Management to Optimise the Genetic Improvement of Australian Dairy Sheep
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by

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Foreword

The research was initiated by Meredith Dairy, which had been milking sheep since 1991, and manufacturing it into cheese and yoghurt. The main cause of inadequate sheep milk production in Australia has been the lack of a transparent model for profitably milking sheep, which in turn has its roots in the lack of a breed or breeds of sheep, purchasable by sheep dairy farmers, with a demonstrable inherited ability to give profitable yields of sheep milk. Nevertheless there are individual sheep within Australia, principally crossbreds derived from the East Friesland breed, that yield in excess of 400 litres in a lactation, which approximates the average yield from the leading European dairy breeds.

The aim of this research was to devise management protocols that both maximise the milk yield of Australian dairy sheep, and optimise the ability to select for milk production.

The project was funded by RIRDC Core funds and the report is an addition to RIRDC’s diverse range of over 2000 research publications, forms part of our New Animal Products R&D program, which aims to accelerate the development of viable new animal industries.

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Executive Summary

What the report is about

The sheep dairy industry in Australia is constrained by the absence of a demonstrably profitable model for producing sheep milk, which in turn is largely because dairy breeds of the standard found in Europe are not commercially available.

This report describes a series of experiments aimed at defining management techniques that optimise the milk production from the available sheep, and optimise selection for genetic gain in these sheep.

Who is the report targeted at?

The findings are targeted to existing and prospective sheep dairy enterprises in Australia.

Background

Sales by Meredith Dairy and all other businesses that process sheep milk in Australia are restricted by inadequate milk supply because Australia has no readily available dairy breeds. Milk production is based on crossbred ewes that incorporate the East Friesland breed, which have individuals that yield similar milk volumes to the better dairy breeds of Europe, but which have average yields that are about 40% lower. The wide variation in milk yield is a necessary prerequisite for rapid genetic gain, but management and selection protocols that most accurately predict the genetic merit of dairy ewes must be defined.

Aims/objectives

1. To define the optimum protocol for recording milk yield in dairy sheep, including determining at which parity recording should be undertaken, a standard lactation length and the number of recordings required within lactations to best estimate genetic merit.
2. To determine the influence of management decisions such as the interval between lambing and weaning, the interval between each lambing, and the interval between drying off and the next lactation on milk yield.
3. The attributes of ewes that determine milk yield, such as their ability to produce milk, or to store milk before milking, or their ability to let down, were to be defined.

Methods used

Historical lactation records from Meredith Dairy were analysed to reveal a negligible repeatability between first and second lactations in milk yield and a trend toward a bimodal distribution in milk yield (ewes either failed to produce much milk, or were productive).

A long term experiment was undertaken to determine whether measurements taken in the suckling period, before ewes entered the dairy, predicted commercial milk yield, and to determine the repeatability of milk yield between lactations.

Further controlled experiments were undertaken to determine the effects of pregnancy and photoperiod on milk yield.

Finally data from relatively high yielding commercial ewes were inserted into a model that predicted the optimum time from lambing until next joining for dairy ewes.
Results/key findings

The key findings of the project were

- Milk yield was correlated between lactations ($r^2=0.39$), and this relationship was as strong between first and second lactations as between subsequent lactations.

- Neither growth rate of lambs nor milk production before weaning predict milk yield.

- Suckling lambs for several weeks before milking causes lactation failure in about 20% of ewes.

- A simple test for milk letdown (residual milk) proved to be of no value in predicting milk yield.

- Milk yield was reduced by pregnancy beyond 2 months from conception.

- Joining ewes every 8 or 9 months rather than every 12 months increases annual milk yield by 10 to 20%.

- Artificial lighting increases autumn and winter milk production by about 15%.

- Milk production per head at Meredith Dairy is about 40% below that achieved by Lacaune and Assaf breeds in France and Spain. The best of these are not available for export to Australia.

Implications and recommendations for relevant stakeholders for:

The key implication is that the only way to select sheep for dairying was to milk them, preferably with milking beginning within days of lambing. Where milk is needed on a year round basis, ewes should be joined at 90 to 120 days after lambing, and the standard lactation on which selection is made should be 150 days, so that pregnancy has no effect on yield.

Further research is needed to determine whether artificial lighting is a commercially viable option for increasing milk production.

East Friesland cross ewes produce about 40% less milk than the best breeds in the world. This is satisfactory when high value, fresh products are made from the milk, but will not permit Australia to competitively produce low value, bulk sheep milk products such as feta.
1. Introduction

The research was initiated by Meredith Dairy, which had been milking sheep since 1991, and manufacturing it into cheese and yoghurt. Milking began using Border Leicester-Merino Cross, Poll Dorset, White Suffolk and Coopworth ewes. Ewes suckled lambs for several weeks before entering the dairy. Milk volume was recorded monthly and used to select for milk yield. In the first year of milking average yields were less than 30 litres per lactation, and this improved only slightly over the next few years. Exceptional individual ewes yielded 200 or more litres.

Since commencing operations, obtaining sufficient sheep milk has always constrained sales at Meredith dairy. Other small cheese factories had been prevented from processing sheep milk due to a lack of supply. The main cause of inadequate sheep milk production in Australia has been the lack of a transparent model for profitably milking sheep, which in turn has its roots in the lack of a breed or breeds of sheep, purchasable by sheep dairy farmers, with a demonstrable inherited ability to give profitable yields of sheep milk (Lindsay & Sterret, 2003).

The highest yielding dairy breeds in the world are the Awassi, the East Friesland, their derivative the Assaf, and the Lacaune. Overseas experience shows the introduction of such breeds can have a big effect on milk yield. For example in Spain, where about 5 million ewes are milked, a mean 180 day milk yield of 432 litres has been reported for the Assaf breed, which is several times the yield of native Spanish breeds (Guitierrez et al, 2006).

Prior to 1996 there were no commercially available breeds of dairy sheep in Australia - the Awassi breed was imported in the 1990’s but came under the control of a foreign owned company that to this day will not sell genetic material or animals. In 1996 the East Friesland breed was imported. The breed in Australia is derived from about 20 individuals that were selected on the basis of their availability rather than for any particular genetic merit.

East Friesland sires were used exclusively at Meredith dairy for 4 years until the year 2000. By then it was obvious that the East Friesland breed suffered from a general lack of fitness, which particularly manifested as a high incidence of pneumonia and mastitis. These diseases were evident in half-bred sheep, and became major problems with further crosses to East Friesland. Thus from 2000 the dairy flock at Meredith Dairy has more or less been closed, and is therefore a self replacing flock based generally on 50% East Friesland genetics. The same health problems were observed in the United States, where sheep milking has also begun in the past decade or so using East Friesland genetics, and there too half bred East Friesland ewes are generally used for milking (although they now have the Lacaune).

The introduction of East Friesland genetics immediately improved milk yields at Meredith Dairy. In 2003 we observed that about 50% of 5 year old ewes had yielded at least 200 litres and 10% at least 300 litres over the course of at least one lactation, but total milk production was only about 100 litres per year per ewe kept for milking. It was hoped that some of this large discrepancy between average milk yield and the yield of the best ewes was due to genetic variation, which could underpin a breeding program. Alternatively much of the variation may have been attributed to management practices and environmental factors that impaired lactation.

The aim of this research was to devise management protocols that both maximise the milk yield of Australian dairy sheep, and optimise the ability to select for milk production. The findings were intended to be of particular benefit to Meredith Dairy – the commercial partner – but will be relevant to existing and prospective sheep dairy enterprises in Australia.
2. Objectives

1. To define the optimum protocol for recording milk yield in dairy sheep, including determining at which parity recording should be undertaken, a standard lactation length and the number of recordings required within lactations to best estimate genetic merit.

2. To determine the influence of management decisions such as the interval between lambing and weaning, the interval between each lambing, and the interval between drying off and the next lactation on milk yield.

3. The attributes of ewes that determine milk yield, such as their ability to produce milk, or to store milk before milking, or their ability to let down, were to be defined.
3. Methodology

The studies were carried out at Meredith dairy using ewes from the 2,000 strong dairy flock. Generally the experimental ewes ran with the remainder of the milking flock. For some of the experiments described below ewes were randomly allocated into experimental groups. Other retrospective studies were made – for example historical data were used to determine milk production in different months of lactation.

All animal procedures were conducted with prior approval by the Animal Ethics Committee at Monash University, as required under the Australian Prevention of Cruelty to Animals Act 1986 and the National Health and Medical Research Council/Commonwealth Scientific and Industrial Research Organization/Australian Animal Commission Code of Practice for the Cure and Use of Animals for Scientific Purposes.

3.1 Sheep husbandry at Meredith Dairy

Meredith Dairy produces sheep milk all year round. For this reason a portion of the flock is joined each month. From July to March fertility is often controlled by the administration of pregnant mare serum gonadotrophin following 10 to 14 days treatment with intravaginal progestagen-impregnated sponges, and for the remaining months ewes are naturally cyclic. Ewes are generally joined 4 months after lambing, regardless of whether they are still lactating. Historically ewes were culled from the dairy flock if they did not achieve a viable yield within their first two lactations. The target yield has steadily increased, and was about 150 litres in 2004 when this study began. Replacement ewe lambs are retained from maiden ewes, and multiparous ewes that have achieved a viable yield. Generally these have been weaned at 3 to 4 weeks of age, and fed pellets, grain and pasture with the intention of joining the ewes at 9 to 12 months of age.

Lambing ewes are inspected twice daily. Generally ewes suckle their lambs for the first 21 to 28 days after lambing, at which time lambs are sold or weaned. This suckling period before entering the dairy has been traditionally practiced in Europe, although in Europe the ewes are generally inspected daily, and often milked daily to ensure the udder is completely emptied. Under the extensive grazing conditions at Meredith this has not been possible. Whether lambs should be weaned at birth, or at 21 to 28 days has been one of the management decisions examined in this study.

Ewes have been milked at 06.00 and 15.00h on a 10 aside herringbone dairy with the milking machine set to provide 160 pulsations per minute on a 60:40 ratio. At each milking ewes received 250 g barley. Generally ewes were run on subterranean clover – perennial ryegrass pasture from July to the end of November. Outside these months ewes were fed the above pasture, lucerne, turnips, and when none of these options were available, a mixed ration of legume hay or silage, barley and a high protein supplement such as canola meal, lupins or beans. The mixed ration was formulated to provide 16% protein. Generally both pregnant and lactating ewes were fed so as to permit full production in the best ewes.

The number of sheep milked each day at Meredith dairy generally ranges from 500 to 800. Milk volume was recorded every four weeks at the morning milking (and more often in some of the experiments described below) using milk meters fitted with goat nozzles (Waikato MK5, Waikato, New Zealand). These volumes were used to calculate daily milk volume and total yield during the lactation. Ewes were dried off at the first test at which their production fell below a commercially viable level – generally 500 ml per day.
3.2 Historical data – Repeatability of milk yield

In 2004 we began analysing the past 6 years milk records at Meredith Dairy (from 1998 we were largely milking ewes that were half East Friesland) hoping to gain an insight into why milk production was so variable. We noted that about half the maiden ewes yielded less than 50 litres and half more (table 1). The data were almost bimodal which we had found in our original studies in ewes with no East Friesland genetics, although among our foundation crossbred ewes about 80% gave less than 20 litres, and the top 20% averaged about 100 litres. We hypothesised that those ewes with failed lactations (less than 50 litres) were fundamentally not adapted to machine milking, perhaps because they would not let down when machine milked. Nevertheless about 20% of ewes had failed lactations even after 4 or more lactations, by which time the population had been selected to include only ewes that had succeeded in at least one earlier lactation (table 1), and this could be explained if inappropriate management decisions led to lactation failure.

Table 1. Number of ewes entering the dairy flock at Meredith dairy for the first through to the seventh time, from 1998 to 2003, that gave more or less than 50 litres.

<table>
<thead>
<tr>
<th>Lactation number</th>
<th>Number of ewes yielding more than 50 litres</th>
<th>Ewes with failed lactation less than 50 litres</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1942</td>
<td>1694</td>
</tr>
<tr>
<td>2</td>
<td>1442</td>
<td>467</td>
</tr>
<tr>
<td>3</td>
<td>955</td>
<td>242</td>
</tr>
<tr>
<td>4</td>
<td>629</td>
<td>138</td>
</tr>
<tr>
<td>5</td>
<td>265</td>
<td>54</td>
</tr>
<tr>
<td>7</td>
<td>125</td>
<td>27</td>
</tr>
<tr>
<td>8</td>
<td>39</td>
<td>14</td>
</tr>
</tbody>
</table>

Variation in milk yield is caused by temporary environmental effects (including consequences of deliberate management decisions and mishaps), permanent environmental effects (for example growth rate before puberty) and genetic variation. The extent to which successive lactations are correlated with each other is determined by the sum of the permanent environmental and genetic components.

Various analyses of commercial milk yields at Meredith Dairy prior to 2004 failed to find a significant correlation between successive milk yields. For example the plot shown below (fig.1) shows the yields for the first and second lactation of fifty 2001 drop ewes, and excluded ewes that were recorded as having prematurely dried off due to mishaps. The coefficient of determination was calculated as 0.07 and was not significantly different from zero. In other words the first lactation provided no information on the likely yield in the second lactation.
Figure 1. Milk yield in litres for 2001 drop ewes that commenced lactation in autumn 2003 (x-axis) and late Spring 2003 (y-axis); $r^2=0.07$ (NS).

The low repeatability for milk yield within a large flock, managed extensively, is perhaps unsurprising given that a single mishap in early lactation (for example disease, missing successive milking through mismustering) may cause lactation to fail. Therefore we wished to identify simple measurements that could preferably be made either prior to, or shortly after machine milking began, that would correlate with commercial milk yield.
4. Predicting milk yield in dairy sheep.

4.1 Introduction

High-yielding dairy ewes produce relatively large amounts of milk compared with the requirement of the lamb (McKusick et al., 2001) and they release this milk in response to milking by machine rather than suckling by the lamb (Labussiere, 1988, McKusick et al. 2001). High-yielding dairy ewes are capable of storing milk for up to 16 hours between milking (Labussiere, 1988) and they persist in lactating for 6 months or more.

The aim of the following experiment was to identify traits that are simple to measure and correlate with milk yield when ewes are milked by machine so as to facilitate selection of dairy ewes from a population of relatively unselected East Friesian crossbred ewes.

4.2 Methodology

Two consecutive lactations of 217 primiparous and 113 multiparous ewes (second parity, n = 51; third parity = 40; and fourth parity, n = 22) were studied. The following measurements were made during early lactation a) milk production and growth rates of the lambs measured during the suckling period, b) milk yield, milk production, and residual milk measured during the first 4 wk of machine milking. Thereafter, daily milk yield was measured at regular intervals until milking was discontinued when daily milk yield fell below 500 ml per day.

4.2.1 Measurements during the Suckling Period.

Growth rate (g/d) was determined by weighing lambs within 24 h of parturition and at weaning 24 to 28 d later.

Milk production (mL/d) during the suckling period was measured using a 4-h milk production test. Ewes were separated from their lambs and injected with 5 IU of oxytocin and milked immediately with a milking machine. A second injection of 5 IU of oxytocin was given and milking was repeated to ensure that as much milk as possible was removed from the udder. After 4 h, ewes were milked again following an i.m. injection of 5 IU of oxytocin. The volume of milk was recorded and used to calculate daily milk production. The purpose of 5 IU oxytocin was to ensure milk was let down.

4.2.2 Measurements during the Milking-Only Period.

Milk volumes were recorded at the morning milking at weekly intervals for the first 8 weeks of machine milking, and thereafter once a month until daily production fell below 500 ml per day. Estimates of milk yield to 120 d were used to standardise the length of lactation and to avoid potential biases due to the effect of pregnancy on lactation.

Milk production and residual milk were measured at the morning milking following weaning, 1 week later, and at 4 weeks after weaning.

Milk production was measured using an interval of 16 h between milking to measure the ability of each ewe to store milk and maintain milk secretion.

Residual milk is the milk remaining in the udder after machine milking is completed. Residual milk has been used as a measure of the effectiveness of milk let down. Milk let down is a consequence of the milk ejection reflex, whereby stimulation of the teats leads to endogenous release of oxytocin. A
satisfactory milk ejection reflex will expel most of the alveolar milk to the cistern from where it will be removed by the milking machine. Therefore relatively low levels of residual milk are thought to be an indicator of efficient milk ejection.

The residual milk is extracted by administering a pharmacological dose of oxytocin (5 IU) that stimulates the alveoli to expel all their milk into the cistern, from where it can be extracted by re-applying the milking machine. The fraction of milk recovered in this way is expressed as a percentage of the total milk obtained at the milking session.

### 4.2.3 Statistical Analysis

Data from these experiments were statistically analyzed using repeated-measures ANOVA and by correlation and regression. Correlation analyses were used to examine relationships between lamb growth rates, estimates of milk production, residual milk and milk yield. Prior decisions to exclude ewes (first lactation n = 74; second lactation n = 93) from analysis were made if any of the following conditions were met: ewes bearing triplets, lamb mortality during the suckling period, lameness, involution of one udder half, injuries to the teats due to biting, or clinical mastitis.

Post hoc comparisons were made where appropriate using least significant differences. Data are presented as the mean ±SEM and results are considered significant when $P < 0.05$.

### 4.3. Results

#### 4.3.1 Lamb growth and milk production during the suckling period

For primiparous ewes, the growth rate for single lambs ($0.351 \pm 0.003$ kg/d) was greater than for twin lambs ($0.274 \pm 0.002$ kg/d). For multiparous ewes, the growth rate for single lambs ($0.370 \pm 0.014$ kg/d) was greater than for twin lambs ($0.295 \pm 0.008$ kg/d).

There were differences in the growth rates due to the sex of the lamb ($F(1, 197) = 7.257, P = 0.008$). Single male lambs grew faster than single female lambs ($0.363 \pm 0.008$ and $0.343 \pm 0.010$ kg/d for male and female, respectively) and twin male lambs grew faster than twin female lambs ($0.306 \pm 0.007$ and $0.268 \pm 0.009$ kg/d for male and female, respectively).

Milk production on the day of weaning was greater in multiparous ewes than in primiparous ewes (Figure 2).

Milk production was not correlated with lamb growth.
Figure 2. Mean (± SEM) daily milk production (ml) in primiparous and multiparous ewes measured during the first 4 wk of machine milking (at weaning, after 1 wk, and after 4 wk). Daily milk production was affected by time ($P \leq 0.001$) and parity ($P \leq 0.001$). Differences between parity at each time point are represented by * ($P < 0.05$).

4.3.2 Correlations with 120-d Milk Yield

The coefficient of determination ($r^2$) for 120-d milk yield between consecutive lactations was 0.39 ($P \leq 0.001$, $n = 113$; Figure 3).

Daily milk yield after 4 wk of machine milking explained $>60\%$ of the variability in 120-d milk yield within lactations ($r^2 = 0.65$, $P = 0.001$, $n = 243$ and $r^2 = 0.60$, $P = 0.001$, $n = 132$, respectively), but measurements of daily milk yield after 4 wk of machine milking were lowly correlated between lactations ($r^2 = 0.08$, $P = 0.005$, $n = 104$). Similarly, daily milk production, estimated from 16 h of milk accumulation, after 4 wk of machine milking, explained $>50\%$ of the variability in 120-d milk yield within lactations ($r^2 = 0.50$, $n = 243$ and $r^2 = 0.53$, $n = 115$, respectively), but measurements of daily milk production after 4 wk of machine milking were lowly correlated between lactations ($r^2 = 0.08$, $P = 0.005$, $n = 99$).

Daily milk yield or milk production, measured during the first lactation at 4 weeks after the commencement of machine milking, were low predictors of 120-d milk yield in the subsequent lactation ($r^2 = 0.17$, $P \leq 0.001$, $n = 112$, and $r^2 = 0.11$, $P \leq 0.001$, $n = 111$, respectively).
Milk production at weaning, measured using either a 4-h milk production test \((r^2 = 0.03, P = 0.013, n = 244)\) or a 16-h milk production test \((r^2 = 0.07, P \leq 0.001, n = 255)\) explained almost none of the variability in 120-d milk yield.

Residual milk at weaning explained almost none of the variability in 120-d milk yield in either lactation \((r^2 = 0.01, P = 0.142, n = 255, \text{ and } r^2 = 0.01, P = 0.201, n = 115, \text{ respectively})\).

The growth rate of the lamb explained almost none of the variability in 120-d milk yield \((r^2 \leq 0.08, \text{ in both lactations } P = 0.062)\).

**Figure 3.** Correlation \((r^2 = 0.39, P \leq 0.001, n = 113)\) between 120-d milk yield \((L)\) during the first lactation and 120-d milk yield during the second lactation
4.4. Production Data for East Friesian Crossbred Ewes

During the first lactation, the machine-milking period was similar for primiparous (n = 180) and multiparous (n = 76) ewes (130.2 ± 3.7 and 131.8 ± 4.5 d, respectively), and estimates of total milk yield during that period were 109.6 ± 4.0 and 126.8 ± 5.7 L for primiparous and multiparous ewes, respectively (P = 0.016).

Milk yield to 120 d was greater in multiparous ewes (107.1 ± 4.2 L) than in primiparous ewes (82.7 ± 2.8 L) during the first lactation of this study. In comparison, ewes (n = 132) were milked for 160.1 ± 4.0 d in the second lactation and the total milk yield was 192.9 ± 6.9 L, and the 120-d milk yield for the second lactation was 146.4 ± 3.7 L. The coefficient of variation of total milk yield was 49.2%.

4.5. Conclusions and recommendations arising

The most significant practical finding of this study was that of the 330 ewes introduced into the study only 113 completed two lactations. This was largely due to ewes being excluded from the study due to problems occurring during the suckling period, particularly ewes going one-sided, suffering teat damage, or drying off after losing lambs. We conclude that lambs should be weaned at birth from dairy ewes unless the suckling period can be closely monitored.

Milk yield to 120 d explained 39% of the variation in milk yield between lactations. This suggests that the repeatability of milk yield is sufficient to permit selection of ewes based on 120-d milk yield. The relationship was similar for primiparous and multiparous ewes and implied that selection could be based on first lactations.

The repeatability between lactations sets an upper limit to the heritability of milk yield.

Milk yield to 120 d can be predicted early in lactation by daily milk yield after 4 weeks of machine milking. Milk production (using a 16-h milk production test) after 4 weeks of machine milking predicted 120-d milk yield and may be used to eliminate low-yielding ewes from the milking flock. This measurement was, however, a poor predictor of milk yield in the subsequent lactation, so cannot be used for ewe selection.

Lamb growth during the suckling period did not predict 120-d milk yield, so this trait cannot be used to identify ewes that would be suited to machine milking. This is counterintuitive, but follows the lack of correlation between milk production and lamb growth, and milk production at weaning and milk yield. The lack of correlation between lamb growth and milk production may be explained by the suggestion of others that dairy ewes produce quantities of milk in excess of the requirements of the lamb (McKusick et al., 2001).

The rates of milk production at weaning were not correlated to 120-d milk yield and this may be explained by the observation that milk production declined rapidly over the first week of machine milking, a finding that is consistent with the 30 to 50% decrease in milk production reported by others in the less highly selected dairy breeds (Labussiere, 1988; McKusick et al., 2001).

Milk production after 16 h of milk accumulation was correlated with milk yield after 4 wk of machine milking, which suggests that the rate of milk production measured at 16-h intervals reflects the ability of ewes to store milk between each milking.

Residual milk was measured in the expectation that low residual milk would reflect an effective milk ejection reflex. Within the Lacaune breed, milk yields are higher in the population that has a milk ejection reflex (Labussiere, 1988). We found no relationship between residual milk and 120-d milk yield. In addition, the normal distribution of residual milk eliminated the possibility of identifying ewes that do not eject their milk. Either none of the ewes in the study had a milk ejection reflex, which is improbable, or residual milk is not a good indicator of milk ejection.
5. How frequently should ewes be joined?

Dairy ewes are not usually milked while they are pregnant in Mediterranean countries, where most of the world’s sheep dairying occurs. Sheep milk production is seasonal and ewes are typically milked by machine for 180 d and there is no overlap between lactation and pregnancy. There is opportunity, however, due to the short gestation of sheep (150 days) to increase milk production by lambing, on average, 1.3–1.5 times each year.

Ewes at Meredith Dairy are managed to lamb every 9 months in an attempt to obtain year round milk supply, and to increase total milk yield, and this results in significant overlap between lactation and pregnancy in ewes with persistent lactations. If pregnancy reduces milk production, then this intensive management may instead act to reduce milk yields. On the other hand, if daily milk yield is much greater in early lactation than late lactation, then more frequent joining will lead to ewes being in early lactation for an increased proportion of their lifetime, which would tend to increase their lifetime milk production.

To determine the optimum frequency of joining, we first determined what effect pregnancy had on lactation, in a controlled experiment. We then examined the milk records of ewes that were capable of persistent lactation to determine what proportion of total milk yield was delivered in early and late lactation. Finally these data were used to calculate the effect that joining ewes at eight, 9 or 12 month intervals would have on annual milk yield.

5.1 The effect of pregnancy on commercial milk yield.

5.1.1 Methodology

A total of 194 ewes were used in this study. These were managed according to the usual management practice at Meredith Dairy (see Fig. 4). All ewes in this experiment were treated with sponges and PMSG at day 90 of lactation, as described earlier. Ewes allocated to the pregnant group were then mated to rams and pregnancy was diagnosed by ultrasound 40 d later. Non pregnant ewes from this group were excluded from the analyses. Ewes allocated to the control group did not receive an injection of PMSG at sponge withdrawal and were not exposed to the rams. Once mating was completed and the rams removed, the two groups were managed as a single flock. These were milked until daily yield fell below 500 ml.
Figure 4. Management timeline for dairy ewes on 9-month lambing intervals. Ewes suckle their lambs for the first 28 d of lactation, after which the lambs are weaned and ewes are milked exclusively by machine. Commercial milk yield is recorded during the period of machine milking only and the first day of machine milking is designated day 0. After 90 d of machine milking ewes are mated (pregnancy is diagnosed 40 d later) and milking is discontinued after approximately 180 d of milking by machine. Ewes are then subjected to 60-d dry period (the non-lactating period prior to parturition) to allow sufficient time for regenerative involution prior to the next lactation.

5.2 Results

Daily milk yield was higher ($P < 0.05$) in non-pregnant ewes compared to pregnant ewes at days 157, 173 and 184 of machine milking (Figure 5). Of the 91 pregnant ewes and 102 non-pregnant ewes studied, there were differences in the number of ewes dried off within treatments at day 173 (41 pregnant ewes vs. 23 non-pregnant ewes, $P = 0.008$), and day 184 of machine milking (64 pregnant ewes vs. 42 non-pregnant ewes, $P = 0.006$), but not at day 157 (19 pregnant ewes vs. 14 non-pregnant ewes, $P = 0.229$). The rate of decline of dairy milk yield in late lactation is given in Figure 6.

Figure 5. The daily milk yield from pregnant and non pregnant ewes from 90 days after machine milking began. The pregnant ewes conceived following joining on day 90.
Figure 6: Mean (± SEM) daily milk yield (mL) in pregnant and non-pregnant control ewes from mid- to late lactation (day 90 to 180 of machine milking). For both groups, time affected daily milk yield ($P \leq 0.001$) and differences in daily milk yield between groups of ewes are indicated by *, $P < 0.05$.

5.3 Conclusion

These data indicate that pregnancy reduces milk production from about 60 days after conception, but the loss in commercial milk yield in this experiment was relatively minor because the daily milk yield of non pregnant ewes also declined at that time, albeit not quite so rapidly and because the experiment concluded when ewes were 90 days pregnant.

The dry period is non-productive and a further reduction of the dry period may be possible in those ewes that have persistent lactations. The milking of ewes was discontinued on day 94 of pregnancy, allowing approximately 56 d for the turnover of mammary epithelial cells (Capuco et al., 2003). We assume that a dry period of this length is suitable for ewes because it is optimal for dairy cattle (Annen et al., 2004; Kuhn et al., 2005) and involution in ewes takes 30 d (Tatarczuch et al., 1997). A comparison of commercial milk yield between lactations while omitting the dry period may provide data to test these assumptions.
6. Milk yield at different stages of lactation

6.1 Introduction

At Meredith Dairy ewes are selected to remain in the dairy flock if they are capable of yielding at least 200 litres of milk in the first 180 days of milking, when milking commences within a few days of lambing. We wished to measure how daily milk yield and cumulative milk yield varied across lactation for such selected ewes.

6.2 Methods

Milk records from 40 ewes were used to calculate the mean daily milk yield, and cumulative milk yield for the first 210 days after entering the dairy. The ewes were selected on the basis that they were multiparous, they yielded at least 200 litres of milk in 180 days, they did not suckle lambs for more than a few days before entering the dairy, and their lactations were not prematurely curtailed by disease, or other mishaps. Twenty of the ewes were the first twenty such ewes to lamb in March 2007, and the other 20 were the first 20 to lamb in September 2007. The ewes were milked for the entire 210 days, unless daily milk yield fell below 500 ml per day. The results were analysed by analysis of variance. Ewes that dried off before 210 days were recorded as having zero milk yield each day thereafter.

6.3 Results

The results (Figure 7) were that ewes yielded an average 169 litres of milk in the first 90 days of lactation, and only just over half that (87 litres) in the last 90 days. The mean daily milk yield declined significantly after the first 90 days of milking, then declined progressively after day 150. The cumulative milk yield was similar for March and September lambing ewes (296 and 292 litres respectively).

![Figure 7](image.png)  
Figure 7. Mean daily milk yield and cumulative milk yield for 40 selected dairy ewe from Meredith Dairy.
6.4 Modeling the effects of frequent joining of dairy ewes

Data from the above two experiments were incorporated into a model to predict whether joining selected dairy ewes at Meredith for an 8 or 9 month lambing interval would increase the annual milk yield. The crossbred ewes at Meredith Dairy only join naturally during April, May and June, so it was assumed that ewes joined for an 8 or 9 month lambing interval would be joined at cycles controlled by the use of progestagens and PMSG as described in the introduction, at which average conception rates are approximately 60%, with dry ewes joined 2 months later after a negative pregnancy test. Only 60% conception rates are achieved at this and subsequent joining, so joining 3 months after lambing with the intention of achieving an 8 month lambing interval results in an average of a 9 month lambing interval.

6.5 Results and implications

The actual annual milk production recorded for the 40 ewes in this study was 293 litres (±10,SEM) from a single lactation. The model predicted this would be significantly increased to 341 (±12) litres if joining began 3 months after lambing and 328 litres (±11) if joining began 4 months after joining. Varying conception rate varied the outcome of the model to a small extent. For example the mean milk production for ewes first joined 3 months after lambing with a 50%, 60% and 70% conception rate resulted in mean milk production rising from 322, to 341, then 352 litres per year. The relatively small effect of conception rate arises because ewes that do not conceive yield more milk in late lactation.

A conclusion from these studies is that given the substantial effort and expense involved in joining at 8 month intervals after lambing this would only be worthwhile for producers who were obliged to produce milk all year round, whether to supply markets, or to optimise the use of staff and facilities, and who therefore were already committed to using controlled breeding techniques.
7. The effect of artificial lighting on milk production

7.1 Introduction

Milk production in dairy animals is affected by season (Svennersten-Sjaunja and Olsson, 2005), and without manipulation of photoperiod, reach a nadir during winter. Numerous studies in dairy cows have demonstrated that the imposition of long day photoperiod during winter increases milk production by 1 to 3L per day (reviewed by Dahl et al., 2000). In comparison to dairy cows, similar basic research in dairy ewes is limited, as all levels of the sheep milk industry, from primary production to processing remain seasonal in Mediterranean countries (Bencini and Pulina, 1997). Due to this lack of corroborating data, it is uncertain if manipulation of photoperiod can be used as a management tool to increase milk production in dairy ewe flocks.

7.2 Methods

Fifty primiparous and 170 multiparous ewes were studied. These were milked from within one day of giving birth, and were beginning the second month of lactation when the experiment began. All were yielding at least one litre of milk per day at the start of the experiment.

This experiment began on Monday 7 May 2007 when each experimental group was housed in separate barns. Ewes were fed an ad libitum (ewes consumed approximately 2.8 kg/ewe/d) mixture of vetch hay, silage, canola meal and barley (designed to be 16% CP) and at each milking ewes received an additional 250 grams of barley. Voluntary food intake, ewe weight and condition were measured weekly.

Ewes were ranked according to milk yield in the week prior to the experiment and allocated into two groups with similar average daily production. Due to illness, 22 ewes were subsequently excluded from the analysis and this resulted in a difference between groups in the mean milk production at the start of the experiment (2051 ± 672 mL/d and 1887 ± 672 mL/d (mean ± S.D.) for ewes exposed to natural declining photoperiod and 16h light, respectively, \( P = 0.073 \)) . One group (n = 110, including 26 primiparous ewes) was subjected to natural declining day length while the other group (n =110, including 24 primiparous ewes) was exposed to 16 h of artificial lighting (500 lux at the eye level of the ewe).

Milk volumes (mL) were recorded twice weekly at the morning milking. From a subset of ewes (n = 20 per group, same individuals each measurement) samples of milk were collected twice weekly at the morning milking from which the percent (%) lipid, protein and lactose were measured in duplicate (10 mL aliquots) using a Bentley 2000 Infrared Milk Analyzer (Bentley Instruments Chaska, MN, USA). From the same subset of ewes, blood samples (7 mL) were collected once a week (at 11am) by venipuncture and plasma was separated by centrifugation and stored at −20 °C. The concentration of prolactin in the weekly plasma samples was measured using a routine radioimmunoassay.

7.3 Results

The mean daily milk yield (as a percentage of pre-experimental milk yield) was higher (\( P < 0.05 \)) in ewes housed under long day photoperiod compared to ewes housed under natural declining day length during weeks 2 to 8 of the experiment (Figure 8). By week 8 of the experiment, ewes housed under long day photoperiod produced 15.4% more milk compared to ewes housed under natural declining day length.
Time (wk) affected mean plasma prolactin concentrations (ng/mL) \( (F(7,266) = 10.596, P \leq 0.001) \) and there was an interaction between time and treatment \( (F(7,266) = 4.261, P \leq 0.001) \). Mean plasma prolactin levels were higher \( (P < 0.05) \) in ewes housed under long day photoperiod \( (n = 20) \) compared to ewes housed under natural declining day length \( (n = 20) \) at week 6 \( (168 \pm 27 \text{ ng/mL} \text{ vs } 72 \pm 19 \text{ ng/mL}) \), week 7 \( (125 \pm 28 \text{ ng/mL} \text{ vs } 37 \pm 7 \text{ ng/mL}) \), and week 8 \( (132 \pm 35 \text{ ng/mL} \text{ vs } 31 \pm 7 \text{ ng/mL}) \) of the experiment (Figure 9).

Milk composition remained unaffected by time and from these ewes \( (n = 20 \text{ per group}) \) contained, on average, 6.1 \( \pm 0.05 \% \) lipid, 4.8 \( \pm 0.02 \% \) protein, 5.4 \( \pm 0.01 \% \) lactose \( (n = 309 \text{ samples}) \).

The mean weights and conditions score increased for both groups, by similar amounts, across the experiment. Ewes housed under long day photoperiod was 75.4 \( \pm 1.0 \text{ kg} \) at the beginning of this experiment and 79.4 \( \pm 1.0 \text{ kg} \) 8 weeks later, and on average, these ewes gained 0.072 kg/d. Similarly, ewes housed under natural declining day length weighed 74.9 \( \pm 0.9 \text{ kg} \) at the beginning of this experiment and 81.1 \( \pm 0.9 \text{ kg} \) 8 weeks later, and on average, gained 0.112 kg/d. Mean condition score of ewes housed under long day photoperiod were 2.9 \( \pm 0.05 \) and 3.0 \( \pm 0.04 \), and for ewes housed under natural declining day length, mean condition scores were 2.8 \( \pm 0.07 \) and 3.2 \( \pm 0.05 \), at the beginning and end of this experiment, respectively.
Figure 9. Mean (± SEM) plasma prolactin concentrations (ng/mL) in ewes housed under 16h photoperiod and ewes housed under natural declining day length during the 8 weeks of experiment.

Prolactin concentrations were affected by time ($P \leq 0.001$) and differences between the groups at each time point are represented by *, $P < 0.05$.

7.4 Discussion

Daily milk production was increased after 2 weeks exposure to long days, illustrating a stimulatory effect of photoperiod on milk production in crossbred dairy ewes. The 15% increase in milk yield observed after 8 weeks lighting would represent about 170 ml per head per day for the milking flock at Meredith dairy, which in turn is worth about $2.00 per week. Further work is justified to determine the how much extra milk is produced by artificially lighting ewes across the whole winter, to determine whether the extra milk justifies the capital expenditure required to provide lighting.

Because the photoperiod was altered during lactation, the effect on milk yield is probably due to an effect on galactopoiesis rather than mammogenesis. It is possible that a greater increase in milk production can be achieved if long photoperiods are imposed during late pregnancy as manipulation of photoperiod has been shown to affect mammogenesis in cattle, an long photoperiods in late pregnancy have been reported to increase milk production in sheep (Bocquier et al., 1997), although in a study with too few subjects to form the basis of a major capital expenditure program.

In the previous section we reported that we found similar milk yields for ewes commencing lactation in March or September. Our explanation for this is that because both groups lactated for 210 days, both were exposed to periods of increasing and declining photoperiod and perhaps the March lambing ewes benefited from being pregnant during long days. Based on the limited data available we suggest that for ewes experiencing natural lighting, the date on which lactation commences may have little effect on total milk yield, so need not be allowed for in genetic improvement programs.
8. Implications and recommendations

The first recommendation from this work is that under extensive Australian conditions ewes should be milked within a few days of giving birth. This is because about 20% of lactations fail due to events such as lamb mortality and teat injuries if lambs suckle for 3 to 4 weeks before milking. In Europe ewes generally suckle lambs for 4 weeks before milking, but the ewes and lambs are invariably housed during the suckling period, inspected at least daily, and often milked once a day to remove milk in excess of the lambs' needs. This intensive management is possible because labour is less than half the cost in Europe compared to Australia, being provided by South Americans, Eastern Europeans or family members (directly observed in Spain and France).

A further reason for milking ewes from soon after birth is that milk production is about twice as high in the first three months compared to last three months of seven month lactations. This corroborates experience in the United States where East Friesland cross ewes sacrificed about one quarter of their milk yield if lambs were suckled for 4 weeks (McKusick et al, 2001).

The second recommendation arising from the research results is that ewes be selected for milk production based on milk yield from the first lactation, because milk yield was correlated between lactations ($r^2=0.39$), and this relationship was as strong between first and second lactations as between subsequent lactations.

At Meredith Dairy, milk production has been produced according to the above guidelines for the past 18 months. Milk production at Meredith Dairy is now largely from maiden ewes, and older ewes that have yielded at least 200 litres in 180 days. When such ewes are milked without mishap they are producing an average of about 260 litres in 180 days (see the experimental sections above). These yields are about double the flock average of 4 years ago. Nevertheless the yields at Meredith equate to only 50 to 60% or less of those obtained in improved dairy breeds in Europe. For example the Lacaune breed yield about 350 litres in France (we obtained this information from visiting France in 2007) but this follows a 28 day suckling period which we would expect to reduce milk yield by about 100 litres. The average yield for the Assaf in Spain was reported as 430 litres (Gutierrez et al 2006), and again followed a suckling period. The availability of importing high genetic material of these breeds is prohibitive at the moment and quarantine restrictions also hinder cost effective importation of inferior geno types. It is therefore strongly recommend that Australian policy makers do not encourage sheep dairying in Australia built on competing with European producers.

Meredith Dairy specialises in short shelf life products that are difficult to import. These require year round milk supply. On the basis of studies presented in this report we suggest that ewes be joined 3 or 4 months after lambing to maximise total milk production. For producers aiming to supply markets that do not need milk all year around it will almost certainly be more profitable to lamb every 12 months.

Our finding that artificial lighting increases autumn and winter milk production is the first study of its kind that is based on large numbers of ewes. We suggest follow up studies be made to determine the magnitude of the response to lighting across the whole of winter, and to determine whether there are additional benefits from extra lighting before lambing. Such studies are required before the return on investment needed to artificially light can be calculated.
9. References


The sheep dairy industry in Australia is constrained by the absence of a demonstrated profitable model for producing sheep milk, which in turn is largely because dairy breeds of the standard found in Europe are not commercially available.

This report describes a series of experiments aimed at defining management techniques that optimise the milk production from the available sheep, and optimise selection for genetic gain in these sheep.