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Role of reproductive technologies in reducing the time lag associated with the commercial application of genetic discovery in the sheep industry.

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ABSTRACT

The recent and escalating emphasis on gene discovery has major implications for genetic improvement of the NZ sheep industry. However, the long lag phase in the dissemination of new genetic material through current breeding structures is a major impediment to rapid uptake of the improvements. Effective reproductive technologies are considered necessary for achieving the desired rates of dissemination but there is little evidence of their practical and economic values. To provide evidence, a series of modelling exercises were undertaken. This involved defining a particular commercial outcome (advancing the pattern of lamb kill in Otago/Southland by 1 month without changing lambing date), deciding on the relevant genetic trait to achieve this (terminal sires with a 20% increase in mature size), modelling the rate of genetic gain using a number of breeding scenarios that included artificial insemination (AI) and multiple ovulation and embryo transfer (MOET), to determine the time required for sufficient commercial rams to be available to achieve the outcome. Selected scenarios were then chosen for more detailed modelling to ascertain the economic implications to the farm (Otago/Southland lamb finishing farm) and to the industry of adopting the technology. The advancement of the kill pattern by one month was worth \$12,714 on the commercial farm. Based on a two-tiered breeding system (stud and commercial) without any reproductive technology it takes 26 years to achieve the outcome (assuming that the animal with this genetic advantage had been identified at the start). The use of AI at the stud level reduced this time by 11 years. The additional use of MOET on stud ewes gave a further reduction in time of 7 years and the application of AI using stud rams at the commercial level an additional 2 years. These results confirm the importance of reproductive technologies in reducing the lag phase in gene dissemination and their value to the industry. There is a need to further refine the efficiency and efficacy of the chosen technologies.

Keywords: AI; MOET; genetic gain; sheep; economics; breeding system; models; growth rate; pattern of lambkill.

INTRODUCTION

The recent and escalating emphasis on gene discovery has major implications for genetic improvement of the NZ sheep industry. However, the long lag phase in the dissemination of new genetic material through current breeding structures is a major impediment to rapid uptake of the improvements. Effective reproductive technologies such as artificial insemination (AI) and multiple ovulation and embryo transfer (MOET) are considered necessary for achieving the desired rates of dissemination. Examples of their effects on rates of genetic improvement have been presented (Evans, 1991; Maxwell and Wilson, 1990; Smith, 1986). Windsor and Vanbueren (1994) have showed the benefits of their use in the Australian merino wool industry, but there is little published evidence of the practical and economic values of their use in the New Zealand sheep industry. These values would depend on the end product, the particular genotype selected for dissemination and the extent of that dissemination.

METHODS

Approach. This was to select a particular end product and farming scenario, decide on an appropriate genotype, model the effect of the use of different reproductive technologies on the time taken to achieve the genetic gain required to achieve the desired effect, and then evaluate the benefits of the new scenario on individual farm economics.

Selection of farming scenario.

This was done in consultation with K. Geenty

(WoolPro), N. Clarke and M. Aspin (Meat NZ). The scenario selected was "to advance the pattern of lambkill in Otago and Southland by one month without altering lambing date". To achieve this objective the characteristic chosen for selection was increased growth rate in terminal sire rams. The increase in the 'potential mature size' parameter - which sets growth rate – required to achieve a 1 month advance in lamb weights was determined using 'Stockpol™' (Marshall *et al.*, 1991; Webby *et al.*, 1995). An Otago/Southland lamb finishing farm was modelled with the model set to maintain the same feeding conditions (thresholds for minimum pasture cover) on both farms.

Model methodology for animal breeding scenarios.

The sheep breeding structure in New Zealand is two-tiered, consisting of a closed nucleus of ram breeders providing sires for a commercial sector (Stewart and Garrick, 1996), and here we conceptualise this as one stud flock (Terminal sire) and one commercial flock (Coopworth). Eight different scenarios of selection and use of reproductive technologies were evaluated (Table 1) in a specially constructed genetic gain model. These were used to determine the time required to achieve the desired level of genetic improvement. The animal-breeding model used the assumption of a two tiered breeding structure with stud and commercial flocks with different levels of selection intensity and generation interval depending on the scenario used (Table 2).

TABLE 1. Scenarios for the application of reproductive technologies used in model to determine time taken to achieve target increase in lamb growth rate.

Scenario	Description
1	Natural mating with stud sires No female stud selection
2	Natural mating with commercial sires AI mating with stud sires No female stud selection
3	Natural mating with commercial sires AI mating with stud sires No female stud selection
4	AI for 1 cycle and natural mating for remainder with commercial sires
5	As for scenario #1 but with Selection of stud females
6	As for scenario # 2 but with Selection of stud females
7	As for scenario # 3 but with Selection of stud females
8	As for scenario # 3 but with MOET on stud females
	As for scenario # 3 but with MOET on stud females

The reproductive technologies evaluated were AI either in the stud or in both stud and commercial flocks and MOET with selected stud ewes.

Mathematical Outline of breeding model. It was assumed that the variance and heritability in yearling weight are the same for both commercial and stud flocks, and unaffected by selection.

Following Bulmer (1980) and Dalton (1980), if selection is based solely on yearling weight, the progress of the stud flock is given by: $\mu_s(T)=\mu_s(0) + T(i_a+i_b)h^2s_s^2/2G_s$,

where $\mu_s(T)$ is the yearling weight of rams in year T after selection began (year 0), i_a and i_b are selection intensities for stud rams and ewes respectively, h^2 is the heritability of yearling weights, and s_s^2 is the phenotypic variance for yearling weight. G_s , the generation interval for the progeny, is the average of the generation intervals for stud rams and ewes. It was assumed that there is no genetic gain in the commercial flock, which has a mean yearling weight of μ_c . In year T , the stud rams used as sires across the commercial flock are those just matured in the stud flock $\mu_s(T)$ plus rams of the three previous years. If the stud sires across the commercial flock come from the top p_1 sires minus the top p_2 sires ($p_2 < p_1$), then the corresponding selection intensity is derived to be: $i_{p1,p2}=(p_1 i_{p1} - p_2 i_{p2})/(p_1-p_2)$.

Assuming hybrid vigour, V_h is additive. The average yearling weight of offspring from the commercial flock is taken as the phenotypic averages of the sire selection and the ewes (unselected), plus hybrid vigour. For year T : $\mu_p(T) = (2V_h + \mu_c + \mu_s(0))/2 + h^2s_s^2(0.5 i_{p1,p2} + (2T-3)(i_a+i_b)/8G_s)$ where the first term is the base value (without selection in the stud flock) and the second term is the advantage over the base.

Assumptions made for breeding model;

- Heritability (h^2) estimates of 0.25, 0.30 and 0.35 were used for growth rate (selection on yearling live weight) in the model to determine the sensitivity to heritability.
- Phenotypic standard deviations (s_{sp}) of 4.5 kg and 5.5 kg were used.

- Mean yearling live weight of terminal sire flock was 55 kg at the start of selection.
- Mean yearling live weight of the commercial flock was assumed to be constant at 48 kg.
- Hybrid vigour was assumed to contribute 10% (5.2 kg) on top of base starting average.
- For natural mating (NM), selection intensities were based on using rams from the top 5% across the breed (for growth rate) in stud flocks and next top 55% in commercial flocks.
- For AI in studs, selection intensities were based on using the top 0.1% rams across the breed (for growth rate) in stud flocks and the next top 55% used for NM in commercial flocks.
- For AI in both stud and commercial flocks, the top 0.1% of rams was used in stud flocks and the top 2% in commercial flocks. In the commercial flock only 65% of ewes became pregnant to one 'cycle' of AI thus the remaining 35% were assumed to become pregnant to NM by rams from the next top 18% on genetic merit.
- When selection was placed on stud ewes the best 55% of ewes were used and this was reduced to 20% if MOET was employed.
- NM rams were used for an average of 4 years on commercial farms and 2 years in stud flocks.

Economic Model. 'Stockpol™' was used and modelled an Otago / Southland lamb finishing farm.

Assumptions used in the 'Stockpol™' evaluation;

- Farm size of 170 ha.
- Stock numbers were adjusted to achieve a biologically sustainable maximum (2093 Coopworth ewes) and all ewe replacements were purchased.
- All rams used were terminal sires and a ram to ewe ratio of 1:100 was used.
- Ewe mating weight of 60kg with mating date of April 9 and 120% lambs weaned early December.
- Pasture growth of 11 tonne /annum/ ha distributed as per the 'Southland pattern' in the 'Stockpol™' database. Hay (4,280 bales) was made on the property and fed back between mid-May and mid-August. Shearing occurred in January and wool returns were calculated using \$3.00/kg net (i.e. shearing costs subtracted).
- The 'standard' 16.3 kg average carcass weight was based on ewe lambs at 14.1 kg and ram lambs at 18.5kg.
- Average value of a 'standard' 16.3 kg lamb was \$40.
- The standard lamb slaughter pattern was based on throughput data from Alliance meat works in Otago and Southland. [Killing pattern: Dec. 9%, Jan. 17%, Feb. 14%, Mar. 21%, April 15%, May 18%, and June 6%.] The advanced pattern brought this forward one-month with the same carcass weights (Figure 1).
- Added value of earlier lamb was to be reflected in the premiums paid for lambs slaughtered in November and December, compared to the remainder of the season. Two premium schedules were used based on past premiums paid by Alliance. These were premiums of 40% and 20% for lambs slaughtered in November and December, or premiums of 30% and 15%, respectively.
- Breakeven advantages and costs were calculated from

- a Net Present Value analysis over the next 26 years. Twenty-six years was chosen as this is the time taken under current breeding structures to achieve the target genetic gain. A NPV discount rate of 5% was used.
- Commercial ram costs were assumed to be \$450 for calculation of AI breakeven cost analysis in commercial flocks.

Industry Assumptions.

That there was a potential for 35% of ewes to be mated to the terminal sire ram in Otago / Southland area, with the remainder mated to Coopworth rams to produce flock replacements and with 23% of those lambs retained. Thus lambs sired by terminal rams could potentially represent 41% of the 12.64 million lambs slaughtered (NZ Meat and Wool Economic Service –Farm Production Statistics 1999) = 5.18 million.

RESULTS

Rates of genetic progress.

Advancing the pattern of lamb kill by one month via genetic means requires a 10% increase in lamb growth potential. This means an increased growth potential of approximately 20% is required in terminal sire rams.

The effect of the mating scenario on the time taken to achieve the required increase in lamb growth rate is presented in Table 2. Assuming a heritability of 0.30 and a phenotypic standard deviation of 4.5 kg, the current system (Scenario 1) using NM and selection on the sire alone takes 26.4 years. The implementation of AI in the stud (Scenario 2) reduced this to 15.0 years and use of AI in both stud and on commercial flocks (Scenario 3) further reduced this to 12.8 years. The use of selection on the stud ewes produced a reduction of 6.5 years under NM (Scenario 4), and further reductions of 7.2 and 9.1 years when combined with AI (Scenarios 5&6). The gain from the use of AI +NM in commercial flocks was small compared to that achieved with NM alone (scenarios 3 vs. 2 = 2.2 years and scenarios 5 vs. 6 = 1.9 years). The implementation of MOET and AI showed the greatest reduction in time to outcome with values of 7.9 and 6.8 years (Scenarios 7&8) respectively. The level of heritability had an effect with the higher the values the shorter the interval and similarly with phenotypic standard deviation (data not shown). However, there was no indication of any interaction with the different scenarios.

Economic outcome.

Summaries of the results are shown below and the farm performance values are shown in Table 3.

- The advantage to the Southland /Otago sheep industry of advancing the pattern of kill by one month via growth genetics of terminal sire rams is \$26.2 million/year. Thus advancing the lamb kill by one month without altering lambing date would be worth \$12,714 per ‘standard farm’ in Otago / Southland.
- Half the advantage comes from the 5.4% increase in ewe stocking rate made possible from reduced lamb feed demands.
- The increase in average lamb value (\$2.08) was not great and reflects that, even for the ‘advanced kill farm’, premiums were paid on only 26% of lambs slaughtered.
- The sensitivity to the premium level is shown in that the advantage in total returns over the standard farm at the lower premium level was \$11,312.
- NPVs over 26 years of the benefits from the adoption of the advanced pattern of lamb kill is shown in Figure 2 with the effects of the different breeding scenarios reflected in the years taken to achieve the goal. The shorter the period the greater the benefit.
- The breakeven advantage of the extra value of using superior terminal sire rams, sourced from studs selecting for increased growth rate used NM, in commercial flocks, over the next 26 years is \$960 per ram. If AI

FIGURE 1: Patterns of lamb kill for Otago/Southland finishing farms. Standard is current pattern used for the control or unselected farm and advanced is the desired scenario with the pattern advanced by 1 month.

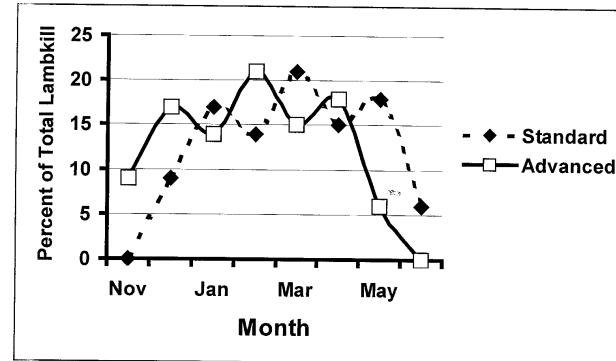


TABLE 2. Years taken to reach a 10% increase in lamb growth rate of commercial lambs with different mating scenarios assuming heritabilities of 0.25, 0.30, 0.35 and a phenotypic standard deviation of 4.5kg..

Scenarios	Selection*	GI	Years to target		
			$h_s^2 = 0.25$	$h_s^2 = 0.30$	$h_s^2 = 0.35$
1	$ss_{NM} = 0.05$; $sf = 1$; $sc_{NM} = 0.6 - 0.05$	2.5+4	31.7	26.4	22.6
2	$ss_{AI} = 0.001$; $sf = 1$; $cs_{NM} = 0.55 - 0.001$	2+4	18.0	15.0	12.9
3	$ss_{AI} = 0.001$; $sf = 1$; $cs_{AI} = 0.02 - 0.001$; $cs_{NM} = 0.2 - 0.02$	2+4	15.8	12.8	10.7
4	$ss_{NM} = 0.05$; $sf = 0.55$; $cs_{NM} = 0.6 - 0.05$	2.5+4	23.8	19.9	17.1
5	$ss_{AI} = 0.001$; $sf = .55$; $cs_{NM} = 0.55 - 0.001$	2+4	15.1	12.7	10.9
6	$ss_{AI} = 0.001$; $sf = 0.55$; $cs_{AI} = 0.02 - 0.001$; $cs_{NM} = 0.2 - 0.02$	2+4	13.3	10.8	9.1
7	$ss_{AI} = 0.001$; $sf = 0.2$; $cs_{NM} = 0.55 - 0.001$	2+2	9.3	7.9	6.9
8	$ss_{AI} = 0.001$; $sf = 0.2$; $cs_{AI} = 0.02 - 0.001$; $cs_{NM} = 0.2 - 0.02$	2+2	8.2	6.8	5.8

Notes:-1* ss = selected proportion of rams (sires) used for mating in studs ; sf = selected proportion of stud ewes used; cs = selected proportion (range) of stud rams used for mating in commercial flocks.

2 GI = generation interval based on the time that males and females remain in the stud flock.

was used in those studs this would increase by an extra \$700 up to \$1660 per ram in today's dollars.

- Assuming that one saleable stud ram is obtained from every three stud ewes mated, the breakeven cost to stud farmers if they received all of this advantage is \$320 and \$555 per stud ewe mated in today's dollars for the NM and AI scenarios respectively. The increment of \$235 for the use of AI will more than cover the costs.
- The breakeven cost of AI in the commercial flock is \$3.13 for one insemination of every ewe joined (\$0.72 of this comes from savings on NM ram costs).

TABLE 3: Farm performance parameters assuming operation at maximum stocking rate.

Parameter	Standard farm	Advance kill farm	Advantage
No. Ewes	2093	2207	114
No. Lambs	2512	2648	136
Lamb carcass wt (kg)	16.3	16.3	
Lamb Value ⁽¹⁾	\$40.72	\$42.80	\$2.08
Lamb returns	\$102,272	\$113,352	\$11,079
Wool (kg)	9607	10152	545
Wool returns (net) ⁽²⁾	\$28,821	\$30,456	\$1,635
Total returns	\$131,093	\$143,808	\$12,714
Sensitivity to lamb premium			
Total return at lower premiums.			\$11,312

Notes:- ⁽¹⁾ Average price received for all lambs over the whole killing period.

⁽²⁾ Net value in that shearing costs have been subtracted.

DISCUSSION

The financial benefit of achieving the outcome of the selected farming scenario was shown to be substantial (Table 3). Benefits were derived both from the increased proportion of the lambs sold that attained the premium prices but also through the increased stocking rate that was possible through the earlier sale of lambs and, thus, the reduced feed demands.

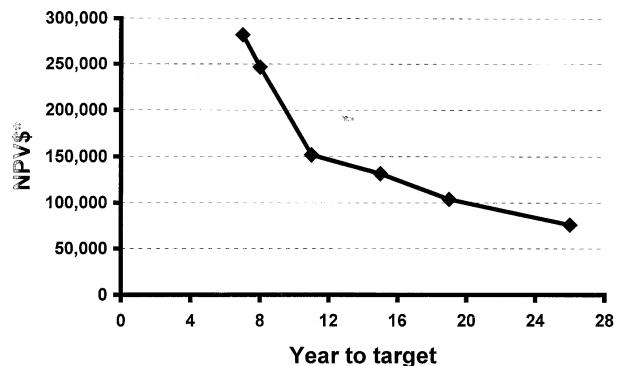
The genetic improvement (20% increase in yearling weight of terminal sires) required to achieve the production scenario outcome was realistic. However, the time required to achieve that outcome under present breeding systems must cause concern among those advocating that the industry become flexible and dynamic. A 26-year lag time does not fit that image.

The value in the use of reproductive technologies to hasten the achievement time of the outcome was very evident from the results presented in Table 2 and Figure 2.

The majority of this gain in time comes through the increased selection intensity available with AI in particular and with the reduction in generation interval with MOET. The use of AI in the commercial flocks, as well as in studs, did not realise any great extra advantage over AI in studs alone and this was partly due to the selection intensity being only marginally lower as a result of the need for backup NM rams. The advantage of the increased financial returns to the studs from higher value rams would more than adequately cover the costs of AI using laparoscopic insemination. This illustrates the benefit of the technology when the progeny are retained for breeding purposes and the resulting compounding of genetic merit and value. However the very low breakeven costs for AI on the commercial farms is such that it is unlikely that any method

FIGURE 2: Net present value (NPV) \$ of benefits in advanced commercial flock relative to standard flock flock and effect of time taken to reach the target growth rate.

NPV\$* NPV of relative benefits of advancing the season of kill accruing to commercial farm over 26 years compared to standard farm. Values are on basis of no additional costs for the reproductive technologies. Year to target calculated from breeding model depends on scenario of selection and reproductive technologies used.



of AI could be used economically for this farming scenario. This highlights the fact that where the offspring from AI are designated for slaughter, the price differential for those animals needs to be considerable for any AI technique to be economic. It also means that low cost AI techniques such as the use of frozen semen via the cervical route need to be researched and perfected. These results emphasise the economic benefits of the use of reproductive technologies and causes one to question why their current usage in the industry is so low. The reason often given is the lack of any apparent benefit from the increased value of the resulting offspring. One must then question the rationale used for the choice of particular sires, the short-term expectations of returns, the lack of any industry wide co-ordination as to outcome scenarios and, thus, the lack of consensus on the specific characteristics to be selected for that would benefit the industry. It is also obvious that any hope the industry has of utilising the current advances in gene discovery requires both the application of economic methods of rapid gene dissemination and also some industry cohesion to determine the desired outcome scenarios and, thus, traits to be selected. The economic benefits of selection for certain reproductive traits (Amer *et al.* 1999) and disadvantage of delays in sheep genetic improvement (Amer, 1999) are supported by the findings of the present work.

The use of marker-assisted selection was not considered in the present exercise as the estimates for heritability and generation interval are dependent on the trait involved and the particular marker chosen. However, while the use of such markers could further decrease the lag time involved, there will still be a need for techniques such as AI and MOET for the dissemination of these genes to be effective.

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