INTRODUCTION

In Canada, sheep are raised primarily to produce slaughter lambs. Genetic improvement programs focus on growth traits and positive genetic trends have been realized (OMAFRA, 2001), but the weight of lambs marketed has upper limits. Selling more lambs boosts income. Thus the Sheep Flock Improvement Program (SFIP) in the province of Ontario provides genetic evaluations for litter size traits as well as growth and carcass characteristics measured on live lambs. Accelerated lambing schemes, which increase lambing frequency to more than once per year, have considerable potential for increasing productivity. However, seasonality of the estrous cycle, common in many breeds, is unacceptable to accelerated lambing. Rideau Arcott, a synthetic developed by the federal government (Ainsworth et al., 1987) and dispersed for commercial use in the early 1980’s, is composed of Finnish Landrace (40%), Suffolk (20%), East Friesian (14%), Shropshire (9%), Dorset (8%), and other breeds (9%). Rideau Arcott ewes cycle out of season, bearing twins or triplets (mean = 2.2 lambs) with good survivability to weaning. Slaughter lambs are of moderate size with adequate muscling and carcass quality. Rideau Arcott has become the third most popular breed in Ontario. Most studies such as those summarized in the review by Fogarty (1995) consider fertility expressed in the usual breeding season. The objective of this research was to determine whether ewes varied in their ability to conceive with exposures throughout the year, and to estimate heritability of fertility in four seasons.

MATERIALS AND METHODS

Several years of breeding data were obtained from a large commercial flock of Rideau Arcotts. Standard production practices had been used. Ewes were managed under an accelerated scheme aimed at having them lamb five times in three years. Hormonal treatments to induce ovulation were applied in about 20% of recorded matings.

Breeding data consisted of lists of ewes and mates with start and end dates of exposures, spanning years 1993 to 1999. Lambing data from SFIP were used to determine conception dates, assuming a gestation of 145 d. Ewes with <100 d between their first and last recorded exposure day were deleted, which simultaneously removed ewes that conceived after their last known exposure and apparently had been sold out of the flock. Pedigrees of ewes were also drawn from the SFIP database.
Mating seasons were defined as the four quarters of the year. Season 4 (October, November, December) was considered the usual breeding period. Season 3 (July, August, September) represented the beginning and Season 1 (January, February, March) the end of the normal period of breeding. Season 2 (April, May, June) was out of season for this flock.

Binary fertility outcomes (conception or not) were assigned within seasons. As females were continually with rams, some recorded exposures might not have been genuine breeding opportunities. Records on ewe lambs 182 d of age or less at a conception or, if no conception occurred, at the first day of exposure in the season were disregarded; all would not have reached puberty by then, though four did conceive. Days of exposure during the 187 d period in which the ewe was deemed pregnant, lambing, or had not yet undergone uterine involution were eliminated, preventing false negatives. Exposures of 5 d or less within a season not resulting in a conception were dropped. Failures therefore occurred for ewes >182 d of age and exposed >5 d in a season but without conceiving. In 6% of the remaining outcomes, the ewe was >182 d old and conceived seemingly without exposure. These cases arose from removing illogical exposure days and assuming a 145 d gestation to determine season of conception, and were treated as successes. The final data set consisted of 5043 outcomes from 682 ewes with 58 sires. Details on the data by season are in Table 1.

**Table 1. Scope of the data (binary outcomes of exposures to rams in four seasons) used to analyze fertility**

<table>
<thead>
<tr>
<th>Season</th>
<th>1 End</th>
<th>2 Out</th>
<th>3 Begin</th>
<th>4 In</th>
</tr>
</thead>
<tbody>
<tr>
<td>Records</td>
<td>875</td>
<td>1555</td>
<td>1417</td>
<td>1196</td>
</tr>
<tr>
<td>Years</td>
<td>6</td>
<td>7</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Ewes</td>
<td>478</td>
<td>624</td>
<td>565</td>
<td>623</td>
</tr>
</tbody>
</table>

End = January, February, March; Out = April, May, June; Begin = July, August, September; In = October, November, December.

Fertility data did not span all four seasons every year. Mating records were unavailable for the first few weeks of the first year of study (1993); information was complete for Seasons 2 to 4. The last year (1999), with no lambing data from the next year, included only Seasons 1 to 2.

General linear model procedures were used to identify factors affecting fertility. The model included fixed effects of season (1 to 4), year (1993 to 1999), and age of ewe (8 classes) as well as random effects of the ewe. Age of ewe when she conceived or otherwise on the first day exposed within a season was initially calculated in days, then converted to years, and truncated to integers that ranged from 0 (i.e., < 1 yr of age) to 11. Ewes ≥7 yr old were grouped together creating eight classes with at least 289 observations each. Season-age subclasses contained 41 or more observations.

Variance components were estimated for fertility in each season, taking into account additive genetic relationships among animals and using derivative-free REML procedures (Graser et al., 1987), specifically software of Boldman et al. (1993). Seasons were presumed to involve
separate traits. For phenotypic variances, a prior of 0.25 was used, which is appropriate for a binomial distribution with equal chance of either outcome. The prior for heritabilities was 0.10. Convergence continued until variance of the log likelihood was less than $10^{-8}$. Though resultant estimates were rerun as priors to prevent fixation on local optima, log likelihoods increased by less than 0.001 with the second run. Convergence proceeded rapidly, with single-trait analyses requiring 26 iterations or less.

**RESULTS AND DISCUSSION**

Fertility was affected by season, year, and age of ewe ($P < 0.001$). Least squares means (Table 2) show a typical pattern: conception rates were highest in the usual breeding season, lowest out of season, and intermediate during transitional periods. Random effects of ewe were also a significant source of variation in fertility. However, separate analyses of seasons revealed that ewe effects were not important ($P > 0.70$) in the usual breeding season or the three-month period afterwards (Season 1). Ewe effects existed out of season ($P < 0.01$) and during the three-month period prior to the usual season ($P < 0.001$).

Heritability estimates (Table 2) verify that the proportions of genetic variation in fertility differed among seasons. In a review of the literature, Fogarty (1995) found a mean estimate of 0.06. Most literature values would pertain to gene expression in the usual breeding season. Al-Shorepy and Notter (1994) obtained estimates for heritability of spring fertility that ranged from 0.08 to 0.18 ($\overline{x} = 0.11$) depending on the analytical model, and closely agree with values reported here for spring and summer (Seasons 2 and 3). Jairath et al. (1998) reported a value of 0.08 for fertility during the same period as Season 3; but they could not confirm exposures. Iniguez et al. (1986) estimated the heritability of probability of conception to be 0.30 for ewes continuously exposed to rams. Results suggest little genetic variation in fertility during the usual breeding season, though higher levels at other times of the year.

**Table 2. Estimates of the mean, heritability, and phenotypic variance of conception rate (%) in four seasons**

<table>
<thead>
<tr>
<th>Season</th>
<th>1 End</th>
<th>2 Out</th>
<th>3 Begin</th>
<th>4 In</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>54.2 ± 5.1</td>
<td>40.6 ± 4.1</td>
<td>62.8 ± 3.9</td>
<td>85.4 ± 3.8</td>
</tr>
<tr>
<td>Heritability</td>
<td>0.01</td>
<td>0.08</td>
<td>0.16</td>
<td>0.03</td>
</tr>
<tr>
<td>Phenotypic variance</td>
<td>22.3</td>
<td>21.5</td>
<td>23.9</td>
<td>15.5</td>
</tr>
</tbody>
</table>

A = Least squares means and SE. End = January, February, March; Out = April, May, June; Begin = July, August, September; In = October, November, December.

Fertility can be viewed as having an underlying normal distribution with an all-or-none phenotypic expression. Heritability on the observed scale (Dempster and Lerner, 1950) depends on the relative incidences of the two possible outcomes, and is maximum but not greater than the underlying heritability when the success rate is 50%. Tosh et al. (1994) illustrated such effects on heritability of ewe fertility. Assuming equal underlying heritabilities...
for all seasons, the conception rates (Table 2) indicate Season 1 should have had the largest heritability on the observed scale and Season 4 the lowest. All-or-none heritabilities would be 63, 62, 61, and 42% of the underlying heritability, for Seasons 1 through 4. The estimates obtained (Table 2) do not show this pattern, suggesting that the proportions of genetic variance truly differed among seasons.

A bivariate analysis of fertility in Seasons 2 and 3 was conducted. The proportions of genetic variance did not warrant investigating correlations among other seasons. Heritability estimates increased by 0.01 compared with single-trait analyses, for both seasons. Estimates of phenotypic and genetic correlations were 0.75 and 0.61, respectively, which might be affected by autocorrelation between outcomes from exposures in adjacent seasons.

CONCLUSION
The estimates of heritability found imply that potential exists for improving fertility outside usual breeding periods using selection. Expanding the breeding season especially by selecting ewes that cycle earlier in the year seems feasible, and would increase conception rates and flock productivity. Little opportunity for increasing fertility in the usual breeding season is evident. Selecting ewes with the ability to breed any time of year would not be expected to harm fertility in the usual season.

ACKNOWLEDGEMENTS
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REFERENCES