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A SYSTEM OF IDENTIFYING FACTORS LIMITING THE REPRODUCTIVE PERFORMANCE OF COMMERCIAL SHEEP FLOCKS

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SUMMARY

A study being conducted to identify the factors limiting the reproductive performance of commercial sheep flocks is described. Errors associated with the various measurements are presented, and include 5.0% (s.e. 0.9) of ewes being recorded as mated but cycle unknown, false returns to service, and errors resulting from the measurement of ovulation rate. With ovulation rates varying from 1.12 to 2.27 ovulations per ewe in the flocks studied, it was concluded that an acceptably small error in estimating the true value for the flock could be obtained by examining 100 ewes in flocks of up to 1000 animals.

INTRODUCTION

Lamb tailing percentages in New Zealand vary greatly between farms within and between areas, ranging from below 70% to more than 130% (NZMWBES, 1977). The relative importance of factors limiting reproductive performance and contributing to this variability is not known, since no investigation has considered the factors as part of the total reproductive process from mating to tailing. For instance, lamb losses of up to 15% of lambs born (Quinlivan and Martin, 1971) may not be as significant as losses due to 32 to 47% of ewes with two ovulations having only one lamb (Quinlivan *et al.*, 1966; Kelly and Allison, 1976a) particularly in flocks with high ovulation rates (*e.g.*, greater than 1.50 ovulations per ewe).

As the reproductive performance of sheep flocks is affected by number of ova shed at mating (ovulation rate), number of ewes mated and reproductive wastage in the mated ewes, it is necessary to adequately measure all three to diagnose the factors limiting reproductive performances. A study to record these three parameters in commercial sheep flocks was commenced in 1975 using an approach similar to that outlined by Chopping and Lindsay (1970). This study has now run long enough to justify publication of the method used together with its limitations and errors, particularly because of the desirability of encouraging similar studies in other regions.

CONDUCT OF THE STUDY

Farmers co-operating in the study were selected primarily on their willingness to assist and to provide a range in lambing percentages. Consideration was also given to time of commencement of mating and distance between farms for co-ordinating farm visits within areas.

Approximately 400 4-tooth ewes were provided by each farmer. The single age class of ewes was chosen to remove any bias due to age differences in comparing performances between flocks. No restrictions were placed on the breed of sheep, so that Romney, Coopworth, Perendale, Borderdale and Drysdale were represented. Apart from being run as a separate flock during mating and lambing, farmers were asked to manage the "study flock" in the normal farm manner. All ewes were individually identified with numbered eartags. The farms were in the region from mid-Canterbury to West Otago.

The following data were recorded for each flock of ewes:

(a) Liveweights on a random sample of 100 ewes three weeks before the commencement of mating, 12 to 17 days after mating commenced (*i.e.,* at laparoscopy) and 2 to 3 weeks before the start of lambing. The liveweight at laparoscopy was recorded after a 12- to 24-hour fast.

(b) Mating records for each ewe. Rams were fitted with "Sire-Sine" harnesses and crayons, and crayon colours were changed on day 17 and day 34 of mating. Crayon marks on the ewes were recorded at day 34 and day 51 when the rams were removed, and from this information the percentage of ewes marked, and returns to service, in each 17-day period of mating were calculated.

(c) Ovulation rate of the flock was estimated from a random sample of marked ewes laparoscoped (Kelly and Allison, 1976b) 12 to 17 days after mating commenced. The number of ewes examined per flock was 50 in 1975, and sufficient to provide either 50 to 55 ewes with two ovulations or at least 80 ewe records in 1976 and 1977.

(d) Lambing records for the flock were taken by each farmer. All of the laparoscoped ewes in 1975 and 1976, and only the laparoscoped ewes with multiple ovulations in 1977, were fitted with neck tags and individual lambing performances (date of birth, number of lambs born) were recorded. Lamb deaths, birth-rank of the dead lambs (*i.e.,* all multiple born lambs marked and therefore identifiable when picked up), number of lambs tailed and ewe deaths were noted for the laparoscoped ewes and the remainder of the flock. At the end of tailing the tag number of each barren ewe was recorded.

The total number of ewes in the flock was checked at all yardings so that any large discrepancies could be investigated and corrected.

From these records tables of mating and lambing performance and components of reproductive wastage per 100 ewes (Chopping and Lindsay, 1970) were calculated. The format of the reproductive wastage table is shown in Table 1. For the component partial failure of multiple pregnancies it has been assumed that in multiple ovulating ewes all ova are either fertilized or not fertilized. This appears to be a valid assumption, based on the evidence of Restall *et al.* (1976) and I. D. Killeen (pers. comm.), the latter finding that of 416 ewes with multiple ovulations only nine (2.2%) had both fertilized and unfertilized ova, with 380 (91.3%) having all ova fertilized and 27 (6.5%) having all ova unfertilized.

ERRORS ASSOCIATED WITH VARIOUS RECORDS

MATING AND LAMBING

The use of "Sire-Sine" harnesses and crayons to record the mating performance of sheep is subject to errors from both

TABLE 1: COMPONENTS OF REPRODUCTIVE WASTAGE FROM MATING TO TAILING PER 100 EWES AT MATING

Source	*Ewes*	*Lambs*	*Lambs Lost*
(a) Ewes joined	100		
(b) Potential lambs (ovulation rate)		(b)	
(c) Ewes			
(i) failing to mate	c_1		$c_1 \times$ (b)
(ii) mated but failing to lamb	c_2		$c_2 \times$ (b)
(iii) dying mating-lambing	c_3		$c_3 \times$ (b)
(d) Ewes lambing	(d)		
(e) Potential lambs from ewes lambing		(e) = (d) × (b)	
(f) Lambs born		(f)	
(g) Loss due to partial failure of multiple ovulations			(g) = (e) — (f)
(h) Losses birth to tailing			(h)
(i) Total lambs tailed (lamb tailing %)		(i) = (f) — (h)	
(j) Total lambs lost			(j) = (h) + (g) + (c)

failure to mark ewes (Radford *et al.*, 1960) and failure of marked ewes to be inseminated (Cahill *et al.*, 1974). An estimate of the error associated with failure to record mating is available from the 49 flocks studied during 1975-77, with a total of 19 876 ewe observations. A mean of 5.0 (s.e. 0.9) of these ewes was initially recorded as being not mated, but as they lambed it is apparent that they should be recorded as "mated but cycle unknown". Returns to service are affected by failure of insemination, variations in cycle length of the ewes, ewes being marked by two colours on the day crayon changes are made, or rams "raping" the ewes. Rams should be removed when ewes are yarded, and if possible when supplementary feeds (grain, hay, silage) are offered to the flock to minimize the error due to rapes. False returns to service are almost impossible to correct in the field situation unless records are taken at least twice during each cycle of mating. However, the number of ewes lambing each day recorded at times related to the times of crayon change can be used to indicate the approximate time of conception and so verify whether a high rate of return to service is a true figure or not. Errors in lambing records are usually minor, except where large areas of bush may result in failure to pick up dead lambs. These situations should be avoided if possible.

Ovulation Rate

The relative importance of the various sources of reproductive wastage listed in Table 1 depends to a large extent on the ovulation rate, and hence the errors associated with its measurement. There are three possible sources of error, failure to observe corpora lutea at laparoscopy, changes in ovulation rate during the period of mating, and sampling error associated with examining only a proportion of the flock.

Failure to observe corpora lutea can be corrected to a certain extent from the lambing records of the laparoscoped ewes. However, it is still likely that the corrected value will slightly underestimate the true value, as death of one of two embryos during pregnancy and returns to service could obscure some errors. Of 3005 laparoscoped ewes with lambing records in the "study flocks", 82 (2.7%) had one more lamb than the recorded number of corpora lutea, and none had two or more. Complications in estimating the potential lambing percentage from the ovulation rate owing to monozygotic twinning are negligible, since identical twinning is a rare phenomenon in sheep (Barton, 1949). This observation is supported by the fact that of 37 ewes with one recorded corpus luteum but two lambs (sex known) only 20 (54%) were of like sex; this is not significantly different from the 1:1 ratio expected with fraternal twins.

Ovulation rate is measured at about the end of the first cycle of mating. The ovulation rate of the ewes that conceive to the second or third cycle of mating, or are not mated or mated but do not lamb (source *c*, Table 1), is assumed to be the same as that of ewes that conceive to the first cycle. This may not be the case, since seasonal and liveweight effects could influence the ovulation rate. Also levels of barrenness are higher in ewes with one than two ovulations (Kelly and Allison, 1976a). This error is likely to be small in the "study flocks" as about 90 to 95% of the ewes are mated in the first cycle, and returns to service are of the order of only 10%. When rates of return to service are high or the proportion of ewes mated in the first cycle is low, as in some hill country areas (Knight and Hight, 1976), several estimates of ovulation rate may be necessary.

The third source of error is that associated with operating on a sample of ewes from the flock. The number of ewes required to give an estimate of the ovulation rate which has a 95% chance of being within ± 0.1 of the true value for the flock is derived from equation 1:

$$0.1 = 1.96 \sqrt{ \{ (1/n) \, [p_1 (1-p_1) + 4p_2 (1-p_2) + 9p_3 (1-p_3) - 4p_1 p_2 - 6p_1 p_3 - 12p_2 p_3] \, (1-n/N) \} }$$

where p_i = proportion of ewes which ovulate i times (i = 1, 2, 3)
n = number of ewes laparoscoped
N = size of population

In order that the estimate has a 95% chance of being within ± 0.05 of the true ovulation rate, the value of n_1 is given by equation 2:

$$n_1 = 4nN/(N + 3n)$$

The value of n_1 in many cases is twice the size of n.

The derivation of both equations is given in the Appendix.

When the sampling error was examined, it appeared that, with the amount of work required, an error of ± 0.1 for the true ovulation rate was acceptably small. A selection of sample sizes for flocks of 100, 400 and 1000 ewes which gives this degree of accuracy where the true ovulation rate varies from 1.10 to 2.20 ovulations per ewe mated is given in Table 2. This covers most of the situations encountered. The maximum proportion of ewes with three ovulations in the "study flocks" with ovulation rates of 1.50 to 2.00 ovulations per ewe was 0.11, and only 6/1378 (0.4%) of ewes in 13 flocks with an ovulation rate of less than 1.50 had three ovulations. If the flock being considered is larger than 1000 ewes, in order that the estimated ovulation rate has a 95% chance of being within 0.1 ovulations per ewe of the true value, the number examined for 1000 ewes should be increased by the difference in n between flocks of 400 and 1000 ewes. The proportion of ewes with three ovulations can markedly influence the number of ewes that need to be examined, the difference being most pronounced for the ovulation rate of 1.80. A change in the proportion of ewes with three ovulations from zero to 0.10 approximately doubles the number of ewes that need to be examined.

TABLE 2: SIZE OF A RANDOM SAMPLE FOR 95% OF ESTIMATES TO BE WITHIN ± 0.1 OF THE TRUE OVULATION RATES FOR N EWES

Ovulation Rate	p_1*	p_2*	p_3*	*Size of sample for values of N* (N=100)	(N=400)	(N=1000)
1.10	0.90	0.10		26	32	34
1.20	0.80	0.20		39	54	58
1.30	0.70	0.30		45	68	75
1.40	0.60	0.40		48	75	85
1.50	0.50	0.50		49	78	88
1.60	0.40	0.60	0.00	48	75	85
	0.45	0.50	0.05	57	99	116
	0.50	0.40	0.10	63	119	145
1.70	0.30	0.70	0.00	45	68	75
	0.35	0.60	0.05	55	92	107
	0.40	0.50	0.10	62	113	136
1.80	0.20	0.80	0.00	39	54	58
	0.25	0.70	0.05	50	80	91
	0.30	0.60	0.10	58	103	122
1.90	0.15	0.80	0.05	43	62	68
	0.20	0.70	0.10	53	88	101
2.00	0.10	0.80	0.10	44	65	72
	0.15	0.70	0.15	54	90	104
	0.20	0.60	0.20	61	111	134
2.10	0.05	0.80	0.15	43	62	68
	0.10	0.70	0.20	53	88	101
2.20	0.00	0.80	0.20	39	53	58

*p_1, p_2, p_3 = proportion of ewes with 1, 2 or 3 ovulations.

GENERAL DISCUSSION

The technique described in this paper to diagnose factors limiting the reproductive performance of commercial sheep flocks has many errors, but the majority of them are small. At least in the initial examination of the reproductive performance of the flock, the technique is adequate, and it is not necessary to resort to more refined techniques (vaginal swabbings to detect sperm, recovery of ova for fertilization rates, etc.) until there is sufficient evidence to justify an intensive approach. However, there is one aspect of the technique that can profoundly affect a diagnosis, and that is the accuracy of estimating ovulation rate of the flock. In 1975 only 50 ewes were examined per flock to estimate ovulation rate, and it was apparent that, with ovulation rates varying from 1.42 to 2.27 ovulations per ewe (range 1.12 to 2.18 in 1976 and 1977), insufficient ewes were being examined to have an acceptable degree of accuracy. It is likely that ovulation rates also vary considerably between flocks in other parts of New Zealand. Therefore it is essential for the diagnosis of poor reproductive performance due to low ovulation rates and the assessment of the relative importance of the components of reproductive wastage that ovulation rate be measured as accurately as possible.

At present about 40 ewes per hour can be examined using a laparoscope and a team of six people. It is therefore possible to visit at least two farms per day examining between 70 and 100 ewes per farm. This generally gives a 95% chance for the estimate of ovulation rate to be within 0.1 of the true value in flocks of up to 1000 ewes (Table 2). As a general rule it is recommended that, when little is known of the potential ovulation rate of a flock of ewes, this degree of accuracy can be attained if either 100 ewes or sufficient ewes to provide 50 to 55 ewes with two ovulations are examined, whichever comes first.

Other systems used to analyse and correct low lamb tailing percentages can be divided into two categories on whether or not ovulation rate is recorded. Those proposed by Connors (1971) and Quinlivan (1977) fall into the category of not measuring ovulation rate. Connors (1971) uses the system of considering the potential of the flock to be 100% of the ewes rearing lambs, with all wastage calculated on a per-ewe basis. This system is not appropriate to New Zealand flocks as it takes no account of ovulation rate (which in this study has accounted for about 50% of the variation between farms in lamb tailing percentages), partial failure of multiple pregnancies, or death of multiple versus single-born lambs. Quinlivan (1977) outlines many techniques for defining and correcting poor reproductive performance in sheep, but considers measurement of ovulation rate to have little application in the average flock situation. Until relationships between the lambing observations proposed by Quinlivan (1977) and ovulation rate are established, similar limitations exist in these techniques as in that proposed by Connors (1971).

Methods involving measuring ovulation rate to help to identify factors limiting reproductive performance have been proposed by Chopping and Lindsay (1970) and Cutten (1975). Both methods are similar to the approach used in the survey outlined in this paper, the main differences being that fewer lambing records are taken, smaller numbers of ewes are examined to estimate ovulation rate (Chopping and Lindsay, 1970) and a more frequent recording of ewe performance during mating (Cutten, 1975). The frequency of yarding for the method suggested by Cutten (1975) varies from weekly to fortnightly with three yardings to record crayon marks and three to draft out ewes for laparotomy. Such intensive recordings do not appear justified until specific problems related to poor mating performances have been diagnosed.

Application of Studies Defining the Limitations of Reproductive Performance

The information accruing from studies such as that outlined in this paper has two immediate applications. The first is that it highlights to local farm advisory personnel factors limiting reproductive performance of flocks in their areas and allows the immediate application of present knowledge to overcome some of these problems. For instance, mating records can be used to define low percentages of ewes mated in the first cycle, failure of fertilization or early embryonic mortality (large percentage of ewes returning to service at an interval of one cycle), or late embryonic mortality (ewes returning at intervals of more than one cycle). These can be corrected by adjusting the time of mating, serum testing of rams, the use of trace elements (*e.g.*, selenium) and other strategies.

Ovulation rate defines the potential lambing percentage for a flock. Although impossible to measure on all flocks the establishment of correlations between ovulation rate and lambs born per ewe lambing (LB/EL) for particular regions can, if the correlation is sufficiently high, result in LB/EL being used as a diagnostic tool to define low ovulation rates. For the flocks studied, the correlation coefficients between mean ovulation rate and mean LB/EL were 0.89 and 0.79 in 1976 and 1977, respectively ($p < 0.001$). This suggests that measurements of liveweight at mating and LB/EL could be used to define low ovulation rates in the regions covered by the study. It is important that similar relationships be investigated in other regions so that either general or specific recommendations can be made.

The second application of this work is to allow the economic analyses of the identified losses and the establishment of justifiable research priorities. Early indications are that low ovulation rates and partial failure of multiple pregnancies are major factors limiting the reproductive performance of commercial sheep flocks.

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APPENDIX

Derivation of sampling formulae in text

The ovulation rate r^1 in a random sample of ewes from a flock is given by

$$r^1 = p^1_1 + 2p^1_2 + 3p^1_3$$

where p^1_i $(i = 1, 2, 3)$ is the number of ewes in the sample ovulating i times. The variance of r^1 as an estimate of the true ovulation rate r for the flock as a whole is then given by the equation

$$\text{var } r^1 = \text{var } p^1_1 + 4 \text{ var } p^1_2 + 9 \text{ var } p^1_3 + 4 \text{ cov } p^1_1 p^1_2 + 6 \text{ cov } p^1_1 p^1_3 + 12 \text{ cov } p^1_2 p^1_3 \quad \text{(A1)}$$

where the variances and covariances on the right-hand side are for p^1_1, p^1_2, p^1_3 as estimates of the true values p_1, p_2, p_3 for the flock.
p_3 for the flock.
For the multinomial distribution

$$\text{var } p^1_i = p_i \ (1 - p_i)/n, \ \text{cov } p^1_i p^1_j = - p_i p_j/n \quad \text{(A2)}$$

and when these are substituted in (A1) and a finite sampling correction $(1 - n/N)$ applied we obtain the approximate formula

$$\text{var } r = (1/n) \ [p_1 (1 - p_1) + 4p_2 (1 - p_2) + 9p_3 (1 - p_3) - 4p_1 p_2 - 6p_1 p_3 - 12p_2 p_3] \ (1 - n/N) \quad \text{(A3)}$$

Use of a normal approximation to the distribution of r then leads to equation 1 of the text. If the left-hand side of 1 is taken as 0.05 instead of 0.1, var r has to be reduced to a quarter, so that the corresponding sample size n_1 has to satisfy the relation

$$1/n_1 . (1 - n_1/N) = 1/4 . 1/n . (1 - n/N) \quad \text{(A4)}$$

which reduces to equation 2 of the text.