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Increasing lamb supply through improving the reproductive performance of Merino ewe lambs

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Abstract

Few farmers mate ewe lambs as their reproductive performance is generally poor and variable. This project identified that using teasers, joining liveweight, growth rate during joining, and genetic fat, muscle and breach wrinkle are critical control points to improving their reproductive performance. An extra 5kg of liveweight at joining increased reproductive rate by 15 to 20% and an additional gain of 15 to 20% was achieved by growing lambs an extra 100 g/day during joining. Achieving these gains requires improving nutrition from birth until the end of joining and using sires with higher Australian Sheep Breeding Values (ASBVs) for post-weaning weight. Ewe lambs from sires with higher ASBVs for fat and muscle also mature earlier and achieve better reproductive performance at lower joining weights, as do those from sires with lower ASBVs for early breach wrinkle. The success of joining ewe lambs will rely on achieving a high survival rate, especially of twins, and improving ewe liveweight in late pregnancy appears to substantially increase birth weights and should therefore increase survival.

Executive summary

Projected market demand for Australian produced lamb and sheep meat can only be met by radical increases in carcase weight and a 10% lift in reproduction rate over the next five years. Mating ewe lambs at 8 to 10 months of age has potential to improve lamb supply and ewe numbers over the short term, however the reproductive performance of ewe lambs is much lower than that achieved by mature ewes, and the success from mating ewe lambs is highly variable regardless of breed. For these reasons only about 18% of non-Merino and 3% of Merino ewe lambs are joined as ewe lambs each year, and adoption is unlikely to change unless genetic and management strategies that result in repeatable and cost-effective lamb production from ewe lambs can be developed. Preliminary economic modelling suggested that mating Merino ewe lambs could be profitable if weaning rates greater than 60% could be achieved and lamb prices were about $4/kg carcase weight, or greater. Furthermore, lamb supply could be increased by more than 1 million lambs per year if these weaning rates could be achieved from 20% of Merino ewe lambs.

This project has successfully completed two large field experiments and compiled and analysed data from 22 different commercial and research flocks to better understand the factors influencing the reproductive performance of ewe lambs. It initially developed a capacity to measure ovulation rate and embryo mortality from around Day 10 of pregnancy using rectal ultrasonography, and consolidated collaboration with researchers in Uruguay and New Zealand. This basic research established that ovulation rate does not appear to be a major constraint to the reproductive performance of ewe lambs but failure to conceive after being mated, embryo mortality and failure to return to service are major limitations.

The average ovulation rate in this experiment was 150% but 84% of this potential was lost by weaning. Most of these losses occurred during the first 17 days post breeding, but losses between pregnancy scanning and lambing were also greater than what is generally reported for adults. The pattern of mating and conception in ewe lambs was less concentrated in the first cycle compared to adults, especially after teasing, and only 75% of all lambs that were scanned pregnant conceived during the first 34-days. Perhaps more significantly, almost 50% of ewe lambs that were mated for the first time during the first or second 17-day period, but failed to get pregnant, then either skipped a cycle or did not recycle before the end of the 68-day breeding period. In other words, these ewe lambs would not have returned to service within a normal 35-day breeding after teasing. There is some evidence that the viability of embryos improves with subsequent cycles, and further work is needed to optimise use of teasers to induce cycling, the period between puberty and mating and the duration of mating.

The reproductive performance of ewe lambs varied greatly across flocks and years regardless of breed, which highlights that there is significant scope to improve performance. The project confirmed that liveweight at joining is a key driver of reproductive performance. The responses to liveweight at joining varied between experiments, but for Merino ewe lambs an extra 5kg of liveweight at joining typically increased reproductive rate by 15 to 20%. The national analysis suggested that the effect of liveweight on reproductive rate may be greater in Merino than Composite ewe lambs, and it is likely that the responses in reproductive rate to improving liveweight at joining are much greater in ewe lambs than in adult ewes regardless of breed. This implies that management to achieve target liveweights at joining to optimise reproductive performance will be more critical in growing ewe lambs mated at 8 to 10 months than in adult ewes.

Improving the growth rate of Merino ewe lambs during joining also significantly increased their fertility and reproductive rate and the effects of liveweight at joining and growth rate during joining were additive. The effects of increasing growth rate on reproductive performance was close to linear across the range from liveweight maintenance to nearly 300g/day, and an extra 100g/day during joining had a similar impact on reproductive rate as an extra 5kg of liveweight at the commencement of joining. A preliminary attempt to validate the prediction of reproductive rate from liveweight at joining and growth rate during joining indicated that 10 of 14 other flocks fitted within the 95% confidence limits. Further development of the matrix of liveweight at joining plus liveweight change during joining in relation to reproductive rate will enable the development of optimum management strategies prior to and during joining to maximise profits from joining ewe lambs. Further work is also required to develop and validate this prediction matrix using non-Merino ewe lambs.

A simple feed budget suggests that investing is supplementary feed during joining may be more cost effective than prior to joining, but this needs to be confirmed. In addition to nutritional management, ewe lambs from sires with higher ASBVs for post-weaning weight were consistently heavier at joining and grew faster during joining, so were more fertile and achieved a higher reproductive rate. The magnitude of the response in reproductive rate to sire ASBV for post-weaning weight varied from 2.7% to 7.9% per kg post-weaning weaning weight ASBV, and was greater in Merinos than Composites, but nevertheless suggest that indirect selection for improving reproductive rate of Merino ewe lambs can be achieved from using sires with higher breeding values for early growth.

Increasing condition score at joining had a large positive impact on the fertility and reproductive rate of both Merino and Composite ewe lambs mated at 8 to 10 months of age, and these effects were in addition to correlated increases in liveweight. An extra condition score at joining improved reproductive rate by 20 to 25% when ewe lambs weighed 45 kg or more at the start of joining. Condition score is a measure of fat and muscle depth, and this result was consistent with the positive effect of sire post-weaning fat and muscle on both fertility and reproductive rate for Merino and Composite ewe lambs over and above liveweight at joining. The effect of genetic fat and muscle on fertility and reproductive rate were greater in composites than Merinos, possibly because liveweight was a lesser determinant of reproductive rate in the Composites. Ewe lambs that were genetically fatter or more muscled achieved similar fertility and reproductive rates at a lower liveweight than those from sires with lower ABSVs for fat and muscle. Given the genetic correlation between post-weaning fat and muscle, it is likely that genetically high fat and muscled ewe lambs are physiologically more mature at a given liveweight and hence their greater reproductive performance.

Further work is needed to relate liveweight, expressed as a proportion of their mature weight, to the reproductive performance of ewe lambs. It is a reasonable hypothesis that there will be no additional effects of fat and muscle on reproductive performance over and above liveweight at joining when liveweight is expressed as a percentage of mature size. We also found that Merino ewe lambs from plainer body sires achieved comparable reproductive rates at a lower liveweight at joining than those from sites with more wrinkles. Overall, the analysis indicates that selection of sires with high growth, fat and muscle, and in the case or Merinos low wrinkle, is likely to improve the reproductive performance of ewe lambs joined at 8 to 10 months.

Improving reproductive rates also increases the number of twin born lambs. The survival of twin born lambs from ewe lambs varied in the two intensive experiments from 54 to 68%, indicating that improving the survival of these lambs also represents a opportunity for improving the overall reproductive performance of ewe lambs joined at 8 to 10 months of age. It appears that liveweight at conception has a similar effect on the birth weight of lambs from ewe lambs that occurs in older Merino ewes, but liveweight change during late pregnancy has a much greater impact on birth weight of lambs born to ewe lambs. For every 10 kg increase in ewe liveweight change during late pregnancy, lamb birth weights increased by 0.6 kg. The effects of liveweight profile on birth weight were similar for single and twin born lambs, and higher birth weight increased survival. Regardless of breed, further work is clearly required to develop management systems to improve the survival of lambs born from ewe lambs, as high mortality rates will compromise the cost effectiveness of the strategy and the contribution it could make to increasing farm profitability and lamb supply. We believe it is also critical to quantify carryover effects of having a lamb at 12-14 months on lifetime reproductive performance, wool production and ewe longevity.

The outcomes from this project will benefit lamb producers regardless of ewe breed. Further packaging of the information is required, including development of the ewe lamb decision tool to assess the cost effectiveness of joining ewe lambs, but the project outcomes have already been extended to more than 1500 producers. This has occurred via large industry forums such as LambEx 2012, Best Wool Best Lamb Conferences and Livestock Updates. The material has also been incorporated into the ewe lamb module of ‘Bred Well Fed Well’ and presented on about 15 occasions during the last 12 months.

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1. Project background

Projected market demand for Australian produced lamb and sheep meat can only be met by radical increases in carcase weight and a 10% lift in reproduction rate over the next five years (Palmer 2010). Mating ewe lambs at 8 to 10 months of age has potential to improve lamb supply and ewe numbers over the short term, however in Australia about 82% of non-Merino and 97% of Merino ewes are bred for the first time at two years of age (Curtis and Croker 2005). The reproductive performance of ewe lambs is much lower than that achieved by mature ewes and the success from mating ewe lambs at this age is highly variable regardless of breed (reviewed by Kenyon *et al.* 2013). Specifically, ovulation rates (Quirke and Hanrahan, 1977; Davies and Beck, 1993; Beck *et al*., 1996; Mulvaney, 2011), pregnancy rates (Donald *et al.,* 1968; Forrest and Bichard, 1974; Annett and Carson, 2006; Mulvaney, 2011), litter sizes at birth (Forrest and Bichard, 1974; Munoz et al., 2009; Mulvaney, 2011) and lamb survival (Donald *et al.,* 1969; Munoz *et al.,* 2009; Morel *et al*., 2011; Mulvaney *et al.,* 2011) have all been reported to be lower for ewe lambs compared to older ewes. This poorer performance contributes to low rates of ewe lamb breeding in both Australia (Curtis and Croker 2005) and New Zealand (Anon 2012).

However, it is known that successful breeding of ewe lambs can increase profitability (Young *et al.* 2010; Young 2012), so understanding the causes for poorer and more variable results could enable the development of genetic and management strategies that result in predictable and cost-effective improvements in the reproductive performance of ewe lambs to improve farm profit and increase lamb supply. The variation in the reproductive performance of ewe lambs is undoubtedly due to interactions between genotype, age, liveweight at joining and other factors probably including liveweight change during joining and response to teasers. The Merino dominates the Australian flock, and pre-experimental economic modelling indicated that mating Merino ewe lambs could be profitable when lamb prices were above $4/kg carcase weight and lamb weaning rates were greater than 60% of lambs weaned per ewe mated (Young 2012). The reproductive performance of Merino ewes lambs is the main focus of this report and lamb supply could be increased by more than 1 million lambs per year if these weaning rates could be achieved from 20% of Merino ewe lambs.

Liveweight is a critical factor influencing the reproductive performance of ewe lambs. Ewe lambs that are heavier either due to superior genetics or improved nutrition pre and post weaning will achieve puberty at a younger age, are more fertile and have a higher reproductive rate when joined at 7 to 10 months of age (Rosales *et al.* 2011, 2012, 2013). Nevertheless at the same liveweight at joining, there is a large range in reproductive rates between different experiments and between individual sheep within experiments, indicating that other factors are involved. Increasing liveweight during joining is known to increase the ovulation rate of adult ewes (Gunn and Maxwell 1989), although it is not clear if this results from ewes being heavier at the time of conception or whether liveweight gain has a positive influence on ovulation rate over and above the effects of liveweight *per se*. Short term supplementation of lupins for 4 to 6 days prior to conception also increases ovulation rates in adult ewes in the absence of detectable increases in liveweight (Smith and Stewart 1990). Mulvaney *et al.* (2010) reported that feeding to increase growth rates from just prior to the commencement of joining until after joining, increased the proportion of cross-bred ewe lambs that cycled and increased fertility and the number of foetuses per ewe. No such data exists for Merino ewe lambs, but it is expected that feeding Merino ewe lambs to gain more liveweight during joining will also increase fertility and reproductive rates, and that this effect will be additive to the effects of correlated increases in liveweight at joining.

In addition to the influence of liveweight at joining and liveweight change, the variation in the reproductive performance of ewe lambs will also undoubtedly relate to genotype. The reproductive performance of ewe lambs is known to be influenced by breed (Fogarty *et al.* 2007), and Rosales *et al.* (2012, 2013) has reported positive relationships between the ewe lambs own breeding values for growth and their reproductive performance. However, relatively little is known about the genetic basis for differences in the reproductive performance of Merino ewe lambs or the interaction between genotype, liveweight and liveweight change. The ewe lambs' breeding values for growth are influenced by both its own phenotypic data and the genetic merit of its parents, and it is yet to be confirmed that the breeding value for growth of the sire of the ewe lambs is also significantly related to the reproductive performance of their daughters when they mated at 8-10 months of age.

Fat is known to play an essential role in reproduction, and this has been demonstrated in adult ewes as a positive correlation between condition score at joining and subsequent fertility and reproductive rate (Kenyon et al. 2009). Genetic potential for fat is also positively related to fertility and fecundity in adult Merino ewes (Ferguson *et al.* 2010). Clear relationships between genetic fatness and reproductive performance in Merino ewe lambs are yet to be established, possibly due to the small range of condition score and or breeding values for fatness and the relatively low number of animals used in previous studies (Rosales *et al.* 2012, 2013). It is therefore reasonable to expect that increases in genetic potential for growth and fatness will be positively related to reproductive performance of Merino ewe lambs, and that the effects of genetic fatness, liveweight at joining and liveweight change during joining will be additive.

High rates of embryo mortality may also contribute the poorer reproductive performance of ewe lambs. In two-year-old and mature ewes 25 to 44% of potential lambs, as identified by ovulation rate, have been reported to be lost by weaning, with approximately two thirds of this potential loss occurring prior to lambing (Knight *et al.* 1975, 1982; Kelly *et al.,* 1982). Results from our recent work suggest that between 20 and 60% of Merino ewe lambs that appear to be reaching puberty at 7 to 8 months of age, as identified by crayon marks from teasers, failed to subsequently scan as pregnant. This suggests very high rates of early reproductive losses in Merino ewe lambs, but to our knowledge no studies have attempted to determine where the major reproductive losses occur in ewe lambs. A reason for the lack of studies is that the capability to enable quantification of embryo mortality is not currently available in Australia. If higher rates of embryo mortality are a major cause of lower fertility in naturally ovulating ewe lambs then more work will be required to determine the pre-disposing factors that are likely to lead to high rates of embryo mortality in ewe lambs and develop strategies to reduce these losses.

The overall management packages that result in predictable improvements in the reproductive success of Merino ewe lambs are also dependent on developing management guidelines for pregnancy. Nutritional management of liveweight during pregnancy has been shown to influence reproductive success of non-Merino ewe lambs (Kenyon *et al.* 2013). In nutritional studies with total live weight gains of up to 230 g/day, including the weight of the conceptus, Schreurs *et al.* (2010) reported that total ewe live weight had a positive influence on the live weight of the progeny and the effects of live weight during early in pregnancy were greater than those during later stages of pregnancy. Other work in NZ has also reported positive influences of the nutrition of ewe lambs on lamb weaning weights (Morris *et al.* 2005; Annett and Carson *et al*. 2006, Kenyon *et al.* 2008; Munoz *et al.* 2009, Mulvaney *et al.* 2010abc, 2012). In contrast, in studies with nutritional regimens resulting in total live weight gains in excess of 230 g/d after embryo transfer, negative effects on conception rates, pregnancy maintenance, lamb live weight and survival to weaning have been reported (Wallace *et al.* 2003, 2008). It therefore appears that the birth weights of lambs are highly sensitive to the nutrition of the ewe lamb during pregnancy, but the responses could differ from those observed in adult ewes (Oldham *et al.* 2011). To date, no studies have attempted to relate the liveweight profile of Merino ewe lambs during pregnancy to the birth weight and survival of their own lambs.

2. Project objectives

1. Train staff from several research institutions in the use of trans-rectal ultrasonography to measure the number of corpora lutea and embryos at various stages of development.

2. Determine the impacts of growth and carcass breeding values and growth path to and during joining on the fertility, fecundity, embryo mortality and peri-natal mortality of lambs from Merino ewe lambs mated at 8 to 10 months of age.

3. Complete a combined statistical analysis of ewe lamb reproduction data from multiple projects funded by Sheep CRC and MLA in WA and Victoria.

These three objectives were addressed by completing four different activities, experiments or analyses. Each of these will be reported separately in this final report. In addition, a review paper on the successful breeding of ewe lambs has been submitted to *Small Ruminant Research.*

3. Activity #1 - Development of research capacity to quantify ovulation rate and embryo mortality

A 10-day training program with Dr Carolina Vinoles, from the National Research Institute for Agriculture in Tacuarembo, Uruguay, a world expert in the specialist skills of ovarian ultrasonography, was conducted in January 2012 at the Medina Research station near Perth. The training involved seven participants from three research organisations in Western Australia (University of Western Australia - UWA, Department of Agriculture and Food Western Australia - DAFWA and Murdoch University) and one institution from South Australia (South Australian Research and Development Institute – SARDI). Twelve adult ewes were synchronised using CIDRs for 14 days prior to the start of the training course. The training involved a 1-day theory session and then each day over 7-8 days the participants were trained in measuring the number of corpora lutea and embryos at various stages of development using trans-rectal ultrasonography (Figure 1). The participants were also tutored on the interpretation and statistical analysis of the data collected. After Dr Vinoles departure, Dr Sergio Ferrio from the University of the Republic of Uruguay joined our team for a further two months of data collection and coaching in the newly learned technique. To complete this project Murdoch University invested in a new ALOKA ProSound 2 ultrasound machine. The image quality of the machine is excellent and it has the capacity to record images for individual sheep which has enabled us to consult with Dr Vinoles regarding interpretation of images via email (Figure 2). After Dr Ferrios departure, staff from WA completed a further 6 to 8 weeks of intensive measurements of ovarian activity.

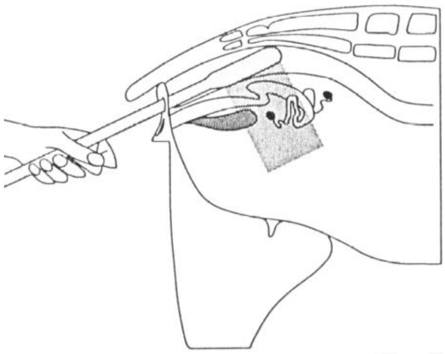

Figure 1: Schematic of the technique of rectal ultrasonography used in the training course.

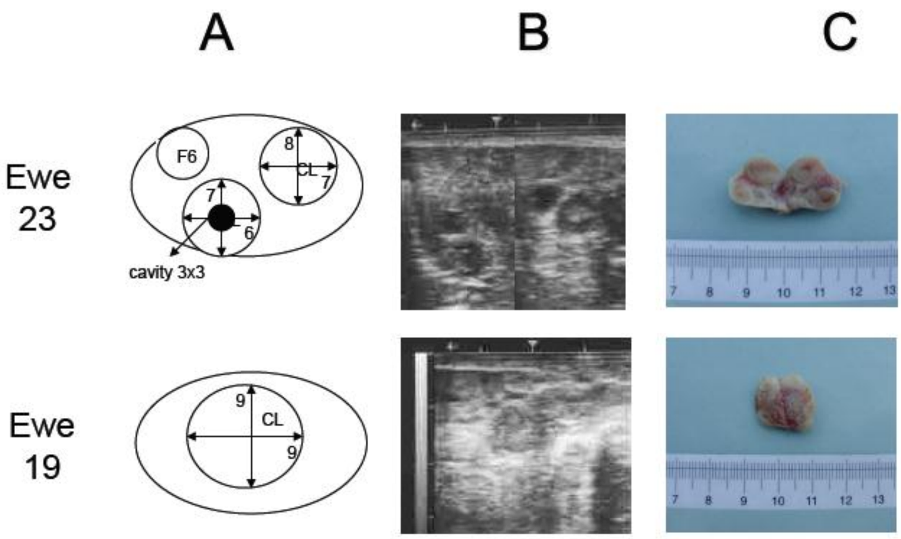

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Figure 2. Diagrams (A), ultrasound images (B) and the dissected ovaries (C) of two cycling Merino ewes.

At the completion of the training program Dr Vinoles was very satisfied with the level of competency of all the participants and the rectal scanning procedure has subsequently been used for early pregnancy diagnosis in two other projects. A number of opportunities exist to capitalise on this new capability, including: (i) making the machine and operator available to any projects funded by the National RDE reproduction strategy; (ii) expanding the international collaboration with Uruguay including post-graduate students; and (iii) incorporating the technology into undergraduate and postgraduate teaching programs in Veterinary and Animal Science at Murdoch University and UWA.

4. Activity #2. The effects of genotype and growth path during joining on fertility, fecundity, embryo mortality and peri-natal mortality of lambs

Methods

Animals and measurements

Experiment 1 used 224 Merino ewe lambs born from ten sires. The ewe lambs were weighed and weaned on the 20th of October 2011 (aged 55 to 111 days) onto pasture at the University of Western Australia, Ridgefield research farm (32° 32'S, 117° 05'E) and at the end of November 2011 they were transported to the Department of Agriculture and Food Research Station at Medina, Perth ($32^0$13'S, $115^0$48'E). They were then fed *ad libitum* hay and 300 g/hd/day of grower pellets with a crude protein content of 18% and 12.5 MJ metabolisable energy in outdoor pens. The pellet ration was increased by 100-200g/day until *ad libitum*. On the 16th of December the ewes were grouped by liveweight and randomised by sire into 15 pens (approximately 15 ewe lambs per pen) and housed indoors. Individual feed intake was recorded using electronic identification and weighing daily intake. Briefly, each pen had a feeder set up to allow only one ewe lamb to feed at a time. To access the feeder ewe lambs walked past a radio-frequency identification aerial that recorded their electronic tag. The duration of feeding as well as the weight of feed eaten was automatically recorded through electronic scales and weigh bars. Feed intake was measured for a total of 46 days and the ewes were weighed twice weekly during this period. The feed intake data was collected primarily for the purposes of another project relating feed intake and feed-use efficiency to methane production, and is not reported in this report.

On 31st January, after the completion of feed-intake measurements, the 224 ewe lambs were balanced for liveweight, age and sire and allocated to one of two nutritional treatments; High *versus* Medium liveweight gain. The High treatment group were fed the same pellets they received during the feed intake period *ad libitum*. The Medium treatment group were offered *ad libitum* pellets with an ME of 9 MJ/kg DM. The ewe lambs remained on these nutritional treatments for 68 days. After 68 days (end of breeding period; see below section) they were transported back to Ridgefield research farm and managed under commercial conditions and their liveweight was recorded monthly. All ewe lambs had eye muscle and fat depth (with a 7.5 meg probe) at the 'C site' (45 mm from the spine along the 12th rib; Palsson, 1939) using an ALOKA ultrasound scanner at Day -14, prior to the introduction of vasectomised rams.

On 31st January 2012, five vasectomised rams fitted with harnesses and crayons were introduced to each treatment group. All ewe lambs were weighed and the appearance of crayon marks on their rumps recorded daily (excepting Sundays). After 14 days (Day 0, 14th February) the five vasectomised rams were removed and replaced with three entire rams for 68 days (14th February to 23rd April). The crayon colours on the harnesses of entire rams were changed every 17 days.

All ewe lambs were blood sampled on Day -25 (20th January), Day -21, Day -17, Day -13, Day -9, and Day -4. A ewe lamb was deemed to have reached puberty if progesterone concentrations were greater than 1 ng/ml (Wells *et al.* 2003; Valasi *et al*. 2006) on two consecutive occasions during the period prior to the introduction of entire rams (Day -25 to Day 0). During the breeding period, additional blood samples were collected from ewe lambs 5, 12 and 17 days after the first presence of a crayon mark on their rump from entire rams (an indicator of a breeding event). These additional samples were used to determine if a corpus lutea was still active or not as an indicator of early embryo loss (see later section). Plasma progesterone was measured in duplicate using a standard kit (IM 1188 Immunokit; Beckman Coulter, Melbourne, Australia) as described by Gray Bartol *et al.* (2000). The limit of detection was 0.05 ng/mL and the measurement range was 0.05 – 50 ng/mL. Two replicates of 6 control samples were used in all assays to generate a standard curve (0, 0.12, 0.55, 2.0, 8.7 and 49 ng/mL). The intra-assay co-efficient of variation was 6.5% and inter assay co-efficient of variation was 7.2 %.

Ultrasonography using a trans-rectal probe (7.5 MHz linear array; ALOKA) was used to measure the presence of a corpus luteum, as a proxy for ovulation rate (Vinoles *et al.* 2010). All ewe lambs were ultra-sounded 9 days after the first presence of a crayon rump mark during the breeding period. This ultrasound measurement was to determine the ovulation rate to that breeding event. A further trans-rectal ultrasonography was undertaken 30 days after the presence of the crayon mark from the entire ram to determine pregnancy status and count the number of embryos. If a ewe lamb returned to service (failed to conceive) as indicated by a new crayon mark, post the first mark and prior to 30 days, the blood sampling and ultrasonography recording procedure was repeated with this new crayon mark being recorded as a new Day 0. If a ewe lamb was determined to be pregnant 30 days after breeding a trans-abdominal ultrasound scan was undertaken between 50 and 100 days to confirm pregnancy status and count the number of fetuses. An example of a complete blood and ultrasound regimen is given in Figure 3.

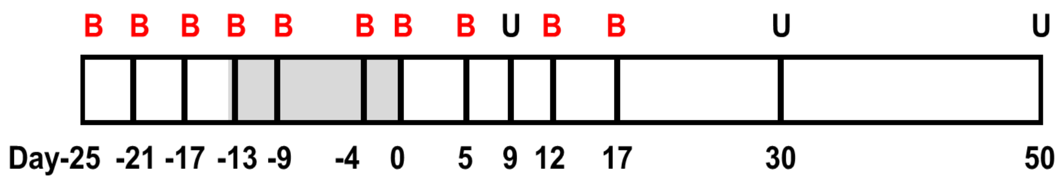


Figure 3: An example of an individual ultrasonography (U) and blood sampling (B) program for a given ewe lamb which displayed a crayon rump mark on Day 0 and did not return to service and maintained her pregnancy. The period when vasectomised rams were joined with the ewes is shaded in grey.

The timing and causes of reproductive wastage in ewe lambs was based on the previous studies of Knight *et al.* (1975, 1982) and Kelly *et al.* (1982). Loss in the first 17 days post breeding was determined to have occurred if progesterone concentrations dropped below 1 ng/mL or the ewe lamb returned to service (i.e. displayed a new crayon rump mark). Loss during the period Days 18 to 30 was deemed to have occurred if the ewe lamb returned to service during that period or if they were found to be non-pregnant at the first pregnancy scan. A further loss was deemed to have occurred if a ewe was pregnant at Day 30 but not at the second pregnancy scan. A late pregnancy loss occurred when ewe lambs were pregnant at the second pregnancy scanning then failed to lamb. Partial failure of multiple ovulations (PFMO) was judged to have occurred if a multiple ovulating ewe lamb, as indicated at day 9 of pregnancy, had fewer embryos at Day 30 or gave birth to fewer lambs than the number of corpus lutea identified. The PFMO recorded was the loss in number of ova that did not result in an embryo or live lamb.

Prior to lambing, pregnant ewe lambs were side-branded with an individual number for ease of identification and randomly allocated to lambing paddocks of approximately 2 ha each. Twice-daily lambing rounds were conducted, with lambs identified to their dams. given individual tags and weighed within 12 hours of birth. The sex of the lamb was also recorded. All ewes and lambs were weighed again at weaning (22^{nd} October, 2012).

Statistical Analysis

All statistical analyses were performed using Genstat (Genstat committee 2008). Achievement of puberty was analysed by fitting a Generalised Linear Mixed Model. The approach used a logit-transformation and binomial distribution. Logits were predicted as a function of relevant effects; birth and rear type, age and live weight were fitted as fixed effects and sire was fitted as a random effect. All live weights and growth rates were analysed by fitting Restricted Maximum Likelihood (REML). Within this procedure date of birth, sex, birth and rear type, nutritional treatment, plus all significant two-way interactions were fitted as fixed effects and sire and dam were fitted as random effects, where appropriate.

Fertility was analysed using General Linear Mixed Models. The approach used a logit-transformation and binomial distribution. Logits were predicted as a function of relevant effects, ewe birth and rear type, age at weaning, nutrition and live weight at introduction of entire rams or residual feed intake were fitted as fixed effects and sire was fitted as a random effect. Ovulation and reproductive rate were analysed using a General Linear Model with a multinomial distribution and logit link function with birth and rear type, age at weaning, nutritional treatment and either live weight at introduction of entire rams or residual feed intake fitted as fitted as fixed effects.

Feeding treatments were not undertaken on an individual animal basis therefore within each feeding treatment there was a large range in live weight changes which overlapped between treatments. This allows us to investigate the effects of live weight change independently of nutritional treatment. To calculate live weight changes during pregnancy the live weights of the ewe lambs were corrected for fleece and conceptus weight using the Grazfeed model ((corrected live weight = total birthweight*1.43*EXP(3.38*(1-EXP(0.91*(1-dayspregnant/150), Freer *et al.* 2005). Days pregnant were calculated by estimating conception date; subtracting 150 days from the birth dates of the lambs. Mean live weights were modelled over time separately for each animal using a random coefficient regression including a cubic spline for time (Verbyla *et al*. 1999). The model fitted was: Liveweight = μ + day + animal + animal.day + spline(day) + animal.spline(day). The term 'day' was fitted as a fixed effect while all other terms were fitted as random effects, with a covariance between the animal intercept (animal) and slope (animal.day). The likelihood ratio test was used to assess any spline effects after the previously mentioned terms (day, animal and animal.day) had been fitted. Ewe lamb live weights at day 0, day 90 and day 140 of pregnancy were estimated using the PREDICT function.

Lamb birth and weaning weights were analysed using REML. Within this procedure birth and rear type, date of birth, nutritional treatment, sex, ewe live weight at introduction of entire rams, live weight change from day 0 to day 90 of pregnancy and live weight change from day 90 of pregnancy to lambing, plus all significant two-way interactions were fitted as fixed effects and sire was fitted as a random effect.

Lamb survival to weaning was assessed by fitting Generalized Linear Mixed Models. The approach used a logit-transformation and binomial distribution. Logits were predicted as a function of relevant effects; birth weight plus birth weight squared, sex, dam conception weight, dam live weight change from day 0 to day 90 of pregnancy and dam live weight change from day 90 of pregnancy to lambing, were fitted as fixed effects and sire fitted as a random effect.

Data from two additional experiments using the same flock of sheep (Rosales *et al.* 2012, 2013) was added to this data for a combined analysis of puberty, fertility, and reproductive rate, and the effects of ewe lamb liveweight and liveweight change on birth weights, weaning weights and survival of their lambs. Each of these analyses was done as described above, but with 'year' fitted as a fixed effect.

Results

Liveweight and liveweight gain

Ewe lambs weighed 27.2 ± 1.82 kg at weaning (range from 17.5 to 40.5 kg) and gained 195 ± 2 g/hd/day between weaning and the commencement of feed intake measurements. Over the 46 days that feed intake was measured the ewe lambs gained 175 ± 3 g/hd/day resulting in a liveweight of 43.2 ± 0.42 kg (range from 30 to 64 kg) when the vasectomised rams were introduced. When the entire rams were introduced at the beginning of the nutritional treatments, ewe lambs weighed 44.6 ± 0.39 kg (range from 31 to 61 kg). Surprisingly, the liveweights of the two nutritional treatments did not differ until Day 40 after the introduction of rams ($P<0.05$; Figure 4). The overall liveweight gain during the breeding and nutritional period was greater ($P<0.001$) in the High (187 ± 4.9 g/hd/day; range from 100 to 351 g/hd/day) than in the Medium (158 ± 4.9 g/hd/d; range from 36 to 257 g/hd/day) nutritional treatment (Figure 4). At the end of the nutritional treatment the High ewe lambs weighed 58.1 ± 0.43 kg and Medium ewe lambs weighed 55.8 ± 0.43 kg ($P<0.001$). The final weight of ewe lambs pre-lambing (25th June) did not differ ($P>0.05$) between nutritional treatments (57.6 ± 0.81 kg vs. 56.3 ± 0.79 kg for the High and Medium groups respectively).

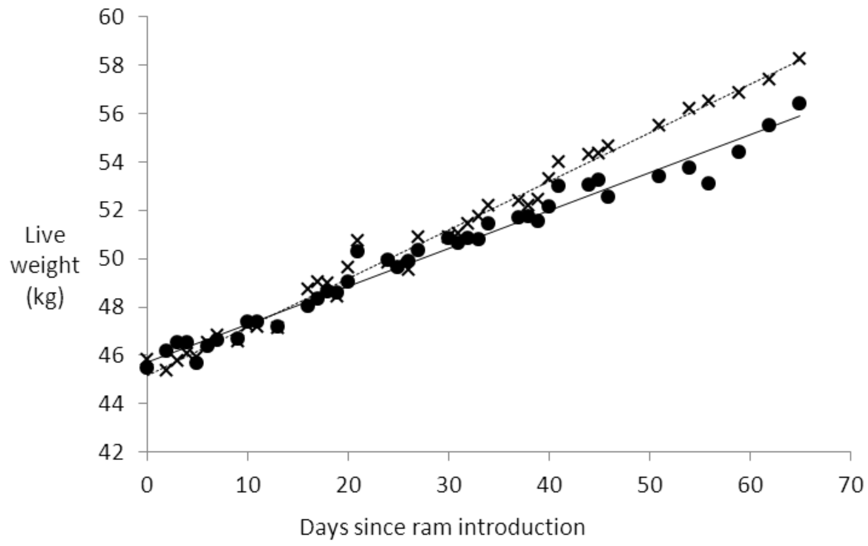


Figure 4. Liveweights (kg) of Merino ewe lambs fed High (*ad libitum* pellets of 12 MJ/kg; ×), or Medium (*ad libitum* pellets of 9 MJ/kg; ●) nutrition for 68 days after the introduction of entire rams.

Puberty onset

Sixteen percent of ewe lambs (n = 35) achieved puberty, as indicated by the analysis of progesterone data, prior to the introduction of vasectomised rams. The lambs that achieved puberty prior to the introduction of vasectomised rams were heavier than those which had not achieved puberty (45.7 ± 1.11 *vs*. 42.8 ± 0.44 kg, P=0.008). The probability of achieving puberty at this time, increased by 3-9% for every 5 kg increase in liveweight (P=0.009; Figure 5). There was no effect (P>0.05) of age, birth or rear type (i.e. being born or reared as a twin, etc.), fat or muscle depth on the probability of achieving puberty prior to the introduction of vasectomised rams. By the end of teasing, 60% of ewe lambs had achieved puberty and older and heavier lambs appeared to be more responsive to teasers (ewe lambs that responded to the teasers were 4 days older and 3.4 kg heavier than ewes that showed no response P<0.01). About 83% of ewe lambs had achieved puberty by 35 days after introduction of entire rams, and by the end of breeding when the average age of ewe lambs was 304 days, 93% of ewe lambs had achieved puberty and their average weight at puberty was 45.4 ± 0.53 kg.

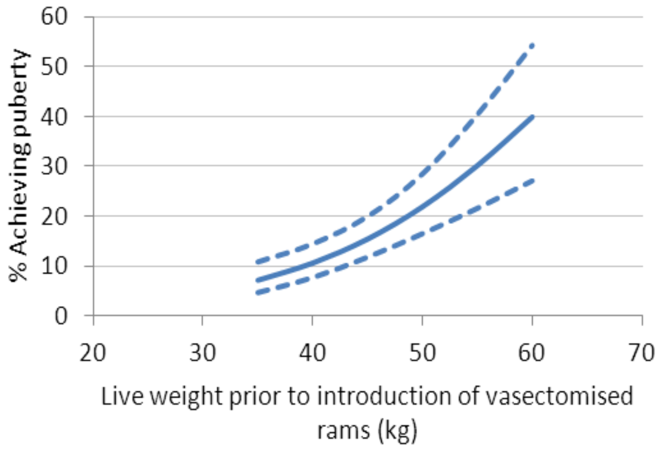


Figure 5. The effect of liveweight on the proportion of Merino ewe lambs achieving puberty prior to the introduction of vasectomised rams. Dashed lines represent 95% confidence limits.

Effect of nutritional treatments on reproductive performance

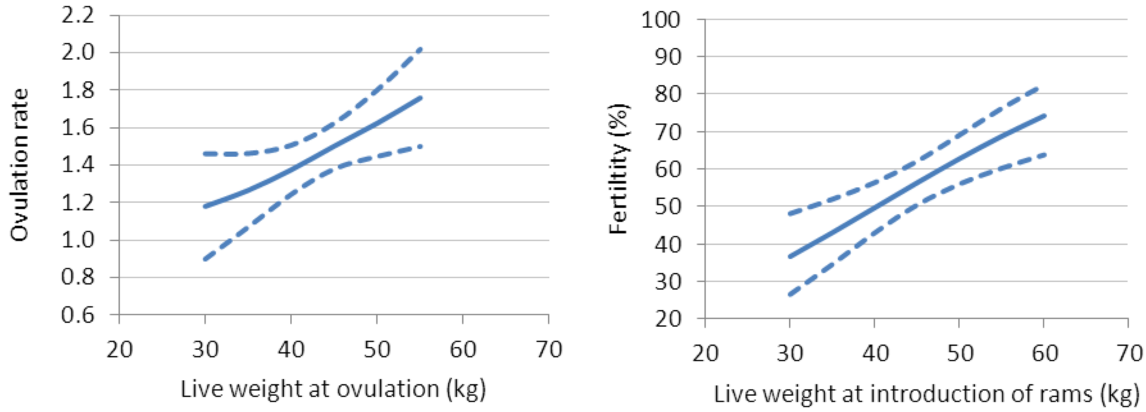
There was no significant effect of nutritional treatment on the ovulation rate, pregnancy percentage, number of lambs born, lamb birth weight, lamb weaning weight, lamb survival to weaning or lamb weaning percentage (P>0.05; Table 1).

Table 1. The effect of nutritional treatment on ewe lamb reproductive performance from breeding to weaning.

	Nutritional treatment	
	Medium	High
Based on first breeding event only		
Ovulation rate	1.5 ± 0.06	1.5 ± 0.06
Pregnancy percentage	29.6	36.7
Number of lambs born per ewe bred	0.34	0.30
Lamb weaning percentage	20.9	27.8
Based on entire breeding period[1]		
Ovulation rate	1.6 ± 0.09	1.7 ± 0.09
Pregnancy percentage	53.5	52.7
Number of lambs born per ewe bred	0.53	0.55
Lamb weaning percentage	44.6	46.4

[1] Includes ewes that had more than one breeding event

While there was no direct effect of nutritional treatments on fertility rate, ovulation rate or reproductive rate, these traits were related to actual liveweight at joining or the time of ovulation measurements. Ewe lambs that were heavier at the start of joining were more fertile ($P<0.05$), had a higher ovulation rate ($P<0.001$) and achieved a higher reproductive rate ($P<0.05$). On average, fertility increased by 1.3% and reproductive rate increased by 1.6% per 1kg increase in liveweight at the introduction of entire rams, whereas the increase in ovulation rate was 2.4% per 1kg increase in liveweight (Figure 6). The sire of the ewe lambs ASBVs for PWT were significantly related to fertility and reproductive rate, but there were no effects of sire breeding values for fat or muscle on these traits. Ewe lamb fertility increased by 6.3% and reproductive rate by 9.3% for each 1kg increase in the ASBV for PWT of their sire.



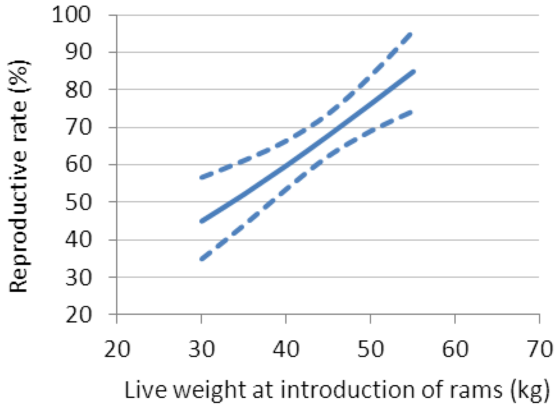


Figure 6: The effect of live weight on (a) ovulation rate, (b) fertility and (c) reproductive rate (foetuses/100 ewes scanned) of Merino ewe lambs mated at 8 to 10 months of age. Dashed lines represent 95% confidence limits.

Reproductive losses

The date of first mating could be identified with confidence for 182 of the 208 ewe lambs that achieved puberty before the end of the breeding period. Eighty five of these ewe lambs got pregnant and a summary of the reproductive performance of ewe lambs that were mated for the first time during different periods after introduction of the entire rams is given in Table 2. Almost 50% of ewes that got pregnant conceived during the first 17 days after introduction of entire rams, 75% of all pregnancies were conceived during the first 35 days and 96% of all pregnancies were conceived during the first 52 days. About 44% of ewe lambs (46 out of 104) that were mated for the first time during the first or second 17-day period but failed to get pregnant, then either skipped a cycle or did not recycle before the end of the breeding period. A further 67% of ewe lambs (10 out of 15) mated for the first time during the third period that failed to get pregnant were also not mated on their subsequent cycle.

Table 2. Reproductive performance for ewe lambs mated for the first time during different periods after introduction of entire rams.

	Day 0 to 17	Day 18 to 34	Day 35 to 52	Day 53+
Number of ewes mated	101	59	20	2
Number of ewes pregnant	40 (39.6%)	16 (27.1%)	5 (25.0%)	1 (50.0%)
Number of ewes not-pregnant	61 (60.4%)	43 (72.9%)	15 (75.0%)	1 (50.0%)
Number of ewes pregnant one cycle later	8 (13.1%)	9 (20.9%)	2 (13.3%)	
Number of ewes that failed again one cycle later	29 (47.5%)	12 (27.9%)	3 (20.0%)	
Number of ewes that skipped cycle and then pregnant	4 (6.6%)	-	-	
Number of ewes that skipped cycle and then failed again	9 (14.8%)	-	-	
Did not cycle again after first mating	11 (18.3%)[1]	22 (51.2%)[2]	10 (66.6%)[3]	

[1] Three further mating chances, [2] two further mating chances and [3] 1 further mating chance.

The extent and time of reproductive wastage for Merino ewe lambs is summarised in Table 3. Based on the outcome of each ewe's first breeding event, only 24 lambs were alive at weaning from the 150 ova released by 100 ewe lambs joined. It is apparent that the majority of these reproductive losses occurred during the first 17 days of breeding, as losses in this period were greater than the total for all other periods. It is not possible to determine if the loss during the first 17-days were due to failure of conception or early embryonic loss. The other major sources of reproductive wastage were the partial failure of multiple ovulations anywhere between Day 9 and lambing and loss of foetuses between pregnancy scanning and lambing.

Table 3. Reproductive wastage of Merino ewe lambs; potential lambs, pre and post natal losses and total lambs weaned are expressed per 100 ewes joined

Event	Number	Percentage lost
Number of potential lambs[1]	150	
Prenatal losses		
Loss in first 17 days[2]	79	52.6
Loss days 18-30[3]	9	6.3
Loss days 30 – pregnancy[4] scanning	2	1.2
Partial failure of multiple ovulations[5]	20	13.3
Loss pregnancy scanning to lambing[6]	10	6.7
Lambs born	30	
Postnatal losses - lamb death[7]	6	3.9
Total lambs at weaning	24	

[1] based on number of corpus lutea (CL) observed 9 days after breeding
[2] based on those that returned to service or had progesterone concentrations below 1 ng/ml
[3] based on those which either returned to service post day 17 or were detected non pregnant at day 30
[4] based on those found to be non-pregnant at pregnancy scanning (approximately day 50)
[5] partial loss of multiple ovulation anywhere between day 9 and lambing (i.e. those who had multiple corpora lutea but had only one embryo/fetus present at scanning or one lamb born)
[6] based on ewes which failed to lamb but were pregnant at pregnancy scanning
[7] based on lambs that died in the peri- and post-partum period to weaning

Effect of ewe lamb live weight and live weight change on their lambs' live weight

The average liveweight of ewe lambs on the estimated day of conception was 49.9 ± 0.53 kg (range from 35 to 64 kg). The effect of liveweight at day of conception on lamb birth weight was positive but not significant (0.02 ± 0.012 kg; P=0.18). This was similar for ewe lamb liveweight at Day 90 (0.02 ± 0.012 kg; P=0.105) and Day 140 (0.02 ± 0.012 kg; P=0.090) of pregnancy (fleece and conceptus-free). Liveweight change from Day 0 to 90 of pregnancy (Day 0-90) was -0.8 ± 0.17 kg (range from -6.3 to 3.2 kg) and from Day 90 to 140 (Day 90-140) was 1.3 ± 0.09 kg (range from -1.7 to 3.6 kg). Across all pregnant ewe lambs, there was also no significant effect of liveweight change of individual ewes' between Day 0 and 90 and Day 90 and 140 on the birth weights of their lambs (P>0.05). On average, single lambs weighed 4.5 ± 0.09 kg at birth and twin lambs weighed 3.6 ± 0.12 kg (P<0.001). There was no significant difference between in the average birth weight of male (4.1 ± 0.11 kg) and female (4.0 ± 0.11 kg) lambs (P=0.63). Survival of single lambs to weaning was higher (83 %) than for twins (68 %; P<0.05). Ignoring birth type, survival increased by only 3% for every extra 1 kg in birth weight, however the relationship was not strong (P=0.08).

The average liveweight of ewe lambs at weaning was 55.1 ± 0.78 kg for those that reared singles and 53.0 ± 1.80 kg for those that reared twins. The effect of liveweight at day of conception on lamb weaning weight was positive but not significant (0.08 ± 0.054 kg; P=0.13). This was similar for ewe lamb liveweight at Day 90 (0.07 ± 0.050

kg; P=0.18) and Day 140 (0.06 ± 0.047 kg; P=0.21) of pregnancy. There was no effect of liveweight change during Day 0 to 90 and Day90 to 140 on the weaning weights of their lambs (P>0.05). Single born and reared lambs weighed 24.0 ± 0.36 kg at weaning, twin born and single reared lambs weighed 22.1 ± 1.28 kg and twin born and reared lambs weighed 19.1 ± 0.09 kg (P<0.001). Male lambs were also heavier than female lambs at weaning (22.4 ± 0.64 kg vs 21.1 ± 0.59 kg; P=0.03).

Combined analysis of liveweight effects on puberty, fertility and reproductive rate of ewe lambs

When the data from this experiment was combined with data from two previous experiments using the same flock of sheep (Rosales *et al.* 2012, 2013), both liveweight and fat depth had significant positive effects on the proportion of ewe lambs achieving puberty by the end of the ‘teasing period’ (removal of vasectomised rams). Ewe lambs achieving puberty by the end of teasing increased by approximately 1.5% for every 1 kg increase in liveweight at the start of the teasing period (P<0.001; Fig. 7). Increasing fat depth at the C-site increased ewe lambs achieving puberty during teasing by approximately 4% per mm (P=0.08; Fig. 7). This positive effect of fat was in addition to the effect of liveweight.

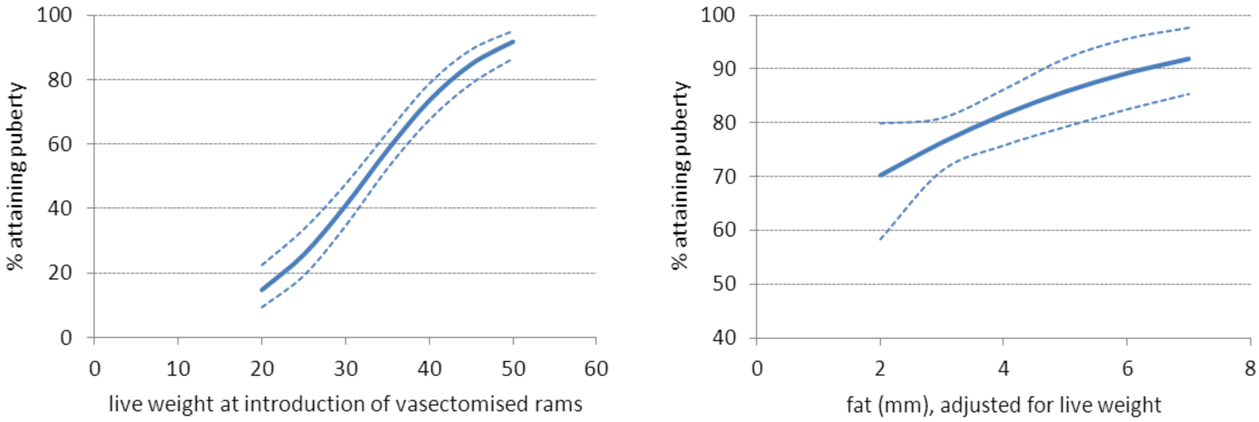


Figure 7: The effect of liveweight at introduction of vasectomised rams (left) and fat depth (right; adjusted for liveweight) on the proportion of ewe lambs achieving puberty prior to the removal of vasectomised rams. Dashed lines represent 95% confidence limits

Sire breeding value for post weaning weight had a positive effect on the proportion of ewe lambs achieving puberty by the end of the ‘teasing period’ (removal of vasectomised rams). Ewe lambs achieving puberty by the end of teasing increased by approximately 4.2% for every 1 kg increase in the breeding value for post weaning liveweight (P<0.001; Fig. 8). The other sire breeding values for carcass and wool traits were not significantly related to likelihood of achieving puberty.

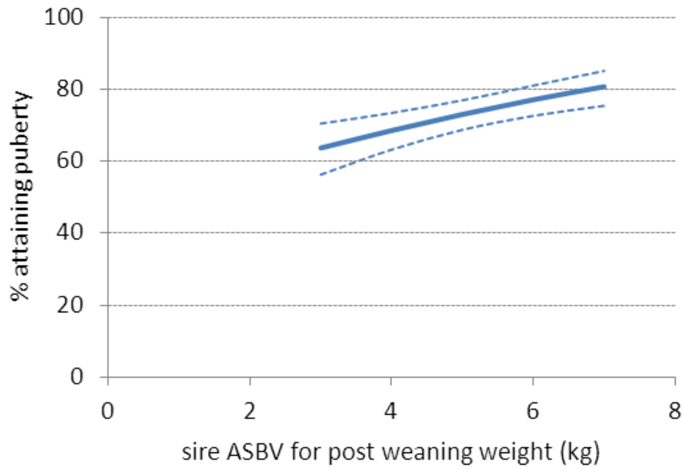


Figure 8: The effect of sire breeding values for post weaning weight on the proportion of ewe lambs achieving puberty prior to the removal of vasectomised rams. Dashed lines represent 95% confidence limits.

Across experiments, liveweight at joining varied from 33 to 64 kg over three years (Table 4), and there were significant positive relationships between liveweight at joining, the proportions of dry, single and twins and overall reproductive rate. These traits were also positively related to the ASBV for PWT of the sire of the ewe lambs (Fig. 9). Ewe lamb fertility increased by 4.3% and reproductive rate by 7.9% for each 1 kg increase in the ASBV for PWT of their sire.

Table 4. The number of ewe lambs mated, their estimated liveweights at conception (LW_{d0}), liveweight change from conception to Day 90 of pregnancy (LWC_{d0-90}), liveweight change from Day 90 of pregnancy to Day 140 of pregnancy ($LWC_{d90-140}$) and survival to weaning (%) of their lambs.

Drop	No. ewes	No. lambs	LW_{d0}	(range)	LWC_{d0-90}	(range)	$LWC_{d90-140}$	(range)	Lamb survival%
2010	102	106	44.8	33-61	8.2	+3 to +13	10.3	+8 to +13	86
2011	62	71	49.0	38-61	-1.3	-10 to +7	-3.7	-8 to +1	77
2012	108	125	49.6	35-64	-0.8	-6 to +3	1.4	-2 to +4	73

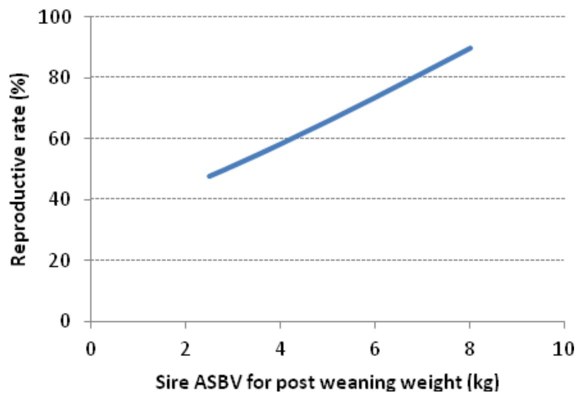


Figure 9: The effect of sire breeding values for post weaning weight on the reproductive rate of ewe lambs mated at 8 to 10 months of age. The data combined from three experiments including Rosales *et al.* (2012, 2013).

Combined analysis of liveweight of ewe lambs in relation to the birth weight and survival of their lambs

Across experiments, liveweight change during early pregnancy varied from maintenance to +8 kg and liveweight change during late pregnancy varied from -4 kg to +13 kg (Table 4). Liveweight profile during pregnancy also had a significant effect on lamb birth weights. For every 10 kg increase in liveweight of ewe lambs at the start of joining there was a 0.2 kg increase in lamb birth weight (Table 5). Liveweight change during early pregnancy had no significant effect on birthweight, whereas liveweight change during late pregnancy had a large positive effect on lamb birth weights. For every 10 kg increase in ewe liveweight change during late pregnancy, lamb birth weights increased by 0.6 kg. The effects of liveweight profile on birth weights were similar for single and twin born lambs.

Table 5. The effect of sex, birth type, date of birth (DOB), dam liveweight at joining (LW_{d0}), dam liveweight change from Day 0 to Day 90 of pregnancy (LWC_{0-90}) and dam liveweight change from Day 90 to Day 140 of pregnancy (LWC_{90-140}) on progeny birth weights.

Factor	Effect	SE	Significance
Constant	2.67	0.470	
		Sex	
Female	0.00		
Male	0.30	0.099	**
		Birth type	
1	0.00		
2	-0.98	0.105	***
		Coefficients	
DOB	0.02	0.003	***
LW_{d0}	0.02	0.009	**
LWC_{d0-90}	0.01	0.024	n.s.
LWC_{d90-L}	0.06	0.019	**

There was no significant effect of ewe liveweight at mating on lamb weaning weights (p=0.69). However, there were positive effects of liveweight gain during pregnancy on lamb weaning weights (Table 6). For every 1 kg gain in ewe lamb liveweight during early pregnancy, lamb weaning weights increased by 0.16 ± 0.085 kg (P=0.06). For every 1 kg increase in ewe lamb liveweight gain during late pregnancy lamb weaning weights increased by 0.29 ± 0.153 kg (P=0.06). The effects of ewe liveweight profile were similar regardless of rear rank, but twin born and reared lambs were about 5 kg lighter than single born and reared.

Table 6. The effect of sex, birth type, dam liveweight at joining (LW_{d0}), dam liveweight change from Day 0 to Day 90 of pregnancy (LWC_{0-90}) and dam liveweight change from Day 90 to Day 140 of pregnancy (LWC_{90-140}) on progeny weaning weights.

Factor	Effect	SE	Significance
Constant	25.4	0.55	
	Sex		
Female	0.0		
Male	0.8	0.32	***
	Birth type		
1-1	0.00		
2-1	-1.2	0.58	
2-2	-4.8	0.49	***
	Coefficients		
LW_{d0}	0.00	0.004	n.s.
LWC_{d0-90}	0.16	0.084	*
LWC_{d90-L}	0.29	0.153	*

Additional survival data from Moojepin 2011 (Rosales *et al*. 2013) and 2012 (activity #3) was added to experiments from above for a combined analysis of lamb survival. Survival of singles varied from 79-89% and twins from 61-67% between experiments. Birth weights varied significantly between experiments for singles and twins, and was related to survival as expected albeit not quite significant (P=0.08; Fig. 10).

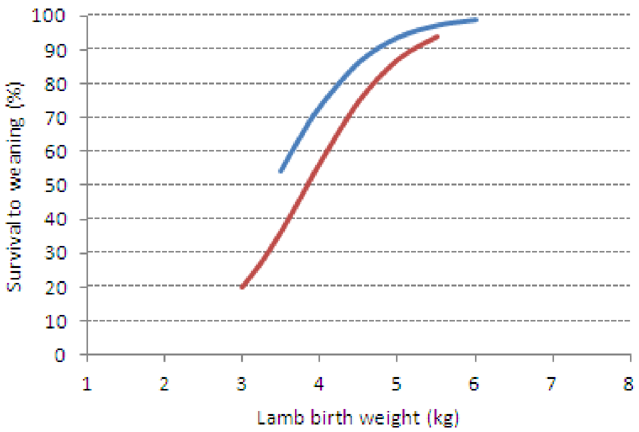


Figure 10. The relationship between birth weight and survival for single (blue) and twin (red) lambs born to Merino ewe lambs from the 'Maternal Efficiency Flock' in Pingelly (2010-2012) and 'Moojepin' in Katanning (2012).

Discussion

A low proportion of Merino ewe lambs had achieved puberty by seven and a half months of age despite reaching 43 kg or more than 70% of their estimated mature size at the start of teasing. Merino ewe lambs were however responsive to teasing and by the end of the 15-day teasing period more than 60% of the lambs had achieved puberty and more than 90% had achieved puberty by between 9 and 10 months of age. The average age and liveweight at puberty in this experiment were greater than that reported by Rosales *et al.* (2012, 2013), possibly because in this experiment puberty was verified using the concentration of blood progesterone whereas the earlier experiments relied on crayon marks only which are subject to greater errors.

Ewe lambs that were heavier at the start of teasing, presumably due to better nutrition pre- or post weaning and genetics, were more likely to have achieved puberty prior to teasing and where also more responsive to teasing. The effect of genetics for growth on the likelihood of achieving puberty was confirmed when the data was combined with earlier experiments using the same flock (Rosales et al. 2012, 2013). The combined analysis indicated that ewe lambs from sires with higher ASBVS for post weaning weight (PWT) were more likely to achieve puberty by a predetermined age, which extends the results of Rosales *et al.* (2012, 2013) who reported relationships between likelihood of achieving puberty and the ewe lambs own breeding value for growth. Across the three experiments, more than 80% of ewe lambs from sires with a PWT ASBV greater than 5 achieved puberty by the end of teasing, whereas only about 50% of ewe lambs from sires with a PWT ASBV of 1. A PWT ASBV of 1 corresponds closely with the average for the most recent drop of Merino sires in the Sheep Genetics MERINOSELECT database.

Our data indicates that using high growth sires in conjunction with teasers, even when joining within the normal breeding season, are key components of the overall strategy to enable Merino ewe lambs to reach puberty at a younger age. If ewe lambs can reach puberty at a younger age they can potentially be mated at a younger age and their second mating can also be more easily integrated with mating of the adult ewe flock the following year.

Liveweight was positively related to fertility, ovulation rate and reproductive rate. The increase in reproductive rate was only 1.6% per 1 kg increase in liveweight at the start of joining, which is comparable to that observed in adult Merino ewes (Ferguson *et al*. 2011), but much less than the responses reported for other datasets in this report and by Rosales *et al.* (2012, 2013). These latter studies using the same flock of sheep reported an extra 4.5 to 4.8 fetuses per per 100 ewe lambs mated per 1 kg increase in liveweight. Interestingly, the response in reproductive rate was also less than the increase in ovulation rate of 2.4% per 1 kg increase in liveweight, and occurred despite fertility increasing with liveweight. It is possible that the high levels of intervention required to accurately quantify the magnitude and timing of embryo losses in the current study actually contributed to embryo losses, and these effects were greater in heavier lambs, such that the overall impact of liveweight on reproductive rate were less that that observed in other experiments.

The impacts of liveweight on reproductive performance can explain the higher overall fertility and reproductive rate of Merino ewe lambs from sires with higher ASBVS for PWT. Ewe lamb fertility increased by 6.3% and reproductive rate by 9.3% for each 1 kg increase in the ASBV for PWT of their sire. The responses were slightly less when a combined analysis of data from this experiment and Rosales *et* *al.* (2012, 2013) was completed. These results confirm that selection for high early growth, as well as nutritional management prior to joining, can be used to improve the fertility and reproductive rate of Merino ewe lambs mated at 8 to 10 months of age.

Nutrition during joining had no significant effect on ovulation rate, fertility rate or reproductive rate of Merino ewe lambs. This result was not surprising given the differences in liveweight between treatments were not observed until 40 days after treatments began and the overall difference in growth rates between nutritional treatments was less than 30 g/day (187 *vs*. 158 g/day). More than 90% of all pregnancies in the current experiment were conceived during the first 35 days when unfortunately there were no effects of nutritional treatments on growth rates and liveweight. Experiment 2 in this report generated larger differences in growth rate during the entire joining period and the prediction equations suggest that increasing growth rates by 100 g/day during joining increased reproductive rates by about 20% (see Fig. 13). The differences in growth rates between nutritional treatments in the current study after Day 40 of joining were about 100 g/day, so given that only 10% of pregnancies were conceived during this time, it is reasonable to predict that nutritional treatment would have only increased reproductive rates by 1-2%.

The effects of nutrition during joining on reproductive rate in this experiment (see Table 1, 55% *vs.* 53% for high vs medium nutritional treatments) are entirely consistent with the time and extent of the differences in growth achieved during joining. There is convincing evidence elsewhere in this report that improving nutrition during joining can substantially increase reproductive performance of ewe lambs, and these effects are over and above the gains expected from increases in absolute liveweight. To maximise the benefits from improving nutrition during joining the differences in nutrition must be achieved from introduction of rams, and especially the first cycle, when most of the lambs are conceived.

The average ovulation rate in this experiment was 150%, which is extremely high for ewe lambs regardless of breed and comparable to that reported for adult Merino ewes (Oldham *et al.* 1990; Kleemann *et al.* 2005; Vinoles *et al.* 2010, 2011, 2012), however up to 84% of this potential was lost by weaning. Most lambs were conceived from the first breeding event, and from this breeding event a weaning percentage of only 21 to 24% resulted from the ovulation rate of 150%. The level of reproductive wastage between ovulation and weaning was greater than that reported previously for older ewes. Knight *et al.* (1975) and Kleemann *et al.* (2005) reported in two-year-old and older Merino ewes that reproductive wastage to weaning was approximately 45% and Kelly (1982) reported losses of only 25 to 30% in strong wool breeds. A major difference between studies is that in our study more than 90% of the total losses occurred pre-natal, whereas in the studies with adults the losses were more equally shared between pre- and post-natal sources.

The major contributor to reproductive wastage in our study was the loss that occurred during the first 17 days post breeding. The exact cause of these losses is unknown but would include ova loss prior to fertilisation, failure of conception and embryonic loss. Oestrus can be shorter and less intense in ewe lambs compared to mature ewes (Dyrmundsson, 1973; Edey *et al*. 1978; McMillan and Parker, 1981; Schick, 2001) and Allison *et al.* (1975) reported that ewe lambs need to be served by the ram on at least three occasions before 100% of ewe lambs actually have semen inside their reproductive tract. Furthermore, ewe lambs can also display oestrus without ovulation and ovulation without oestrus in the period post puberty (Edey *et al.* 1977; Chu and Edey, 1978; Quirke, 1981) and embryonic losses have previously been reported to be greater in ewe lambs compared to mature ewes. McMillan and

McDonald (1985) reported that fertilised ova from ewe lambs were less likely to survive than those from mature ewes and Quirke (1981) suggested that the higher rates of embryonic loss in ewe lambs were due to the poor quality of fertilised eggs. Mulvaney (2011) also found greater differences between ovulation rate and the number of fetuses in mid-pregnancy in Romney ewe lambs compared to mature ewes. Partial failure of multiple ovulations were similar in our study to that reported by Kleemann *et al.* (2005), but losses between pregnancy scanning and lambing were greater than what is generally reported for adults (Vinoles *et al.* 2012). These studies suggest higher rates of loss post fertilisation may also have contributed to the loss observed prior to day 17 in the present study. Overall the results of the present study, and those of previous studies, clearly indicate that further research on the breeding and early pregnancy period is required if greater levels of reproductive performance are to be achieved from ewe lambs.

The impacts of these early reproductive losses can be masked by the opportunity a ewe has to rebreed in later cycles during the breeding period, but if she does conceive to a later breeding event her lamb(s) will be born later and will be on average lighter and of lower value at a given weaning age. In addition, conceiving to a later breeding event will disadvantage the ewe in her ability to recover from lactation and be at a desirable weight for breeding with the mature flock in the following joining. Less than 50% of all the ewe lambs that got pregnant conceived during the first 17-days after introduction of entire rams, 75% were conceived during the first 34 days and 96% by 52 days of the 68-day breeding period. This pattern of conception is more evenly distributed between successive cycles than occurs is adult merino ewes, especially after teasing. Perhaps more significantly, about 44% of ewe lambs (46 out of 104) that were mated for the first time during the first or second 17-day period, but failed to get pregnant, then either skipped a cycle or did not recycle before the end of the 68-day breeding period. In other words, these ewe lambs would not have returned to service within a normal 35-day breeding after teasing.

Together, these results suggest that improving reproductive rates will require either more ewes conceiving on the first cycle and or a longer joining period. Given the effectiveness of teasers in inducing puberty, and evidence in other studies that the viability of embryos improves on subsequent cycles, an opportunity could be to reduce age at puberty by management or genetics but then delay introduction of rams for one or two cycles after the removal of teasers. The option of extending the joining period is unlikely to be practical, as mating ewe lambs already tends to occur after mating the adult ewes so an extended joining would result in very late born lambs and even less time for the young ewes to recover for their normal hogget joining. This could have negative long term effects on their reproductive performance but this is yet to be quantified.

There was no significant relationship between changes in maternal liveweight during pregnancy and lamb birth weight in this experiment, however relationships between liveweight profile and birth weight were apparent when this data was combined with other data from the same flock. The absence of an effect of liveweight profile on birth weights in the individual study could be attributed to low animals numbers or the relatively small range in maternal liveweight changes, especially during late pregnancy.

In the combined analysis, ewe lambs that were heavier at joining had heavier lambs, and the size of the response was similar to that reported by Oldham *et al.* (2011) and Paganoni *et al.* (2013) for adult Merino ewes. This is not entirely surprising given there is a strong genetic correlation between birth weight and liveweights during growth and at maturity (Huisman and Brown 2009). Liveweight change during early pregnancy had no effect on birth weights, where as birth weights were highly sensitive to liveweight change of the ewe lamb dam during late pregnancy. For every 10 kg increase in ewe liveweight change during late pregnancy, lamb birth weights increased by 0.6 kg and the effects of liveweight profile on birth weights were similar for single and twin born lambs. The effects of nutrition during late pregnancy on birth weights may be greater in ewe lambs than adults (Oldham *et al*. 2011), but this is still to be confirmed using the same flock across ages. Paganoni *et al*. (2013) analysed more than 20,000 records from the Sheep CRC Information Nucleus Flock and reported that birth weight responses to ewe liveweight changes during pregnancy were similar for ewes aged 2 to 9 years of age, but there were no ewe lambs in that analysis. The results from our combined analysis differ to several studies involving cross bred ewes lambs that have generally shown that nutrition of ewe lambs during pregnancy had little effect on the birth weight of their lambs (Morris *et al.* 2005; Kenyon *et al.* 2008; Munoz *et al.* 2009; Meyer *et al*. 2010; Mulvaney *et al*. 2010; Peel *et al.* 2012). Nevertheless, none of these authors have attempted to predict birth weights from the liveweight profile of individual ewe lambs and several studies also used low numbers of animals. In our analysis, liveweight at joining and liveweight change during pregnancy also influenced the liveweight of progeny at weaning, and the effects were again probably greater than reported for adult Merino ewes (Thompson *et al.* 2011). This confirms that improving the nutrition of Merino ewe lambs during late pregnancy will also be an important component of the overall management packages to improve the reproductive performance from Merino ewe lambs mated at 8 to 10 months of age.

5. Activity #3. The effects of genotype and growth path during joining on fertility, reproductive rate, birth weight and peri-natal mortality of lambs

Methods

Animals and measurements

Experiment 2 used 500 Merino ewe lambs from Moojepin Multi-Purpose Merino stud located at Katanning, Western Australia (33°63'S, 117°89'E). The ewe lambs had full pedigree and ASBVs (Brown *et al.* 2007). The sires of the ewe lambs had a range in ASBVs for post-weaning weight (PWT, 2.8 to 9.4 kg), post-weaning fat depth (PFAT, 0 to 1.4 mm), post-weaning eye muscle depth (PEMD, 0.2 to 2.4 mm), yearling greasy fleece weight (YGFW, -1 to 18%), yearling fibre diameter (YFD, -0.9 to 0.6 um) and early breach wrinkle (EBWR, -1.4 to -0.4 units). The experiment was conducted from October 2011 to June 2012. Ewe lambs were managed under commercial conditions from weaning to be 43.6 kg (range was 31 to 59 kg) at the start of joining on 09-Mar-2012 (Day 0); the average age of the ewe lambs at the start of joining was 224 days. Blood samples were also collected prior to introduction of rams to determine if the ewe lambs had reach puberty and a single sample was collected about 17-days after been marked; the data relating to puberty and loss of embryos after day 17 is not included in this report.

Ewe lambs were allocated on Day 0 into two nutritional treatment groups to achieve growth rates of 100 or 200 g/day during the joining period. The nutritional treatments were achieved by manipulating grazing pressure and access to a commercial pellet with a metabolisable energy content of 11.0 MJ/kg and a crude protein of 14.5%. From Day 0, each group of ewe lambs was syndicate mated with five rams for 49 days and rams where fitted with harnesses and crayons to monitor puberty and mating activity. During joining ewe lambs were weighed twice weekly and crayon marks were recorded. The crayon colour was changed 4 times over the joining period, and when ewe lambs were yarded for routine measurements the rams were temporarily removed from the group to avoid false marks while ewes were constrained. Ewe lambs were condition scored at the start and end of joining. Ewe lambs were ultrasound scanned on Day 33 for fat and eye muscle depth. Between joining and lambing they were weighed monthly and pregnancy scanned 109 days after the start of joining. All pregnant ewes were side-branded just prior to lambing and during the lambing period all newborn lambs were weighed, and their birth rank and sex determined with 24 hours of birth. Ewes and lambs were weighed again at marking and at weaning.

Statistical analysis

All statistical analyses were performed using GENSTAT (GENSTAT Committee 2008). Joining liveweight, liveweight change over the joining period and nutritional treatment were analysed using the method of Residual Maximum Likelihood to fit each trait with birth type, rear type, age, and relevant coefficients as fixed effects. Sire and ID were fitted as random effects. Estimates of fertility were assessed separately by fitting General Linear Mixed Models. The approach used a logit-transformation and binomial distribution in additive models. Logits were predicted as a function of relevant effects, ewe joining liveweight, ewe growth rate during joining, sire breeding values for PWT, PFAT, PEMD, YGFW, YFD and EBWR and nutrition group were fitted as fixed effects either singly or in combination, and sire and id were fitted as random effects. Reproductive rate (dry, singles and multiples) were analysed as a function of the same variables as above, either singly or in combination using the method of generalised linear model with a multinomial distribution and logit link function, and adjustment for sire and ID.

Results

Liveweight and liveweight gain

The average growth rate of ewe lambs in the high and low nutrition treatment groups during joining were 200 g/day and 95 g/day respectively ($P<0.001$), and the high group remained about 2 kg heavier at lambing (Fig. 11). At the end of the joining period ewes from the high group were about 0.3 of a condition score fatter than those from the low group (3.5 vs. 3.2; $P< 0.001$).

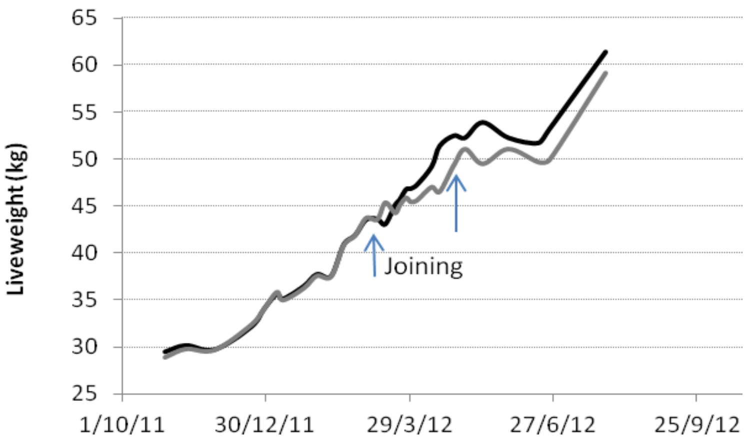


Figure 11. Liveweights (kg) of Merino ewe lambs at 'Moojepin' fed to achieve a fast (black; 200g/day) or moderate (grey; 100g/day) growth rates during joining.

Fertility and reproductive rate

Ewe lambs that were older and heavier at the start of joining were more fertile and achieved a higher reproductive rate (P<0.001); on average, reproductive rate increased by 4 to 4.5% per 1 kg increase in liveweight at the start of joining. Single born lambs were also more (P<0.05) fertile and had a higher reproductive rate than ewes that were born as twin lambs. There was no significant effects of condition score of ewe lambs at joining that were in addition to these effects of liveweight, possibly because more than 80% of ewe lambs were condition score 3 to 3.5. Improving nutrition during joining also significantly increased fertility (74% *vs.* 55%; P<0.001) and reproductive rate (107% *vs*. 70%; P<0.001), and the effects were evident regardless of liveweight (Fig. 12).

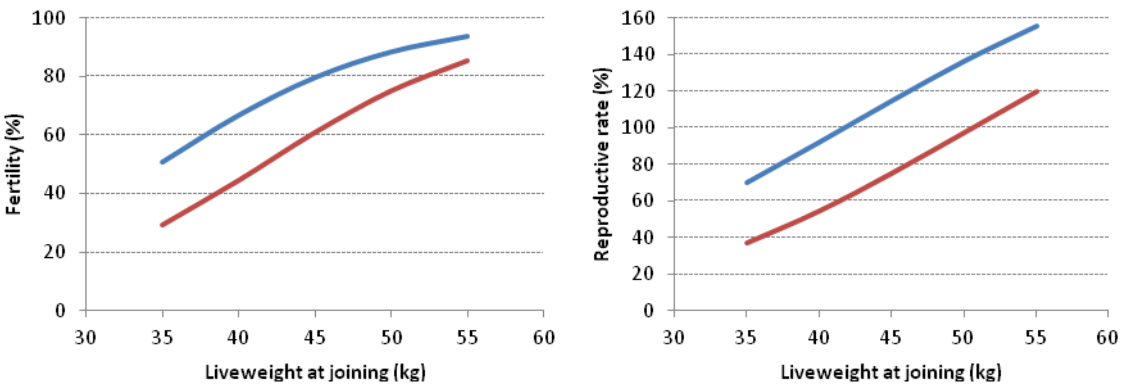


Figure 12. The effect of liveweight at joining on fertility (left) and reproductive rate (right) for Merino ewe lambs at 'Moojepin' fed to achieve a fast (blue) or moderate (red) growth rates during joining.

As expected, the effects of nutrition during joining on fertility and reproductive rate of Merino ewe lambs were largely explained by differences in liveweight change (Fig. 13). Across all sheep, regardless of nutritional treatment, the prediction equations suggest that growing an extra 100g/day during joining increased fertility by between 8 and 18%. Even though the interaction was not statistically significant (P>0.05), the effects of liveweight change on fertility were less at higher liveweights as very few ewe lambs that were greater than 50 kg at the start of joining and grew near potential during joining failed to get pregnant. As there is no ceiling to reproductive rate, an extra 100 g/day improved reproductive rate by about 20% irrespective of liveweight at the start of joining.

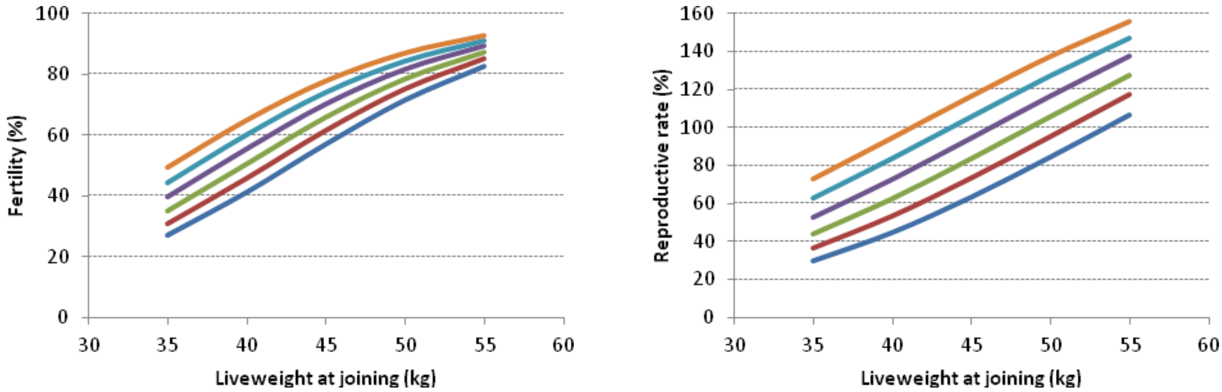


Figure 13. The effect of liveweight at joining on fertility (left) and reproductive rate (right) for Merino ewe lambs at 'Moojepin' that grew at different rates during joining [0 (bottom), 50, 100, 150, 200 and 250g/day (top)].

The reproductive performance of ewe lambs mated at 8 to 10 months of age was also influenced by sire, and their breeding values for growth. There was no significant interactions between sire breeding values and nutrition, so the effects of nutrition during joining and breeding value of sire were additive. The fertility and reproductive rate of ewe lambs increased by between 2.2 to 3.1% and 4.5 to 4.7% respectively for each 1 kg increase in the ASBV for PWT of their sire. This was presumably because ewe lambs from sites with higher PWTs were heavier (P<001) at joining and grew faster during joining regardless of nutritional treatment (P<0.05). Sire breeding value for PFAT was significantly related to both fertility (P<0.05) and reproductive rate (P<0.01). When PWT was added to the model the additional effects of PFAT on fertility were not significant (P = 0.19) but the effects on reproductive rate remained (P = 0.08) and the effect of increasing sire PFAT by 1 mm resulted in a 22% increase in reproductive rate. There were no significant effects of sire breeding values for PEMD, YGFW, YFD or EBWR.

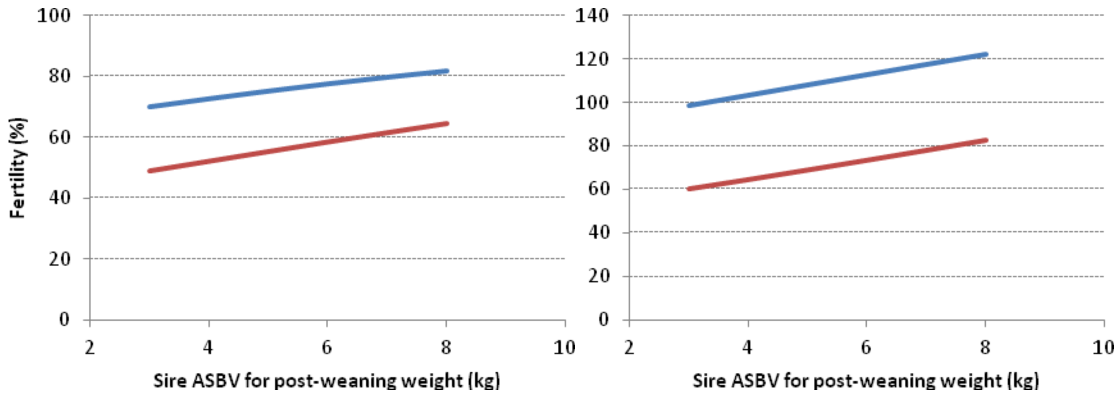


Figure 14. The effect of sire breeding value for post-weaning weight on fertility (left) and reproductive rate (right) for Merino ewe lambs at 'Moojepin' fed to achieve a fast (blue) or moderate (red) growth rates during joining.

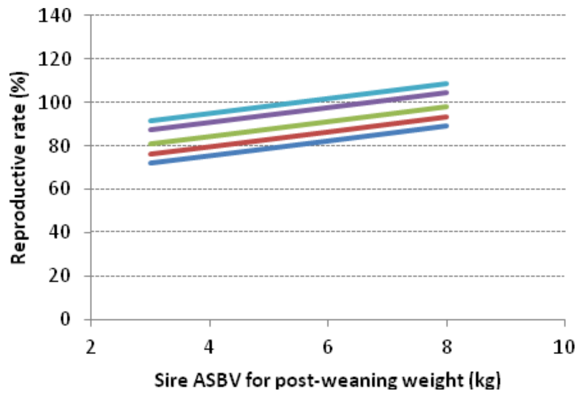


Figure 15. The effect of sire breeding value for post-weaning weight and post-weaning fat [0.3 (bottom), 0.5, 0.7, 1.0 and 1.2 mm (top)] on reproductive rate for Merino ewe lambs at 'Moojepin'. Values represent the average of ewe lambs fed to achieve a fast or moderate growth rates during joining.

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Lamb birth weights and survival

Single lambs were significantly heavier (5.4 kg) than twin lambs (4.6 ± 0.13 kg) at birth ($p<0.001$); these weights were comparable to a similar experiment at Moojepin in 2011 (5.2 kg and 4.5 kg respectively). There was no significant effect of nutrition during joining on the birth weight of single or twin lambs, however across all ewes irrespective of nutritional treatment a 1 kg increase in ewe liveweight at the start of mating was associated with a 0.03 kg increase in the birth weight of lambs irrespective of birth type ($p<0.001$). There were no significant effects of liveweight profile during early/mid or mid/late pregnancy on the birth weight of the lamb. Lamb survival to weaning was not affected by nutrition during mating, but survival of single lambs to weaning was significantly higher than survival of twin lambs (93 vs. 54%). The poor survival of twin born lambs eroded the 40% differences in reproductive rate between ewe lambs fed high or low nutrition during joining, such that differences in weaning rates between these treatments was only 15% (71% and 56%; $P<0.05$).

Discussion

Merino ewe lambs that were heavier at the start of joining were more fertile and achieved a higher overall reproductive rate than ewe lambs that were lighter. The relationship between liveweight at joining and reproductive rate was linear over the range 35 to 55 kg, rather than a threshold response, and reproductive rate increased by 4 to 4.5% per 1 kg increase in liveweight at the start of joining. This response is directly comparable to earlier studies which reported increases of 4.5 to 4.8 extra foetuses per 100 ewes mated (Rosales *et al.* 2012, 2013). These responses are however much greater than that observed in the other experiment in the current report (see Fig. 6), which could reflect the high rates of pregnancy failure in that study due to the intensive measurement protocol required to accurately quantify embryo losses. There is also evidence in the other experiment that the rate of pregnancy failure was greater for ewe lambs which were already heavier at joining, because the relationship between liveweight and ovulation rate was much steeper than the relationship between liveweight and reproductive rate.

Overall, it is likely that the responses in reproductive rate to improving liveweight at joining are much greater in ewe lambs than in adult ewes regardless of breed (Oldham *et al.* 2011; Paganoni, INF analysis). This is not surprising, and may imply that management to achieve target liveweights at joining to optimise reproductive performance will be more important in growing ewe lambs mated at 8 to 10 months than in adult ewes.

Improving the nutrition of Merino ewe lambs during joining also significantly increased their fertility and reproductive rate when mated at 8 to 10 months of age. The fertility and reproductive rate of ewe lambs fed a higher level of nutrition during joining was 74% and 107% compared to 55% and 70% for those feed a lower level of nutrition during joining. The effects of nutrition during joining on fertility and reproductive rate were evident regardless of liveweight, indicating that their effects were additive. Mulvaney *et al.* (2010) reported that extra feeding from just prior to joining until after joining increased the proportion of cross-bred ewe lambs that cycled and increased their fertility and the number of foetuses per ewe, but no studies to our knowledge have published this effect for Merino ewe lambs. Rosales *et al.* (submitted) recently examined the effects of liveweight change during joining on reproductive performance of ewe lambs in this same flock as the current study. Whilst the ewe lambs in the previous study were only 40 kg at the start of joining and the low nutrition group only maintained weight during joining, improving nutrition during joining increased reproductive rate by 38% (46% vs 8%) which was similar to the 43% (107% vs 74%) improvement in reproductive rate in the current study.

Most ewe lambs that conceived in the current study did so during the first 25 days after the rams were introduced (data not shown), so given the high nutrition group grew at about 100 g/day faster than the low nutrition group, the average liveweight at conception is likely to differ between nutritional groups by 2 to 3 kg. Differences in liveweight at conception would therefore explain less than one-third of the 37% difference in reproductive rate between treatments, indicating the main effects of improving nutrition during joining are over and above those resulting from gains in absolute liveweight. There is limited evidence in adult ewes that liveweight gain can influence ovulation rate over and above the effects of liveweight *per se* (Gunn *et al.* 1992), but studies with larger numbers of adult ewes have generally failed to detect significant effects of liveweight change during joining on reproductive performance of adult ewes (Adalsteinsson 1979).

Short term supplementation of lupins for 4 to 6 days prior to conception can also increase ovulation rates in adult ewes even in the absence of detectable increases in liveweight, but these ‘acute’ effects often increase reproductive rate by less than 10 to 15% (Smith and Stewart 1990; Vinoles *et al.* 2010). Regardless of the mechanism, improving nutrition during joining had very large positive effects on the reproductive performance of Merino ewe lambs regardless of their liveweight at the start of joining, and it again appears that nutrition during joining may be more important in ewe lambs than adults. Maximising the reproductive performance of Merino ewe lambs therefore requires good nutrition from pre-weaning until at least the end of joining.

The effects of nutrition during joining on fertility and reproductive rate of Merino ewe lambs logically reflected differences in liveweight change during joining, and the effects of increasing growth rate on reproductive performance was close to linear across the range from liveweight maintenance to nearly 300g/day. Across all sheep, regardless of nutritional treatment, the prediction equations suggest that growing an extra 100g/day during joining had a similar impact on reproductive rate as an extra 5 kg of liveweight at joining. In other words, ewe lambs that weighed 40 kg at the start of joining and grew at 200 g/day during joining achieved similar reproductive performance to those that weighed 45 kg at the start of joining and grew at 100 g/day or weighed 50 kg at the start of joining and maintained weight during joining.

It is likely that a difference in liveweight gain during joining is a major factor contributing to the variable effects of liveweight at the start of joining on the resulting reproductive rate of ewe lambs. Rosales *et al*. (2012) reported a reproductive rate of about 100% from Merino ewe lambs that were 43 kg at the start of joining and gaining more than 200 g/day during joining, whereas in a second study a reproductive rate of 50% was achieved when ewe lambs were 48 kg at the start of joining and only gained about 50 g/day during joining (Rosales *et al*. 2013). A preliminary attempt to validate the prediction equations for reproductive rate in Figure 13 against 14 other data sets indicates that the data from the current study may represent the upper limit for what is achievable from Merino ewe lambs joining at about 8 to 10 months of age. Nevertheless, there was reasonable fit as the actual reproductive rate for 11 or the 14 flocks was within the 95% confidence limits of Figure 13 which was ± 20%. Combining data with Rosales et al. (2013b) who also imposed nutritional treatments at Moojepin is expected to reduce the confidence limits.

This suggests that development of a matrix of liveweight at joining plus liveweight change during joining in relation to reproductive rate will enable the development of optimum management strategies prior to and during joining to maximise profits from joining Merino ewe lambs. The optimum strategy will depend on the supply and quality of paddock feed in relation to the time and duration of joining, but a simple feed budget suggests that investing in supplementary feed during joining may be more cost effective than prior to joining. This needs to be confirmed. The cost effectiveness of segregating ewe lambs at or soon after weaning and only feeding a proportion of the flock to be joined also needs to be investigated, given the linear responses between liveweight and liveweight gain during joining and reproductive rate and the high rate of mortality of twin-born lambs in this study.

Ewe lambs from sires with more potential for growth were heavier at joining and grew faster during joining, so not surprisingly ewe lambs from sires with high ASBVS for PWT were more fertile and achieved a higher reproductive rate. The reproductive rate of ewe lambs increased by about 4.6% respectively for each 1 kg increase in the ASBV for PWT of their sire. This was less than the corresponding value of 7.9% for the Maternal Efficiency Flock (Fig. 9), but much greater that 2.7% estimated from almost 5000 records from 13 different Merino flocks (Fig. 17). This indicates that the magnitude of the response from selecting high growth sires may vary between flocks, for reasons not known. Nevertheless, the results from this study, and the other analysis in this report, suggest that indirect selection for improving reproductive rate of Merino ewe lambs can be achieved from using sires with higher breeding values for growth. This is consistent with Afolayan *et al.* (2008, 2009) who reported moderate positive genetic correlations between early growth and reproductive performance over first three breeding seasons, but they did not compare the genetic correlations for ewes mated at 7 months of age compared to those mated at older ages.

The economic benefit from improving reproductive rate via genetic selection for PWT will also depend on whether increasing PWT improves liveweight and growth via increases in feed intake or feed conversion efficiency. It would seem likely that reproductive performance of ewe lambs could also be improved by direct selection. Newton *et al.* (2013) has recently reported that the heritability estimates for the number of lambs born and weaned by ewe lambs of 0.16 ± 0.05 and 0.13 ± 0.05. These estimates are similar to Fogarty *et al.* (1994) who reported heritability estimates for number of lambs born and weaned by ewe lambs of 0.17 ± 0.06 and 0.08 ± 0.05 respectively, and possibly slightly higher that that reported for adult ewes (Safari *et al.* 2005, 2007; Afolayan *et al.* 2008a, 2009). Despite low heritability estimates, direct selection would be possible given the high phenotypic and genetic variation in reproductive traits. However, a constraint to this approach is that sires need to be selected on the performance of their female relatives which are not expressed until they are at least one or two years of age. Our results confirm that selection for high growth, as well as nutritional management prior to and during joining, can be used to improve the fertility and reproductive rate of Merino ewe lambs mated at 8 to 10 months of age.

Sire breeding value for PFAT was also significantly related to the reproductive rate of Merino ewe lambs mated at 8 to 10 months of age, and the effects remained almost significant (P=0.08) when PWT was added to the model. From a biological perspective the effects of extra genetic fat remain large, as a 1 mm increase in sire PFAT resulted in a 22% increase in reproductive rate regardless of PWT. Fat is known to play an essential role in reproduction in mammals and genetic potential for fat is positively related to fertility and fecundity in adult Merino ewes (Ferguson *et al.* 2010), but this is the first time the relationship has been identified in Merino ewe lambs. The studies of Rosales *et al.* (2011, 2012, 2013) used sires with a limited range in PFAT and they also used fewer animals that the current experiment.

Surprisingly there was no significant correlation between condition score at joining and reproductive performance, as this has been reported previously for cross bred ewe lambs (Kenyon *et al.* 2013) and is also evident in the combined analysis reported in Activity 4 of this report. This may suggest that the range of condition scores at the start and end of joining of the ewe lambs in this experiment was too small for a significant relationship with fertility to be established. Most significantly, it appears that the effects of genetic fat (PFAT), genetic growth (PWT) and nutrition during joining are additive indicating that all three are critical points to maximising the reproductive performance of Merino ewe lambs mated at 8 to 10 months of age.

Age of the ewe at joining had a significant effect on fertility and reproductive performance of Merino ewe lambs in this experiment. However some caution is needed in interpreting age effects as age was partly confounded with sire, as ewe lambs were born in two distinct periods following artificial insemination.

Nevertheless, it appeared that ewes that were older at joining were more fertile than those that were younger. This is consistent with Fogarty *et al.* (2007) that found ewe lambs joined at an older age resulted in higher lambing percentages. Moreover, ewes that were born and reared as a single lamb were more fertile and had a higher reproductive rate than those born and reared as a twin. However, when liveweight was added to the separate analysis of age at joining and birth type both of these factors were not significant. In other words, differences in liveweight explained the effect of both age at joining and birth type on fertility and reproductive rate. Merino ewes born as twin lambs will probably require additional management and feeding to increase liveweight from weaning to joining to be the equal to those ewes born as single lambs for successful mating at 7 to 10 months of age.

Across all ewes irrespective of nutritional treatment a 1 kg increase in ewe liveweight at the start of mating was associated with a 0.03 kg increase in the birth weight of lambs irrespective of birth type. This is similar to that quantified from a combined analysis of three years of data from the Maternal Efficiency Flock (Table 5) and similar to that reported for adult Merino ewes (Oldham *et al.* 2011; Paganoni, INF analysis). There was no significant effect of liveweight change during pregnancy on birth weights, but as this is evident in the combined analysis shown in Table 5 this simply indicates that there were insufficient animals to quantify the relationship from the data in this experiment. As birth weights are also related to the survival of lambs born to ewe lambs, and only 55% of twin lambs survived in the current experiment, it is very clear that improving the survival of twin born lambs is a high priority if joining ewe lambs is to become a cost-effective management option that also meets animal welfare requirements

6. Activity #4 - Combined statistical analysis of ewe lamb reproduction

Methods

Data

Data was sourced from 22 different flocks, including the Sheep CRC Information Nucleus Flock, Bestwool Bestlamb Producer Demonstration Site project (MLA Project Code B.PDS.0903) and research and commercial flocks in WA. The data for each flock had been collected over 1 to 5 years. The combined data comprises about 8,000 records for Composite ewe lambs and almost 9,000 records for Merino ewe lambs. About 2,000 of the Composite ewe lambs and almost 5,000 of the Merino ewe lambs have ASBVs for growth, carcass, wool and easy-care traits (Table 7).

Combined statistical analysis

Merinos and composites were analysed separately by the following methods using GENSTAT (GENSTAT Committee 2008). In the first analysis pregnancy rate was assessed by fitting General Linear Mixed Models. The approach used a logit-transformation and binomial distribution. Using additive models, logits were predicted as a function of different variables, including joining weight, condition score at joining, sire ASBVs for growth, carcass and wool traits plus wrinkle. Year nested within location was fitted as random effects. In the second analysis estimates of reproduction (dry, singles and multiples) were analysed as a function of different variables, as per the fertility analysis, using the method of generalised linear model with a multinomial distribution and logit link function and adjustment for location by year.

Results

Overall performance

On average, composite ewe lambs were more fertile (P<0.001) and had a higher reproductive rate (P<0.001) than Merino ewe lambs, but the feature of the data is the huge variation in performance between flocks even within breeds and between years (Table 9). The average reproductive rate of composite ewe lambs from the Information Nucleus Flock was about half that of the commercial producers in the MLA-funded PDS (57% *vs.* 102%), and this will influence the responses determined in relation to ASBVs given that 80% of the composites with ASBVs were from the INF. Dohnes and SAMMS from the Information Nucleus Flock, which were categorised as Merinos, also performed very poorly compared to commercial Merino and research flocks (39% *vs*. 63%). Their contribution to the analysis related to ASBVs was less as only 15% of Merino data with ASBVs was from the Information Nucleus Flock.

Table 7. Summary of data collated on the reproductive performance of Composite and Merino ewe lambs from 22 flocks measured across 1-5 years and mated at 7 to 10 months of age. The INF Merino data includes Dohnes and SAMMS.

Breed and flock	Years	Pregnancy scan	Liveweight at joining	CS at joining	ASBVs
Composites					
INF					
- Armidale	5	276	202	195	272
- Trangie	4	117	117	116	117
- Cowra	5	182	182	137	176
- Rutherglen	5	153	151	130	153
- Hamilton	4	131	130	93	130
- Struan	5	193	190	113	193
- Turretfield	4	148	148	105	145
- Katanning	5	357	330	329	328
BWBW PDS					
- Hayes	2	1592	1581	1581	-
- Peddie	2	3151	3149	3151	-
- Leeming	2	1205	1200	1200	133
Other					
- SHGEN	2	240	240	-	240
Total composites		**7745**	**7620**	**7157**	**1887**
Merinos					
INF					
- Armidale	4	110	110	109	110
- Trangie	3	58	58	58	58
- Cowra	3	73	73	73	73
- Rutherglen	3	57	57	57	57
- Hamilton	2	50	50	50	50
- Struan	3	45	42	28	45
- Turretfield	2	26	26	26	26
- Katanning	5	426	419	416	396
BWBW PDS					
- Wall	1	389	389	389	-
- Dean	1	384	376	376	-
- de Fegley	1	192	138	192	-
- Duxson	2	1904	1892	1785	1896
- McGregor	2	999	999	999	-
- Kubeil	1	444	444	444	-
- Michael	1	458	-	-	458
- Robertson	1	680	680	680	-
- Hooke	1	719	712	716	-
Other					
- DAFWA/MU	3	545	541	135	545
- Thompson	2	1017	1007	406	1007
- SHGEN	1	166	165	-	161
Total Merino		**8742**	**8178**	**6939**	**4882**
Total all breeds		**16496**	**15806**	**14102**	**6769**

Table 9. Summary of liveweight and condition score at joining, fertility and reproductive rate for Composite and Merino ewe lambs from 22 flocks measured across 1-5 years and mated at 7 to 10 months of age. The INF Merino data includes Dohnes and SAMMS.

Breed and flock	Liveweight at joining (kg)	CS at joining	Fertility (%)	Reproductive rate (%)
Composites				
INF				
- Armidale	35.6	3.0	0.38	0.42
- Trangie	51.7	3.1	0.45	0.62
- Cowra	47.1	3.3	0.40	0.60
- Rutherglen	42.1	2.9	0.44	0.67
- Hamilton	39.8	3.6	0.37	0.50
- Struan	40.6	3.4	0.28	0.34
- Turretfield	45.8	3.4	0.64	0.85
- Katanning	43.0	2.9	0.46	0.62
BWBW PDS				
- Hayes	39.5	3.0	0.74	0.95
- Peddie	43.8	3.3	0.84	1.26
- Leeming	41.2	3.1	0.59	0.85
Other				
- SHGEN	38.1		0.40	0.51
Mean of composites	**42.1**	**3.2**	**0.68**	**0.97**
Merinos				
INF				
- Armidale	36.3	3.3	0.29	0.31
- Trangie	48.5	2.9	0.38	0.55
- Cowra	46.7	3.4	0.44	0.58
- Rutherglen	41.5	2.8	0.23	0.26
- Hamilton	38.8	3.5	0.20	0.26
- Struan	36.4	3.3	0.11	0.11
- Turretfield	41.5	3.9	0.42	0.54
- Katanning	37.9	2.8	0.23	0.28
BWBW PDS				
- Wall	44.5	3.1	0.75	0.90
- Dean	38.0	3.1	0.75	0.90
- de Fegley	35.5	2.8	0.65	0.84
- Duxson	42.1	3.4	0.59	0.73
- McGregor	38.1	3.1	0.64	0.81
- Kubeil	39.2	3.1	0.14	0.17
- Michael			0.53	0.67
- Robertson	33.8	2.8	0.21	0.22
- Hooke	44.9	3.1	0.56	0.73
Other				
- DAFWA/MU	44.2	3.6	0.52	0.66
- Thompson	41.7	3.2	0.43	0.57
- SHGEN	39.2		0.32	0.40
Mean of Merinos	**40.6**	**3.1**	**0.49**	**0.62**
Mean of all flocks	**41.3**	**3.1**	**0.58**	**0.78**

Liveweight and condition score effects on fertility and reproductive rate

Liveweight at the start of joining explained a significant proportion of the variation in fertility and reproductive rate between flocks, between years within flocks, and between individual ewes within a flock in a single year. The combined analysis across all ewe lambs indicated that within breed a 1 kg increase in liveweight at joining above 35 kg was associated with a 3.3 and 3.9% increase in reproductive rate for Composite and Merino ewe lambs respectively. There were also significant additional effects of condition score of ewe lambs at joining on fertility and reproductive rate over and above correlated changes in liveweight (Fig. 16). The effects of increasing condition score on the fertility and reproductive rate responses were greater at heavier weights, with the exception of the fertility of composite ewe lambs, and an extra condition score improved fertility and reproductive rate by 20 to 25% when ewe lambs weighed 45 kg or more at the start of joining.

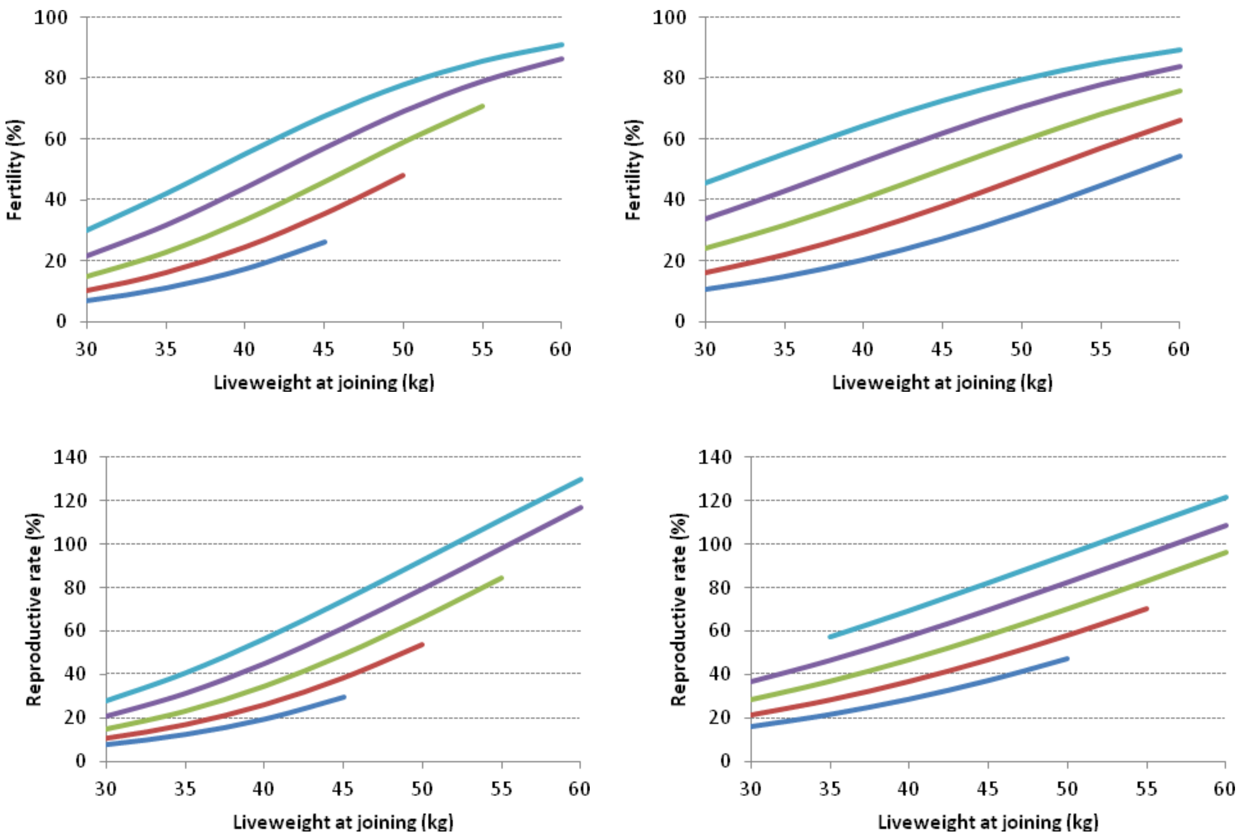

Figure 16. The effect of liveweight and condition score at joining [2 (bottom), 2.5, 3, 3.5 and 4 (top)] on the fertility and reproductive rate of Merino (left) and Composite (right) ewe lambs from 22 flocks measured across 1-5 years and mated at 7 to 10 months of age.

Sire breeding values in relation to fertility and reproductive rate

Ewes lambs from sires with higher ASBVs for growth were heavier at the start of joining ($P<0.001$). Across all ewe lambs, there were linear relationships between sire ASBVs for PWT and the fertility and reproductive rate of ewe lambs when mated at 8 to 10 months of age (Fig. 17). The fertility (2.0 *vs.* 1.1 % per 1 kg PWT) and reproductive rate (2.8% *vs*. 1.7% per 1 kg PWT) of the Merino ewe lambs was much more responsive to increasing sire PWT than was the case for the composite ewe lambs.

The sire ASBVs for fat and muscle at post-weaning age were also positively related to their fertility and reproductive rate. The effects of sire fat on fertility (3.9 vs. 3.8% per mm PFAT) and reproductive rate (5.9 vs. 6.8% per mm PFAT) were very similar for Merino and composite ewe lambs. By contrast, the effects of sire muscle on fertility (2.5 *vs*. 8.1% per mm PEMD) and reproductive rate (4.6 *vs*. 11.5% per mm PEMD) was much less evident in Merino ewe lambs than composite ewe lambs (Fig. 17).

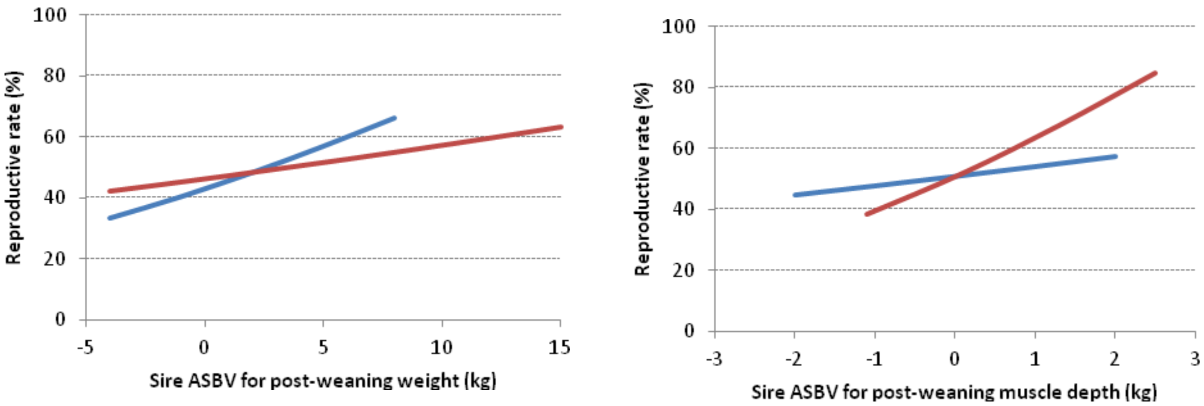

Figure 17. The effect of sire breeding value for post weaning weight (left) and muscle depth (right) on the fertility and reproductive rate of Merino (blue) and Composite (red) ewe lambs from 15 flocks measured across 1-5 years and mated at 7 to 10 months of age.

When sire PWT was added to the statistical models that included sire PFAT or sire PEMD, the effects of fat and muscle remained more evident in Composite ewe lambs than Merino ewe lambs. For the Merinos, the effects of sire PFAT became non-significant but there was some evidence that PEMD influenced fertility (P=0.06) over and above the effects of PWT. By contrast, a significant effect of sire PFAT on both the fertility (P<0.01) and reproductive rate (P<0.001) of Composite ewe lambs remained after including sire PWT (Fig. 18); the average effect of sire PFAT across the range in sire PWT was equivalent to +4.0% fertility per 1 mm sire PFAT and +7.4% reproductive rate per 1 mm sire PFAT. When sire PWT and sire EMD where included in the same statistical model, sire PEMD still had a significant impact on the fertility (P<0.001) and reproductive rate (P<0.001) of Composite ewe lambs and indeed sire PWT was no longer significant.

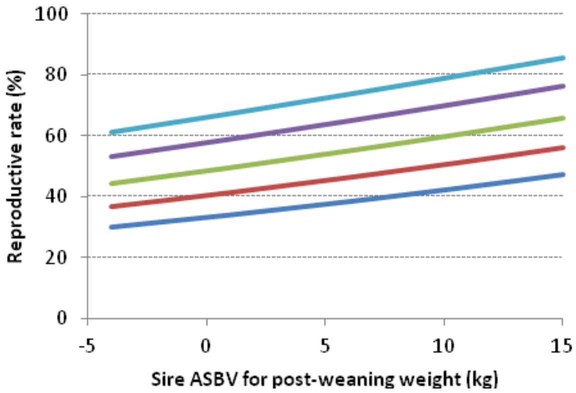

Figure 18. The effect of sire breeding value for post-weaning weight and fat [-2 (bottom), -1.2, 0.1, 1.4 and 2.5 mm (top)] on the reproductive rate of Composite ewe lambs from 15 flocks measured across 1-5 years and mated at 7 to 10 months of age.

Sire ASBV for PFAT and PEMD were not significantly (P>0.05) related to joining weight for either Merino or Composite ewe lambs. Sire PFAT and PEMD were highly significant when added to the model relating liveweight at joining to both fertility and reproductive rate for Merino (P<0.05) and Composite (P<0.001) ewe lambs. This implies that sire PFAT and PEMD had additional effects on fertility and reproductive rate to that attributed to liveweight, and ewe lambs from sires with higher ASBVs for PFAT or PEMD achieved comparable fertility and reproductive rates at much lower joining weights. To achieve a reproductive rate of 60%, a 1 mm increase in sire PFAT reduced the required joining weight by 3.0 kg in Merinos and 4.4 kg in composites (Fig. 19). Similarly, to achieve a reproductive rate of 60%, a 1 mm increase in sire PEMD reduced the required joining weight by 1.5 kg in Merinos and 3.8 kg in composites (Fig. 20).

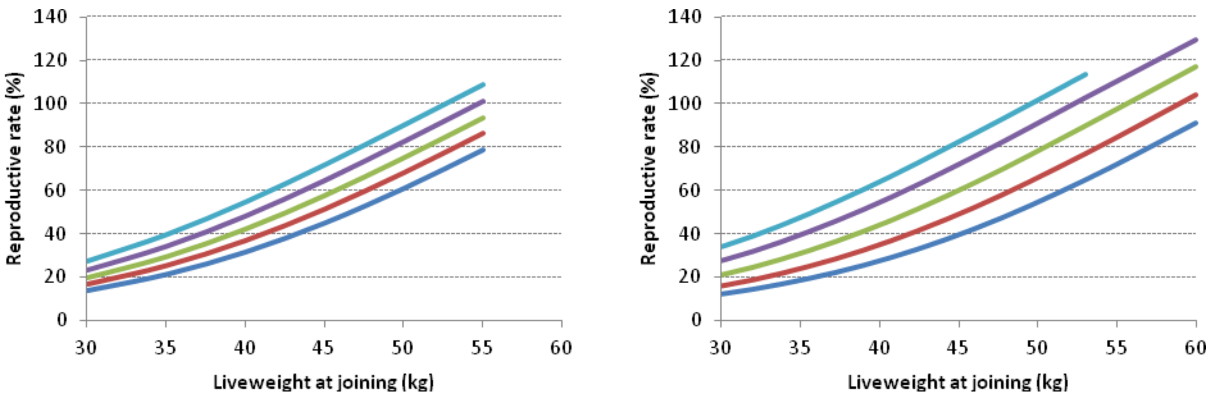

Figure 19. (left) The effect of liveweight at joining and sire breeding value for post-weaning fat on the reproductive rate of Merino [-1.5 (bottom), -0.8, -0.1, 0.6 and 1.3 mm PFAT (top)] and (right) Composite [-2.5 (bottom), -1.2, 0.1, 1.4 and 2.5 mm PFAT (top)] ewe lambs from 15 flocks measured across 1-5 years and mated at 7 to 10 months of age.

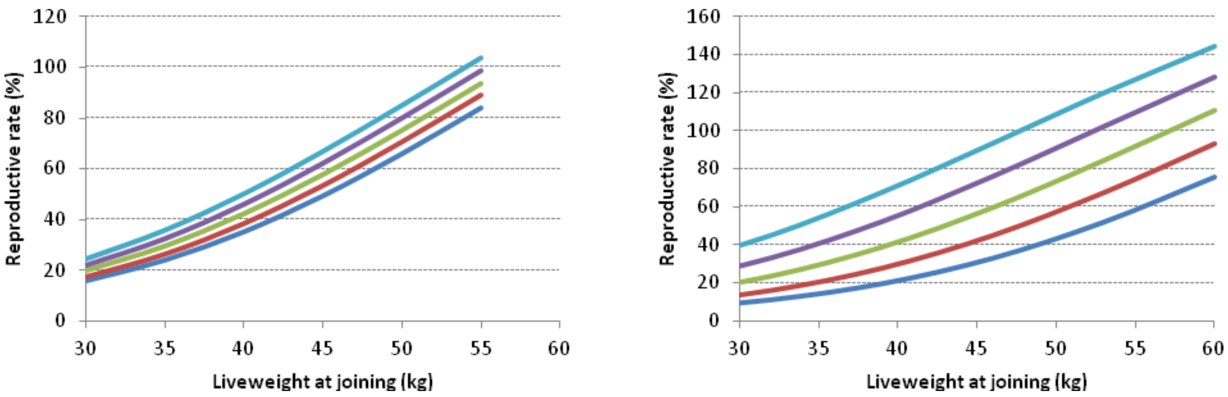

Figure 20. (left) The effect of liveweight at joining and sire breeding value for post-weaning muscle on the reproductive rate of Merino [-2 (bottom), -1, 0, 1 and 2 mm PEMD (top)] and (right) Composite [-2.3 (bottom), -1.1, 0.1, 1.3 and 2.5 mm PEMD (top)] ewe lambs from 15 flocks measured across 1-5 years and mated at 7 to 10 months of age.

Sire ASBV for YGFW was negatively (P<0.05) related to the fertility and reproductive rate of Composite ewe lambs, but surprisingly sire YGFW had no significant effect on the reproductive performance of Merino ewe lambs. By contrast, sire ASBV for YFD was positively related to fertility and reproductive rate in both Merino (P<0.05) and Composite (P<0.001) ewe lambs. When PWT was included in the model in the model with YGFW, the effects of PWT became negative but further interrogation of this analysis is required. In Merino ewe lambs, sire ASBV for EBWR was negatively (P<0.05) related to fertility and reproductive rate (Fig. 21), and ewe lambs from plainer body sires could achieve comparable reproductive rates at a lower liveweight at joining than those from sites with more wrinkles. When PWT was included in the model the effects of EBWR was not significant, however it remained near-significant (P=0.06) when actual liveweight at joining was included in the model. An increase in sire ASBV for wrinkle score reduced the required joining weight to achieve a reproductive rate of 60% by 4.1 kg.

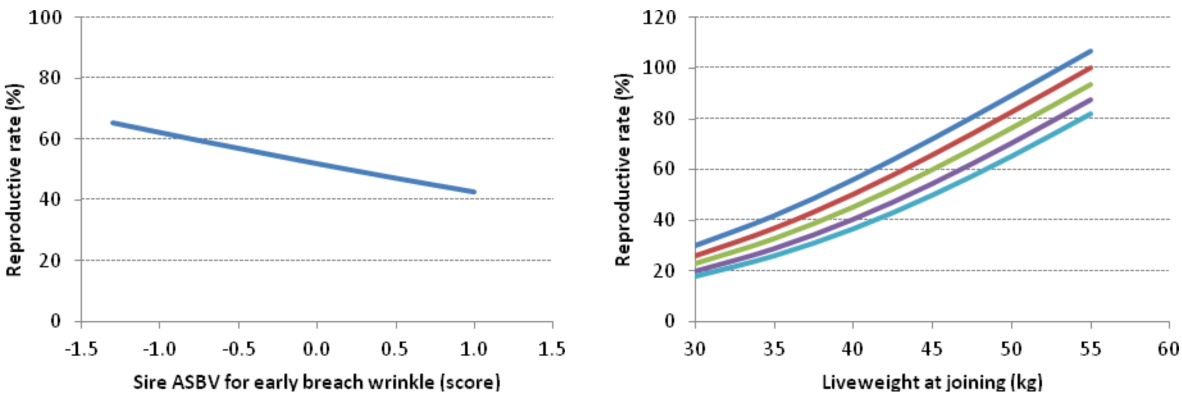

Figure 21. (left) The effect of sire ASBV for early breach wrinkle of reproductive rate of Merino ewe lambs, and (right) the effect of liveweight at joining and sire breeding value for early breach wrinkle on the reproductive rate of Merino [-1.3 (bottom), -0.7, -0.1, 0.5 and 1.0 score EBWR (top)] ewe lambs from 15 flocks measured across 1-5 years and mated at 7 to 10 months of age.

Discussion

The results from the national data analysis largely confirm our earlier results for Merino ewe lambs reported by Rosales *et. al.* (2011, 2012, 2013), and those reported earlier in this report, but also extends these results to demonstrate that many of the key principles also apply to Composite ewe lambs. Regardless of breed, liveweight is clearly a key determinant of the reproductive success of ewe lambs mated at 8 to 10 months of age. From a practical perspective, the responses to increasing liveweight are effectively linear across the liveweight range from 35 to 55 kg, and there is no evidence of a threshold response that has occasionally been reported for mature sheep. Across this liveweight range a 1 kg increase in liveweight at joining was associated with a 3.3 and 3.9% increase in reproductive rate for Composite and Merino ewe lambs respectively. Not surprisingly, this is within the range reported in our published work and elsewhere in this report for Merino ewe lambs, as this earlier data contributed to the National data set, and to the best of our knowledge this may be the first study that has quantified the slope of the relationship for Composite ewe lambs. Unfortunately the average performance of the composite ewe lambs in the National analysis was very poor, but this is likely to be due to factors other than liveweight. At 45 kg, the average reproductive rate of Composites in the national dataset was 62% compared to 110% in the MLA PDS (B.PDS.0903, Kubeil and Trompf 2013. We have also analysed 15,000 records from Romney-based ewes lambs in New Zealand and the corresponding reproductive rate at 45 kg was 133% (Kenyon and Paganoni, unpublished data), which demonstrates the huge scope to improve and the large impact of other factors.

Increasing condition score at joining had a large positive impact on the fertility and reproductive rate of both Merino and Composite ewe lambs mated at 8 to 10 months of age, and these effects were in addition to correlated increases in liveweight. We have not previously reported this additional effect of condition score on reproductive performance of ewe lambs, possibly because of a limited numbers of animals used in the individual studies and the limited range in condition scores between animals. In the national analysis, an extra condition score at joining improved fertility and reproductive rate by 20 to 25% when ewe lambs weighed 45 kg or more at the start of joining. This effect of an extra condition score at joining was equivalent to an extra 6 to kg at joining. This result is also consistent with the positive effect of sire PFAT on both fertility and reproductive rate for Merino and Composite ewe lambs over and above liveweight at joining. Ewe lambs that were phenotypically or genetically fatter at joining could achieve similar fertility and reproductive rates at a lower liveweight than those with a lower condition score and or from sires with lower ABSVs for PFAT. As early maturing animals are fatter at a given liveweight (Butterfield 1988), this suggests that early maturing ewes achieve higher reproductive performance when mated as ewe lambs. Further work is needed to relate liveweight, expressed as a proportion of their mature weight, to the reproductive performance of ewe lambs. It is a reasonable hypothesis that there will be no additional effects of fat and muscle on reproductive performance over and above liveweight at joining when liveweight is expressed as a percentage of mature size.

Sire ASBV for PWT was related to fertility and reproductive rate of ewe lambs when mated at 8 to 10 months of age, as ewe lambs from high PWT sires are heavier at joining and grow faster during joining and both these factors influence reproductive performance. This is consistent with our earlier work but extends these findings to composites. The fertility and reproductive rate of the Merino ewe lambs was almost twice as responsive to increasing sire PWT as the response for Composite ewe lambs. This is consistent with the small difference we observed between ewe breeds in the effects of liveweight itself on reproductive performance, and we have also shown in adult ewes in the Information Nucleus Flock that reproductive rate in relation to liveweight is less responsive in crossbred ewes than Merino ewes (Paganoni *et al*. unpublished data). More significantly, and possibly because liveweight is a lesser driver of reproductive performance of Composite ewes, it appears that genetic fat and especially muscle are more important determinants of reproductive performance of Composite than Merino ewe lambs. The effects of sire PFAT and sire EMD on fertility and reproductive rate of Merino ewe lambs largely disappeared when sire PWT was added to the models, but they remained significant when actual liveweight was included instead of PWT. The effect of sire EMD on fertility and reproductive rate was 2 to 3 fold greater in composites than Merinos, and it remained highly significant when either PWT or actual liveweight was added to the model. This is the first time we have shown an effect of sire PEMD on fertility and reproductive rate in ewe lambs, even though it has been shown to influence fertility and fecundity in adult Merino ewes (Ferguson *et al.* 2007). Given the genetic correlation between PFAT and PEMD, and that PEMD is negatively related to adult weight, it is likely that genetically high muscled ewe lambs are also physiologically more mature at a given liveweight and hence their greater reproductive performance. This raises questions about interpretation of the data reported with respect to the effects of liveweight and body composition on reproductive performance in this and other studies. Obviously liveweight includes fat and muscle, but an important consideration is that liveweight *per se* is simply mass and so encompasses no physiological or mechanistic process that would affect the reproductive system. On the other hand, tissues that are metabolically, physiologically and hormonally active, such as muscle and fat, can become involved in control processes at the brain, pituitary, ovarian and uterine levels. Moreover, the activities of fat and muscle can be affected by nutrition, whether or not liveweight responses are detectable. Regardless of the precise mechanism, analysis of this larger database confirms that selection for high fat and muscle genetics will have beneficial impacts on the reproductive performance of ewe lambs mated at 8 to 10 months of age.

Sire ASBVs for wool production and easy-care traits like wrinkle were also related to the reproductive performance of Merino and or Composite ewe lambs. It appears that increasing genetic potential for fleece weight can reduce fertility and reproductive rate at constant liveweight, but it is not clear why this response was only evident in the Composite ewe lambs. If fat is an important driver of reproductive performance, as appears to be the case, then the effects of sire YGFW are consistent with the negative effect that selection for fleece weight has on subcutaneous fat (Greeff *et al*. 2003; Fogarty *et al.* 2003) and whole body fat (Adams *et al*. 2005). Several authors have reported negative genetic correlations between fleece weight and reproductive performance in adult ewes (Ferguson *et al.* 2007; Safari *et al.* 2007; Afalayan *et al*. 2009). Further analysis is required of the wool data within the national ewe lamb dataset to reach a firm position concerning its effects on the reproductive performance of ewe lambs.

By contrast, the analysis indicates that sire ASBV for EBWR was negatively related to fertility and reproductive rate in Merino ewe lambs, and that ewe lambs from plainer body sires achieved comparable reproductive rates at a lower liveweight at joining than those from sites with more wrinkles. Overall, the analysis indicates that selection of sires with high growth, fat and muscle, and in the case of Merinos low wrinkle, is likely to improve the reproductive performance of ewe lambs joined at 8 to 10 months. As feeding ewe lambs to achieve a target joining liveweight represents a major cost, the right genetics will need to be matched with efficient nutritional management to ensure the practice is cost effective. For this reason, joining ewe lambs, especially Merino ewe lambs, is likely to be only relevant to some producers and some years, depending on seasonal conditions, feed costs and lamb prices.

7. Communications

This project has focused on completing robust research and data analysis to better understand the impacts of genetics and management on the reproductive success of mating ewe lambs at 8 to 10 months of age. Outputs from the project have been included into the ewe lamb module of 'Bred Well Fed Well', which was presented on about 15 occasions during the last 12 months. They also featured in three presentations at LambEx 2012 in Bendigo, two Best Wool Best Lamb Conferences (2012 and 2013), Livestock Updates in Perth in July 2012 and the AWI Forum in Kojonup in August 2012. The project has also been profiled at several ram field days run by the 'Multi-Purpose Merino' group who were intimately involved in the research. Overall, more than 1500 producers would have attended forums during the past 12 months where the project was presented.

8. Acknowledgements

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