1973). This is due to the confounding of postpartum anestrous and seasonal anestrous.

Kiracofe (1980) reviewed the process of uterine involution in the ewe. Several investigators agree on the description of the involution process and its timing. Necrotic tissue over the caruncle was very loosely attached by day 14 postpartum and was sloughed by day 20 to 25. Shrinkage in uterine size was relatively complete and necrotic tissue was absent from the uterus by 25 days. Epithelium had also regenerated from the uterine glands and intercaruncular areas. Caruncles were covered with epithelium by 25 to 30 days. Thus, the uterus appears to be at or near its nonpregnant state by 25 days after lambing.

Because of the confounding of the effects of seasonal anestrous and postpartum anestrous in ewes that lamb near the end of their normal breeding season, only information on ewes lambing during their breeding season will be presented to determine the effects of pregnancy and lactation on subsequent ovulation and estrus. Some literature reports of average interval from parturition to first ovulation, interval from parturition to first estrus, and interval from parturition to first conception in fall lambing ewes are shown in table 1.

Table 1. Literature estimates of postpartum intervals to first ovulation, first estrus and first conception in fall lambing ewes.

Source	Breed[a]	Postpartum interval (days) to		
		ovulation	estrus	conception
Mallampati et al. (1971)	Targhee(S)		45	
	Targhee (NS)		31	
Land (1971)	Finnsheep(1968)		34.9	41.4
	Dorset (1968)		41.9	50.6
	Finn-Dorset (1968)		30.2	45.9
	Finn-Dorset (1969)		41.4	44.5
Lewis and Bolt (1983)	Rambouillet (S)		31.5	
	Rambouillet (NS)		29.5	
Quirke et al. (1983)	Rambouillet	22.7	53.0	
	Dorset	25.2	51.0	
	Finnsheep	22.5	49.7	
Hunter and Van Aarde (1973)	Mutton Merino (Nov-S)	46.5	62.9	
	Mutton Merino (Nov-NS)	48.4	68.2	
	Mutton Merino (March-S)	28.9	54.2	
	Mutton Merino (March-NS)	26.3	47.5	
Fitzgerald and Cunningham (1981)	FinnxDorsetxScot. Blackface		47	
Ford (1979)	3/4 Finnsheep (S)		45.5	
	3/4 Finnsheep (NS)		26.8	
Fletcher (1973)	Merino		47.3	

[a] S = Suckled; NS = Not Suckled; 1968 and 1969 indicated year of observation. Nov and March indicate month of lambing in Southern Hemisphere. If not indicated otherwise, all ewes were suckled.

A significant percentage of ewes (up to 50%) exhibit an anovulatory estrus within three days postpartum (Barker and Wiggins, 1964; Land 1971). These are not included in the mean intervals to first estrus in table 1. Most researchers have reported the occurrence of one or more silent ovulations prior to the first behavioral estrus, which is reflected in differences between the mean intervals to ovulation and first estrus in Table 1 (also see reviews by Kiracofe, 1980 and Wetteman, 1980). Ovulation without behavioral estrus will likely not be important in most management schemes. It appears that a significant percentage of ewes could conceive within 40 days postpartum if they are still in their normal breeding season, since the uterus has involuted and some ewes are exhibiting estrus and ovulating.

The effect of lactation on the interval to first postpartum estrus has been investigated extensively, but the results are conflicting. Hunter (1971), Fletcher (1973), Hunter and Van Aarde (1973), Fitzgerald and Cunningham (1981) and Lewis and Bolt (1983) concluded that lactation did not increase the interval from parturition to first estrus. Barker and Wiggins (1964), Sefidbakht et al. (1971), Call et al. (1976), and Ford (1979) concluded that lactation did extend the postpartum interval to estrus. This disagreement may result from differences in breed, season, location, and management, such as nutrition. Even if extremely early weaning (3 days or less) would decrease the postpartum interval to first estrus, it would not likely be a management scheme that would maximize efficiency of lamb production.

Pope et al. (1989) compared rebreeding activities of spring- vs fall-lambing Polypay, Dorset, St. Croix and Targhee ewes that either suckled their lambs for 40 d or had lambs weaned at birth. They reported that Dorset ewes had similar conception rates between spring and fall but a shorter interval from lambing to first ovulation in the fall. Polypay and Targhee ewes were the opposite; they had higher conception rates in fall than in spring matings with no seasonal influence on postpartum interval. Postpartum ewes in the fall had higher conception rates, and fewer of these ewes became anestrous or had estrous cycles of abnormal duration than of those ewes lambing in the spring. Ewes that suckled for 40 d in the spring had delayed estrous activity, but when these ewes became estrual they had higher conception rates than ewes whose lambs were weaned at birth. Lactation had no inhibitory affect on the postpartum interval of fall lambing ewes. The authors wrote that the response of different breeds to various components of postpartum fertility varies with season and management of the flock.

Land and McClelland (1971) reported the performance of Finnsheep x Dorset ewes that had the opportunity to mate on four occasions between July 27, 1967, and April 4, 1969. These matings were a consequence of other experiments and were not at six-month intervals. Ewes that were two years old or older at the start of the experiment carried an average of three pregnancies. The proportion of ewes lambing was reduced from 93 to 32% by the occurrence of lambing six-months previously, but litter size was unaffected.

Lewis et al. (1996) wrote that in their study, matings occurring within the typical breeding season (August, October, and January) were more fertile than those occurring in March and June. They reported that fertility also varied with the age of the ewe and the time since the ewe's last lambing. Except in June, fertility at the first postpartum mating increased as ewes aged. In March and June matings, adult ewes that had just weaned lambs were less fertile than ewes that had failed to conceive in the previous season and therefore had longer postpartum intervals. However, in October and January, ewes that had just weaned lambs were more fertile.

Whiteman et al. (1972) evaluated 60 Dorset, 60 Rambouillet and 62 Dorset x Rambouillet ewes on a twice-yearly breeding schedule. The breeding seasons were arbitrarily chosen to begin on April 20 and October 20 and to last for 60 days. All ewes were exposed to fertile rams during these periods except ewes were not exposed to rams until 11 days postpartum. Thirty-five percent of the ewes that could have lambed during the fall had lambs as compared to 84% during the spring. As a measure of the extra lambs resulting from mating at six-month intervals, 36% of lambs born were conceived during a season that the dam lambed. Of the ewes that lambed, the percentage conception and interval to conception were 71% and 44 days for fall lambers and 23% and 66 days for spring lambers. Breed differences were not large.

Walton and Robertson (1974) evaluated the performance of a small flock of Finnsheep ewes in which the adult ewes were exposed to rams in the fall and spring of each year for five consecutive breeding periods. Lambs were weaned 24-28 hours postpartum. Overall, 33.3% of the ewes conceived at each of the five breeding periods and 72.2 % conceived at least four times. The mean conception-to-conception interval for all intervals of eight months or less was 189.3 (range 171-237) days and 42.6% of the consecutive conceptions occurred within 182 days. The breeding seasons in this study began in January and August and were about four months in length.

Goot and Maijala (1977) reported the performance of 118 Finnsheep ewes kept on a twice-yearly lambing system in a commercial flock in Finland. Ewes were exposed to rams throughout the year except June and July. Fifty-five percent of the ewes lambed once within a calendar year and 45% lambed twice. The consecutive lambings over the five and one-half years of the study did not indicate any decline in reproductive performance. The estimated lambing to conception interval was 116 ± 64.3 days. For ewes which lambed twice within a calendar year, the lambing to conception interval was 71.7 ± 24.71 days. Litter size was not affected by lambing frequency. This is an impressive performance under conditions of extreme change in light, temperature, and possibly nutrition, with ewes that were subject to high physiological demands during pregnancy and lactation.

Duncan and Black (1978) reported the performance of Finnsheep-Dorset ewes mated at six-month intervals in July and January of 1971 and 1972. Estrus was synchronized in all ewes at each mating. Satisfactory conception was obtained in July matings of each year (76% and 97%) but not in January (10% and 35%). While a number of ewes (48 out of about 97) were induced to lamb at least once at a six-month interval, only one ewe lambed four times in 24 months.

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Effects of Three Twice-a-Year Breeding Schedules in Four Breeds of Sheep

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Abstract

Straightbred populations of Dorset, Finnsheep, Composite I (50% Finnsheep, 25% Dorset, and 25% Rambouillet), and Composite II (50% Finnsheep, 25% Suffolk, and 25% Targhee) sheep were evaluated under three different twice-a-year breeding schedules. Ewes were exposed for 32 d starting on August 13 and February 5 for schedule I, on September 15 and March 10 for schedule II, and on October 22 and April 11 for schedule III. Approximately 100 ewes of each breed were exposed to rams during each breeding season. The experiment was conducted for five complete cycles starting with matings in the fall of 1984 and ending with matings in the spring of 1989. Data were obtained on 9419 lambs produced from 2334 ewes and 257 rams. Traits of primary interest were conception rate, litter size at birth, weaning weight, weaning weight adjusted for conception rate, litter weaning weight and litter weaning weight per ewe exposed. Lactation status had a significant effect on conception rate and litter size while number of lambs suckling did not have a significant effect on conception rate. Composite I ewes had the highest conception rates and litter size ($P < 0.01$) while Composite II had the heaviest litters, highest weaning weight adjusted for conception rate and greatest litter weaning weight per ewe exposed (P < 0.01). Dorset and Composite II lambs had similar weights at weaning (P > 0.10). However, they were heavier than Finnsheep and Composite I lambs (P < 0.01). While there was no difference between straightbred Finnsheep and Composite I (P > 0.10), both had larger litters (P < 0.01) than the other two breeds. Ewes giving birth in spring had the highest conception rate and heaviest lambs (P < 0.01). Animals bred in schedule I had the heaviest and largest litters, highest conception rate, heaviest lambs and highest litter weaning weight per ewe exposed (P < 0.01). Efficiency of twice-a-year lambing systems is greatly affected by breeds, breeding schedules and seasons.

Keywords: season, conception, lactation, composite breeds, twice-a-year lambing.

Introduction

This experiment was conducted to evaluate performance of four genetic groups in three twice-a-year lambing schedules. The study was carried out for a period of five cycles to measure long-term effects of the system. Dorset and Finnsheep breeds were included for their superiority for reproductive and weight traits. Fogarty et al. (1984) reported that Dorset and Finnsheep ewes produced more weight of lamb per ewe exposed than Rambouillet, Suffolk or Targhee ewes because of higher Dorset and Finnsheep conception rate, higher Dorset lamb survival and larger Finnsheep litters.

With a gestation of 5 mo and an interval of 1 to 2 mo from parturition to the resumption of estrous activity (in the breeding season), sheep have the potential to lamb every 6 mo. A twice-a-year schedule is simpler and easier to manage than 8-mo lambing schedules because the breeding seasons are consistent across years and there is more synchrony among ewes in stage of production. Twice yearly breeding of ewes has been attempted, but results have been variable (Duncan and Black, 1978; Goot and Maijala, 1977; Whiteman et al., 1972). Breed, location and timing of breeding seasons could influence the effectiveness of twice yearly breeding programs. Effectiveness of various accelerated lambing schemes is dependent upon annual estrous activity of the breed utilized (Dzakuma and Harris, 1985). None of the above studies have attempted to determine which twice-yearly lambing schedule gives maximum lamb production for a given breed.

This research provides estimates of productivity of four breeds under three different twice-a-year schedules and of the ability of ewes of these breeds to conceive during lactation.

Materials and Methods

This study was initiated at the U.S. Meat Animal Research Center (MARC), Clay Center, NE with breeding in the fall of 1984 and completed with the lamb crop born in the fall of 1989. It included five cycles of breeding, composed of fall and spring matings. During the experiment, 9419 lambs were produced by 2334 ewes and 257 rams. Breeds used were Dorset, Finnsheep, Composite I and Composite II. Breed composition was 50% Finnsheep, 25% Dorset, and 25% Rambouillet for Composite I and 50% Finnsheep, 25% Suffolk, and 25% Targhee for Composite II. Approximately 100 ewes of each breed were assigned to each of three schedules (Table 1).

The breeding flock originated from another project terminated in 1984 at MARC (Fogarty et al., 1984). In the fall of 1984, only 60 Finnsheep and 65 Dorset ewes were assigned to each schedule due to insufficient numbers in these breeds. Ewes were exposed to fertile (semen checked), sound rams of their own breed at each assigned period in single-sire pens. After mating, ewes were put on pasture until 4 to 6 wks before parturition and then were taken to open-front drylot barns where they were fed late gestation rations with medium to high energy and protein content (silage, silage supplement, soybean meal, corn and alfalfa hay). Animals were treated for parasites, vaccinated against type C and D Enterotoxemia and given vitamins A, D & E. About a week before parturition, ewes were moved to a closed barn with slotted floor. When the first lambs were born, the ration was changed to a lactation ration which had slightly higher protein content than the late gestation ration.

For the first day after parturition, lambs and ewes were kept isolated in small separate pens. Ram lambs were not castrated. Ewes were given an opportunity to raise up to three lambs. Remaining lambs were reared in the nursery. Crossfostering was used when appropriate, but only among ewes of the same breed. All naturally reared lambs were offered creep feed by 7 d of age. If a lamb's nutritional status was failing and the lamb was younger than 7 d, it was transferred to the nursery. Approximately 0.09 % of lambs were in nursery. Lambs in the nursery were given milk replacer until weaning. Nursery lambs also had access to water and dry-ground feed. Naturally reared lambs were not weaned until the end of the breeding season. Weaning age ranged from 26 to 43 d for nursery lambs whereas it was between 32 and 83 d for naturally reared lambs. Nursery lambs were mixed with naturally reared lambs at about 8 wks of age.

At 18 wks of age, a random sample of no less than six ram lambs was chosen to provide replacement rams. All ewe lambs were kept as potential replacements. Older ewes were culled for health reasons and at random to keep similar distributions of ewe ages among breeds within a schedule.

There were two groups of ewes for breeding, lactating and non-lactating. Dry (non-lactating) ewes were mated to rams located outside of the lambing barns; whereas wet (lactating) ewes were mated in the lambing barn, where they stayed with their lambs until weaning. Ewes were not treated with hormones to induce estrus.

Traits analyzed were weaning weight, weaning weight adjusted for conception rate, litter weaning weight, litter weaning weight per ewe exposed, conception rate and litter size at birth.

Litter weaning weight is largely determined by litter size whereas litter weaning weight per ewe exposed includes weaning weight, litter size and conception rate. Weaning weight adjusted for conception rate was calculated by multiplying individual lamb weaning weights by the respective breed’s conception rate. Litter weaning weight per ewe exposed was calculated by multiplying litter weaning weights by the respective breed conception rate. Conception rates for Dorset, Finnsheep, Composite I and Composite II were 480.8, 620.5, 620.1 and 60.3 percent, respectively.

Data were analyzed using the MIXED procedure of SAS (1999). Statistical model used was:

$$Y_{iklmno} = \mu + A_i + B_k + C_l + D_m + E_n + F_o + G_p + S_r\ (B_k) + e_{iklmno}$$

where;

Y_{iklmno} = individual observation for weaning weight, weaning weight adjusted for conception rate, litter weaning weight, litter weaning weight per ewe exposed, litter size at birth and conception rate.

A_i = fixed effect due to lactation status (dry, or lactating for conception rate and litter size analyses only),

B_k = fixed effect due to breed (Dorset, Finnsheep, Composite I, Composite II),

C_l = fixed effect due to cycle (1, 2, 3, 4, 5),

D_m = fixed effect due to season (fall, spring)

E_n = fixed effect due to schedule (I, II, III),

F_o = fixed effect due to age of ewe (1, 2, 3, 4, 5 and older),

G_p = fixed effect due to sex of lamb or ratio of males to total number in litter (p = 0,…,1 for litter weaning weight and litter weaning weight per ewe exposed, male and female for weaning weight and weaning weight adjusted for conception rate),

S_r (B_k)= random sire effect within breed,

e_{iklmno} = random element assumed to be normally and independently distributed with mean of zero and variance σ^2_e.

All two-way interactions were included in the initial model, those non-significant were deleted in later analyses. Lactation stress (0, 1, 2 or 3 lambs) was used in one analysis to examine its effects on conception rate and litter size. For weight traits, age of lamb at weaning was added as a covariate. For conception rate, logistic analyses were performed in addition to the mixed model analyses.

RESULTS and DISCUSSION

Estimates of breed effects for weight traits, conception rate and litter size are given in Table 2. Composite II litters were heavier than all others ($P < 0.01$). Differences among other breeds were small ($P > 0.10$). This result shows that using the right composite breed can be quite useful in twice-a-year lambing programs.

Composite II ewes had the highest litter weaning weight per ewe exposed ($P < 0.01$) while Dorset ewes had the lowest performance of all breeds ($P < 0.01$). There was no significant difference between Finnsheep and Composite I. Litter weaning weight per ewe exposed is a measure of total productivity. Ercanbrack and Knight (1985) reported that Finnsheep ewes had the lightest lambs but not the lightest litters. Oltenacu and Boylan (1981) found that Finnsheep produced the heaviest total weight of weaned lamb among Targhee, Suffolk and Minnesota 10. Lewis and Burfening (1988) compared reproductive efficiency of ¼ Finnsheep crossbred ewes (Finnsheep x Rambouillet) with Columbia, Rambouillet and Targhee ewes. At 1 yr of age, ¼ Finnsheep crosses had 140.0 kg more lamb weaned per ewe exposed to breeding ($P < 0.01$) than Columbia, Rambouillet and Targhee crossbred ewes.

Weaning weight adjusted for conception rate emphasizes weaning weight of individual lambs and conception rate while litter weaning weight includes litter size. Litter weaning weight per ewe exposed emphasizes litter weaning weight, conception rate and litter size. Composite II ewes had the heaviest weaning weight adjusted for conception rate (10.34 ± 0.11 kg) followed by Composite I (90.11 ± 0.11 kg), Finnsheep (80.57 ± 0.12 kg) and Dorset lambs (80.11 ± 0.10 kg). All breed differences were highly significant.

Breed by cycle interaction was highly significant for weaning weight adjusted for conception rate. However, there was no trend through the cycles.

Composite II and Dorset lambs had similar weights at weaning ($P > 0.10$). Both breeds had heavier lambs ($P < 0.01$) than the other two breeds while Composite I lambs were heavier ($P < 0.01$) than Finnsheep lambs. Finnsheep were used in the experiment to increase the number of lambs, as they are known for their prolific capabilities (Ercanbrack and Knight, 1985). However, they may have lighter lambs than other breeds. Cochran et al. (1984) reported that lambs from Dorset dams had higher preweaning average daily gains and adjusted 90-d weights (0.26 kg/d and 280.3 kg) than lambs from ¼ Finnsheep (0.24 kg/d and 250.4 kg) or ½ Finnsheep (0.24 kg/d and 250.1 kg) dams ($P < 0.01$).

Least squares means for birth litter size of different breeds are given in Table 2. Finnsheep and Composite I ewes had significantly larger litters than Composite II and Dorset. The difference between Finnsheep and Composite I was not large ($P > 0.10$). Composite II litters were larger than Dorset litters ($P < 0.01$)

Estimates of conception rates by breed are given in Table 2. Composite I ewes had the highest conception rate

($P < 0.01$), followed by Composite II ($P < 0.01$), Finnsheep and Dorset ewes. There was no significant difference between Dorset and Finsheep ewes ($P > 0.10$). Though all breeds had lower conception rates when lactating, the most marked difference was observed for Finnsheep (0.62 vs. 0.36).

Least squares means by season and schedule are given in Table 3. Spring-born litters were heavier than autumn-born litters ($P < 0.01$) and had more litter weaning weight per ewe exposed ($P < 0.01$). Spring-born lambs had larger weaning weights adjusted for conception rate than autumn-born lambs ($P < 0.01$) and were 20.5 kg heavier at weaning ($P < 0.01$). Ewes giving birth in the spring had higher ($P < 0.01$) conception rates than ewes bred in spring (Table 3). This was expected because sheep normally give birth in spring due to their seasonal breeding cycles (Thimonier, 1981). Litters born in spring were larger ($P < 0.01$) than litters born in autumn.

Ewes bred in schedule I had heavier ($P < 0.01$) litters than ewes bred in schedule II and III. The weight difference between schedule I and II lambs was 10.31 kg ($P < 0.01$). Differences between schedule I and III and II and III were 20.11 and 0.80 kg, respectively ($P < 0.01$, $P = 0.03$). The breed by cycle (year) interaction was not large

($P > 0.10$), indicating that rank of the breeds did not change over the years for this trait. Breed by cycle was not significant for litter weaning weight per ewe exposed. All ranks and significance statements were essentially the same for litter weaning weight and litter weaning weight per ewe exposed (Table 3).

Ewes in schedule I produced the largest weaning weights adjusted for conception rate, followed by ewes bred in schedule III and II. Only the difference between schedules I and II was significant.

Schedule I lambs were heaviest followed by lambs from schedule II and III. Differences between lambs in schedule I and lambs in schedule II and III were large ($P < 0.01$). However, lambs born of ewes bred in schedule II and III did not differ for weaning weight ($P > 0.10$). For all four weight traits (litter weaning weight, litter weaning weight per ewe exposed, weaning weight and weaning weight adjusted for conception rate), spring born lambs were heavier than autumn born lambs and schedule I yielded the heaviest lambs. Pope et al. (1989) wrote that the response of different breeds to various components of postpartum fertility varied with season. Lewis et al. (1996) reported that matings occurring within the typical breeding season

(August, October, and January) were more fertile than those occurring in March and June.

Ewes bred in schedule I had higher conception rates and litter size (P < 0.01) than ewes bred in schedules II or III (Table 3). Further, conception rates and litter size were higher in schedule II than in schedule III (P < 0.01).

In general, litters weighed more as the ratio of males to females increased.

Cycle*breed interaction was highly significant (P < 0.01). However, rank of breeds did not change through the cycles. Although there was no real trend across cycles, there was a curve of decline and then increase for all breeds.

Lactation stress or lactation status was included in different models. The four different levels of lactation stress were 0, 1, 2 or 3 lambs suckling. The only difference among levels of lactation stress was between dry and lactating ewes (P < 0.01, Table 4). There were no differences (P > 0.10) among one, two, or three levels of lactation stress. This indicates that lactating or not lactating has a large effect on conception. However, prolificacy does not seem to have any direct negative effect on conception through lactation.

In addition to mixed model analyses, logistic regression analyses were carried out for conception rate. The model for the logistic analysis was the same as mixed model analyses with the exception of the random variable, sire within breed. The probability of no conception was modeled using maximum likelihood methods. Results from logistic analysis were similar to results from mixed models.

Ewes with two lambs, and ewes with three lambs suckling had similar succeeding litter sizes ($P > 0.10$). However, ewes nursing one lamb had bigger succeeding litters (0.93 ± 0.03) than ewes nursing two (0.82 ± 0.03) or three (0.73 ± 0.07) lambs ($P < 0.01$). Lactating ewes (0.87 ± 0.02) had smaller ($P < 0.01$) litters than dry ewes (10.47 ± 0.01); except in schedule III ($P > 0.10$). In contrast, Land and McClelland (1971) reported the litter size of Finnsheep x Dorset ewes was unaffected by the occurrence of lambing six-months previously. Goot and Maijala (1977) reported the performance of 118 Finnsheep ewes kept on a twice-yearly lambing system in a commercial flock in Finland. Litter size was not affected by lambing previously.

Least squares means for interactions are given in tables 5 through 12. Because there were excessive number of contrasts to be made, difference tests were adjusted by the Tukey (1953) method. Since the data was unbalanced, adjustments were approximated using a method defined by Kramer (1956). Conception rates for Finnsheep changed drastically between dry and lactating ewes (Table 5). This was not due to large Finnsheep litters suckling, because number of lambs suckling had no significant effect on conception rate for Finnsheep in addition to having no overall effect. There was about 15 % lower conception rates for lactating vs. dry ewes in the other breeds.

There were no differences in conception rates ($P > 0.10$) between dry and lactating ewes in spring births while the difference was vast in fall ($P < 0.01$, Table 6). All breeds had similar and low conception rates in fall. Conception rates for all breeds were higher in spring (Table 7) with significant differences among breeds. Composite breeds had higher conception rates in spring ($P < 0.01$) than Finnsheep or Dorset.

In schedule III, conception rates of breeds were not different ($P > 0.10$, Table 8). In addition, ewes bred in schedule III had similar conception rates whether they were dry or lactating ($P > 0.10$, Table 9) during breeding time. In contrast, conception rates of breeds and differences between conception rates of lactating and dry ewes were significant in schedule I and II, and overall in all schedules. Differences between Dorset and Finnsheep in schedule I and between Finnsheep and Composite II in schedule II were the only exceptions ($P > 0.10$). This may be because schedule III was not in sync with the internal timing of sheep causing them to have very low performances regardless of breed or lactation status.

All differences were large for season by schedule interaction ($P < 0.01$). The lowest cell was the fall season births and schedule III (Table 10). In overall analysis they had the lowest conception rates. Ewes bred for fall season births in schedule III, had the lowest conception rate.

Finnsheep, Composite I and II had larger litters than Dorset ($P < 0.01$) but did not differ among themselves in spring births ($P > 0.10$, Table 11). Finnsheep had the largest litters ($P < 0.01$) in fall births. Fall season births from ewes bred in schedule III produced the smallest litter size ($P < 0.01$). All other differences for season by schedule interaction were large ($P < .O1$, Table 12) as well.

IMPLICATIONS

Twice-a-year lambing programs must use the correct breeding schedule. Further, using composite breeds can be of great benefit.

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Table 1. The three breeding schedules.

Schedule	Fall Breeding	Spring Breeding
1	August 13 to September 12	February 5 to March 7
2	September 15 to October 16	March 10 to April 9
3	October 22 to November 20	April 11 to May 12

Table 2. Least squares means for breed effects.

	Breed				
Item	Dorset	Finnsheep	Composite I	Composite II	SE[e]
Litter weaning weight, kg	32.67[a]	33.04[a]	32.48[a]	37.47[b]	1.09
Litter/exp, kg[f]	16.76[a]	20.65[b]	20.19[b]	22.67[c]	0.66
Weaning weight, kg	16.39[a]	12.94[b]	14.08[c]	16.53[a]	0.25
ww/cr, kg[g]	8.11[a]	8.57[b]	9.11[c]	10.34[d]	0.12
Conception rate, %	0.49[a]	0.49[a]	0.58[b]	0.53[c]	0.01
Litter size at birth	0.75[a]	1.36[b]	1.31[b]	1.25[c]	0.03

[a,b,c,d]Row values with different superscripts differ ($P < 0.05$).
[e]Pooled standard error based on most conservative number in a breed group.
[f]Litter weaning weight per ewe exposed; litter weaning weights multiplied by their respective breed conception rates.
[g]Weaning weight adjusted for conception rate; weaning weight of individual lambs multiplied by their respective breed conception rates.

Table 3. Least squares means for different schedules and seasons.

Item	Schedule			SE[e]	Season of birth		SE[e]
	1	2	3		Fall	Spring	
Litter weaning weight, kg	35.06[a]	33.75[b]	32.95[c]	1.04	31.00[a]	36.83[b]	1.10
Litter/exp, kg[f]	20.73[a]	19.97[b]	19.51[c]	0.62	18.36[a]	21.78[b]	0.65
Weaning weight, kg	15.67[a]	14.91[b]	14.37[b]	0.48	13.72[a]	16.25[b]	0.36
ww/cr, kg[g]	9.28[a]	8.82[b]	9.01[ab]	0.20	8.44[a]	9.63[b]	0.15
Conception rate, %	0.58[a]	0.52[b]	0.47[c]	0.01	0.27[a]	0.77[b]	0.01
Litter size	1.41[a]	1.15[b]	0.95[c]	0.02	0.64[a]	1.70[b]	0.02

[a,b,c]Row values with different superscripts differ ($P < 0.05$).
[e]Pooled standard error based on most conservative number in a group.
[f]Litter weaning weight per ewe exposed; litter weaning weights multiplied by their respective breed conception rates.
[g]Weaning weight adjusted for conception rate; weaning weight of individual lambs multiplied by their respective breed conception rates.

Table 4. Least squares means for conception rate and litter size for dry and lactating ewes.

Item	Lactation Status		SE^e
	Dry	Lactating	
Conception rate, %	0.62^a	0.43^b	0.01
Litter size at birth	1.47^a	0.87^b	0.02

[a,b]Row values with different superscripts differ ($P < 0.05$).
[e]Pooled standard error based on most conservative number in a group.

Table 5. Least squares means for lactation status by breed interaction for conception rate.

Lactation Status	Breed				
	Dorset	Finnsheep	Composite I	Composite II	SE[a]
Dry	0.56	0.62	0.65	0.63	0.010
Lactating	0.41	0.36	0.51	0.44	0.016

[a]Pooled standard error based on most conservative number in a group.

Table 6. Least squares means for lactation status by season interaction for conception rate.

	Lactation Status		
Season	Dry	Lactating	SE[a]
Fall	0.44	0.10	0.010
Spring	0.79	0.76	0.017

[a]Pooled standard error based on most conservative number in a group.

Table 7. Least squares means for season by breed interaction for conception rate.

Season	Breed				
	Dorset	Finnsheep	Composite I	Composite II	SE[a]
Fall	0.25	0.29	0.30	0.25	0.01
Spring	0.72	0.69	0.86	0.82	0.01

[a]Pooled standard error based on most conservative number in a group.

Table 8. Least squares means for breed by schedule interaction for conception rate.

Schedule	Breed				SE[a]
	Dorset	Finnsheep	Composite I	Composite II	
I	0.56	0.51	0.66	0.60	0.013
II	0.44	0.52	0.59	0.53	0.013
III	0.46	0.44	0.49	0.48	0.015

[a]Pooled standard error based on most conservative number in a group.

Table 9. Least squares means for lactation status by schedule interaction for conception rate.

Lactation Status	Schedule I	Schedule II	Schedule III	SE[a]
Dry	0.78	0.60	0.46	0.01
Lactating	0.38	0.43	0.48	0.01

[a]Pooled standard error based on most conservative number in a group.

Table 10. Least squares means for season by schedule interaction for conception rate.

Season	Schedule I	Schedule II	Schedule III	SE[a]
Fall	0.54	0.21	0.06	0.010
Spring	0.62	0.83	0.87	0.017

[a]Pooled standard error based on most conservative number in a group.

Table 11. Least squares means for season by breed interaction for litter size.

Season	Breed				
	Dorset	Finnsheep	Composite I	Composite II	SE[a]
Fall	0.45	0.84	0.68	0.58	0.03
Spring	1.06	1.88	1.94	1.93	0.03

[a]Pooled standard error based on most conservative number in a group.

Table 12. Least squares means for season by schedule interaction for litter size.

Season	Schedule I	Schedule II	Schedule III	SE[a]
Fall	1.30	0.40	0.21	0.03
Spring	1.52	1.91	1.68	0.03

[a]Pooled standard error based on most conservative number in a group.

Genetic Parameters for Four Breeds in Twice a Year Lambing Systems

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Abstract

Genetic parameters for conception rate, litter size at birth, weaning weight, weaning weight adjusted for conception rate, litter weaning weight and litter weaning weight per ewe exposed were estimated using REML with animal models in populations of Dorset, Finnsheep, Composite I (50% Finnsheep, 25% Dorset, and 25% Rambouillet) and Composite II (50% Finnsheep, 25% Suffolk, and 25% Targhee). Data were obtained on 9419 lambs produced from 2334 ewes and 257 rams. Heritability estimates for conception rate were adjusted to a normal scale. Standard errors of heritabilities for conception rate were calculated using three methods, including bootstrapping. Heritabilities were estimated overall and within breed. Estimates of heritability for conception rate ranged from 0.17 ± 0.01 (Dorset) to 0.27 ± 0.01 (Composite I). Heritability estimates for litter size were 0.08 ± 0.01, 0.19 ± 0.01, 0.14 ± 0.01 and 0.13 ± 0.01 for Dorset, Finnsheep, Composite I and Composite II, respectively. Heritabilities for litter weaning weight and litter weaning weight per ewe exposed were similar across breeds and ranged from 0.31 ± 0.01 to 0.36 ± 0.01. Heritability for weaning weight was higher for Dorset (0.65 ± 0.01) than for

Composite I (0.57 ± 0.01). Finnsheep and Composite II had similar heritabilities (0.41 ± 0.01). Overall heritabilities for litter weaning weight, litter weaning weight per ewe exposed, weaning weight, weaning weight adjusted for conception rate, conception rate and litter size were 0.33 ± 0.02, 0.35 ± 0.01, 0.64 ± 0.01, 0.64 ± 0.01, 0.24 ± 0.01 and 0.16 ± 0.01, respectively. Overall Spearman rank-order correlations of litter weight traits with conception rate or litter size ranged from 0.81 to 0.88. Correlations within breed were generally high and positive. Genetic correlations between dry and lactating ewes for conception rate and litter size were small (0.009 and 0.108, respectively), indicating that rank of sires was inconsistent under different environments (lactation status). Selection should be practiced among lactating animals for conception rate and litter size in twice-a-year lambing systems.

Keywords: heritability, genetic correlation, lactation, twice-a-year lambing.

Introduction

Genetic improvement of reproductive efficiency has been attempted by many. Results of these attempts have been variable, mainly due to the low heritabilities of reproductive traits. Matos et al. (1997) worked with Finnsheep and reported an adjusted heritability of 0.17 for fertility. Lee et al. (2000) reported that the heritability for number of lambs born was 0.06. Composite breeds may provide increased genetic variance in low heritability traits (Smith et al., 1979).

Accelerated lambing methods attempt to provide a lamb crop in addition to the regular spring-born lambs. Twice-a-year lambing programs are more stable and are easier to manage than three lambings in two-year programs such as the STAR system (Hogue, 1986).

Genetic parameters are necessary for construction of selection indexes and for understanding of the complex associations among important traits. Objectives of this study were to obtain estimates of overall and within breed heritabilities, overall and within breed genetic correlations and their standard errors. Further, conception rate for dry and lactating ewes may be viewed as two separate traits. Hence, the genetic correlation between conception rates in dry and lactating ewes was obtained.

Materials and Methods

Data were collected from fall 1984 to fall 1989 on 9419 lambs produced by 2334 ewes and 257 rams at the U.S.

Meat Animal Research Center, Clay Center, NE. The experiment consisted of five cycles, starting with breeding in fall of 1984 and ending with the lamb crop born in fall of 1989. About 100 ewes of Dorset, Finnsheep, Composite I (0.5 Finnsheep, 0.25 Dorset, 0.25 Rambouillet) and Composite II (0.5 Finnsheep, 0.25 Suffolk, 0.25 Targhee) were assigned to each breeding schedule (Table 1).

All healthy ewe lambs were kept as potential replacements. At 18 weeks of age, a random sample of no less than six ram lambs per breed was chosen as replacement rams. Rams were used across schedules, and a small portion of the rams was used across cycles and years. A report on this experiment described management practices, defined traits and detailed description of data collection (Pala et al., 2001).

It was planned originally that all rams exposed to lactating ewes would be equipped with a marking device to determine occurrence of estrus. However, that procedure was terminated because it was not efficient or accurate. Therefore, estrus was not recorded and conception rate was the only indication of estrus activity. Ewes that gave birth to lambs in one season were designated as lactating during the next breeding season. If all lambs of a ewe were sent to nursery, fostered by another ewe, or died before weaning, that ewe was designated nonlactating. Ewes that aborted were not credited with lambing. Not only lactational status of ewes, but also effects of lactational stress on conception rate were investigated. It may be suggested that a ewe suckling three lambs has greater lactational stress than a ewe suckling one lamb.

Within breed heritabilities were estimated for conception rate, litter size at birth, litter weaning weight, litter weaning weight per ewe exposed, weaning weight and weaning weight adjusted for conception rate. Definitions of these traits were given in Pala et al. (2001). Data were analyzed with a derivative-free algorithm (Smith and Graser, 1986, Graser et al., 1987) using MTDFREML (Boldman et al., 1995). In addition, SAS V8 (SAS Institute Inc., 1999) was used for bootstrapping. REML procedures executed by SAS (1999) did not involve the relationship matrix. Convergence criterion was 1E-8 in both programs. To ensure global convergence, the algorithm by Boldman et al. (1995) was restarted with estimates until the log likelihood did not change at the fourth decimal.

Fixed effects included lactation stress (no stress, 1 lamb, 2 lambs, 3 lambs), age of ewe (1, 2, 3, 4, 5 and older), breed (dorset, finnsheep, composite I, composite II), cycle (1, 2, 3, 4, 5), season (fall, spring) and schedule (1, 2, 3) for conception rate, litter size at birth, litter weaning weight, litter weaning weight per ewe exposed, weaning weight and weaning weight adjusted for conception rate. In addition, the percentage of males in a litter was included as a fixed effect when analyzing litter weaning weight and litter weaning weight per ewe exposed. Lactation stress was used only for conception rate and litter size analyses. Heritability estimates for conception rate were adjusted to heritability in normal scale using the equation suggested by Dempster and Lerner, 1950 (Van Vleck, 1972):

$$h^2_n = h^2_t * [(p*q)/z^2] \quad (1)$$

where h^2_t is the calculated heritability of the threshold character, h^2_n is heritability in normal scale, p is the proportion of ewes that conceived, q is the proportion of ewes that did not conceive and z is the ordinate of the normal distribution at p.

Bootstrapping calculations do not require the usual normal distribution assumptions and are useful when only approximate formulas exist (Efron, 1982). Standard errors for heritability of conception rate were calculated using bootstrapping with REML including the relationship matrix, bootstrapping with REML without the relationship matrix, and classical REML standard error calculations including the relationship matrix (no bootstrapping). The bootstrap procedure involved 50 bootstrap samples, which is a reasonable number of runs for a standard error calculation (Efron, 1982). Bootstrap samples were prepared using macros in SAS (1999) and analyzed using both MTDFREML (Boldman et al., 1995) and SAS (1999).

Genetic correlation between conception rates of lactating and dry progeny of sires was calculated using the following equation:

$$r_g = \sigma^2_S / [\sigma^2_S + \sigma^2_{S*ENV} - var(\sigma_{SI})] \quad (2)$$

where σ^2_S is the sire variance component and σ^2_{S*ENV} is the sire by environment (lactating or dry) component and $Var(\sigma_{SI})$ is the variance of sire standard deviations within each environment (lactating or dry). The variance components were computed using REML procedures. Standard error of the correlation was calculated using the formula derived from Reeve (1955) and Robertson (1959). Same calculation methods were used for litter size also.

Overall spearman rank-order correlations (Spearman, 1904) between conception rate and litter weaning weight, conception rate and litter weaning weight per ewe exposed, litter size and litter weaning weight, and litter size and litter weaning weight per ewe exposed were calculated as well as within breed rank-order correlations. Standard errors were calculated using the bootstrap method, defined by Efron 1982. 50 bootstrap samples were used for each correlation.

Results and Discussion

Heritabilities for the four genetic groups were calculated (Table 2) using REML procedures (Boldman et al., 1995). Smith et al. (1979) reported that composite breeds may have increased heritabilities due to either higher genetic variance or lower environmental variance. Composite breeds may be more resistant to environmental fluctuations, or they may simply have higher additive genetic variation. Although there were statistical differences among genetic groups, these differences would not be of practical importance for litter weight traits. Heritabilities for litter weaning weight and litter weaning weight per ewe exposed were similar across breeds and ranged from 0.31 to 0.36. Overall heritability for litter weaning weight (0.33 ± 0.02) was approximately the same as that for litter weaning weight per ewe exposed (0.35 ± 0.01). Snowder et al. (2001) estimated heritabilities separately for Colombia, Polypay, Rambouillet and Targhee. They reported low to moderate heritability estimates for litter weight weaned; ranging from 0.08 to 0.22.

Heritability for weaning weight was higher for Dorset (0.65 ± 0.01) than for Composite I (0.57 ± 0.01). Finnsheep and Composite II had similar heritabilities (0.41 ± 0.01) which were lower than that for Composite I. Overall heritability estimates for weaning weight and weaning weight adjusted for conception rate were the same, 0.64 ± 0.01. Okut et al. (1999) reported heritabilities of weaning weight for young, middle aged and older age of dam classes. They reported that heritabilities of young class were 0.24 for Targhee, 0.79 for Rambouillet and 0.35 for Polypay. They also reported heritabilities across breeds, which were 0.25 for young, 0.17 for middle and 0.22 for older age of dam classes.

Heritabilities adjusted to normal scale for conception rate were highest for Composite I (0.27) and for Composite II (0.24). Finnsheep and Dorset had lower heritabilities (0.20 and 0.17, respectively). Overall heritability estimate for conception rate in binary scale was 0.17. Adjustment of the estimate to normal scale resulted in an estimate of 0.24. Van Vleck (1972) wrote that this adjustment yields only a slightly inflated heritability estimate. Matos et al. (1997) worked with Finnsheep and reported an adjusted heritability estimate of 0.17 for fertility. Al-Shorepy and Notter (1996) studied reproduction in a sheep flock containing 50% Dorset, 25% Rambouillet, and 25% Finnsheep breeding. They reported heritability estimates for spring fertility ranging from 0.07 to 0.11 with an average of 0.09.

Heritability of conception rate estimated using REML (Boldman et al., 1995) was 0.17 ± 0.011 (binary scale). Fifty bootstrap samples yielded a standard error of 0.016. Heritability calculations with SAS (method=REML) resulted in h^2= 0.08 (binary scale). The standard error calculated using 52 bootstrap samples was 0.019, which was higher than the two previous numbers. Estimates from SAS procedures using REML method did not involve the relationship matrix.

Heritability estimates for litter size are shown in table 2. Heritability estimates for litter size (0.08 to 0.19) were lower than heritabilities of weight traits. Lee et al. (2000) reported that the heritability for number of lambs born was 0.06. Rao and Notter (2000) estimated heritability of litter size for Suffolk (0.09), Polypay (0.09) and Targhee (0.11) sheep.

Genetic correlation between conception rates in dry and lactating ewes was obtained using equation 2. The correlation estimate was 0.009 ± 0.026. The small correlation estimate is an indication of inconsistent rank of sires under different environments. This may be explained with the eating habits of ewes. Ewes with large appetites have high conception while lactating, but have low conception while dry because they are still on a high plane of nutrition and may be overweight. Pope et al. (1989) wrote that lactating ewes had higher conception rates than ewes whose lambs were weaned at birth. In contrast, Warren et al. (1989) reported that lactation status had no significant effect on conception rate. However, Pala et al. (2001) reported high conception rates for dry ewes and low conception rates for lactating ewes. Genetic correlation between litter sizes in dry and lactating ewes was obtained also. The correlation estimate was 0.108 ± 0.018. The small estimate indicates that rank of sires is different under different environments for litter size. Selection should be practiced among lactating animals for conception rate and litter size in twice-a-year lambing systems.

Spearman rank-order correlations between conception rate and litter weaning weight, conception rate and litter weaning weight per ewe exposed, litter size and litter weaning weight, and litter size and litter weaning weight per ewe exposed were calculated for the four genetic groups (Table 3). Overall correlations were high and favorable, indicating those traits can be improved together in a twice-a-year lambing program.

Spearman rank-order correlation between conception rate and litter weaning weight was 0.83 ± 0.01. Litter size had high correlations with the litter weaning weight traits also. This suggests that litter weaning weight can be increased along with conception rate and litter size in a selection program based on twice-a-year lambing. Correlations between litter size and litter weight traits were higher than correlations between conception rate and litter weight traits. Al-Shorepy and Notter (1996) reported a genetic correlation between spring fertility and fall litter size per ewe lambing of 0.56.

All correlations were consistent within breed and overall. They were highest for Dorset and lowest for Finnsheep. Composite II ranked higher than Composite I for conception and litter weight traits correlations while Composite I surpassed Composite II for correlations between litter size and litter weight traits. Selecting for these traits together can be useful for all the breeds used in this study.

IMPLICATIONS

Heritability estimates were moderate to high for weight traits and low to moderate for reproduction traits, indicating that selection in twice-a-year lambing programs is feasible. There was no substantial evidence that heritabilities and rank correlations were different among the four breeds. Litter weaning weight may be increased along with conception rate and litter size in a selection program based on twice-a-year lambing. Small genetic correlation between dry and lactating ewes indicated that grouping sires according to the lactation status of the ewes is necessary in a selection program.

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Table 1. The three breeding schedules.

Schedule	Fall Breeding	Spring Breeding
1	August 13 to September 12	February 5 to March 7
2	September 15 to October 16	March 10 to April 9
3	October 22 to November 20	April 11 to May 12

Table 2. Overall and within breed heritabilities.

Item	Breed					
	Dorset	Finnsheep	Composite I	Composite II	Overall	SE[d]
Litter weight	0.33	0.33	0.33	0.36	0.33	0.02
Litter/exp[a]	0.35	0.35	0.31	0.35	0.35	0.01
Weaning weight	0.65	0.41	0.57	0.41	0.64	0.01
ww/c[b]	0.34	0.37	0.60	0.37	0.64	0.01
Conception rate[c]	0.17	0.20	0.27	0.24	0.24	0.01
Litter size	0.08	0.19	0.14	0.13	0.16	0.01

[a]Litter weaning weight per ewe exposed; litter weights multiplied by their respective breed conception rates.
[b]Weaning weight adjusted for conception rate; weaning weight of individual lambs multiplied by their respective breed conception rates.
[c]Adjusted to normal basis according to Van Vleck (1972).
[d]Pooled standard error based on most conservative number in a breed group.

Table 3. Overall and within breed rank-order correlations.

Item	Breed				
	Dorset	Finnsheep	Composite I	Composite II	Overall
Conception and litter weaning weight	0.825 ± 0.005	0.830 ± 0.005	0.856 ± 0.006	0.810 ± 0.009	0.834 ± 0.003
Conception and Litter/exp[a]	0.825 ± 0.005	0.830 ± 0.005	0.856 ± 0.006	0.810 ± 0.008	0.834 ± 0.003
Litter size and litter weaning weight	0.850 ± 0.005	0.843 ± 0.007	0.883 ± 0.008	0.815 ± 0.009	0.850 ± 0.004
Litter size and Litter/exp[a]	0.850 ± 0.005	0.843 ± 0.008	0.883 ± 0.007	0.815 ± 0.011	0.859 ± 0.003

[a]Litter weaning weight per ewe exposed; litter weights multiplied by their respective breed conception rates.

APPENDIX

Table 1. Age of Ewe by breed interaction for litter weaning weight.

Age of Ewe	Breed	Estimate	SE
1	Dorset	27.0274	1.1885
1	Finnsheep	29.3147	1.1377
1	C I	27.4872	1.1210
1	C II	31.2248	1.1378
2	Dorset	32.9627	1.1902
2	Finnsheep	33.6624	1.1819
2	C I	32.9649	1.1450
2	C II	37.8710	1.1623
3	Dorset	35.9909	1.2424
3	Finnsheep	34.1026	1.2878
3	C I	36.0985	1.1659
3	C II	38.6326	1.1929
4	Dorset	34.2836	1.3436
4	Finnsheep	33.3062	1.4742
4	C I	35.1551	1.2303
4	C II	40.3063	1.2719
5	Dorset	33.1069	1.5370
5	Finnsheep	34.8149	1.8197
5	C I	30.7136	1.7279
5	C II	39.3073	1.5531

Table 2. Age of Ewe by cycle interaction for litter weaning weight.

Age of Ewe	Cycle	Estimate	SE
1	1st	32.1146	1.1835
1	2nd	29.7332	1.1999
1	3rd	24.5887	1.2287
1	4th	29.0062	1.1992
1	5th	28.3749	1.1309
2	1st	35.2736	1.2380
2	2nd	35.6942	1.2525
2	3rd	29.3211	1.1837
2	4th	35.9382	1.2539
2	5th	35.5992	1.1536
3	1st	36.8976	1.3350
3	2nd	36.6717	1.3027
3	3rd	32.5029	1.2719
3	4th	36.8852	1.2148
3	5th	38.0733	1.2524
4	1st	36.6794	1.4983
4	2nd	36.4697	1.5284
4	3rd	31.3759	1.4323
4	4th	38.6105	1.3252
4	5th	35.6786	1.2022
5	1st	36.4262	2.3934
5	2nd	33.8850	1.7665
5	3rd	31.2582	1.7415
5	4th	36.9041	1.5177
5	5th	33.9548	1.6313

Table 3. Breed by season interaction for litter weaning weight.

Season	Breed	Estimate	SE
fall	Dorset	30.2583	1.2854
spring	Dorset	35.0903	1.0734
fall	Finnsheep	30.8604	1.2341
spring	Finnsheep	35.2199	1.0592
fall	C I	28.4935	1.2542
spring	C I	36.4742	1.0439
fall	C II	34.3979	1.2794
spring	C II	40.5389	1.0496

Table 4. Cycle by Schedule interaction for litter weaning weight.

Cycle	Schedule	Estimate	SE
1st	1	35.0670	1.2362
1st	2	34.8497	1.2790
1st	3	36.5181	1.3344
2nd	1	36.1714	1.2112
2nd	2	33.9814	1.2363
2nd	3	33.3195	1.2603
3rd	1	34.8003	1.1771
3rd	2	28.5925	1.2170
3rd	3	26.0353	1.2447
4th	1	33.7192	1.1246
4th	2	37.8645	1.2063
4th	3	34.8227	1.2499
5th	1	35.5390	1.1333
5th	2	33.4398	1.1359
5th	3	34.0297	1.1710

Table 5. Age of ewe by breed interaction for weaning weight adjusted for conception rate.

Age of Ewe	Breed	Estimate	SE
1	Dorset	8.2666	0.1542
1	Finnsheep	8.1448	0.1264
1	C I	8.8111	0.1256
1	C II	10.1871	0.1359
2	Dorset	8.3625	0.1464
2	Finnsheep	8.6211	0.1402
2	C I	9.2930	0.1342
2	C II	10.2044	0.1445
3	Dorset	8.2154	0.1607
3	Finnsheep	8.7089	0.1841
3	C I	9.3602	0.1498
3	C II	10.3766	0.1574
4	Dorset	8.2313	0.2036
4	Finnsheep	8.2804	0.2378
4	C I	9.2828	0.1826
4	C II	10.3930	0.1896
5	Dorset	7.5874	0.2413
5	Finnsheep	9.0239	0.3080
5	C I	8.8897	0.2904
5	C II	10.6292	0.2452

Table 6. Age of ewe by cycle interaction for weaning weight adjusted for conception rate.

Age of Ewe	Cycle	Estimate	SE
1	1st	9.5939	0.1430
1	2nd	9.2838	0.1486
1	3rd	7.4465	0.1645
1	4th	9.3883	0.1521
1	5th	8.5495	0.1223
2	1st	9.8543	0.1609
2	2nd	9.9468	0.1630
2	3rd	7.6421	0.1435
2	4th	9.3368	0.1606
2	5th	8.8213	0.1323
3	1st	9.9840	0.2005
3	2nd	9.8604	0.1818
3	3rd	7.9513	0.1724
3	4th	9.2264	0.1579
3	5th	8.8042	0.1595
4	1st	9.8383	0.2452
4	2nd	9.6419	0.2520
4	3rd	7.9439	0.2077
4	4th	9.2856	0.1918
4	5th	8.5247	0.1879
5	1st	9.7753	0.4040
5	2nd	10.1194	0.3067
5	3rd	7.8429	0.2801
5	4th	9.2213	0.2405
5	5th	8.2039	0.2631

Table 7. Breed by cycle interaction for weaning weight adjusted for conception rate.

Cycle	Breed	Estimate	SE
1st	Dorset	9.2587	0.1915
2nd	Dorset	8.6489	0.1837
3rd	Dorset	6.8401	0.1814
4th	Dorset	8.1149	0.1659
5th	Dorset	7.8006	0.1496
1st	Finnsheep	9.4063	0.2013
2nd	Finnsheep	9.3855	0.2035
3rd	Finnsheep	7.3703	0.1952
4th	Finnsheep	8.5002	0.1646
5th	Finnsheep	8.1169	0.1542
1st	C I	9.6642	0.1927
2nd	C I	9.8414	0.1731
3rd	C I	7.8090	0.1576
4th	C I	9.6368	0.1541
5th	C I	8.6855	0.1513
1st	C II	10.9075	0.1826
2nd	C II	11.2061	0.1820
3rd	C II	9.0419	0.1588
4th	C II	10.9149	0.1607
5th	C II	9.7198	0.1470

Table 8. Breed by season interaction for weaning weight adjusted for conception rate.

Season	Breed	Estimate	SE
fall	Dorset	7.6677	0.1963
spring	Dorset	8.5976	0.07293
fall	Finnsheep	7.7655	0.2151
spring	Finnsheep	9.3462	0.09999
fall	C I	8.3271	0.2111
spring	C I	9.9276	0.06806
fall	C II	10.0927	0.2190
spring	C II	10.6234	0.06781

Table 9. Breed by schedule interaction for weaning weight adjusted for conception rate.

Breed	Schedule	Estimate	SE
Dorset	1	8.2724	0.1232
Dorset	2	7.9987	0.1395
Dorset	3	8.1268	0.2150
Finnsheep	1	8.8855	0.1257
Finnsheep	2	8.1967	0.1525
Finnsheep	3	8.5853	0.2554
C I	1	9.6144	0.1062
C I	2	8.6606	0.1255
C I	3	9.1071	0.2427
C II	1	10.4618	0.1095
C II	2	10.2179	0.1367
C II	3	10.3944	0.2399

Table 10. Cycle by season interaction for weaning weight adjusted for conception rate.

Cycle	Season	Estimate	SE
1st	fall	9.5583	0.2415
1st	spring	10.0600	0.1042
2nd	fall	9.4564	0.2394
2nd	spring	10.0845	0.09244
3rd	fall	6.6412	0.2234
3rd	spring	8.8894	0.08624
4th	fall	9.0696	0.2213
4th	spring	9.5138	0.07210
5th	fall	7.5908	0.1960
5th	spring	9.5707	0.07668

Table 11. Cycle by schedule interaction for weaning weight adjusted for conception rate.

Cycle	Schedule	Estimate	SE
1st	1	9.6543	0.1509
1st	2	9.0934	0.1663
1st	3	10.6798	0.2588
2nd	1	10.0930	0.1401
2nd	2	9.3586	0.1615
2nd	3	9.8598	0.2492
3rd	1	8.8184	0.1227
3rd	2	7.2064	0.1488
3rd	3	7.2711	0.2502
4th	1	8.8571	0.1111
4th	2	9.9269	0.1442
4th	3	9.0911	0.2462
5th	1	9.1197	0.1138
5th	2	8.2573	0.1259
5th	3	8.3651	0.2256

Table 12. Season by schedule interaction for weaning weight adjusted for conception rate.

Season	Schedule	Estimate	SE
fall	1	8.2714	0.1099
fall	2	8.2149	0.1654
fall	3	8.9035	0.4133
spring	1	10.3457	0.08852
spring	2	9.3221	0.06305
spring	3	9.2033	0.05679

Table 13. Age of ewe by breed interaction for weaning weight.

Age of Ewe	Breed	Estimate	SE
1	Dorset	16.5354	0.3135
1	Finnsheep	12.3316	0.2555
1	C I	13.6378	0.2513
1	C II	16.3879	0.2694
2	Dorset	16.8299	0.2738
2	Finnsheep	12.9080	0.2770
2	C I	14.3272	0.2529
2	C II	16.1569	0.2666
3	Dorset	16.7945	0.2840
3	Finnsheep	13.1917	0.3358
3	C I	14.5848	0.2645
3	C II	16.6488	0.2829
4	Dorset	16.5354	0.3267
4	Finnsheep	12.4642	0.4082
4	C I	14.2426	0.2942
4	C II	16.5168	0.3057
5	Dorset	15.2569	0.3851
5	Finnsheep	13.8023	0.5638
5	C I	13.6099	0.4620
5	C II	16.9231	0.4093

Table 14. Age of ewe by cycle interaction for weaning weight.

Age of Ewe	Cycle	Estimate	SE
1	1st	16.0606	0.2587
1	2nd	15.5294	0.2621
1	3rd	12.3427	0.2880
1	4th	15.5925	0.2759
1	5th	14.0908	0.4648
2	1st	16.3655	0.2701
2	2nd	16.5005	0.2748
2	3rd	12.6081	0.2518
2	4th	15.4552	0.2776
2	5th	14.3481	0.4382
3	1st	16.8122	0.3239
3	2nd	16.5103	0.2977
3	3rd	13.2423	0.2915
3	4th	15.4035	0.2663
3	5th	14.5564	0.4592
4	1st	16.2491	0.3832
4	2nd	16.1427	0.4053
4	3rd	13.1832	0.3454
4	4th	15.3046	0.3116
4	5th	13.8192	0.4591
5	1st	15.9962	0.6700
5	2nd	16.8243	0.4944
5	3rd	12.7615	0.4590
5	4th	15.3635	0.3851
5	5th	13.5448	0.5806

Table 15. Breed by cycle interaction for weaning weight.

Cycle	Breed	Estimate	SE
1st	Dorset	18.5365	0.3355
2nd	Dorset	17.2800	0.3240
3rd	Dorset	13.8656	0.3251
4th	Dorset	16.4633	0.3027
5th	Dorset	15.8066	0.4684
1st	Finnsheep	14.3528	0.3537
2nd	Finnsheep	14.4679	0.3544
3rd	Finnsheep	11.1049	0.3476
4th	Finnsheep	12.8639	0.3009
5th	Finnsheep	11.9082	0.5067
1st	C I	14.9069	0.3377
2nd	C I	15.3794	0.3061
3rd	C I	11.9565	0.2863
4th	C I	14.8686	0.2824
5th	C I	13.2910	0.4553
1st	C II	17.3906	0.3212
2nd	C II	18.0784	0.3247
3rd	C II	14.3831	0.2890
4th	C II	17.4997	0.2957
5th	C II	15.2816	0.4702

Table 16. Breed by season interaction for weaning weight.

Season	Breed	Estimate	SE
fall	Dorset	15.6688	0.4331
spring	Dorset	17.1120	0.1212
fall	Finnsheep	11.0595	0.4583
spring	Finnsheep	14.8196	0.1657
fall	C I	12.4482	0.4390
spring	C I	15.7127	0.1123
fall	C II	15.6913	0.4619
spring	C II	17.3621	0.1083

Table 17. Breed by schedule interaction for weaning weight.

Breed	Schedule	Estimate	SE
Dorset	1	16.8439	0.2250
Dorset	2	16.5382	0.2664
Dorset	3	15.7892	0.4922
Finnsheep	1	13.7921	0.2340
Finnsheep	2	12.7279	0.2735
Finnsheep	3	12.2987	0.5385
C I	1	15.1386	0.1908
C I	2	13.7081	0.2228
C I	3	13.3946	0.5261
C II	1	16.9099	0.1969
C II	2	16.6646	0.2520
C II	3	16.0055	0.5249

Table 18. Cycle by season interaction for weaning weight.

Cycle	Season	Estimate	SE
1st	fall	15.5879	0.4370
1st	spring	17.0055	0.1708
2nd	fall	15.5748	0.4362
2nd	spring	17.0281	0.1526
3rd	fall	10.7100	0.4232
3rd	spring	14.9450	0.1415
4th	fall	14.7840	0.4265
4th	spring	16.0637	0.1194
5th	fall	11.9280	0.8227
5th	spring	16.2157	0.1298

Table 19. Cycle by schedule interaction for weaning weight.

Cycle	Schedule	Estimate	SE
1st	1	16.2298	0.2374
1st	2	15.4622	0.2737
1st	3	17.1982	0.5281
2nd	1	17.0357	0.2303
2nd	2	16.0032	0.2667
2nd	3	15.8654	0.5092
3rd	1	14.8427	0.1996
3rd	2	12.2539	0.2503
3rd	3	11.3860	0.5213
4th	1	14.9617	0.1833
4th	2	16.8705	0.2432
4th	3	14.4394	0.5240
5th	1	15.2857	0.4164
5th	2	13.9588	0.4242
5th	3	12.9712	0.6379

Table 20. Season by schedule interaction for weaning weight.

Season	Schedule	Estimate	SE
fall	1	13.8882	0.2247
fall	2	13.9981	0.3198
fall	3	13.2646	0.9547
spring	1	17.4540	0.1256
spring	2	15.8213	0.09489
spring	3	15.4795	0.09021

Table 21. Lactation status by age of ewe interaction for conception rate.

Lac Status	Age of Ewe	Estimate	SE
DRY	1	0.5192	0.006093
DRY	2	0.6674	0.008383
DRY	3	0.6767	0.01024
DRY	4	0.6318	0.01241
DRY	5	0.5791	0.01640
LAC	1	0.4017	0.01417
LAC	2	0.4439	0.01325
LAC	3	0.4383	0.01490
LAC	4	0.4017	0.01841
LAC	5	0.4647	0.02200

Table 22. Lactation status by breed interaction for conception rate.

Lac Status	Breed	Estimate	SE
DRY	104	0.5585	0.008941
DRY	108	0.6237	0.01001
DRY	114	0.6492	0.009620
DRY	115	0.6279	0.008704
LAC	104	0.4126	0.01526
LAC	108	0.3573	0.01600
LAC	114	0.5092	0.01256
LAC	115	0.4411	0.01450

Table 23. Age of ewe by breed interaction for conception rate.

Age of Ewe	Breed	Estimate	SE
1	104	0.3388	0.01460
1	108	0.5163	0.01218
1	114	0.5109	0.01138
1	115	0.4759	0.01222
2	104	0.5333	0.01358
2	108	0.5297	0.01279
2	114	0.5976	0.01110
2	115	0.5620	0.01132
3	104	0.5526	0.01445
3	108	0.5036	0.01611
3	114	0.6013	0.01220
3	115	0.5725	0.01272
4	104	0.4850	0.01765
4	108	0.4504	0.02127
4	114	0.5968	0.01474
4	115	0.5346	0.01577
5	104	0.5182	0.02095
5	108	0.4524	0.02891
5	114	0.5893	0.02380
5	115	0.5276	0.02311

Table 24. Lactation status by cycle interaction for conception rate.

Lac Status	Cycle	Estimate	SE
DRY	1st	0.6255	0.01417
DRY	2nd	0.5732	0.01222
DRY	3rd	0.5598	0.009304
DRY	4th	0.6026	0.008845
DRY	5th	0.7130	0.009199
LAC	1st	0.5370	0.02367
LAC	2nd	0.4205	0.01632
LAC	3rd	0.4168	0.01452
LAC	4th	0.4318	0.01352
LAC	5th	0.3441	0.01351

Table 25. Age of ewe by cycle interaction for conception rate.

Age of Ewe	Cycle	Estimate	SE
1	1st	0.5960	0.01854
1	2nd	0.3821	0.01312
1	3rd	0.4442	0.01338
1	4th	0.4592	0.01351
1	5th	0.4209	0.01189
2	1st	0.5866	0.01573
2	2nd	0.5611	0.01582
2	3rd	0.5296	0.01141
2	4th	0.5390	0.01304
2	5th	0.5620	0.01227
3	1st	0.5513	0.01957
3	2nd	0.5550	0.01694
3	3rd	0.5619	0.01459
3	4th	0.5607	0.01229
3	5th	0.5584	0.01422
4	1st	0.5853	0.02424
4	2nd	0.4749	0.02452
4	3rd	0.4529	0.01805
4	4th	0.5215	0.01668
4	5th	0.5490	0.01477
5	1st	0.5870	0.04415
5	2nd	0.5114	0.03043
5	3rd	0.4529	0.02251
5	4th	0.5057	0.01941
5	5th	0.5524	0.02339

Table 26. Cycle by breed interaction for conception rate.

Cycle	Breed	Estimate	SE
1st	104	0.5826	0.02000
2nd	104	0.4762	0.01722
3rd	104	0.4151	0.01461
4th	104	0.4560	0.01415
5th	104	0.4979	0.01429
1st	108	0.5023	0.02230
2nd	108	0.4611	0.01991
3rd	108	0.4519	0.01660
4th	108	0.5230	0.01382
5th	108	0.5142	0.01388
1st	114	0.6187	0.01818
2nd	114	0.5462	0.01536
3rd	114	0.5561	0.01240
4th	114	0.5840	0.01205
5th	114	0.5908	0.01253
1st	115	0.6214	0.01920
2nd	115	0.5041	0.01579
3rd	115	0.5301	0.01247
4th	115	0.5059	0.01283
5th	115	0.5112	0.01264

Table 27. Lactation status by season interaction for conception rate.

Lac Status	Season	Estimate	SE
DRY	fall	0.4419	0.009135
DRY	spring	0.7878	0.005634
LAC	fall	0.1007	0.007856
LAC	spring	0.7594	0.01724

Table 28. Age of ewe by season interaction for conception rate.

Age of Ewe	Season	Estimate	SE
1	fall	0.2406	0.008918
1	spring	0.6803	0.01188
2	fall	0.2890	0.009404
2	spring	0.8223	0.01251
3	fall	0.3066	0.01149
3	spring	0.8084	0.01377
4	fall	0.2730	0.01411
4	spring	0.7605	0.01671
5	fall	0.2472	0.01720
5	spring	0.7965	0.02071

Table 29. Season by breed interaction for conception rate.

Season	Breed	Estimate	SE
fall	104	0.2538	0.01042
spring	104	0.7174	0.01368
fall	108	0.2888	0.01171
spring	108	0.6922	0.01410
fall	114	0.2964	0.01021
spring	114	0.8620	0.01213
fall	115	0.2462	0.009901
spring	115	0.8229	0.01330

Table 30. Cycle by season interaction for conception rate.

Cycle	Season	Estimate	SE
1st	fall	0.2903	0.01464
1st	spring	0.8722	0.02158
2nd	fall	0.3267	0.01318
2nd	spring	0.6671	0.01571
3rd	fall	0.1784	0.01069
3rd	spring	0.7982	0.01290
4th	fall	0.2235	0.01021
4th	spring	0.8110	0.01209
5th	fall	0.3375	0.01044
5th	spring	0.7195	0.01213

Table 31. Lactation status by schedule interaction for conception rate.

Lac Status	Schedule	Estimate	SE
DRY	1	0.7843	0.007416
DRY	2	0.6043	0.007979
DRY	3	0.4558	0.01025
LAC	1	0.3798	0.01335
LAC	2	0.4316	0.01201
LAC	3	0.4788	0.01711

Table 32. Age of ewe by schedule interaction for conception rate.

Age of Ewe	Schedule	Estimate	SE
1	1	0.4948	0.01102
1	2	0.4539	0.01066
1	3	0.4328	0.01330
2	1	0.6208	0.01100
2	2	0.5485	0.01006
2	3	0.4976	0.01241
3	1	0.6268	0.01307
3	2	0.5647	0.01106
3	3	0.4809	0.01343
4	1	0.5883	0.01631
4	2	0.4955	0.01394
4	3	0.4663	0.01608
5	1	0.5796	0.02231
5	2	0.5272	0.01954
5	3	0.4588	0.02184

Table 33. Breed by schedule interaction for conception rate.

Breed	Schedule	Estimate	SE
104	1	0.5567	0.01323
104	2	0.4387	0.01184
104	3	0.4614	0.01404
108	1	0.5135	0.01386
108	2	0.5157	0.01322
108	3	0.4423	0.01536
114	1	0.6614	0.01158
114	2	0.5857	0.01011
114	3	0.4904	0.01272
115	1	0.5966	0.01235
115	2	0.5318	0.01059
115	3	0.4751	0.01283

Table 34. Cycle by schedule interaction for conception rate.

Cycle	Schedule	Estimate	SE
1st	1	0.7509	0.02005
1st	2	0.5320	0.01567
1st	3	0.4609	0.02432
2nd	1	0.6847	0.01623
2nd	2	0.5181	0.01328
2nd	3	0.2879	0.01920
3rd	1	0.4627	0.01254
3rd	2	0.5029	0.01186
3rd	3	0.4993	0.01274
4th	1	0.5284	0.01164
4th	2	0.4871	0.01153
4th	3	0.5362	0.01206
5th	1	0.4836	0.01172
5th	2	0.5498	0.01151
5th	3	0.5522	0.01231

Table 35. Season by schedule interaction for conception rate.

Season	Schedule	Estimate	SE
fall	1	0.5426	0.01038
fall	2	0.2082	0.008808
fall	3	0.06306	0.01018
spring	1	0.6215	0.01012
spring	2	0.8278	0.01092
spring	3	0.8715	0.01787

Table 36. Age of ewe by breed interaction for litter size.

Age of Ewe	Breed	Estimate	SE
1	104	0.2542	0.03561
1	108	1.0875	0.03114
1	114	0.7798	0.02895
1	115	0.7655	0.02949
2	104	0.8038	0.03647
2	108	1.5168	0.03392
2	114	1.3176	0.02949
2	115	1.2975	0.02979
3	104	1.0007	0.03947
3	108	1.5512	0.04299
3	114	1.4475	0.03306
3	115	1.4201	0.03402
4	104	0.8099	0.04812
4	108	1.3989	0.05838
4	114	1.5009	0.04066
4	115	1.4226	0.04246
5	104	0.8953	0.05799
5	108	1.2374	0.08072
5	114	1.5009	0.06746
5	115	1.3647	0.06305

Table 37. Age of ewe by cycle interaction for litter size.

Age of Ewe	Cycle	Estimate	SE
1	1st	0.9569	0.04087
1	2nd	0.6088	0.03505
1	3rd	0.6618	0.03424
1	4th	0.6910	0.03468
1	5th	0.6902	0.03053
2	1st	1.2865	0.04089
2	2nd	1.1743	0.04391
2	3rd	1.1502	0.03006
2	4th	1.1249	0.03556
2	5th	1.4338	0.03278
3	1st	1.2732	0.05292
3	2nd	1.3398	0.04698
3	3rd	1.3345	0.03995
3	4th	1.3968	0.03344
3	5th	1.4301	0.03844
4	1st	1.5001	0.06698
4	2nd	1.0631	0.06903
4	3rd	1.0912	0.04893
4	4th	1.2443	0.04543
4	5th	1.5167	0.04033
5	1st	1.2515	0.1247
5	2nd	1.1581	0.08590
5	3rd	1.1470	0.06274
5	4th	1.2628	0.05393
5	5th	1.4285	0.06613

Table 38. Cycle by breed interaction for litter size.

Cycle	Breed	Estimate	SE
1st	104	0.8589	0.05279
2nd	104	0.7581	0.04741
3rd	104	0.6234	0.03925
4th	104	0.6812	0.03782
5th	104	0.8422	0.03879
1st	108	1.3331	0.05911
2nd	108	1.1634	0.05563
3rd	108	1.2108	0.04542
4th	108	1.4861	0.03712
5th	108	1.5985	0.03743
1st	114	1.3630	0.04940
2nd	114	1.1734	0.04287
3rd	114	1.2833	0.03335
4th	114	1.2639	0.03301
5th	114	1.4631	0.03446
1st	115	1.4596	0.05002
2nd	115	1.1804	0.04376
3rd	115	1.1902	0.03288
4th	115	1.1447	0.03440
5th	115	1.2955	0.03319

Table 39. Age of ewe by season interaction for litter size.

Age of ewe	season	Estimate	SE
1	fall	0.4302	0.02308
1	spring	1.0133	0.02391
2	fall	0.6922	0.02516
2	spring	1.7757	0.02473
3	fall	0.7402	0.03042
3	spring	1.9696	0.02715
4	fall	0.6851	0.03809
4	spring	1.8810	0.03329
5	fall	0.6297	0.04835
5	spring	1.8694	0.05065

Table 40. Season by breed interaction for litter size.

Season	Breed	Estimate	SE
fall	104	0.4457	0.02925
spring	104	1.0599	0.02841
fall	108	0.8405	0.03231
spring	108	1.8762	0.03199
fall	114	0.6789	0.02713
spring	114	1.9398	0.02646
fall	115	0.5769	0.02694
spring	115	1.9313	0.02658

Table 41. Cycle by season interaction for litter size.

Cycle	Season	Estimate	SE
1st	fall	0.6491	0.04108
1st	spring	1.8583	0.04810
2nd	fall	0.7701	0.03669
2nd	spring	1.3676	0.03847
3rd	fall	0.4488	0.02965
3rd	spring	1.7051	0.02694
4th	fall	0.5210	0.02801
4th	spring	1.7669	0.02519
5th	fall	0.7885	0.02866
5th	spring	1.8112	0.02570

Table 42. Age of ewe by schedule interaction for litter size.

Age of ewe	Schedule	Estimate	SE
1	1	0.9268	0.02609
1	2	0.7286	0.02600
1	3	0.5098	0.03160
2	1	1.5281	0.02893
2	2	1.1819	0.02559
2	3	0.9918	0.03169
3	1	1.5913	0.03472
3	2	1.3782	0.02925
3	3	1.0952	0.03502
4	1	1.5385	0.04380
4	2	1.1729	0.03745
4	3	1.1379	0.04284
5	1	1.4551	0.06168
5	2	1.3020	0.05465
5	3	0.9916	0.05979

Table 43. Breed by schedule interaction for litter size.

Breed	Schedule	Estimate	SE
104	1	0.9817	0.03505
104	2	0.6404	0.03088
104	3	0.6363	0.03576
108	1	1.6061	0.03573
108	2	1.4040	0.03549
108	3	1.0649	0.04064
114	1	1.5399	0.03166

Table 44. Breed by schedule interaction for litter size.

Breed	Schedule	Estimate	SE
114	2	1.3156	0.02666
114	3	1.0725	0.03264
115	1	1.5041	0.03222
115	2	1.2507	0.02706
115	3	1.0074	0.03231

Table 45. Cycle by schedule interaction for litter size.

Cycle	Schedule	Estimate	SE
1st	1	1.7119	0.04899
1st	2	1.1589	0.03993
1st	3	0.8902	0.06581
2nd	1	1.5906	0.04395
2nd	2	1.0946	0.03582
2nd	3	0.5213	0.05264
3rd	1	1.1399	0.03329
3rd	2	1.1145	0.03219
3rd	3	0.9764	0.03284
4th	1	1.2767	0.03197
4th	2	1.0740	0.03036
4th	3	1.0811	0.03079
5th	1	1.3207	0.03204
5th	2	1.3215	0.03072
5th	3	1.2573	0.03161

Table 46. Season by schedule interaction for litter size.

Season	Schedule	Estimate	SE
fall	1	1.3008	0.02781
fall	2	0.3955	0.02412
fall	3	0.2102	0.02574
spring	1	1.5152	0.02382
spring	2	1.9099	0.02228
spring	3	1.6803	0.03379

Table 47. Age of ewe by breed interaction for litter weight per ewe exposed.

Age of ewe	Breed	Estimate	SE
1	104	14.1638	0.7100
1	108	18.2661	0.6797
1	114	17.0368	0.6697
1	115	18.8946	0.6798
2	104	16.9374	0.7111
2	108	21.0707	0.7061
2	114	20.4875	0.6841
2	115	22.9301	0.6944
3	104	18.3482	0.7423
3	108	21.3243	0.7694
3	114	22.4493	0.6966
3	115	23.3781	0.7127
4	104	17.4912	0.8027
4	108	20.8097	0.8807
4	114	21.8505	0.7350
4	115	24.3737	0.7599
5	104	16.8560	0.9182
5	108	21.7936	1.0871
5	114	19.1243	1.0323
5	115	23.7747	0.9279

Table 48. Age of ewe by cycle interaction for litter weight per ewe exposed.

Age of ewe	Cycle	Estimate	SE
1	1st	19.1109	0.7071
1	2nd	17.6163	0.7169
1	3rd	14.5877	0.7340
1	4th	17.2710	0.7165
1	5th	16.8657	0.6756
2	1st	20.9117	0.7396
2	2nd	21.1617	0.7483
2	3rd	17.3588	0.7072
2	4th	21.2175	0.7491
2	5th	21.1323	0.6892
3	1st	21.8253	0.7975
3	2nd	21.6663	0.7783
3	3rd	19.2053	0.7599
3	4th	21.7973	0.7257
3	5th	22.3807	0.7482
4	1st	21.7288	0.8952
4	2nd	21.4148	0.9131
4	3rd	18.4878	0.8557
4	4th	22.8873	0.7917
4	5th	21.1376	0.7182
5	1st	21.5161	1.4299
5	2nd	20.0439	1.0554
5	3rd	18.5445	1.0404
5	4th	21.7567	0.9067
5	5th	20.0744	0.9746

Table 49. Breed by season interaction for litter weight per ewe exposed.

Season	Breed	Estimate	SE
fall	104	15.3076	0.7679
spring	104	18.2111	0.6413
fall	108	19.4462	0.7373
spring	108	21.8596	0.6328
fall	114	17.8130	0.7493
spring	114	22.5663	0.6236
fall	115	20.8744	0.7643
spring	115	24.4660	0.6271

Table 50. Cycle by season interaction for litter weight per ewe exposed.

Cycle	Season	Estimate	SE
1st	fall	19.8194	0.8562
1st	spring	22.2177	0.6721
2nd	fall	19.1919	0.8473
2nd	spring	21.5694	0.6489
3rd	fall	14.9507	0.8143
3rd	spring	20.3229	0.6419
4th	fall	19.5443	0.8041
4th	spring	22.4277	0.6231
5th	fall	18.2952	0.7344
5th	spring	22.3410	0.6263

Table 51. Cycle by schedule interaction for litter weight per ewe exposed.

Cycle	Schedule	Estimate	SE
1st	1	20.7655	0.7386
1st	2	20.6670	0.7641
1st	3	21.6233	0.7972
2nd	1	21.3527	0.7236
2nd	2	20.0994	0.7386
2nd	3	19.6898	0.7529
3rd	1	20.6157	0.7032
3rd	2	16.8897	0.7270
3rd	3	15.4050	0.7436
4th	1	19.9320	0.6718
4th	2	22.3950	0.7207
4th	3	20.6309	0.7467
5th	1	20.9646	0.6770
5th	2	19.7911	0.6786
5th	3	20.1987	0.6996