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Lifetime Maternals – development of management guidelines for non-Merino ewes

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Abstract

Non-Merino ewes produce about 45% of lamb supply from Australia. Eight large experiments using a range of ewe genotypes generated production responses relating changes in ewe liveweight and condition score (CS) during pregnancy to lamb birth weights, weaning weights and survival. Condition score targets at lambing of 2.7 for singles and 3.3 for multiple-bearing non-Merino ewes are likely to achieve near-maximum lamb survival and weaning rates. However, poor nutrition during pregnancy reduces weaning weight and these impacts cannot be overcome by improving feed on offer from late pregnancy until weaning. Whole-farm profitability is sensitive to the ewe liveweight and CS profile, however the development of management guidelines for non-Merino ewes to maximise profitability was prevented by a discrepancy between measured liveweight change and liveweight change predicted using Australian Feeding Standards. More specifically, the high rates of liveweight gain measured could not be feasibly achieved in the feed budget, either because the predicted intake for non-Merino ewes is too low and/or the predicted energy requirements for maintenance or weight gain are too high. Further modelling highlighted the importance of each component of the intake and energy equations in determining the optimum nutrition profiles for non-Merino ewes to establish priorities for future research.

Executive Summary

The development of optimum CS profiles for Merino ewes and their adoption via programs such as Lifetime Ewe Management and Bred Well Fed Well have resulted in widespread improvements in productivity, profitability and welfare across the sheep industry. The '*Measure-to-manage'* principals have been adopted by producers with non-Merino ewes, however there has been a lack of confidence in the applicability of the Merino recommendations and how to adjust those targets to maximise the profitability from their non-Merino ewes. Merino and non-Merino ewes generally perform differently when they are managed together, and it is well recognised that the economic value of improving the number and weight of lambs weaned is greater for non-Merino than Merino ewes. Hence, it is reasonable to expect that further increases in reproduction efficiency, lamb supply and profitability would be achieved if the nutritional requirements and CS targets promoted to industry were better tailored to non-Merino ewes. The overarching aim of the '*Lifetime Maternals'* project was to use a combination of experimentation and bioeconomic modelling to develop ewe liveweight and CS profiles to maximise whole farm profit for non-Merino ewes.

Large-scale experiments were conducted across four research sites in both 2014 and 2015. The first experiment at Struan in SA compared the effects of ewe liveweight and CS profile during pregnancy on the birth weight, weaning weight and survival of lambs from Merino versus Border Leicester x Merino ewes. Ewes were managed together to achieve an average CS at lambing varying from 2.5 to 3.6 and the effects on ewe and lamb production were quantified. The same design, but using non-Merino ewes only, was also implemented at sites in Hamilton and Pigeon Ponds in south west Victoria and Mount Barker in WA. In these experiments the treatments continued through until the end of lambing, so ewes in lower CS prior to lambing generally lambed in paddocks with less feed on offer (FOO) than those in higher CS prior to lambing. In 2015, experiments at all four research sites aimed to establish if higher levels of FOO during very late gestation and lactation could mitigate the adverse effects of poor nutrition during early-mid and late pregnancy on the birth weight, weaning weight and survival of lambs from non-Merino ewes. Ewes were managed during pregnancy to reach a target CS of 2.7 or 3.4 at the start of lambing and then allocated to a range of FOO treatments varying from 600 to 800 kg DM/ha to more than 2000 kg DM/ha until lamb weaning. All ewes were then managed together from when treatments finished until their next joining.

When managed together at the Struan site, BLM ewes generally gained more liveweight and achieved a higher CS than Merino ewes which was consistent with expectations. Furthermore, while Merino ewes were not directly compared to non-Merino ewes at the other sites, a feature across all sites in both years was the capacity of the non-Merino ewes to gain more weight than predicted from low levels of FOO in late pregnancy and to compensate during lactation and or post weaning. Despite differences of 10 to 15 kg and 0.7 to 1.2 of a CS at lambing, there were minimal differences in liveweight (2 to 3 kg) and CS (0.1 to 0.2) at the following joining across a range of seasons and environments. Despite this, the reproductive rate of ewes poorly fed during the previous pregnancy was reduced by about 10% depending on seasonal conditions and the effect on carryover reproduction was greater than expected based on liveweight or condition score at next joining.

In 2014 lower CS treatments reduced lamb weights by 0.7 kg at birth, 2.3 kg at marking and 2.0 kg at weaning, and the treatment effects were similar for single and twin born lambs. At an individual ewe level, heavier ewes produced lambs that were heavier at birth and weaning as expected. In addition, a 10 kg change in ewe liveweight during early-mid pregnancy changed lamb birth weight and weaning weight by 0.33 kg and 1.6 kg whereas a 10 kg change in ewe liveweight in late pregnancy changed lamb birth weight and weaning weight by 0.43 kg and 0.9 kg. These effects of ewe liveweight change during early-mid and late pregnancy on lamb weights were similar in magnitude and relative importance to that observed in Merinos at the Struan site or other studies. Lamb birth weight was strongly correlated with survival, but single and twin born lambs were equally likely to survive at the same birth weight which differs to Merinos. Where present, the survival of triple born lambs was significantly lower at the same birth weight compared to singles or twins. Changes in lamb birth weight had minimal effects on the survival of single lambs when ewes varied in CS from 2.7 to 3.4, as even the lightest single lambs still weighed about 5.6 kg. However, on average the survival of single lambs was reduced by 6% in ewes fed to achieve CS 3.7 through to the end of lambing (87% *vs*. 93%). Increasing ewe CS at lambing from 2.6 to 3.6 and especially up to CS 3.3 improved the survival of multiple born lambs by 10% and weaning rate from twin bearing ewes from 162% to 182%.

In 2015, ewe CS treatments had less effects on lamb birth weights than expected and the precise reasons for this are unknown. It was partly due to an effect of the period between allocation to FOO treatments and date of birth on lamb birth weight (20 g/day; $P<0.001$), and that this period was longer for low than high CS ewes (19.0 *vs*. 17.5 days; $P<0.001$). There were also no significant differences in birth weights between the FOO treatments. The could suggest that the either feed intake and hence nutrient supply to the foetus was not compromised even at the lowest FOO levels of 600-800 kg DM/ha and or that any real differences in foetal growth resulting from the different FOO levels were insufficient to result in measurable differences in birth weights. There could also have been compensation in the birth weights of lambs from low CS ewes regardless of FOO level, but this was not reflected in a significant CS x FOO interaction plus the coefficients to predict birth weight from the liveweight change of individual ewes to Day 135 of pregnancy were similar to the 2014 experiment. There were also no significant differences between the CS or FOO treatments on lamb survival at any site due to very high birth weights regardless of nutritional treatment which could in part reflect that the ewes were much heavier and fatter at joining in 2015 compared to 2014. There were nevertheless significant effects of CS treatments on lamb weights at weaning and single and multiple born lambs from the low CS groups were 1.3 and 1.7 kg lighter at weaning than those from the high CS group. Weaning weight was also influenced by FOO during lactation, although less than expected. Across the four sites increasing FOO by 1000 kg/ha during lactation (up to 2000 kg/ha) increased weaning weights by 10%, and there were no additional effects of FOO on weaning weights above 2000 kg/ha.

The results imply that CS targets at lambing of 2.7 for single-bearing ewes and at least 3.3 for multiple–bearing non-Merino ewes are likely to achieve near-maximum lamb survival and weaning rates. This clearly demonstrates the value of pregnancy scanning non-Merino ewes and differentially managing those with multiple foetuses. Further work is still required to establish the scenarios whereby manipulating FOO prior to and during lambing may mitigate potentially adverse effects of poor pregnancy nutrition on the birth weights and survival of twin lambs. However, it is clear that improving FOO from late pregnancy until weaning does not fully counteract the adverse effects of poor nutrition during pregnancy on weaning weight of lambs from non-Merino ewes. Overall, the project has shown that the liveweight and CS profile of non-Merino ewes can predict the production of ewes and their progeny and this new information provides the necessary production responses required to develop optimum liveweight and CS profiles for non-Merino ewe flocks.

An analysis to develop the optimum llliveweight and CS profiles was undertaken using the Hamilton version of the MIDAS model and the coefficients generated from the 2014 experiments. The analyses indicated that whole-farm profitability was sensitive to the liveweight profile of non-Merino ewe flocks and the variation between the most and least profitable profiles was $419 per ha ($42/ewe) using the standard feed budget equations. This range in profit was reduced to between $15 and $25/ewe when adjustments were made to the feed budget equations. The optimum liveweight profiles identified were for the ewes to be joined at 60 kg (CS 3), maintain liveweight in early pregnancy, twins to gain 6 kg in late pregnancy, singles to gain 3 kg in late pregnancy, triplets to lose 3 kg in late pregnancy and the dry’s to either maintain or gain 3 kg. However, the optimum profiles did vary significantly when the feed budget equations were adjusted to represent alternative explanations for the differences observed between the observed liveweight change of non-Merino ewes and that predicted by the standard feed budget equations. The discrepancy between predicted liveweight change against actual liveweight change of non-Merino ewes could be due to greater appetite and potential feed intake or greater efficiency of feed utilisation.

An analysis was undertaken to determine the importance of each component of the intake and energy equations in determining the optimum liveweight and CS profiles for non-Merino ewes with a view to establishing priorities for future research. There were two phases to the analysis; the first phase involved quantifying the effect of a change in the equation component on the liveweight performance of the animals. In the second phase the impact on the optimal liveweight patterns and the magnitude of the effect on profitability was quantified. Each of the components has a different impact on the liveweight change of the ewes in different feeding scenarios and in all cases the variation in liveweight change was less than the discrepancies observed in the trials. This indicates that the magnitude of the sensitivity analysis on the components was conservative, the calculated changes in profit are an underestimate of the changes expected and that the differences observed may be due to a combination of the components acting in tandem. In all cases varying a component of the equations leads to a change in the optimum profile for at least one class of ewes. When the optimum profile from the ‘standard equations’ model was run in the models with varying equation components then profit was reduced by between $0.10 and $7.71/ewe for a 50 g/d change in ewe liveweight change. These profit values are likely to be an underestimate because the discrepancies in liveweight change between the equations and experimental observations were up to 160 g/d. The components identified in this analysis as being important to the calculation of the optimum liveweight and CS profiles were potential intake, relative intake associated with quantity of feed on offer, energy required for maintenance, the efficiency of energy use for maintenance and the energy content of the weight gain and loss. These traits need to be quantified for non-Merino ewes to enable optimum liveweight and CS profiles for non-Merino ewes to be developed and extended to industry.

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1 Background

The impact of ewe nutrition before joining or during pregnancy and lactation is known to effect ewe reproduction (Ferguson *et al*. 2011) and productivity (Ferguson *et al.* 2011), lamb birth weight and survival (Oldham *et al*. 2011; Behrendt *et al.* 2011; Paganoni *et al*. 2014), lamb growth to weaning (Thompson *et al*. 2011a; Paganoni *et al*. 2014) and lifetime performance (reviewed by Greenwood *et al*. 2009; Thompson *et al*. 2011b; Kenyon and Blair 2014). Knowledge of these production responses to ewe nutrition together with whole-farm bioeconomic modelling have been utilised to develop optimum CS profiles and guidelines to manage the nutrition of Merino ewes to improve productivity, profitability and welfare outcomes across multiple environments and production systems (Curnow *et al.* 2011; Young *et al.* 2011). This work established that depending on current ewe management and regardless of stocking rate, whole farm profitability could be improved by up to 15% and the survival of single and twin lambs by 15 and 25% respectively by managing Merino ewes to achieve the optimum CS profile.

These guidelines for Merino ewes subsequently underpinned the development of the Lifetime Ewe Management training program (Trompf *et al*. 2011). This program is based on small groups of producers that meet six times per year with an accredited trainer. During these hands-on sessions, the group visits each participating farm and learn skills in condition scoring, pasture assessment and best practice ewe and lamb management to increase reproduction efficiency mainly through reducing ewe and lamb mortality. Since 2006 Lifetime Ewe Management has become a flag-ship extension program for the Australian sheep industry and more than 3,000 producers responsible for managing 25% of the National ewe flock have participated in the program. These producers have increased stocking rate by about 10%, increased lamb marking percentages by 7% depending on ewe type and decreased ewe mortality by 30% by adopting best practice management of their ewes (Trompf *et al.* 2011; Thompson unpublished data). About 20% of the producers that have participated in LTEM have managed non-Merino ewes, and whilst they have achieved similar gains in productivity, feedback from both trainers and producers is that they lack confidence in both the applicability of the Merino recommendations and how to adjust those targets to maximise the profitability from non-Merino ewes.

The majority of ewes mated in Australia are pure-bred Merinos, however almost 30% of ewes are non-Merinos that produce up to 45% of the lamb supply (B. Thomas unpublished data). Both anecdotal and published reports suggest that when Merino and non-Merino ewes are managed together there is a difference in their productivity, although the effects of ewe breed on liveweight profile varies between sites and years (Blumer *et al*. 2016). It is also well recognised that the economic value of improving the number of lambs weaned and weaning weight is much greater for non-Merino than Merino ewes (Young *et al.* 2014). This evidence suggests that management guidelines developed for Merinos may not be directly transferrable to non-Merino ewes and further increases in reproduction efficiency, profitability and lamb supply should be achieved if the nutritional requirements and CS targets were better tailored to non-Merino ewes. The overarching aim of this project was therefore to use a combination of experimentation and bio-economic modelling to develop ewe liveweight and CS profiles that will maximise whole farm profit for different regions, times of lambing and commodity prices for single and multiple-bearing non-Merino ewes.

2 Project Objectives

By 31 August 2016:

1. Conducted a metanalysis of existing data from Australia and New Zealand to generate more robust predictions of ewe mortality, birth weight, lamb survival and weaning weight from ewe liveweight and CS profiles in non-Merino ewes.

2. Completed bioeconomic modelling, including sensitivity analysis of the responses in lamb survival to changes in birth weight, to develop ewe liveweight and CS profiles that will maximise whole farm profit for different regions, time of lambing and commodity prices for ewes bearing single, twin and triplets.

3. Conducted four intensive research sites over two experimental years to refine and confirm predictions of birth weight, survival and weaning weight from ewe liveweight and CS profiles under commercial conditions.

4. Analysed existing data and results from the above mentioned research sites relating the performance of non-Merino ewes to better define their relative feed requirements.

5. Developed recommended condition score management profiles for non-Merino ewes.

3 Metanalysis to predict birth weight, lamb survival and weaning weight from ewe liveweight profile in non-Merino ewes

A metanalysis of existing data was undertaken to determine if predictions of ewe mortality, birth weight, lamb survival and weaning weight from ewe liveweight and CS profile in non-Merino ewes could be established from existing data. The analysis used data from 20 different sources and consisted of 10,997 records of ewe liveweight profile, 9,607 records of lamb birth weights and 8,341 records of lamb weaning weight. There was no existing data on ewe mortality. As expected, in most cases lamb birth weights and weaning were influenced by ewe live weight at joining. However, lamb birth weights were generally not significantly related to ewe liveweight change during early or late pregnancy and weaning weight was only related to ewe liveweight change during pregnancy on about 50% of occasions. The precise reasons for this is unknown but ewes within most of the existing data sets were managed together so the differences in ewe CS profile within data sets was sometimes limited and probably of genetic origin rather than nutritional. Furthermore, it could be due to the method used to correct ewe liveweights for weight of conceptus, so this component of the metanalysis is being reanalysed. Birth weight was strongly correlated with the survival of lambs in 90% of the data sets and in all data sets single and twin born lambs were equally likely to survive at the same birth weight. This is a significant variation from what is observed in Merino ewes. Some data sets from NZ indicated significantly lower survival of triple born lambs at the same birth weight compared to singles or twins. Many factors are likely to contribute to the variations in the shape of the birth weight versus survival responses, however as lamb survival was close to maximum at the average birth weights for singles and twins the metanalysis suggested that lamb survival may be less sensitive to ewe nutrition in non-Merino than Merino ewes. The met analysis has and will inform the bioeconomic modelling to establish if this variation in the birth weight versus survival responses between data sets has any practical significance in terms of influencing the optimum CS targets and management guidelines for non-Merino ewes.

A full report of the metanalysis is provided in Appendix 1 (Section 13.1).

4 A comparison of Merino vs Non-Merino ewes managed under similar conditions (Experiment 1)

In this experiment undertaken at Struan in SA in 2014 the effect of ewe liveweight and CS profile during pregnancy on lamb birth weight and survival was compared for Merino versus non-Merino ewes. The CS profile of 720 Merino and 680 crossbred (Border Leicester x Merino; BLM) ewes was managed from 50 days after ram introduction to achieve one of four target CS at lambing (CS2.5, CS2.8, CS3.2, CS3.6). Overall BLM ewes gained more liveweight and achieved a higher CS than the Merino ewes when managed in the same plots. At joining the BLM ewes were 0.1 ± 0.03 CS greater ($P<0.001$) and 1.2 ± 0.48 kg heavier ($P<0.01$) than the Merino ewes, whareas by Day 140 the BLM ewes were 0.4 ± 0.03 CS greater ($P<0.001$) and 4.6 ± 0.48 kg heavier ($P<0.001$) than the Merino ewes. The increased liveweight and CS in the BLM ewes compared to Merinos could be due to greater appetite and potential feed intake or greater efficiency of feed utilisation. Liveweight at joining and change in liveweight in late pregnancy of the Merino and BLM ewes had a similar effect on the birth weight and weaning weight of their lambs. However liveweight change in early pregnancy had less effect on birth weight and weaning weight of lambs from BLM compared to Merino ewes. This suggests that ewe management guidelines based on Merino ewe data may be over-estimating the impact ewe liveweight change during early pregnancy has on lamb birth weight in non-Merino production systems. Birth weight versus survival curves were similar in lambs from Merino and BLM ewes, however the absolute survival of the lambs was greater than 87% for single BLM lambs with birth weights from 4 to 8 kg and twin BLM lambs with birth weight from 5 to 7 kg. Managing liveweight of BLM ewes carrying a single foetus is unlikely to improve lamb survival via improvements in birth weight to the same extent as observed from Merino ewes. Increasing birth weight of multiple born lambs from BLM ewes from 4 to 5 kg increased survival from 70% to 85%, therefore there is opportunity to improve survival in multiple-born lambs. In addition, it will be important to manage the liveweight of BLM ewes during pregnancy to optimise the weaning weight of their lambs, as those lambs born to BLM ewes of lower liveweight and CS pre-lambing were significantly lighter at weaning, and this is likely to have an economic impact on lamb production systems. More accurate coefficients, especially during early and mid-pregnancy, need to be generated across production systems and other non-Merino genotypes to inform bioeconomic modelling and the development of more robust CS targets for non-Merino ewes.

A full report presented as a draft paper is provided in Appendix 2 (section 13.2). This paper has been submitted to *Animal Production Science*.

5 Effects of ewe condition score at lambing on performance of non-Merino ewes (Experiment 2)

Three replicated experiments were conducted in 2014 at research sites in Victoria (Pigeon Ponds and Hamilton) and Western Australia (Mount Barker). Ewes (770-792 per site) were allocated to four CS treatments following pregnancy scanning (~day 50) to reach a target of CS 2.5, 2.8, 3.2 and 3.6 at lambing and these nutritional treatments were applied until the end of lambing. Across all sites the actual CS achieved at lambing were 2.7, 2.9, 3.3 and 3.7 and 2.5, 2.8, 3.2 and 3.6 for single and twin-bearing ewes, respectively, but at individual sites the range in ewe condition score at lambing varied from 0.9 to 1.5 between treatments. Across all sites the lower CS treatments reduced lamb weights by 0.7 kg at birth (4.71 *vs*. 5.38 kg), 2.3 kg at marking (11.5 *vs.* 13.8 kg) and 2.0 kg at weaning (28.8 *vs*. 30.8 kg), and the effects of CS treatments were similar for single and twin born lambs. Linear modelling for individual ewes indicated consistent and significant effects of ewe joining liveweight, ewe liveweight change to day 90 of pregnancy and ewe liveweight change from day 90 of pregnancy to lambing on lamb birth weight, marking weight and weaning weight. A 10 kg change in ewe liveweight during early-mid pregnancy changed lamb birth weight and weaning weight by 0.33 kg and 1.6 kg, whereas a 10 kg change in ewe liveweight in late pregnancy changed lamb birth weight and weaning weight by 0.43 kg and 0.9 kg. These effects of ewe liveweight change during early-mid and late pregnancy on lamb weights were similar in magnitude and relative importance to that observed in Merinos at the Struan site or other studies. Across all sites there was a decrease in survival of singles at the highest CS treatment compared to other treatments (87 *vs.* average 93%) and a linear improvement in survival of multiple born lambs with increasing CS at lambing (81 *vs.* 91%). Birth weight was significantly related to survival at all sites with little effect of birth type on survival and effects of sex at only one site, suggesting survival of lambs in maternal ewes is largely driven by birth weight rather than innate differences of being born single or multiple and/or being male or female. In conclusion, manipulating the nutrition of the non-Merino ewes during mid to late pregnancy resulted in predictable impacts on lamb survival and liveweights up to weaning, which should enable bioeconomic modelling to determine the economic optimum ewe liveweight or CS profile. An additional key feature of the site results was that the impacts on weaning weights were largely present by lamb marking, with the differences in growth rate between marking and weaning contributing little to the impacts on weaning weight. Further work is therefore required to determine if high levels of FOO during lambing and early lactation could mitigate the adverse effects of poor nutrition during pregnancy until immediately before lambing.

A full report presented as a draft paper is provided in Appendix 3 (section 13.3).

6 Effects of feed on offer during lambing and lactation on the performance of non-Merino ewes (Experiment 3)

Four replicated experiments were conducted in 2015 at research sites in Victoria (Pigeon Ponds and Hamilton), South Australia (Struan) and Western Australia (Mount Barker). These experiments aimed to validate the prediction equations for birth weight and weaning weight of lambs using liveweight profiles during gestation for non-Merino ewes, and also test the hypotheses that high levels of FOO during very late pregnancy and lactation could mitigate the adverse effects of poor nutrition during early-mid and late pregnancy on the birth weight, weaning weight and survival of lambs from non-Merino ewes. Ewes (480-768 per site) were allocated to two CS treatments following pregnancy scanning (~day 50) to reach a target of CS 2.6 or 3.4 at lambing and then allocated to either four or six target FOO treatments until lamb weaning. Across all sites, the actual CS achieved 15 to 20 days prior to lambing were 2.7 and 3.4 and the FOO levels at allocation varied from 620 to 1020 kg DM/ha for the lowest treatment to 1090 to 2680 kg DM/ha for the highest treatment. FOO generally increased during lactation. At an individual sheep level, a 10 kg gain in ewe liveweight during early-mid or late pregnancy increased birth weight by 0.21 kg and 0.33 kg and weaning weight by 1.5 kg and 1.2 kg, respectively. Nevertheless, a combined analysis across all four sites indicated that at plot level ewe CS treatment had no significant effects birth weights of single lambs and only changed the birth weight of twin lambs by 0.14 kg. This was partly due to a significant effect of period between allocation to FOO treatments and date of birth on birth weight (0.20 kg/day; $P<0.001$), and that this period was longer for low than high CS ewes (19.0 *vs*. 17.5 days; $P<0.001$). There were also no significant differences between the FOO treatments for lamb birth weight for single or multiple born lambs at any site, possibly because pasture consumption even at the lowest FOO levels was not sufficiently restricted, and no significant differences between the CS or FOO treatments for lamb survival to marking at any site in the current study due to very high birth weights. The effects of CS treatments on lamb weights at marking and weaning varied between sites, but across all four sites single and multiple born lambs from ewes in the low CS groups were 0.9 kg and 1.2 kg lighter at marking and 1.3 and 1.7 kg lighter at weaning than those from the high CS group. Weaning weight was also influenced by FOO during lactation, although less than expected. Across the four sites increasing FOO by 1000 kg/ha during lactation (up to 2000 kg/ha) increased weaning weights by 10%, and there were no additional effects of FOO on weaning weights above 2000 kg/ha.

A full report presented as a draft paper is provided in Appendix 4 (section 13.4).

7 Bioeconomic modelling and preliminary guidelines using the research site coefficients

The profitability of lamb production systems in southern Australia is optimised at a stocking rate that provides adequate nutrition for breeding ewes and enables efficient utilisation of grown pasture and supplements. To optimise stocking rate of ewes requires an understanding of the full range of impacts of manipulating nutrition on the performance of the ewe and her progeny. The '*Lifetime Maternals'* project has shown that the liveweight profile of non-Merino ewes can reliably predict the production of ewes and their progeny and this new information provides the necessary production responses required to develop optimum liveweight or CS profiles for non-Merino ewe flocks in different regions and lambing at different times. A preliminary analysis to develop these target liveweight profiles was therefore undertaken using the coefficients generated from the 2014 experiments and the Hamilton version of MIDAS. The optimum liveweight profiles identified were for the ewes to be joined at 60 kg, maintain live weight in early pregnancy, twins to gain 6 kg in late pregnancy, singles to gain 3 kg in late pregnancy, triplets to lose 3 kg in late pregnancy and the dry's to either maintain or gain 3 kg. There was little difference in the optimum profiles despite the different coefficient sets generated from the different genotypes at each of the research sites, which indicated that the optimal management was not varying with the different genotypes that were evaluated. This analysis also highlighted that the equations used to predict energy requirements and intake capacity of the non-Merino ewes did not represent the liveweight measurements taken in Experiments 1 to 3 and did not align with anecdotal observations of the performance of the maternal breeds in the paddock. It was also concluded that the discrepancy was affecting the optimum patterns identified. The analysis could also be improved with the inclusion of information about the impact of FOO levels at lambing and during lactation on lamb survival and weaning weights, but inclusion of these effects was not warranted until both the intake capacity and energy requirements of Merino versus non-Merino ewes are better understood. The optimal management of the triplet bearing ewes requires further investigation because the optimum profile included greater weight loss than was expected. This anomaly could also be due to the energy and intake equations.

A full report of the bioeconomic modelling is provided in Appendix 5 (Section 13.5).

8 Maternal genotypes and predictions of intake and energy requirements

Identifying the optimum liveweight profile requires valuing the trade-off between the extra production achieved and the cost of the feed required to achieve the liveweight profile. MIDAS is an appropriate model to deal with this complexity because it represents the whole flock and it includes a powerful feed budgeting module that optimises animal and pasture management across the whole farm. The MIDAS model feed budget is based on the intake and energy requirement equations as outlined in Feeding Standards for Australian Ruminants and the SheepExplorer spread sheet. The preliminary bioeconomic modelling suggested that the equations used to predict the energy requirements and intake capacity of the non-Merino ewes did not represent the liveweight measurements taken in Experiments 1 to 3 and did not align with anecdotal observations of the performance of the maternal breeds in the paddock. More specifically, the high rates of liveweight gain measured in Experiment 1 to 3 could not be feasibly achieved in the feed budget. This seems to indicate that either predicted intake is too low or the predicted energy requirements for maintenance or weight gain are too high. This study used Sheep Explorer or Grazfeed and aimed to verify these observations by comparing actual and predicted intake and/or liveweight change for a number of experiments that measured feed intake and/or liveweight change of non-Merino ewes. The prediction of intake against the measured data was between 25 and 50% lower for four data sets that had measured intake with *ad-libitum* feed available. The under estimation was consistent across the four data points and suggests from very limited data that there could be a systematic error in the estimation of potential intake capacity. In addition to the errors in intake capacity the predictions of liveweight change from the known level of metabolisable energy intake included errors of 30-50 g/d and the errors did not appear to be systematic. Errors in the prediction of the ewe liveweight change when grazing pasture were substantial, varying from an over estimation of 150 g/d to an under estimation of 150 g/d. This substantial discrepancy would lead to significant changes in nutritional management on-farm. A regression of the predicted liveweight change against actual liveweight change also indicated that the variation in predicted change is about half of the variation in the actual change. It was therefore concluded that the errors in the MIDAS model feed budget are not just associated with the estimation of intake and are also likely to be associated with errors in estimating maintenance requirement and energy use efficiency.

A full report of the analysis is provided in Appendix 6 (section 13.6).

9 Analysis of the components of the energy and intake equations

The increased liveweight and CS in non-Merino ewes compared to Merino ewes under the same grazing condition, and the discrepancy between predicted liveweight change against actual liveweight change of non-Merino ewes, could be due to greater appetite and potential feed intake and/or greater efficiency of feed utilisation. The analysis described in this report was designed to complement the previous analyses and determine the importance of each component of the intake and energy equations in determining the optimum nutrition profiles for non-Merino ewes with a view to establishing priorities for future research. The components include potential intake, impact of relative condition on intake, impact of low availability on intake, impact of low digestibility on intake, maintenance requirement, efficiency of energy use for maintenance, efficiency of use of energy for weight gain and energy value of a kilogram of weight gain/loss. There were two phases to the analysis; the first phase involved quantifying the effect of a change in the equation component on the liveweight performance of the animals. In the second phase the impact on the optimal liveweight patterns and the magnitude of the effect on profitability was quantified. Each of the components has a different impact on the liveweight change of the ewes in different feeding scenarios and in all cases the variation in liveweight change was less than the discrepancies observed in the trials. This indicates that the magnitude of the sensitivity analysis on the components was conservative, however, larger changes led to unrealistic combinations of stocking rate and supplementary feeding from the optimised farm. This means that the calculated changes in profit are an underestimate of the changes expected and also suggests that the differences observed may be due to a combination of the components acting in tandem. In all cases varying a component of the equations leads to a change in the optimum profile for at least one class of ewes. Increasing potential intake or reducing the energy content of weight gain/loss both lead to the optimum profile involving losing weight in early pregnancy and more weight gain in late pregnancy for singles and triplets. A common change for the other components was allowing the dry ewes to lose weight in line with late pregnancy because the changes to the equations made it easier for the ewes to gain weight in the post weaning period. When the optimum profile from the 'standard equations' model was run in the models with varying equation components then profit was reduced by between $0.10 and $7.71/ewe for a 50 g/d change in ewe liveweight change. These profit values are likely to be an underestimate because the discrepancies between the equations and experimental observations were up to 160 g/d. The components that had the largest impacts were potential intake, Relative Intake-Quantity, maintenance requirement, efficiency for maintenance and energy content of gain.

In summary, the components identified in this analysis as being important to the calculation of the optimum profiles were potential intake, relative intake associated with quantity of feed on offer, energy required for maintenance, the efficiency of energy use for maintenance and the energy content of the weight gain and loss. Unfortunately this analysis and the other calculations have not narrowed down the list of traits that need to be quantified for non-Merino ewes as it appears that both intake and energy requirements are important to determining the optimum liveweight and CS profiles for non-Merino ewes.

A full report of the analysis is provided in Appendix 7 (section 13.7).

10 Conclusions/Recommendations

The project results indicate that CS targets at lambing of 2.7 for single-bearing ewes and at least 3.3 for multiple-bearing non-Merino ewes are likely to achieve near-maximum lamb survival and weaning rates. This clearly demonstrates the value of pregnancy scanning non-Merino ewes and differentially managing those with multiple foetuses. This information can confidently be incorporated into existing extension and adoption activities such as Lifetime Ewe Management and Bred Well Fed Well. In addition, as only about 20-25% of non-Merino ewes are currently scanned for multiple births, it is critical that the barriers to adoption of multiple scanning are clearly articulated and new initiatives funded to enhance adoption.

The recommendations on CS targets to improve lamb survival do not necessarily imply that these CS targets will also maximise whole farm profitability across different environments, lambing times and commodity prices. It is well recognised that weaning weights and conception rates are significantly more important in non-Merino than Merino ewes, given that survival rates are inherently higher than in Merinos under similar conditions. Poor nutrition during pregnancy reduces weaning weights by about 1.5 kg across the different birth types, and these adverse impacts cannot necessarily be overcome by improving feed on offer from the point of lambing until weaning. Poor nutrition during pregnancy also reduces reproduction in the following year, despite significant compensatory growth during lactation and post-weaning. These impacts on weaning weights and carryover reproduction are likely to have an economic impact on lamb production systems which are yet to be accurately quantified.

The development of optimum CS profiles for non-Merino ewes to maximise whole farm profit was prevented by a discrepancy between liveweight change predicted using Australian Feeding Standards for Ruminants and measured liveweight change of non-Merino ewes. More specifically, the high rates of liveweight gain measured could not be feasibly achieved in the feed budget, either because the predicted intake for non-Merino ewes is too low and or the predicted energy requirements for maintenance or weight gain are too high. Despite this, the systems modelling did indicate that whole-farm profitability was highly sensitive to the liveweight profile of non-Merino ewe flocks. This highlights that to achieve full value from the findings of the current project, further work is needed to improve the prediction of liveweight gain in non-Merino ewes.

To that end, an analysis was undertaken to determine the importance of each component of the intake and energy equations in determining the optimum nutrition profiles for non-Merino ewes with a view to establishing priorities for future research. The components identified in this analysis as being important to the calculation of the optimum profiles were potential intake, relative intake associated with quantity of feed on offer, energy required for maintenance, the efficiency of energy use for maintenance and the energy content of the weight gain and loss. A research program to address these gaps has been prepared for consideration by MLA. Further work is also still required to establish the scenarios whereby manipulating FOO prior to and during lambing may mitigate potentially adverse effects of poor pregnancy nutrition on the birth weights and survival of twin lambs.

11 Key Messages

Economics:

Ewe nutrition affects the production of Maternal ewes and their progeny therefore it is likely that farm profit will be sensitive to ewe liveweight and condition score profiles.

Joining management:

Heavier (1.5%/kg) or fatter (20 to 25%/CS) Maternal ewes conceive more lambs and the response is linear to 90 kg or CS 4.5.

Ewes that were multiple bearers in the previous year achieved about 10-15% higher reproductive rate than single bearing ewes at the same liveweight.

Aim for CS3 or above at joining (until confirmation from economic modelling).

Pregnancy management:

There are predictable effects of ewe liveweight change during pregnancy on lamb birthweight and weaning weights.

Good nutrition in late pregnancy can overcome the effects of poor nutrition in early pregnancy on lamb birthweight.

Twin bearing maternal type ewes have the ability to maintain liveweight and condition score at FOO levels of 400-600 kg DM/ha, if provided high growth rate and high quality pasture.

Grazing pasture levels between 800 kg/ha and 2500 kg/ha during the 2-3 weeks prior to lambing had a relatively small impact on lamb birthweight (less than 0.2 kg).

In the absence of conclusive evidence manage triplet bearing ewes as per twin bearers.

The birthweight and weaning weight responses of single and twin born lambs to ewe liveweight profile during pregnancy were consistent with the effects observed in Merino ewes.

Lamb survival:

Lamb survival can be predicted from changes in ewe iveweight or condition score during pregnancy due to the effects on birthweight.

At the same birthweight, single and twin born lambs are equally likely to survive, however triplet born lambs have lower survival at the same birthweight.

Preferentially feed twin bearing ewes – increasing ewe condition score from 2.9 to 3.4 at lambing can increase survival to weaning by between 5 and 10% in twin born lambs.

Minimal impact on survival of single born lambs in ewes managed between CS2.7 and CS3.4, but survival rates may decline in single bearing ewes managed at above CS3.5.

Lamb growth:

Pre-lambing condition score affects lamb weaning weights with a one condition score difference at pre-lambing contributing to between 1.5 and 2.5 kg of lamb liveweight at weaning.

Twin reared lambs are typically 6 kg lighter than single reared lambs at weaning.

Increasing FOO by 1000 kg/ha during lactation (up to 2000 kg/ha) contributes an increase of 10% in weaning weight. Above 2000 kg/ha there are no additional effects on weaning weight.

Carry over reproduction:

An additional 5-10% in reproductive rate due to previous management that is not explained by differences in liveweight or condition score at the carryover joining.

12 Bibliography

See individual report in the Appendices

13 Appendix

13.1 Appendix 1 - Metanalysis to predict birth weight, lamb survival and weaning weight from ewe liveweight profile in non-Merino ewes

A metanalysis of existing data was undertaken to determine if predictions of ewe mortality, birth weight, lamb survival and weaning weight from ewe liveweight and condition score profile in non-Merino ewes could be established from existing data.

Data for metanalysis

More than 20 data sets were compiled from Australia and New Zealand and a summary of the data sets is provided in Table 1. The data to relate ewe live weight profile to lamb birth weight and weaning weight consisted of 10,997 records of ewe live weight profile, 9,607 records of lamb birth weights and 8,341 records of lamb weaning weight. An additional 7,000 lamb records from the MCPT data set were collated, but the ewe live weight data was not suitable for use is this analysis due to insufficient measurements of ewe live weight in late pregnancy, so the data was not analysed. The overall rate of lamb survival across all data sets was 83%.

Calculations and statistical analysis

The liveweight of all ewes was adjusted for the weight of the conceptus, by calculating the weight of the gravid uterus and subtracting this from the liveweight. The eqaution for predicting the gravid weight of the uterus was used from the ruminant feeding standards (CSIRO 2011): Y = n SBW exp(A-Bexp(-Ct)), where N = number foetuses; SBW = actual birth weight/standard 4 kg lamb weight at birth; A = 5.17; B = 8.38; C = $6.08*10^{-3}$ and t = time since conception. Time since conception was estimated from lamb biorth date and assuming a gestation length of 148 days.

For most ewes, the mean liveweight was then modelled over time separately for each animal within each flock using a random coefficient regression including a cubic spline for time (Verbyla *et al*. 1999). The model fitted was: The model fitted was: Live weight = 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. Dam live weights at Day 0 (estimated date of conception), Day 90 and Day 140 of pregnancy were estimated from the model. These predicted live weights were then used to calculate live weight change during early pregnancy (Day 90 – Day 0) and during late pregnancy (Day 140 – Day 90). When ewes were actually weighed in closely proximity to Day 9, 90 and 140, the actual live weight data was used rather than predicted live weight.

An analysis was then conducted to determine whether the maternal live weight or change in maternal live weight of ewes during specific periods could be used to predict the birth weight and weaning weight of progeny. Restricted maximum likelihood method (REML) was used to fit progeny birth weight or weaning weight with the live weight of the ewe at joining, change in live weight of the ewe between joining and Day 90 of pregnancy, and change in live weight of the ewe from Day 90 of pregnancy until lambing, sire type, birth type and sex of progeny and interactions thereof, where appropriate, as fixed effects. Replicate, plot, progeny sire and paddock, where appropriate, were fitted as random effects. All possible models were examined with statistical significance of terms and interactions thereof accepted at $P < 0.05$.

Estimates of survival were assessed separately by fitting generalised linear mixed models (GLMM). The approach used a logit transformation and binomial distribution in additive models. Logits were predicted as a function of relevant effects, sex, birth type, sire type, birth weight and birth weight squared, where appropriate, fitted as fixed effects and replicate, plot, progeny sire and paddock, where appropriate, fitted as random effects. All statistical analyses were performed using GenStat (VSN International 2012).

Table 1. Characteristics of data sets compiled for metanalysis of birth weight, lamb survival and weaning weight predictions.

Data	Number of ewe records	Ewe live weight change (Day 90 to lambing; kg)	Ewe live weight change (Day 90 to lambing; kg)	Number of lamb birth weight records	Number of lambs weaning weight records	Lamb survival to weaning (%)
Information Nucleus Flock						
- Base flock maternal ewes[1]	908	+1.0	+0.5	1958	1659	85
- Follower maternal ewes	3274	+0.1	+3.8	3324	2710	81
DEPIVIC data provided by Dr Ralph Behrendt						
- Evergraze (3 years)	653	+10.5	+9.8	1191	941	84
- Lamb Foundation	622	+5.6	+6.2	977	883	90
NZ data provided by Dr Paul Kenyon (Massey University)						
- Riverside[2]	1017	+3.7	-0.8	1766	1399	79
- Shearing RC1[3]	288	-2.0	+5.4	430	363	84
- Shearing RC2[4]	145	-2.7	-0.2	239	188	79
- Tuapaka[2]	827	+3.0	-2.2	1477	1155	78
- Landcorp[5]	864	+0.1	-5.2	1565	1343	81
- Big-Small[6]	308	+6.4	+1.4	462	409	88
- FM 2009 – Twins[7]	380	+2.8	+4.6	756	633	84
- FM 2009 – Triples[8]	88	-1.8	+6.8	258	152	59
- FMG1 2011[9]	230	+4.4	+4.2	375	321	86
- FMG1 2013[10]	193	+3.0	+10.9	311	298	83
- Corner 2009	167	+2.9	-3.1	309	281	91
- Hoggets 2007[11]	150	+2.1	+4.4	259	225	88
- Nutrition RC2[12]	123	Na	Na	299	235	78
Other data						
- Dorper project (K. Pearce)	282	-3.5	+0.5	350	287	82
- Mount Ronan (E. Bowen)	378	+6.1	+10.0	561	528	94
TOTAL	**10,997**	**-**	**-**	**9,607**	**8,341**	**83**

[1] Paganoni *et al*. (2014) and limited to maternal ewes mated to Poll Dorset or White Suffolk rams; [2] Kenyon *et al.* (2006); [3] Corner *et al.* (2006); [4] Corner *et al.* (2007); [5] Hickson *et al*. (2012); [6] Kenyon *et al.* (2009); [7] Kenyon *et al.* (2011a); [8] Kenyon *et al.* (2011b); [9] Paten *et al*. (2013); [10] Kenyon *et al.* (2014); [11]Corner et al. (2013); [12] Corner *et al.* (2008)

Ewe live weight profile and lamb birth weights

As expected, in most cases lamb birth weights were influenced by ewe live weight at joining (Table 2). The effects of live weight at joining are consistent with other published work with Merinos (Oldham *et al.* 2011) and maternals (Paganoni *et al.* 2014), and presumably reflect in part the positive genetic relationship between birth weight and adult weight. When evident, an extra 10 kg of ewe live weight at joining increased lamb birth weights by 0.27 kg, but the range was 0.14 to 0.56 kg. Surprisingly, lamb birth weights were not significantly related to ewe live weight change during early and late pregnancy. The precise reasons for this is unknown given responses have been reported previously in maternal ewes (Paganoni *et al*. 2014). The precise reasons for this is unknown but ewes within most of the existing data sets were managed together so the differences in ewe condition score profile within data sets was sometime limited and probably of genetic origin rather than nutritional.

Table 2. The linear effects (± standard errors; SE) of ewe live weight at joining (LW$_{D0}$), ewe live weight change from day 0 to day 90 of pregnancy (LWC$_{D0-90}$) and ewe live weight change from day 90 to 140 of pregnancy (LWC$_{D90-140}$) on progeny birth weights from multiple data sets. Birth type and sex effects were significant for all analyses and were included in the relevant models.

Experiment	LW$_{D0}$		LWC$_{D0-90}$	LWC$_{D90-140}$
	Coefficient	P value^A		
Information Nucleus Flock				
Combined BF	0.032 ± 0.0012	<0.001	n.s.	n.s.
Armidale followers	0.035 ± 0.0080	<0.001	n.s.	n.s.
Trangie followers	0.021 ± 0.0115	0.07	n.s.	n.s.
Cowra followers	0.011 ± 0.0060	0.06	-0.059 ± 0.0200	n.s.
Rutherglen followers	0.023 ± 0.0097	<0.01	n.s.	n.s.
Hamilton followers	0.039 ± 0.0105	<0.001	n.s.	n.s.
Struan followers		n.s.	n.s.	n.s.
Turretfield followers	0.027 ± 0.0105	<0.001	n.s.	n.s.
Katanning followers	0.016 ± 0.0074	<0.05	-0.055 ± 0.0229	n.s.
Evergraze 2008	0.039 ± 0.0076	<0.001	n.s.	n.s.
Evergraze 2009		n.s.	n.s.	n.s.
Lamb Foundation	0.030 ± 0.0033	<0.001	n.s.	n.s.
Mt Ronan		n.s.	n.s.	n.s.
Riverside	0.015 ± 0.0029	<0.001	n.s.	n.s.
Shearing RC1	0.035 ± 0.0065	<0.001	n.s.	n.s.
Shearing RC2	0.056 ± 0.0070	0.003	0.056 ± 0.0070^B	n.s.
Tuapaka	0.020 ± 0.0032	<0.001	n.s.	n.s.
Big-Small		n.s.	n.s.	n.s.
FM 2009 - Twins	0.019 ± 0.0043	<0.001	n.s.	n.s.
FM 2009 - Triples		n.s.	n.s.	n.s.
FMG1 2011	0.014 ± 0.0067	0.038	n.s.	n.s.
FMG1 2013	0.016 ± 0.0056	0.006	n.s.	n.s.
Corner 2009	0.032 ± 0.0088	<0.001	n.s.	n.s.
Dorpers	0.018 ± 0.0070	0.002	n.s.	n.s.

^{A} n.s., not significant ($P > 0.05$); ^{B} $P<0.001$.

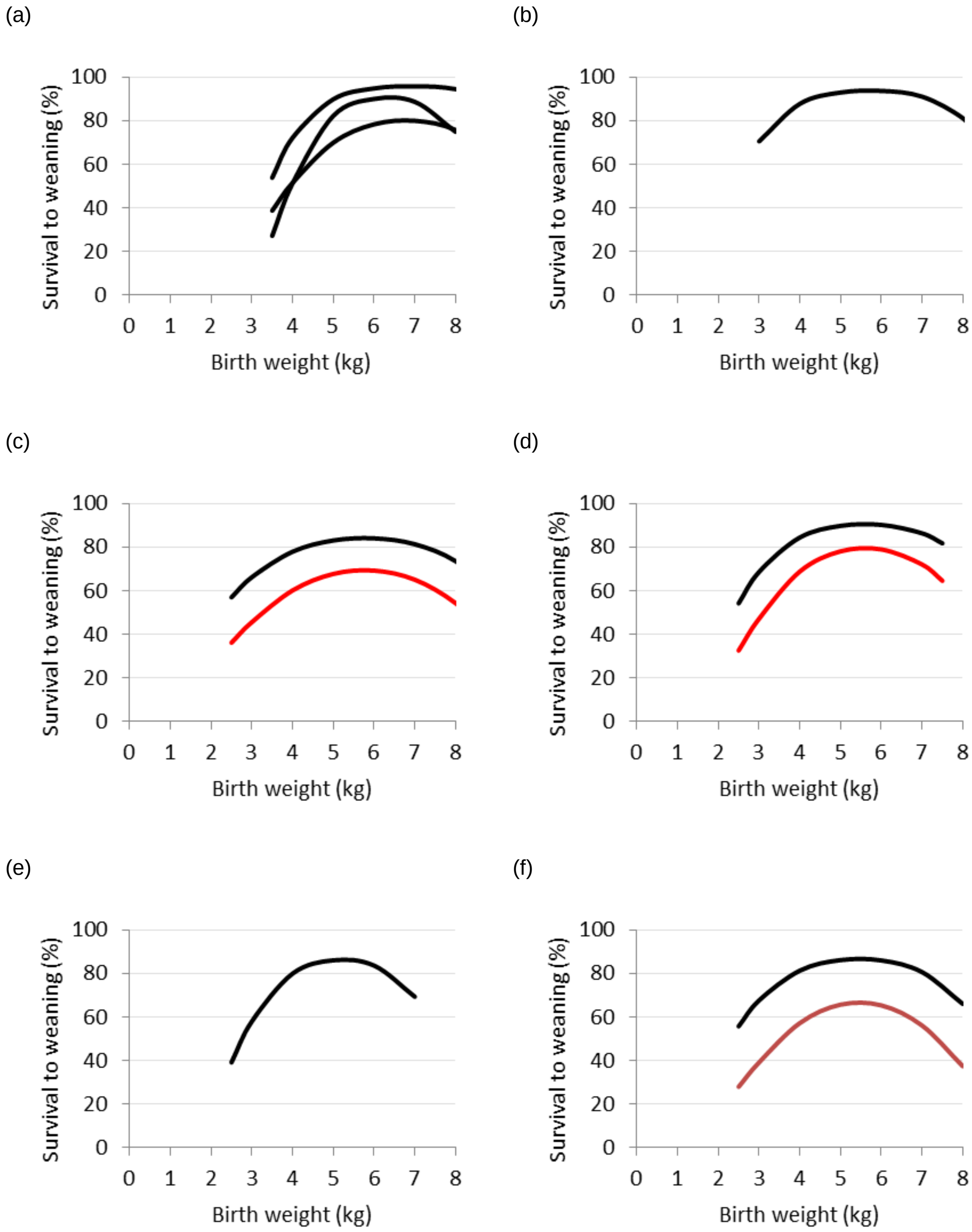
Lamb birth weights in relation to lamb survival

Birth weight was strongly correlated ($P < 0.01$) with the survival of lambs in all but two data sets (Table 3 and Fig. 1). In all data sets single and twin born lambs were equally likely to survive at the same birth weight, and this a significant variation from what is observed in Merino ewes. Some data sets from NZ indicated significantly lower survival of triples and quadruplets at the same birth weight compared to singles or twins. Many factors are likely to contribute to the variations in the shape of the birth weight versus survival response, and further analysis to explore how mature ewe size and chill index and pasture conditions at lambing influence the response could be warranted. Nevertheless, lamb survival was close to maximum at the average birth weights for singles and twins which suggest that lamb survival may be less sensitive to ewe nutrition in non-Merino than Merino ewes. Bioeconomic modelling will establish if this variation in the birth weight versus survival responses between data sets has any practical significance in terms of influencing the condition score targets and management guidelines for non-Merino ewes.

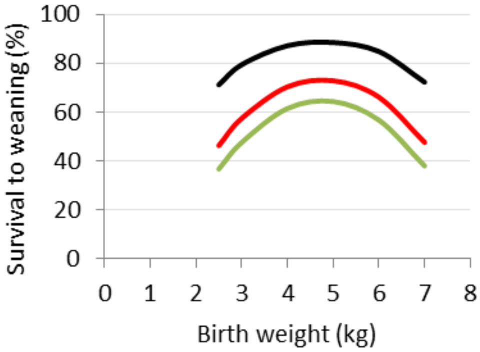
Table 3. Coefficients (logit transformed, ± s.e) and significance of terms for prediction of lamb survival to weaning from lamb birth weight (bwt) from multiple data sets.

Experiment	bwt		bwt^2	
	Coeff.	P value[A]	Coeff.	P value[A]
INF base ewes	2.44 ± 0.139	<0.001	-0.21 ± 0.015	<0.001
Evergraze 2008	3.49 ± 0.915	<0.001	-0.25 ± 0.077	<0.001
Evergraze 2009	5.13 ± 1.096	<0.001	-0.41 ± 0.089	<0.001
Evergraze 2010	2.33 ± 0.847	0.006	-0.17 ± 0.071	0.016
Lamb Foundation[B]	2.80 ± 0.587	<0.001	-0.24 ± 0.053	<0.001
Mt Ronan	3.19 ± 1.324	0.016	-0.31 ± 0.124	0.012
Riverside[C]	1.49 ± 0.327	<0.001	-0.13 ± 0.031	<0.001
Shearing RC1[C]	2.40 ± 0.806	0.003	-0.21 ± 0.083	0.011
Shearing RC2	3.25 ± 1.079	0.003	-0.31 ± 0.113	0.006
Tuapaka[C]	2.04 ± 0.397	<0.001	-0.19 ± 0.041	<0.001
Lancorp[C]	2.11 ± 0.448	<0.001	-0.22 ± 0.053	<0.001
Big-Small		n.s.		n.s.
FM 2009 - Twins	0.28 ± 0.127	0.029		n.s.
FM 2009 - Triples [D]	0.50 ± 0.180	0.006		n.s.
FMG1 2011[D]	2.95 ± 1.193	0.013	-0.26 ± 0.115	0.021
FMG1 2013	2.48 ± 1.031	0.016	-0.20 ± 0.098	0.043
Corner 2009		n.s.		n.s.
Hoggets 2007	0.44 ± 0.195	0.025		n.s.
Nutrition RC2	3.34 ± 1.197	0.006	-0.36 ± 0.149	0.018
Dorpers	3.40 ± 1.080	0.002	-0.29 ± 0.137	0.034

[A] n.s., not significant ($P > 0.05$); [B] Significant sire type effect included in the model; [C] Significant birth type effect included in the model. Singles and twins are not different i.e. one line for these, but offset needed for triples; [D] Significant sex effect included in the model.

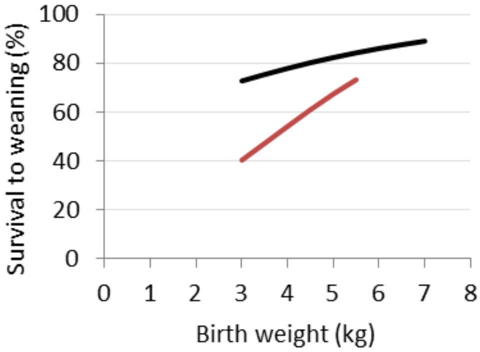

(a)
(b)
(c)
(d)
(e)
(f)
Survival to weaning (%)
0
20
40
60
80
100
Birth weight (kg)
0
1
2
3
4
5
6
7
8

(g)



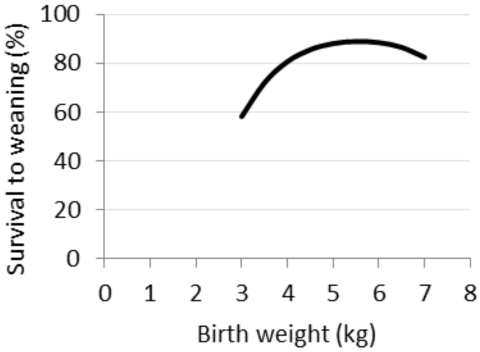
Survival to weaning (%)
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8
Birth weight (kg)

(h)



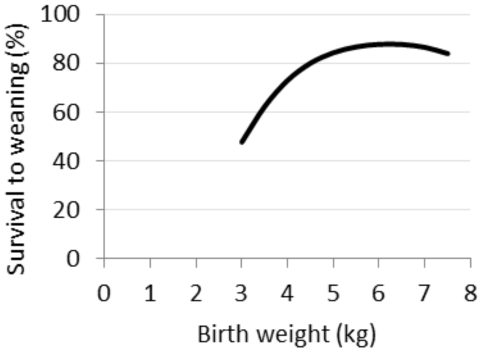
Survival to weaning (%)
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8
Birth weight (kg)

(i)



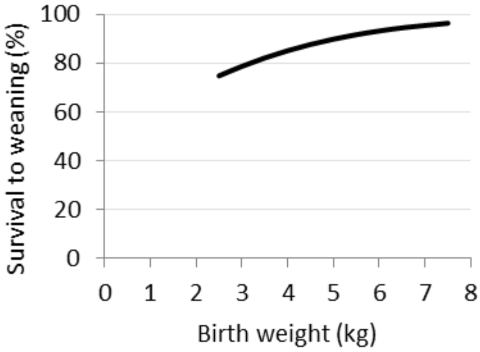
Survival to weaning (%)
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8
Birth weight (kg)

(j)



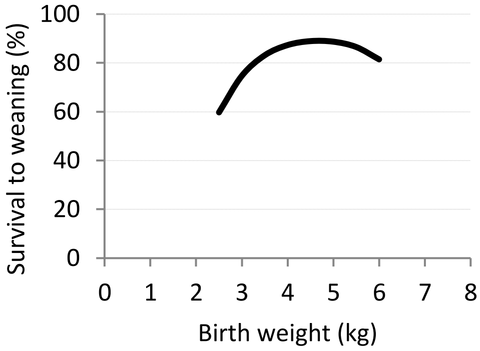
Survival to weaning (%)
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8
Birth weight (kg)

(k)



Survival to weaning (%)
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8
Birth weight (kg)

(l)



Survival to weaning (%)
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8
Birth weight (kg)

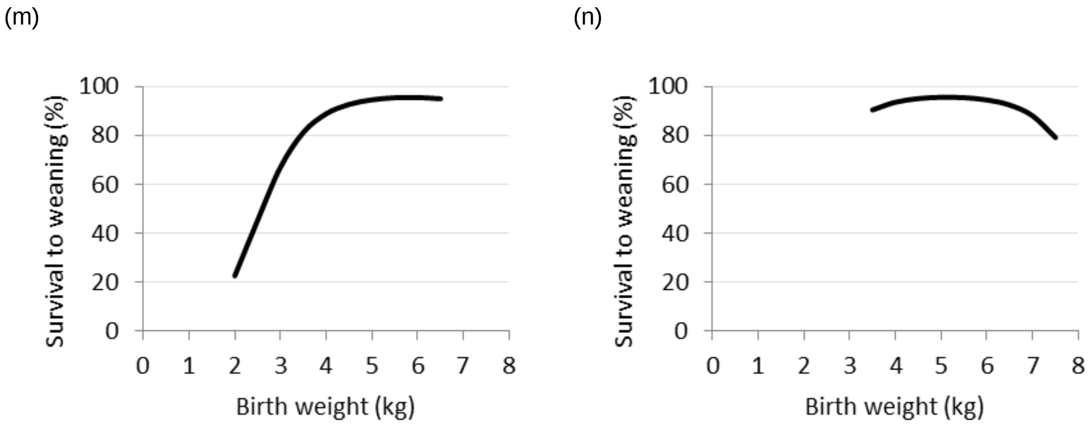


Figure 1. Effect of lamb birth weight and birth type [single and twin (black); triple (red) and quadruple (green)] on survival of individual progeny to weaning. The data is combined across sexes and is from 20 different experiments involving maternal ewes: (a) Evergraze (3 years); (b) Lamb Foundation; (c) Riverside; (d) Shearing RC1; (e) Shearing RC2; (f) Tuapaka; (g) Landcorp; (h) FM 2009 – Twins and Triples; (i) FMG1 2013; (j) FMG1 2013; (k) Hoggets 2007; (l) Nutrition RC2; (m) Dorpers and (n) Mount Ronan.

Effects of ewe live weight profile on lamb weaning weights

The effects of ewe live weight profile on weaning weights are similar to those for birth weight. In almost all cases lamb weaning weights were influenced by ewe live weight at joining (Table 4), and like birth weight, this presumably reflect in part the positive genetic relationship between weaning weight and adult weight. On average an extra 10 kg of ewe live weight at joining increased lamb birth weights by 1.8 kg, but the range was 0.9 to 2.7 kg. However, lamb weaning weight was significantly related to changes in ewe live weight during both early and late pregnancy in more data sets than was the case for birth weight. When evident during both periods, the effects of live weight change during early pregnancy on weaning weights were greater than the effects of live weight change during late pregnancy. This has previously been reported for Merino ewes (Thompson *et al.* 2011) and maternal ewes (Paganoni *et al*. 2014), and may be related to the findings reported by Dove *et al.* (1988) that increasing ewe live weight gain during early pregnancy significantly increased milk production. Confirmation of the size of the effects of ewe nutrition during pregnancy on lamb weaning weights, and establishing whether the effects of pregnancy nutrition can be modified by the subsequent nutrition during lactation, is important to determining the overall profitability of different management strategies for non-Merino ewes in the whole farm context.

Further analysis is being completed to confirm whether the inconsistent effects of ewe liveweight change during pregnancy on lamb birth weights and weaning weights are due to the methods used to correct ewe liveweights for weight of conceptus.

Table 4. The linear effects (± standard errors; SE) of ewe live weight at joining (LW_{D0}), ewe live weight change from day 0 to day 90 of pregnancy (LWC_{D0-90}) and ewe live weight change from day 90 to 140 of pregnancy ($LWC_{D90-140}$) on progeny weaning weights. Birth type and sex effects were significant for all analyses and were included in the relevant models. The data is from 20 experiments involving maternal ewes.

Experiment	LW_{D0}		LWC_{D0-90}		$LWC_{D90-140}$	
	Coefficient	P value[A]	Coefficient	P value[A]	Coefficient	P value[A]
Information Nucleus Flock						
Combined BF	0.24 ± 0.005	<0.001	0.26 ± 0.013	<0.001	0.009 ± 0.0107	<0.001
Armidale followers	0.17 ± 0.048	<0.001		n.s		n.s.
Trangie followers	0.21 ± 0.066	<0.001		n.s.		n.s.
Cowra followers	0.18 ± 0.038	<0.001	0.37 ± 0.108	<0.001		n.s.
Rutherglen followers	0.20 ± 0.060	<0.001	0.51 ± 0.182	<0.001		n.s.
Hamilton followers	0.21 ± 0.053	<0.001	0.35 ± 0.182	0.05		n.s.
Struan followers	0.22 ± 0.068	<0.01		n.s.		n.s.
Turretfield followers	0.17 ± 0.038	<0.001		n.s.		n.s.
Katanning followers	0.18 ± 0.044	<0.001		n.s.	0.40 ± 0.100	<0.05
Evergraze 2008	0.23 ± 0.058	<0.001	0.28 ± 0.073	<0.001	0.22 ± 0.060	<0.001
Evergraze 2009	0.15 ± 0.041	<0.001		n.s.		n.s.
Lamb Foundation	0.19 ± 0.018	<0.001	0.20 ± 0.032	<0.001	0.09 ± 0.038	<0.05
Mt Ronan	0.27 ± 0.030	<0.001	0.35 ± 0.065	<0.001	0.21 ± 0.068	<0.01
Riverside	0.15 ± 0.020	<0.001	0. 16 ± 0.035	<0.001	0.08 ± 0.033	<0.01
Shearing RC1	0.16 ± 0.035	<0.001		n.s.	0.27 ± 0.071	<0.001
Shearing RC2[B]	0.15 ± 0.042	<0.001		n.s.	0.35 ± 0.086	<0.001
Tuapaka	0.19 ± 0.020	<0.001	0.21 ± 0.032	<0.001	0.18 ± 0.042	<0.001
FM 2009 - Twins	0.09 ± 0.026	<0.001	0.10 ± 0.044	<0.01		n.s.
FM 2009 - Triples	0.11 ± 0.044	0.015		n.s.		n.s.
FMG1 2011	0.19 ± 0.043	<0.001	0.29 ± 0.077	<0.001	0.13 ± 0.063	<0.05
FMG1 2013		n.s.		n.s.		n.s.

[A] n.s., not significant (P > 0.05); [B] Sex not significant (P > 0.05)

References

Corner RA, Kenyon PR, Stafford KJ, West DM, Oliver MH (2006). The effect of mid-pregnancy shearing or yarding stress on ewe post-natal behaviour and the birth weight and post-natal behaviour of their lambs. *Livestock Science* 102; 121-129.

Corner RA, Kenyon PR, Stafford KJ, West DM, Oliver MH (2007). The effect of mid-pregnancy stressors on twin-lamb live weight and body dimensions at birth. *Livestock Science* 107; 126-131.

Corner RA, Mulvaney FJ, Morris ST, West DM, Morel PCH, Kenyon PR (2013). A comparison of the reproductive performance of ewe lambs and mature ewes. *Small Ruminant Research* 114; 126–133.

GENSTAT Committee (2008) ‘GENSTAT for Windows.’ 11th edn. (VSN International: Hertfordshire, UK)

Hickson RE, Kenyon PR, Blair HT, Harding JE, Oliver MH, Jaquiery AL, Nicoll GB and Burt KG (2012). The effect of liveweight and liveweight gain of ewes immediately post-weaning on the liveweight and survival of subsequent lambs. *Animal Production Science* 52(6–7); 491–496

Kenyon PR, Revell DK, Morris ST (2006). Mid-pregnancy shearing can increase birth weight and survival to weaning of multiple-born lambs under commercial conditions. *Australian Journal of Experimental Agriculture* 46; 821 – 825.

Kenyon PR, Blair HT, Jenkinson CMC, Morris ST, MacKenzie DDS, Peterson SW, Firth EC, Johnston PL (2009). The effect of ewe size and nutritional regimen beginning in early pregnancy on ewe and lamb performance to weaning. *New Zealand Journal of Agricultural Research* 52; 203 – 212.

Kenyon PR, Pain SJ, Hutton PG, Jenkinson CMC, Morris ST, Peterson SW, Blair HT (2011). Effects of twin-bearing ewe nutritional treatments on ewes and lamb performance to weaning. *Animal Production Science* 51; 406 – 415.

Kenyon PR, Morris ST, Stafford KJ, West DM (2011). Does early pregnancy nutrition affect the performance of triplet bearing ewes and their progeny to weaning. *New Zealand Journal of Agricultural Science* 54; 115 – 123

Kenyon PR, Corner-Thomas RA, Peterson SW, Pain SJ, Blair HT (2014). Pregnancy nutrition does not influence lamb liveweight in developmentally programmed ewes. *Animal Production Science* 54; 1465–1470

Kenyon PR, Thompson AN and Morris ST (2014) Breeding ewe lambs successfully to improve lifetime performance. *Small Ruminant Research* 118; 2-15.

Paganoni BL, Ferguson MB, Kearney G, Thompson AN (2014) Increasing weight gain during pregnancy results in similar increases in lamb birth weights and weaning weights in Merino and non-Merino ewes regardless of sire type. *Animal Production Science* 54(6); 727-735.

Paten AM, Kenyon PR, Lopez-Villalobos N, Peterson SW, Jenkinson CMC, Pain SJ, Blair HT (2013). Maternal nutrition during early and mid-to-late pregnancy: Comparative effects on milk production of twin-born ewe progeny during their first lactation. *Journal of Animal Science* 91; 676-684.

Verbyla AP, Cullis BR, Kenward MG and Welham SJ (1999). The analysis of designed experiments and longitudinal data by using smoothing splines. *Journal of the Royal Statistical Society Series C-Applied Statistics* 48**;**269-300.

13.2 Appendix 2 – A comparison of Merino vs Non-Merino ewes managed under similar conditions (Experiment 1)

Crossbred ewes gain more weight and are fatter than Merino ewes when managed together but similar coefficients predict lamb birth weight and survival.

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Abstract

Current Australian ewe management guidelines are based on research from Merino ewes and have been transposed to non-Merino ewes. It is unknown whether guidelines developed for Merino ewes are applicable to non-Merino production systems. To investigate this, the effect of non-Merino ewe liveweight and condition score profile during pregnancy on lamb birth weight and survival was compared to Merino ewes. Condition score profiles of 720 Merino and 680 non-Merino (Border Leicester x Merino; BLM) ewes were managed from 50 days after ram introduction to achieve one of four target condition scores at lambing (CS2.5, CS2.8, CS3.2, CS3.6). Liveweight at conception and change in liveweight in late pregnancy of the Merino and BLM ewes had a similar effect on the birth weight and weaning weight of their lambs. However liveweight change in early pregnancy had less effect on birth weight and weaning weight of lambs from BLM ewes. Birth weight survival curves were similar in lambs from Merino and BLM ewes, and the survival of lambs from multiple-bearing BLM ewes responded to CS manipulation in a similar pattern to lambs from Merino ewes. Therefore managing liveweight of multiple-bearing BLM ewes is likely to improve lamb survival in a similar fashion to lambs from Merino ewes. In addition, it is important to manage liveweight of both single and multiple bearing BLM ewes during pregnancy to optimise weaning weight of their lambs, as those lambs born to BLM ewes of low liveweight were significantly lighter at weaning. This is likely to have an economic impact on lamb production systems.

Introduction

Small ruminants (sheep and goats) play an essential role in production of food and fibre worldwide, and account for over 50% of all domesticated ruminants (Tedeschi *et al.* 2010). With less land and natural resources available, small ruminant production systems need to become more efficient to remain viable. As such, the Lifetime Ewe Management (LTEM) course was created to extend the outcomes of research from Merino ewes (Behrendt *et al.* 2011; Ferguson *et al.* 2011; Oldham *et al.* 2011; Thompson *et al.* 2011; Young *et al.* 2011), which integrated new and existing knowledge about nutrition and its impact on the ewe, production and whole-farm profitability. With the adoption of new management practices, farmers who participated in the LTEM course increased stocking rate by 14%, increased marking numbers by 11% and 13% (Merino and cross-bred respectively) and decreased annual ewe mortality by 43% (Trompf *et al.* 2011). The majority of ewes mated in Australia are pure-bred Merinos, however, in 2014 28% of ewes were non-pure-bred Merinos (Curtis 2014), including Merino crosses such as Border Leicester x Merino (BLM). The management practices outlined in the LTEM course are recommended for all breeds of ewe and, in the absence of better information, LTEM recommendations are still the best guidelines currently available to Australian sheep producers.

Both anecdotal and published reports suggest that when Merino and non-Merino ewes are managed together there is a difference in their productivity. For example, non-Merino ewes were significantly fatter than Merino ewes when managed on the same pasture (Holst *et al.* 2002; Anon 2015). This increase in fatness was associated with a decrease in lamb survival due to injury during birth and an increase in mal-presentation in the BLM ewes (Holst *et al.* 2002) although the BLM ewes weaned a greater weight of lambs compared to Merino ewes (Anon 2015). Furthermore, analysis of over 18,000 records of Merino and non-Merino ewes grazed together at eight different sites over several years in the Sheep CRC Information Nucleus found that the effects of ewe breed on live weight profile varies between sites and years (Blumer *et al.* 2016). Finally, the economic value of improving the number of lambs weaned is much greater for non-Merino than Merino ewes (Young *et al.* 2014). This evidence suggests that management guidelines developed for Merinos may not be directly transferrable to non-Merino breeds of ewes. In addition, feeding ewes above their nutritional requirements does not have positive effects on lamb performance and welfare (Rooke *et al.* 2015).

The prediction of birth weight and weaning weight of lambs from ewe liveweight profile during pregnancy and the relationship between birth weight and survival was similar for Merino and non-Merino dam breeds in the Sheep CRC Information Nucleus (Paganoni *et al.* 2014) and these coefficients were similar to those used for the development of the LTEM guidelines (Oldham *et al.* 2011; Young *et al.* 2011). Nevertheless, ewes in the Sheep CRC Information Nucleus were managed according to LTEM guidelines and the impact of alternative management strategies has not been well defined. The implication of this is that management recommendations that have been developed for Merino ewes may be over estimating the needs of non-Merino ewes thus, it cannot be inferred that adoption of the Merino guidelines will optimise the performance of non-Merino ewes. This paper tested the hypotheses that (i) there is a difference between body condition score (CS) and liveweight profiles of Merino and non-Merino ewes during gestation when managed together to achieve different condition scores at lambing and; (ii) the prediction equations for birth weight and survival of lambs using liveweight and CS profiles during gestation are the same for Merino and non-Merino ewes.

Materials and methods

All procedures reported within this paper were conducted in accordance with the Australian Code for the Care and Use of Animals Used for Scientific Purposes, under approval from the Primary Industries and Regions of South Australia Animal Ethics Committee (project # 21/13).

Experimental design

The trial was conducted at the Struan Research Centre, near Naracoorte in the south east of South Australia (37.1S/140.48E). Naracoorte experiences a Mediterranean climate, with cold wet winters and hot, dry summers and an average annual rainfall of 500mm, which falls largely in the winter and early spring months.

A randomized block design was used with three replicates (Block 29/30, Block 42, The Gums) of four treatments of ewe condition score targets (CS2.5, CS2.8, CS3.2 or CS3.6 at lambing) and two breeds (Merino and BLM). Treatment groups were managed to achieve the target condition scores through manipulation of pasture availability (Block 29/30, Block 42) and supplementary feeding levels (in all replicates; Table 1). Pasture at the trial site was comprised of mixed annual grasses, subterranean clovers, broad-leaf weeds and *Phalaris aquatica*. Ewes were offered supplementary rations of a mixture of barley (*Hordeum vulgare* 70%) and lupins (*Lupinus albinus*; 30%) at various levels from ram introduction (Day 0) until Day 97, and then barley only until Day 140. Treatment period commenced at 50 days after ram introduction and continued until 140 days after ram introduction.

Table 1. Feed on offer (FOO; kg/DM.ha) and supplementary feed offered (g DM/hd.d) to the ewes in each treatment during gestation.

	CS 2.5		CS 2.8		CS 3.2		CS 3.6	
	FOO	Supp.	FOO	Supp.	FOO	Supp.	FOO	Supp.
Day 52-61	958	0.36	817	0.46	1233	0.64	1283	0.77
Day 62-70	1341	0.35	1025	0.49	1213	0.67	1455	0.89
Day 71-90	1182	0.34	1258	0.52	1437	0.73	1463	0.95
Day 91-109	733	0.33	1198	0.49	1742	0.75	1203	1.12
Day 110-124	666	0.20	1221	0.17	1204	0.89	1920	1.33
Day 125-140	785	0.08	1084	0.11	856	1.20	1377	1.40

Experimental sheep and management

Approximately 1400 ewes (720 Merino and 680 Border Leicester x Merino; BLM) ranging from three to five years of age were naturally mated in seven mobs to Australian Sheep Breeding Values matched pairs of Poll Dorset rams. Rams were put in with Merino ewes on 28 January 2014 (Day 0) and the BLM ewes were added to the mating groups on 31 January 2014 so lambing commenced on a similar date. At 50 days from ram introduction to the

Merino ewes, ewes were pregnancy scanned using real-time ultrasound to determine whether ewes had conceived in the first oestrus cycle after ram introduction. Ewes that conceived in the first cycle (Phase 1) were stratified for liveweight, condition score, age and sire of progeny, and were allocated and split into treatment groups. The remaining ewes were managed as one mob until they were re-scanned at day 66 from rams in to determine those ewes that had conceived in the second oestrus cycle. Ewes that were scanned as pregnant at day 66 (Phase 2) were stratified for liveweight, condition score, age and sire of progeny, and were added to the first cycle ewes in treatment groups. All ewes were again pregnancy scanned at day 90 from rams in to determine the litter size (single or twins). On day 139 from rams in, Phase 2 ewes were separated from Phase 1 ewes, in preparation for lambing of the latter mob. Phase 2 ewes subsequently continued on their treatments until day 160 from rams in. As such, all ewes began treatments at approximately 50 days of pregnancy and treatment ceased at approximately 140 days of pregnancy. All ewes lambed - and remained - in their treatment groups, until 90% of the mob had lambed, after which ewes were boxed into one mob within each replicate.

Ewe liveweight and condition scores

Throughout the treatment period, ewes were weighed and condition scored at approximately three weekly intervals from Day 0 until the end of the treatment period. Ewes were condition scored by a single, experienced operator throughout the duration of the trial, according to the method described by Russel *et al.* (1969). Ewe liveweights were adjusted for conceptus weight using the equations of Wheeler *et al.* (1971).

Lamb measurements

Lambs were tagged within 24hr of birth, and had their birthweight, dam, sex and birth type (single, twin, triplet) recorded, as well as date of death where appropriate. Lambs were subsequently weighed at marking and at weaning. Lamb survival to marking was calculated using the number of lambs recorded at birth (dead + alive) that could be allocated to a ewe and present at lamb marking. Lambs per foetuses scanned was calculated using scanning data to identify number of lambs expected, to account for any lambs that died prior to or at birth and were missed during lambing rounds and to account for dead lambs that could not be allocated to a dam.

Statistical analysis

Data from 1120 ewes was available for analysis of CS and conceptus free weights (BLM N=550; Merino N=570). All statistical analyses were undertaken using SAS statistical package (SAS v9.3, SAS Institute, Cary, NS, USA). Least square means and maximum standard error of difference (calculated from [standard error of the mean] * √2) are presented.

Ewe condition score and conceptus free liveweight were analysed as dependent variables in a linear mixed effects model to determine treatment effects on ewe liveweight and condition score profiles. The fixed effects included in the model were treatment (CS2.5, CS 2.8, CS 3.2, CS3.6), ewe breed (BLM, Merino), foetal number (based on scanning and birth observations; single, multiple) and their interactions. Block (Block 29/30, Block 42, The

Gums), pregnancy cycle (First, Second), mating group (1-7), plot (1-12) and ewe birth year (2009, 2010, 2011) were included as random effects. Day of gestation (Day), calculated from the number of days before birth, was included as a covariate in a new model to determine the treatment effects over time. The curvilinear term Day, along with interactions with treatment, breed and foetal number were also included in the model, and individual ewe identification (Ewe ID) was included as a random effect.

Lamb birth weight and weaning weight data were analysed with a linear mixed effects model. The fixed effects included in the model were treatment, ewe breed, birth type, sex and their interactions. Block, pregnancy cycle, mating group, plot, ewe birth year and ewe ID were included as random effects. A total of 1254 birth weights and 928 weaning weights were available for analysis.

To investigate the effect of ewe liveweight profile on birth weight and weaning weight, a mixed linear model was fitted to the data. To account for the large range in birth dates, liveweight was allocated to the 3 time points based on lamb birth date. Day 0 liveweight measurements ranged from -26 to 20 days of pregnancy, Day 100 measurements ranged from 88 to 116 days of pregnancy and Day 140 measurements ranged from 113 days to 150 days of pregnancy. The model included liveweight at Day 0, change in conceptus free liveweight between Day 0 and Day 100 (Early LWC) and change in conceptus free liveweight between Day 100 and Day 140 (Late LWC) as covariates in a single model. Dam breed, birth type, lamb sex, ewe birth year and pregnancy cycle were included as fixed effects and the random effects were treatment, block, plot, lamb date of birth and ewe ID.

Lamb survival to marking data were analysed using a generalised linear mixed effects model with a logit transformation and binomial distribution. The fixed effects included in the model were treatment, dam breed, birth type and lamb sex, and the random effects included block, plot, dam birth year and mating group. To investigate the relationship between lamb survival and birth weight, the covariates birth weight and birth weight*birth weight and the fixed effects dam breed, birth type and lamb sex and the interaction between the covariates and fixed effects were included in the model. The random effects were block, mating group, plot, dam birth year, pregnancy cycle and treatment.

Results

Effect of treatments on ewe liveweight and condition score

The treatments imposed generated a wide range of maternal liveweights (Figure 1a) and condition scores (Figure 1b). Prior to the commencement of CS treatments (Day 50), there was no difference in liveweight or CS of the ewes between treatments. There was a significant effect of treatment on both liveweight and CS by Day 90 ($P<0.05$) and at Day 140 after rams in ($P<0.0001$; Table 2). The CS2.5 treatment achieved its target condition score by lambing, but the mean CS of the remaining treatments were lower than the target treatment CS; CS2.8 ewes had an average CS of 2.7, CS3.2 ewes had an average CS of 2.9 and CS3.5 ewes had an average CS of 3.3 by commencement of lambing (Table 2).

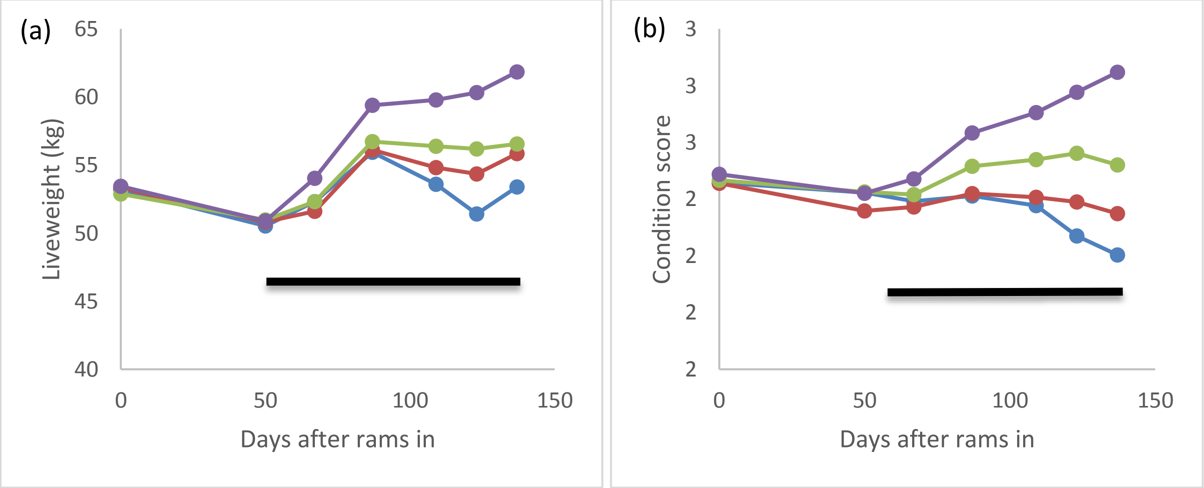

Figure 1. Raw mean ewe conceptus free liveweight (a) and condition scores (c) from rams in (Day 0) to 140 days after rams in with different target condition score (CS) treatments. (CS2.5 – blue; CS2.8 – red; CS3.2 – green; CS3.6 – purple). Black line is treatment period.

When the rams were joined with the ewes, the BLM ewes were 0.1±0.03 CS greater ($P<0.001$) and 1.2±0.48kg heavier ($P<0.01$) than the Merino ewes (Table 2). By Day 140 after rams in, the BLM ewes were 0.4±0.03CS ($P<0.001$) greater and 4.6±0.48kg ($P<0.001$) heavier than the Merino ewes. Multiple bearing ewes were significantly heavier than single-bearing ewes until the final pregnancy measurement, and had a higher condition score ($P<0.001$; Table 2) at the start of mating but by 140 days after ram introduction, single-bearing ewes had a higher CS ($P<0.001$; Table 2). There was no interaction between breed and foetal number nor between treatment and foetal number for liveweight or condition score.

Table 2. Ewe conceptus free liveweights and condition scores of Border Leicester x Merino (BLM) and Merino ewes at key times after rams in (LSM).

Different letters between treatment groups are significantly different.

	Liveweight (kg)				**Condition score**			
	Pre-mate	**Day 50**	**Day 90**	**Day 140**	**Pre-mate**	**Day 50**	**Day 90**	**Day 140**
BLM	55.1	53.2	59.8	60.0	2.9	2.8	2.9	3.0
Merino	54.0	50.8	55.7	55.4	2.8	2.7	2.7	2.6
s.e.d*	4.10	4.04	4.27	4.03	0.07	0.08	0.16	0.07
	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001	P<0.01	P<0.001	P<0.001
Single	53.8	51.4	57.1	57.4	2.8	2.8	2.8	2.9
Multiple	55.3	52.6	58.5	58.0	2.9	2.8	2.8	2.7
s.e.d	4.10	4.04	4.27	4.03	0.07	0.08	0.16	0.07
	P<0.001	P<0.01	P<0.001	n.s.	P<0.01	n.s	ns	P<0.001
CS2.5	54.8	52.1	56.8	54.4^{a}	2.8	2.8	2.7^{a}	2.5^{a}
CS2.8	54.8	52.1	57.1	56.8^{a}	2.8	2.7	2.7^{a}	2.7^{a}
CS3.2	54.2	52.1	57.5	57.4^{a}	2.8	2.8	2.9^{ab}	2.9^{b}
CS3.6	54.4	51.6	59.6	62.1^{b}	2.8	2.8	3.0^{b}	3.3^{c}
s.e.d	4.11	4.05	4.37	4.30	0.07	0.09	0.18	0.10
	n.s	n.s	n.s.	P<0.001	n.s	n.s	P<0.05	P<0.001

* s.e.d is maximum standard error of the difference

At 140 days after rams in, there were significant breed*treatment interaction for condition score (P<0.01). There were differences between all treatments in ewe CS, with the exception that there was no difference in CS between CS2.5 BLM and CS2.8 Merinos nor was there a difference in condition score between CS3.2 BLM and CS3.6 Merino ewes. There was no significant interaction between breed and treatment for conceptus free liveweight. There was no significant 3-way interaction between treatment, breed and foetal number for either CS or conceptus free liveweight. In all treatments the both the multiple-bearing and single-bearing Merino ewes had a lower CS than the single-bearing BLM ewes and both groups of Merino ewes also had a lower CS than the multiple-bearing BLM ewes in all treatments other than the CS2.5 treatment (Table 3).

Table 3. Plot means of ewe condition score at each target condition score (CS) of multiple- and single-bearing Merino (Mo) and Border Leicester x Merino (BLM) ewes at 140 days after ram introduction.

Different lower case letters represent significant differences (P<0.05) between ewe category within treatment. Different upper case letters represent significant differences (P<0.05) between treatment within ewe type.

	Multiple Mo	Single Mo	Multiple BLM	Single BLM
CS 2.5	$2.3^{a\ A}$	$2.4^{a\ A}$	$2.5^{a\ A}$	$2.7^{b\ A}$
CS 2.8	$2.5^{a\ AB}$	$2.6^{a\ AB}$	$2.7^{b\ B}$	$2.9^{c\ A}$
CS 3.2	$2.6^{a\ B}$	$2.7^{b\ B}$	$3.1^{c\ C}$	$3.1^{c\ B}$
CS 3.6	$3.0^{a\ C}$	$3.1^{b\ C}$	$3.4^{c\ D}$	$3.5^{c\ C}$
s.e.d	0.14	0.08	0.12	0.11

Effect of day of gestation on ewe liveweight and condition score

To determine whether there was a difference between breed in their pattern of liveweight change over the experimental period, day of gestation (back calculated from lamb date of birth) was included in the analysis as a covariate. Day of gestation was a significant curvilinear covariate (Day*Day) for CS (P<0.01) and conceptus free liveweight (P<0.0001; Figure 2a). There was a significant interaction between day of gestation, breed and treatment on ewe condition score (P<0.0001; Figure 2b), indicating that the response of ewe CS to the treatments over time differed between breeds. In addition, the condition score, but not liveweight, of multiple and single bearing ewes responded differentially to the treatments between breeds over time (P<0.005).

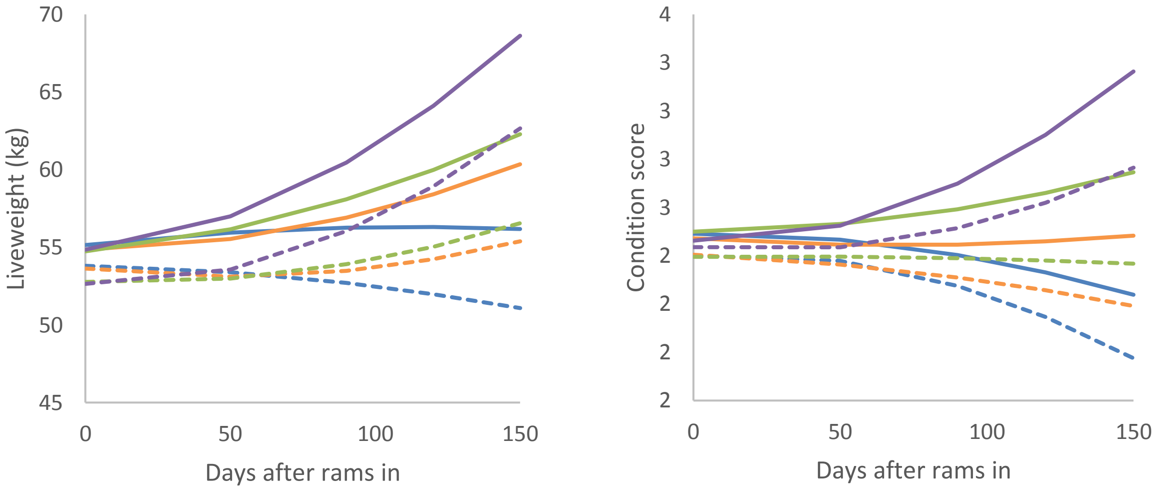

Figure 2. Predicted ewe conceptus free liveweight (a) and condition scores (b) from rams in (Day 0) to 140 days after rams in of BLM (solid lines) and Merino ewes (dash lines) with different target condition score treatments (CS2.5 – blue; CS2.8 – orange; CS3.2 – green; CS3.6 – purple).

Factors influencing the birth weight and weaning weight of lambs

Birth weights from 1227 lambs and weaning weights from 916 lambs were analysed. Overall mean birth weight was 5.14kg (min = 1.9kg; max = 8.8kg) and weaning weight was 25.8kg (min = 13.5kg; max = 40.4kg). There was no effect of treatment on birth weight but there was a significant effect of treatment on weaning weight (P<0.01). At birth, lambs from BLM ewes were 0.46 ± 0.082 kg heavier than lambs from Merino ewes (P<0.001), single born lambs were 1.40 ± 0.080kg heavier than multiple born lambs and female lambs were 0.27 ± 0.062 kg lighter than male lambs (P<0.001). Similarly, at weaning, lambs from BLM ewes were 3.90 ± 0.469 kg heavier than lambs from Merino ewes (P<0.001), single born lambs were 4.65 ± 0.462 kg heavier than multiple born lambs (P<0.001) and females were 0.89 ± 0.334 kg lighter at weaning than male lambs (P<0.001).

There was a significant interaction between breed and treatment on birth weight (P<0.05) and weaning weight (P<0.01; Table 4). Lambs from BLM ewes had similar birth and weaning weights in all treatments, however, lambs from Merino ewes in the CS3.6 treatment were significantly heavier than lambs in the Merino CS2.5 treatment at birth and the Merino cross lambs from the CS3.6 treatment were heavier than all other lambs from Merino ewes at weaning (P<0.01).

There was a significant interaction between breed and foetal number on birth weight (P<0.01) and weaning weight (P<0.001; Table 4). Single born lambs from Merino ewes were 1.23 ± 0.128 kg heavier than multiple born lambs at birth, whereas single born lambs from BLM ewes were 1.57 ± 0.096 kg heavier than multiple born lambs (Table 4). At weaning, single BLM lambs were 6.3 ± 0.49kg heavier than multiple BLM lambs and single Merino lambs were only 3.0±0.78kg heavier than multiple Merino lambs.

Table 4. Birth weight and weaning weight of single- and multiple-born lambs with Merino or BLM dams in four target condition score (CS) treatments (LSM±SEM).

Different letters within a column within treatment or birth type are significantly different.

		Birth weight (kg)				Weaning weight (kg)		
Effect	N	Merino	N	BLM	N	Merino	N	BLM
CS 2.5	119	4.60^{a}	171	5.27^{bc}	69	21.2^{a}	129	26.0^{c}
CS 2.8	140	4.83^{a}	165	5.40^{bc}	98	21.9^{a}	130	26.6^{c}
CS 3.2	147	4.82^{a}	175	5.18^{bc}	101	22.4^{a}	131	25.7^{bc}
CS 3.6	152	5.10^{b}	186	5.35^{c}	115	24.5^{b}	155	27.2^{c}
s.d.		0.278		0.270		1.85		1.78
Single	421	5.45^{A}	323	6.08^{C}	320	24.0^{A}	297	29.6^{C}
Multiple	137	4.22^{B}	373	4.51^{D}	63	21.0^{B}	248	23.2^{D}
s.d.		0.243		0.222		1.81		1.69

Effect of ewe weight and liveweight change on birth weight

Liveweight at conception, liveweight change from conception to Day 100 (Early LWC) and from Day 100 to Day 140 (Late LWC) all had a significant effect on birth weight ($P<0.001$). When both breeds were included in the analysis, a 10kg increase in ewe liveweight at conception resulted in 0.36±0.022kg increase in birth weight, while a 10 kg increase in liveweight during early pregnancy was associated with a 0.49±0.086kg increase in birth weight and a 10 kg increase in liveweight in late pregnancy resulted in 0.45±0.063kg increase in birth weight. Multiple born lambs were 1.2±0.09kg lighter than single lambs and males were 0.3±0.04kg heavier than female lambs at birth. There was a significant effect of breed on birth weight ($P<0.001$), with lambs from BLM 0.5±0.07kg heavier than lambs from Merino ewes. There was a significant interaction between Early LWC and breed ($P<0.001$). Birth weight of lambs from BLM ewes were 0.04±0.010kg less responsive to change in liveweight in early pregnancy than lambs from Merino ewes. Data was analysed by breed to derive coefficients for both breeds (Table 5).

Table 5. Fixed effect solutions and the standard errors (SE) that predict lamb birth weight (kg) from ewe liveweight at joining (Day 0; kg), maternal liveweight change from Day 0 to Day 100 (Early LWC) and Day 100 to lambing (Late LWC) and lamb sex and birth type.

		BLM ewes			Merino ewes	
Effect	Estimate	s.e.	Prob	Estimate	s.e.	Prob
Constant	4.1	0.30	<0.01	3.6	0.33	<0.01
Day0	0.037	0.0052	<0.001	0.035	0.0060	<0.001
Early LWC	0.012	0.0083	n.s.	0.048	0.0088	<0.001
Late LWC	0.039	0.0083	<0.001	0.055	0.0093	<0.001
Birth type - Multiple	-1.5	0.07	<0.001	-1.1	0.08	<0.001
Sex - Female	-0.3	0.06	<0.001	-0.3	0.06	<0.001

*The birthweight constant is for single born, male progeny

Factors influencing lamb survival to marking

Of the 1437 lambs expected from scanning data, 1397 lambs were recorded and it was not possible to allocate a dam to 114 of these lambs. There were 126 ewes with no lambing records – 48 BLM ewes and 78 Merinos. There were 10-14 ewes without lambing records across the 4 treatments within each breed type, with the exception that there were 34 Merino ewes without lambing records in the CS2.5 treatment and 19 Merino ewes without lambing records in the CS2.8 treatment.

More lambs from BLM ewes survived to marking compared to lambs from Merino ewes (88±3.6% cf 68±6.9%; P<0.001), there was a higher survival rate in single lambs than multiple lambs (90±3.0% cf 63±7.4%; P<0.001) and more female than male lambs survived (83±4.5% cf 76±5.8%; P<0.01). Condition score treatment did not have an effect on survival, but there was a significant breed*birth type (P<0.05) and breed*treatment*birth type effect (P<0.01; Table 6).

When lamb survival was calculated based on scanning data (TMT; lambs produced/ 100 foetuses scanned), there was a significant effect of treatment (P=0.05; Table 6) ranging from 61% of potential lambs surviving in the CS2.5 treatment up to 77% of potential lambs surviving in the CS3.6 treatment. More lambs from BLM ewes survived compared to lambs from Merino ewes (80±5.1% cf. 56±7.9%; P<0.001) and there was a higher survival rate in single lambs than twin lambs (83±4.6% cf. 51±7.9%; P<0.001). There was no interaction between breed and foetal number and there was a trend towards a breed*treatment*foetal number effect on survival of potential lambs (P<0.1; Table 6).

Table 6. Observed and potential survival of single- and multiple-born lambs with Merino or BLM dams in four target condition score (CS) treatments (LSM±SD).

Different letters within a column within birth type are significantly different.

		Survival to marking		Lambs per 100 foetuses scanned		
		BLM	Merino	BLM	Merino	TMT
Single	CS 2.5	97	61^{a}	89	51^{a}	61^{a}
	CS 2.8	95	85^{b}	89	76^{b}	66^{ab}
	CS 3.2	95	80^{b}	88	77^{b}	70^{ab}
	CS 3.6	95	89^{b}	90	85^{b}	77^{b}
Max s.e.d		3.8	10.3	5.8	10.1	9.1
Multiple	CS 2.5	64^{a}	69^{a}	60	33^{ab}	
	CS 2.8	69^{ab}	34^{b}	66	23^{a}	
	CS 3.2	70^{ab}	56^{ab}	64	41^{ab}	
	CS 3.6	81^{b}	54^{ab}	73	49^{b}	
Max s.e.d		10.2	14.9	10.1	13.1	

Lamb birth weight & survival to marking

Lambs that died before marking were 0.21±0.129kg lighter at birth than lambs that survived to marking (P<0.001). Birthweight and Birthweight*Birthweight were strongly correlated with survival of lambs (P<0.0001) and there was a significant effect of breed (P<0.001), birth type (P<0.005) and sex (P<0.001) on the relationship between birth weight and survival (Table 7). Lamb survival was greater than 80% for lambs from BLM ewes with birth weights greater than 4.5kg and did not decline below 80% up to 8kg birthweight which was the maximum birth weight modelled. For lambs born to Merino ewes, they needed to be at least 5.5kg to achieve 80% survival and dropped below 80% survival when the birth weight of the lambs was heavier than 7.0kg. At the same birth weight, between 11-26% more lambs from BLM ewes survived than lambs from Merino ewes across the 4-8kg birth weight range. At equal birth weights, multiple born lambs had lower survival than single born lambs, and males had lower survival than females.

Table 7. Fixed effect solutions (± SEM) that predict lamb survival from birth weight (BWT), sex and birth type within dam breed. Combined analysis includes dam breed in the model.

Term	Combined[1]	Prob	Merino[2]	Prob	BLM[2]	Prob
Intercept	-9.2 ± 1.42	ns	-9.5 ± 2.75	ns	-8.0 ± 1.71	ns
BWT	3.4 ± 0.55	<0.001	3.7 ± 1.09	<0.001	3.4 ± 0.69	<0.001
BWT*BWT	-0.3 ± 0.05	<0.001	-0.3 ± 0.11	<0.01	-0.3 ± 0.07	<0.001
BLM	1.5 ± 0.32	<0.001	-	-	-	-
Multiple	-0.5 ± 0.25	<0.05	-0.6 ± 0.27	<0.05	-0.9 ± 0.38	<0.05
Female	0.6± 0.16	<0.001	0.7 ± 0.22	<0.001	0.5 ± 0.24	<0.05

[1]Constant is single male lamb with Merino dam; [2]Constant is single male lamb

There was no interaction between birth type and breed (P=0.1), indicating that the shape of the curve was the same for single and multiple curves across the two breeds, however, they did influence absolute survival at a given birth weight (P<0.05; Figure 3). At a given birth weight, single born lambs from BLM ewes had higher survival than single lambs from Merino ewes (P<0.001) and multiple born lambs from both Merino (P<0.001) and BLM ewes (P<0.01). The single born lambs from the Merino ewes and multiple born lambs from BLM ewes both had higher survival than multiple born lambs from Merino ewes at the same birth weight (P<0.05). However, at a given birth weight, multiple born lambs from BLM ewes had similar survival to single born lambs from Merino ewes (P<0.1), but a higher survival than multiple born lambs from Merino ewes (P<0.001).

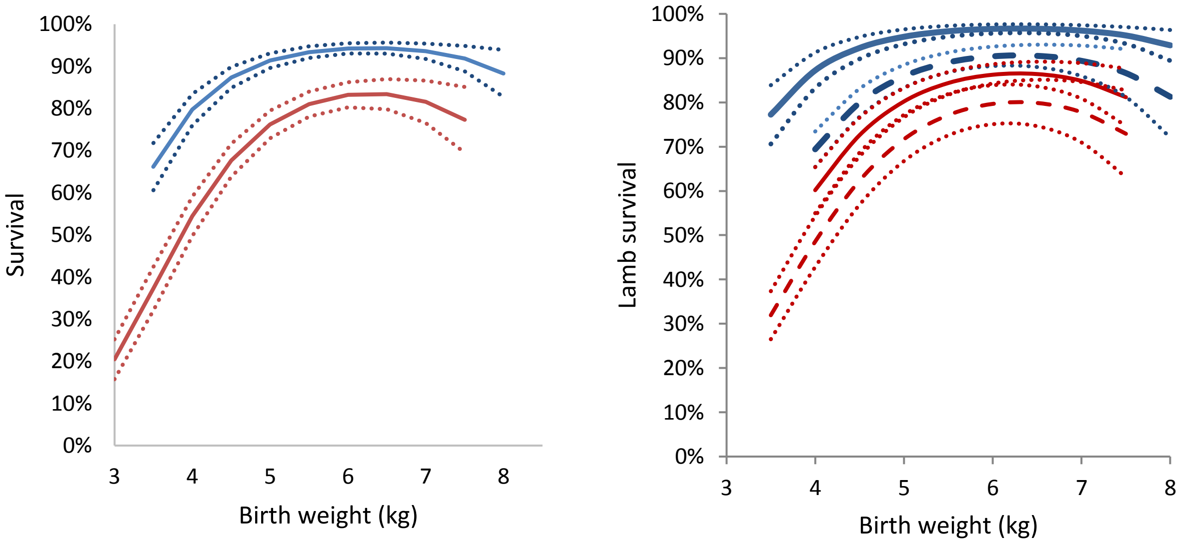

Figure 3. Predicted relationship between birth weight and survival of lambs from (a) BLM (blue) and Merino (red) dams, that were (b) single (solid lines) or multiple (dashed lines) born. Dotted lines are standard errors of the mean.

Liveweight at conception and liveweight change in both early and late gestation all had a significant effect on weaning weight (P<0.01). When both breeds were included in the analysis, a 10kg increase in ewe liveweight at conception resulted in 2.3±0.34kg increase in weaning weight, while a 10 kg increase in liveweight during early pregnancy was associated with a 2.4±0.66kg increase in weaning weight and a 10 kg increase in liveweight in late pregnancy resulted in 1.6±0.76kg increase in weaning weight. Multiple born lambs were 3.3±0.76kg lighter than single lambs (P<0.001) and males were 0.9±0.32kg heavier than female lambs at weaning (P<0.001). Lambs from BLM ewes were 5.4±0.51kg heavier at weaning than lambs from Merino ewes (P<0.001). Lambs from 5 year old ewes were 1.6±0.72kg lighter at weaning than lambs from 3 and 4 year old ewes (P<0.001), and lambs from Phase 2 ewes were 1.6±0.46kg lighter at weaning than the earlier born lambs from Phase 1 ewes. There was a significant interaction between Early LWC and breed (P<0.05) with weaning weight of lambs from BLM ewes being 0.14±0.079kg less sensitive to liveweight change compared to Merino ewes. Data was analysed by breed to derive coefficients for both breeds (Table 8).

Table 8. Fixed effect solutions and the standard errors (SE) that predict weaning weight (kg) from ewe liveweight at joining (Day 0; kg), maternal liveweight change from Day 0 to Day 100 (Early LWC) and Day 100 to lambing (Late LWC) and lamb sex and birth type.

	BLM ewes			Merino ewes		
Effect	Estimate	S.E.D.	Prob	Estimate	S.E.D.	Prob
Constant	17.5	2.39	<0.01	14.4	2.98	<0.05
Day0	0.24	0.042	<0.001	0.21	0.056	<0.001
Early LWC	0.13	0.061	<0.01	0.20	0.075	<0.01
Late LWC	0.09	0.066	n.s.	0.13	0.082	<0.05
Birth type - Multiple	-6.8	0.49	<0.001	-3.0	0.76	<0.001
Sex - Female	-0.9	0.43	<0.01	-0.7	0.48	0.05
Dam Age – 5 y.o.	-1.2	0.83	<0.05	ns		
Conception cycle – 2nd	-1.7	0.62	<0.001	-1.9	0.64	<0.001

*The weaning weight constant is for single born, male progeny from 3yo dams conceived in the first oestrus cycle.

Discussion

Breed differences in ewe performance

The target condition score treatments created a range of liveweights and condition scores across both the BLM and Merino ewes which were sufficient to generate a robust evaluation of the relationship between liveweight change of the two dam types on lamb production. Overall BLM ewes gained more conceptus free liveweight and achieved higher condition score more often than the Merino ewes, despite being managed in the same plots. The Merino ewes in the target CS3.6 treatment had the same conceptus free liveweight and condition score as the BLM ewes in the target CS3.2 treatment and the BLM ewes in the lowest CS treatment had the same condition score and liveweight as the Merino ewes in the intermediate treatments. This supports the outcomes from a review which concluded that non-Merino ewes have improved production outcomes compared to Merino ewes when managed under identical production conditions (Babiszewski and Hocking Edwards 2013). However, recent analyses of a large Australian dataset with BLM and Merino ewes managed together across seven environments and three ages of ewes did not find any consistent pattern of liveweight change over time between BLM and Merino ewes (Paganoni *et al.* 2014; Blumer *et al.* 2016). Nevertheless, the BLM ewes were consistently heavier than Merino ewes and the overall pattern was that BLM ewes lost less and gained more weight than Merino ewes (Blumer *et al.* 2016) despite significant variation among sites, years and ages for liveweight loss and gain. Increased liveweight and condition score in the BLM ewes could be due to greater appetite and feed intake or due to the efficiency of feed utilisation. However, the reason for the difference cannot be determined in the current experiment as feed intake was not measured for each breed.

Factors affecting lamb birth weight and weaning weight

Previous work has evaluated pure Merino lambs to estimate coefficients for the effect of ewe liveweight change on birth weight, weaning weight and their relationship with survival (Oldham *et al.* 2011; Thompson *et al.* 2011). Nevertheless, the current work with first cross lambs from Merino ewes mated to Poll Dorset rams has produced coefficients for liveweight at mating and in late pregnancy consistent with those reported previously for pure Merino lambs as well as those reported for mixed breeds (Paganoni *et al.* 2014). Ewe liveweight at joining had an impact on lamb birth weight, such that a 10 kg increase in both Merino and BLM ewe liveweight at joining resulted in a 350-370g increase in birth weight of their lambs. This is of a similar magnitude to that reported for Merino ewes (Oldham *et al.* 2011; Paganoni *et al.* 2014), although (Paganoni *et al.* 2014) reported a smaller effect of mating weight on birth weight (0.24kg birth weight/10kg joining weight) for BLM ewes and (Fogarty *et al.* 1992) calculated a coefficient of 0.2 for the combined analysis of BLM and Merino x Dorset crosses. Similarly, the coefficients that relate liveweight change in late pregnancy to lamb birth weight are similar across ewe types; for a 10 kg change in ewe liveweight in late pregnancy the associated change in birth weight was 390g for BLM lambs and 550g for lambs from Merino ewes in the present study, 670g for lambs from BLM and Merino Dorset cross ewes (Fogarty *et al.* 1992), 450-480g for Merino born lambs (Oldham *et al.* 2011) and 340g for lambs from four ewe types (Paganoni *et al.* 2014). Indeed, a systematic review of the literature concluded that maternal undernutrition in the last third of pregnancy consistently impairs lamb birth weights (Rooke *et al.* 2015). Thus the coefficients used in economic modelling (Young *et al.* 2011) to predict birth weight and from ewe mating weight (0.027) and liveweight change in late pregnancy (0.045) are likely to adequately predict birth weight of lambs in non-Merino production systems.

A similar pattern to birth weight was evident in the relationship between lamb weaning weight and ewe liveweight at mating and during late gestation. The coefficients for mating weight and Late LWC in the present study are similar to that reported by others for Merinos (Day 0 = 0.16-0.17 and $LWC_{100\text{-}L}$ = 0.10-0.13; (Thompson *et al.* 2011)) and four ewe*sire breed combinations (Day 0 = 0.24 and $LWC_{90\text{-}140}$ = 0.09; (Paganoni *et al.* 2014)). The effect of Early LWC in Merinos on the weaning weight of their lambs was in a similar range to that reported by others ($LWC_{0\text{-}100}$ = 0.19-0.23; (Thompson *et al.* 2011) and ($LWC_{0\text{-}90}$ = 0.26; (Paganoni *et al.* 2014)) providing further support to the conclusion that the effect of nutrition and liveweight change during early pregnancy in Merinos is more important than previously considered (Paganoni *et al.* 2014).

The coefficients that relate BLM ewe liveweight change in early pregnancy to the birth weight of their lambs were different to the coefficients that relate Merino ewe liveweight to their lambs birth weight and weaning weight (Table 5 & 8). During this period, birth weight and weaning weight of lambs from BLM ewes was less responsive to changes in liveweight of their dams than lambs from Merino ewes. Indeed, liveweight change between mating and Day 100 of gestation was not a significant covariate for birth weight of lambs from BLM ewes and weaning weight increased by 130g whereas birth and weaning weights of lambs from Merino dams changed by 480g and 200g, respectively, with a 10kg change in liveweight between conception and Day 100 of gestation. Overall, the responses are within the range of that reported by others where a 10kg change in Merino ewe liveweight in early pregnancy resulted in 320-330g (Oldham *et al.* 2011), 210g (Paganoni *et al.* 2014) and 610g (Fogarty *et al.* 1992) change in birth weight in the lambs and a 190-230g change in weaning weight (Thompson *et al.* 2011). In general, the response of birth weight to undernutrition from conception to Day 100 of gestation is more variable than the response to undernutrition in late pregnancy (Rooke *et al.* 2015). This indicates that ewe management guidelines based on Merino ewe data may be over-estimating the impact ewe liveweight change during early pregnancy has on lamb birth weight in non-Merino production systems. Indeed, the reduced effect of Early LWC in the BLM ewes on lamb birth weight and weaning weight, potentially contradicts the conclusion that liveweight change in early pregnancy may be especially important in meat orientated systems (Paganoni *et al.* 2014). This discrepancy applies to both single and multiple born lambs from BLM ewes and requires further investigation across different lamb production systems.

Females were 0.3kg lighter than male lambs from both Merino and BLM ewes and multiple lambs born to Merino ewes were 1.2kg lighter than single lambs born to Merino ewes, which is similar to that reported by others (Oldham *et al.* 2011; Paganoni *et al.* 2014). However multiple born lambs to BLM ewes were 1.6kg lighter than single born lambs which was greater than the difference in birth weights between single and multiple born lambs to Merino ewes. This suggests that scanning for multiple lambs in non-Merino enterprises and the management of ewe liveweight of multiple-bearing ewes differentially to single-bearing ewes will be even more critical than it is in Merino enterprises (Hocking Edwards *et al.* 2011; Young *et al.* 2016).

Survival

More lambs survived to marking from BLM ewes compared to Merino ewes, and there was a higher survival rate in females compared to males and single born lambs compared to multiple born lambs which is generally consistent with reports of others (Holst *et al.* 2002; Geenty *et al.* 2014; Paganoni *et al.* 2014; Allworth *et al.* 2016). Lamb survival based on scanning rates was lower than observed survival due to the inability to allocate a dead lamb to a ewe if the ewe was not in the vicinity of the lamb, despite daily lambing rounds. This was a particular problem in multiple Merino lambs in the CS2.5 treatment where there is an apparent survival rate of 69%, compared to 33% survival when scanning data was used to estimate expected number of lambs. Although a decrease in conceptus free liveweight and low rates of liveweight gain in ewe lambs are associated with fetal loss (Ridler *et al.* 2015; Ridler *et al.* 2017), the 2.8% foetal loss between scanning and birth in the current experiment is unlikely to be the cause of the anomaly in the CS 2.5 multiple-bearing Merino ewes as overall fetal losses from scanning to parturition are generally less than 2% in Merino ewes (reviewed by (Kleemann and Walker 2005) and about 3% across multiple breed types (Geenty *et al.* 2014). Rather, the difference is due to the inability to allocate dead lambs to ewes and the Merino ewes in the low CS treatment tended not to remain with their lambs after birth. The ewes appeared to abandon their lambs after the lambs death as there was not a large incidence of live lambs without mothers.

There was no effect of CS treatment on survival of single born lambs from BLM ewes which had a survival rate of 88-90% despite a 0.8 range in condition score across the treatments, indicating that condition score of BLM ewes is unlikely to impact lamb survival of single born lambs. Indeed, the birth weight and survival curve of single lambs from BLM ewes was flat and more than 87% of single born lambs survived, as the majority of lambs attained the critical birth weight of between 4 to 8 kg for survival (Casellas *et al.* 2007; Hatcher *et al.* 2009; Geenty *et al.* 2014). This suggests that use of ewe liveweight manipulation during pregnancy is unlikely to have an impact on survival of single born lambs from BLM ewes. This needs to be considered in economic modelling of target condition score profiles of non-Merino ewes. There is potentially an increased risk of dystocia in heavy single lambs (Holst *et al.* 2002; Refshauge *et al.* 2016) but this was not evident in the current work.

The survival of single and multiple-born lambs from Merino ewes was greater in the high CS treatment compared to the low CS treatments and there was 17% range in survival of multiple-born lambs from BLM ewes across the extreme CS treatments which generated 0.9CS difference, although the difference in survival was not significant for live lambs per 100 foetuses scanned ($P<0.1$). This variation is similar to that observed in the Merino progeny. It is thus concluded that the relationship between birth weight and survival mediated through condition score variation is the same for lambs from BLM ewes and Merino ewes. It is likely to be economical to manipulate condition score in multiple bearing non-Merino ewes particularly at joining and in late pregnancy to improve lamb survival in a similar fashion as recommended for Merino ewes (Young *et al.* 2011). However, robust prediction equations for non-Merino ewes need to be developed.

Conclusion

When managed under the same conditions, BLM ewes were heavier and had a higher condition score than Merino ewes. Thus the hypothesis that there is a difference between condition score and liveweight profiles of Merino and non-Merino ewes during gestation when managed together to achieve different condition scores at lambing was supported. Therefore, further research is required to understand why non-Merino ewes have improved liveweight and condition score compared to Merino ewes when managed in the same environment.

The second hypothesis, that the prediction equations for birth weight and survival of lambs using liveweight and condition score profiles during gestation are the same for Merino and non-Merino ewes, was partially supported. The coefficients developed in Merino production systems relating birth weight to joining weight and liveweight change during late gestation and the relationship between birthweight and survival are sufficiently accurate to describe lamb birth weight and survival in systems based on a non-Merino ewe base, particularly for multiple-bearing ewes. However, there was no relationship between birth weight and liveweight change early in pregnancy. More accurate coefficients need to be generated across production systems focussed on non-Merino genotypes that explain the relationship between ewe nutrition and ewe and lamb performance in order to inform economic modelling.

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References

Allworth, MB, Wrigley, HA, Cowling, A (2016) Fetal and lamb losses from pregnancy scanning to lamb marking in commerical sheep flocks in southern New South Wales. *Animal Production Science* https://doi.org/10.1071/AN16166,

Anon (2015) Ewes for the future - lambs, wool and profit. Final Report, Elmore & Districts Machinery Field Days Inc.

Babiszewski, E, Hocking Edwards, JE (2013) Potential industry impact: management of non-Merino ewes. No. Final Report B.LSM.0039, Meat and Livestock Australia Ltd, North Sydney. Available at http://www.mla.com.au/research-and-development/search-rd-reports/final-report-details/Productivity-On-Farm/Potential-Industry-Impact-Management-of-non-Merino-ewes/334.

Behrendt, R, van Burgel, AJ, Bailey, A, Barber, P, Curnow, M, Gordon, DJ, Hocking Edwards, JE, Oldham, CM, Thompson, AN (2011) On-farm paddock-scale comparisons across southern Australia confirm that increasing the nutrition of Merino ewes improves their production and the lifetime performance of their progeny. *Animal Production Science* **51**, 805-812.

Blumer, SE, Gardner, GE, Ferguson, MB, Thompson, AN (2016) Environmental and genetic factors influence the liveweight of adult Merino and Border Leicester × Merino ewes across multiple sites and years. *Animal Production Science* **56**, 775-788.

Casellas, J, Caja, G, Such, X, Piedrafita, J (2007) Survival analysis from birth to slaughter of Ripollesa lambs under semi-intensive management. *Journal of Animal Science* **85**, 512-517.

Curtis, KMS (2014) Stocktake of the Australian sheep flock. Meat & Livestock Australia Ltd, North Sydney No. Final Report BLSM.0055.

Ferguson, MB, Thompson, AN, Gordon, DJ, Hyder, MW, Kearney, GA, Oldham, CM, Paganoni, BL (2011) The wool production and reproduction of Merino ewes can be predicted from changes in liveweight during pregnancy and lactation. *Animal Production Science* **51**, 763-775.

Fogarty, NM, Hall, DG, Holst, PJ (1992) The effect of nutrition in mid pregnancy and ewe liveweight change on birth weight and management for lamb survival in highly fecund ewes. . *Australia Journal of Experimental Agriculture* **32**, 1-10.

Geenty, KG, Brien, FD, Hinch, GN, Dobos, RC, Refshauge, G, McCaskill, M, Ball, AJ, Behrendt, R, Gore, KP, Savage, DB, Harden, S, Hocking Edwards, JE, Hart, K, van der Werf, JHJ (2014) Reproductive performance in the Sheep CRC Information Nucleus using artificial insemination across different sheep-production environments in southern Australia. *Animal Production Science* **54**, 715-726.

Hatcher, S, Atkins, KD, Safari, E (2009) Phenotypic aspects of lamb survival in Australian Merino sheep. *Journal of Animal Science* **87**, 2781-2790.

Hocking Edwards, JE, Copping, KJ, Thompson, AN (2011) Managing the nutrition of twin-bearing ewes during pregnancy using Lifetimewool recommendations increases production of twin lambs. *Animal Production Science* **51**, 813-820.

Holst, PJ, Fogarty, NM, Stanley, DF (2002) Birth weights, meningeal lesions, and survival of diverse genotypes of lambs from Merino and crossbred ewes *Australian Journal of Agricultural Research* **53**, 175-181.

Kleemann, DO, Walker, SK (2005) Fertility in South Australian commercial Merino flocks: sources of reproductive wastage. *Theriogenology* **63**, 2075-2088.

Oldham, CM, Thompson, AN, Ferguson, MB, Gordon, DJ, Kearney, GA, Paganoni, BL (2011) The birthweight and survival of Merino lambs can be predicted from the profile of liveweight change of their mothers during pregnancy. *Animal Production Science* **51**, 776-783.

Paganoni, BL, Ferguson, MB, Kearney, GA, Thompson, AN (2014) Increasing weight gain during pregnancy results in similar increases in lamb birthweights and weaning weights in Merino and non-Merino ewes regardless of sire type. *Animal Production Science* **54**, 727-735.

Refshauge, G, Brien, FD, Hinch, GN, van de Ven, R (2016) Neonatal lamb mortality: factors associated with the death of Australian lambs. *Animal Production Science* **56**, 726-735.

Ridler, AL, Corner-Thomas, R, Kenyon, PR, Griffiths, KJ (2017) Investigation of fetal loss in ewe lambs in relation to liveweight changes and progesterone concentrations in early to mid gestation. *New Zealand Veterinary Journal* **65**, 34-38.

Ridler, AL, Vallee, E, Corner, RA, Kenyon, PR, Heuer, C (2015) Factors associated with fetal losses in ewe lambs on a New Zealand sheep farm. *New Zealand Veterinary Journal* **63**, 330-334.

Rooke, JA, Arnott, G, Dwyer, CM, Rutherford, KMD (2015) The importance of the gestation period for welfare of lambs: maternal stressors and lamb vigour and wellbeing. *The Journal of Agricultural Science* **153**, 497-519.

Russel, AJF, Doney, JM, Gunn, RG (1969) Subjective assessment of body fat in live sheep. *Journal of Agricultural Science* **72**, 451-454.

Tedeschi, LO, Cannas, A, Fox, DG (2010) A nutrition methematical model to account for dietary supply and requirements of energy and other nutrients for domesticated small ruminants: The development and evaluation of the Small Ruminant Nutrition System. *Small Ruminant Research* **89**, 174 - 184.

Thompson, AN, Ferguson, MB, Campbell, AJD, Gordon, DJ, Kearney, GA, Oldham, CM, Paganoni, BL (2011) Improving the nutrition of Merino ewes during pregnancy and lactation increases weaning weight and survival of progeny but does not affect their mature size. *Animal Production Science* **51**, 784-793.

Trompf, JP, Gordon, DJ, Behrendt, R, Curnow, M, Kildey, LC, Thompson, AN (2011) Participation in Lifetime Ewe Management results in changes in stocking rate, ewe management and reproductive performance on commercial farms. *Animal Production Science* **51**, 866-872.

Wheeler, JL, Reardon, TF, Hedges, DA, Rocks, RL (1971) The contribution of the conceptus to weight change in pregnant Merino ewes at pasture. *Journal of Agricultural Science* **76**, 347-353.

Young, JM, Behrendt, R, Curnow, M, Oldham, CM, Thompson, AN (2016) Economic value of pregnancy scanning and optimum nutritional management of dry, single- and twin-bearing Merino ewes. *Animal Production Science* **56**, 669-678.

Young, JM, Thompson, AN, Curnow, M, Oldham, CM (2011) Whole-farm profit and the optimum maternal liveweight profile of Merino ewe flocks lambing in winter and spring are influenced by the effects of ewe nutrition on the progeny's survival and lifetime wool production. *Animal Production Science* **51**, 821-833.

Young, JM, Trompf, J, Thompson, AN (2014) The critical control points for increasing reproductive performance can be used to inform research priorities. *Animal Production Science* **54**, 645-655.

13.3 Appendix 3 – Effects of ewe condition score at lambing on performance of non-Merino ewes (Experiment 2).

Reducing maternal nutrition of non-Merino ewes from mid-pregnancy to the end of lambing results in predictable decreases in birth weight and weaning weight.

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Abstract

Management of nutrition during pregnancy for maternal non-Merino ewes has the potential to improve lamb production and survival in prime lamb production systems but existing condition score guidelines developed for Merinos may not be the optimum. Four replicated experiments were conducted at research sites in Victoria (Pigeon Ponds and Hamilton) and Western Australia (Mount Barker). Ewes (770-792 per site) were allocated to 4 condition score (CS) treatments following pregnancy scanning (~day 50) to reach approximately CS 2.4, 2.8, 3.2 and 3.6 at lambing. Nutritional treatments were applied until the end of lambing after which ewes and lambs were aggregated into single management groups containing all treatments. Ewes achieved a range in maternal ewe live weight and condition score at lambing between treatments of 13.7 to 19.1 kg (average 16.4 kg) and 1.1 to 1.5 of a condition score (average 1.24). On an individual site basis, lower CS treatments resulted in significantly lower birth weight for all lambs at all 3 experimental sites. Birth weight results were reflected in significant differences in weaning weight for two out of the three sites. Single lamb survival to weaning was reduced by the highest CS treatment at one of the sites and twin lamb survival was improved in 2 of the 3 sites with increasing CS during pregnancy. Across site analysis, showed a decrease in survival of singles at the highest CS treatment and an improvement in survival of multiple born lambs with increasing CS at lambing. Across

site analysis also confirmed increasing birth weight and weaning weight with increasing CS at lambing. Linear modelling of the results for each site showed consistent significant effects of ewe joining liveweight, ewe liveweight change to day 90 and ewe liveweight change day 90 to lambing on birth weight and weaning weight. Birth weight was significantly related to survival at all sites with little effect of birth type on survival and effects of sex at only one site. This result suggests survival of lambs in maternal ewes is largely driven by birth weight rather than innate differences of being born single or multiple and/or being male or female.

Introduction

The impact of nutrition in the ewe before joining or during pregnancy and lactation is known to effect ewe reproduction (Robinson *et al*. 2006; Ferguson *et al*. 2011) and productivity (Masters *et al.* 1993; Ferguson *et al.* 2011) and lamb birth weight and survival (Scales *et al*. 1986, Knight *et al.* 1988; Oldham *et al.* 2011; Behrendt *et al.* 2011). Management guidelines tailored to manage the nutrition of the pregnant Merino ewe on Australian farms have improved enterprise productivity, whilst improving welfare outcomes for sheep. For example, participants in the Lifetime Ewe Management program increased stocking rate by 14%, increased lamb marking percentages by 11% and decreased ewe mortality by 43% by adopting best practice management of their ewes (Trompf *et al*. 2011). About 20% of the estimated 2500 sheep producers that have participated in this program have managed non-Merino ewes and they have achieved similar gains in productivity. Nevertheless, it cannot be inferred that adoption of the guidelines developed for Merinos will optimise the performance of non-Merino ewes on Australian farms. A significant proportion of Australian lamb production is from non-Merino ewes and it is well recognised that the value of improving the number of lambs weaned is much greater for maternal than Merino ewes (Young *et al*. 2013). Based on survey data (Curtis 2009a; Martin and Phillips 2011), approximately 3.8 million non-Merino ewes were mated in 2009/10, representing 16% of ewes mated, to produce 3.7 million lambs for slaughter. Thus, approximately 20% of lambs slaughtered are produced from non-Merino mothers, so further increases in reproduction efficiency, profitability and lamb supply would be expected if nutritional requirements and condition score targets were tailored to non-Merino ewes.

An analysis of 18,000 records from the Sheep CRC Information Nucleus Flock has shown that the birth weight and weaning weights of single, twin or triple born or reared lambs can be predicted from the liveweight profile of non-Merino ewes (Paganoni *et al*. 2014). These birth and weaning weight responses to changes in ewe live weight profile during pregnancy did not differ significantly between Merino and non-Merino ewes, but the average birth and weaning weights were greater for non-Merino ewes and ewes mated to terminal sires. The responses also did not differ significantly from those published for Merinos by Oldham *et al.* (2011). However, as the ewes in the Sheep CRC Information Nucleus Flock were all managed to Lifetime wool guidelines and condition score (CS) targets (www.lifetimewool.com.au) there was a limited range in CS within these research sites (Paganoni *et al*. 2014) and the data was not based on flocks managed to different CS targets at lambing.

Paganoni *et al.* (2014) also established the relationships between birth weight and survival for different ewe and sire breed combinations used in the Sheep CRC Information Nucleus Flock. The birth weight versus survival responses were again similar to other reports in the literature, but the average birth weights and survival rates were very high, possibly reflecting the level of intervention and small paddock size at lambing. Survival rates declined below about 4.5 kg; however the average birth weights were 6.0 kg for singles, 4.9 kg for twins and 4.1 kg for triples resulting in survival rates to weaning of 93%, 88% and 71%, respectively. These levels of survival would appear to be greater than typical mortality levels reported for Australian flocks as reviewed by Hinch and Brien (2014). They also appear to be inconsistent with industry benchmarking of the average marking percentages of maternal non-Merino flocks in farm bench marking studies and industry survey data (e.g. Blackshaw and Ough 2015; Curtis 2009b). This same discrepancy between plot scale research and commercial enterprises occurred in Lifetime Wool (Oldham *et al*. 2011), so commercial scale validation sites were required to refine the responses relating live weight profile, birth weight and survival (Behrendt *et al.* 2011), to enable management guidelines to be developed for Merino ewes across multiple environments and production systems (Young *et al.* 2011).

Reviews by Greenwood *et al.* 2009; Kenyon and Blair 2014; Rooke *et al.* 2015 have shown that maternal under-nutrition, particularly in the last third of pregnancy, consistently reduces birth weight of lambs and this has consequences for lamb performance. However, the impact of under-nutrition in early to mid-pregnancy and the impact of nutrition above maintenance requirements appear to be more variable (see reviews by Kenyon and Blair 2014; Rooke *et al.* 2015). Given that non-Merino ewes in prime lamb production systems are managed to produce increased lamb per hectare, largely driven by both the number of ewes mated, live lambs produced by weaning and lamb liveweight at sale, productivity is likely to be sensitive to effects the on lamb survival, birth weight and weaning weight and thus differences in the impact of ewe nutrition during gestation between Merino and non-Merinos may have consequences for the optimum targets for ewe liveweight and CS during pregnancy.

This project conducted three field experiments across southern Australia with different lambing times and genotypes, using a combination of research farm and on commercial farm sites to test the hypothesis that the impact of ewe liveweight change during pregnancy had consistent and predictable effects on lamb birth weight and weaning weight, and that lamb birth weight would subsequently have consequences for lamb survival. A primary aim of the project was to provide similar data to that established in the Lifetime Wool project (Thompson *et al.* 2011) for maternal non-Merino ewes to enable prediction of birth weight responses due to liveweight change during pregnancy in non-merino ewes.

Methodology

All procedures involving animals within this group of experiments were conducted in accordance with the Australian Code for the Care and Use of Animals Used for Scientific Purposes, under approval of the Animal Ethics Committees of the four collaborating research institutions. The approval numbers for each site were R117 (Pigeon Ponds), R2647 (Mount Barker) and 2015-01(Hamilton) for the RIST, Murdoch University and Department of Economic Development, Jobs, Transport and Resources Animal Ethics Committees respectively.

Experimental Sites

The experiments were undertaken at three sites; near Hamilton and Pigeon Ponds, Victoria and Mount Barker, Western Australia. Each site was located in a temperate Mediterranean environment with a winter dominant rainfall pattern. Descriptive data for each research site is shown in Table 1 including the dominant pasture species used at each trial site, rainfall and growing season data.

Ewe Mating

Ewes were mated either naturally (for 5 to 6 weeks) or by artificial insemination (AI) to sires either individually or in syndicate groups as described in Table 2. Ewes were randomly allocated to sires or mating groups based on a stratification for liveweight and CS at joining. Ewes were then scanned at approximately day 50 of pregnancy to determine those ewes that were pregnant. All ewes pregnant to AI at Pigeon Ponds and all ewes assessed as being pregnant in the first 21 days for the Hamilton site were then used for allocation to the experiments at those sites. The same procedure was also used at the Mt Barker site but because insufficient ewes were scanned as pregnant in the first cycle, some second cycle scanned pregnant ewes were also used for the experiment at this site. Across sites these procedures generated 770 to 840 pregnant ewes per site for allocation to the CS treatments that were applied from pregnancy scanning onwards.

Table 1. Descriptive pasture and climatic data for each research site.

Site	Hamilton Victoria	Pigeon Ponds Victoria	Mount Barker Western Australia
Farm Type	Research Farm	Commercial Stud Farm	Commercial Stud Farm
Location (latitude and longitude)	37˚50´S, 142˚04´E	-37.18´S, 141.41´E	-34.38´S, 117.40´E
Altitude (m)	200	300	260
Long term Average Annual Rainfall (mm)	686	600	581
Rainfall in 2014 (mm)	475.6	500	495.6
Predominant Pasture Species	Perennial Ryegrass, Tall Fescue, Lucerne and subterranean Clover	Mixed Perennial Ryegrass, Phalaris, Annual grasses and subterranean clover	Mixed Perennial Ryegrass, Annual ryegrass, and subterranean clover
Typical Length of growing season	7-8 months	7-8 months	7-8 months
2014 Growing Season Length	6 months	6 months	7 months

Table 2. Description and numbers of ewes selected for initial mating in the experiments for each site.

Site	Hamilton, Victoria	Pigeon Ponds, Victoria	Mount Barker, Western Australia
Ewe Breed	Maternal Composite	Maternal Composite	Maternal Composite
Total number of ewes mated	1180	1000	1780
Method of Mating	Natural - individual sire groups	Artificial insemination	Natural - syndicate of sires
Number of Sires	24	2	25
Sire Breed	Maternal Composite	Poll Dorset	Maternal Composite
Date of Joining	14/03/2014	3/02/2014	31/01/2014
End of Joining	17/04/2014	6/02/2014	11/03/2014
Start of Lambing	*23/07/2014 (4/08/2014)	27/06/2014	3/07/2014
End of Lambing	01/09/2014	8/07/2014	4/08/2014

* First birth was premature on 23/07/2014. Actual births from 04/08/2014.

Sire selection

Maternal composite and terminal prime lamb sires were selected to meet the individual aims of the research farm or collaborating farms at each experimental site but represented a broad range in Australian Sheep Breeding Values (ASBVs) for all traits commonly used within the Australian sheep industry. Birthweight (BWT) and post-weaning weight (PWT) ASBVs ranged from +0.2kg to +0.5kg and +6.7 to +16.5kg. The sires selected across all sites represented a broad range of ASBVS for carcass traits with post-weaning fat (PFAT) ranging from -1.7 to 0.4mm and post-weaning eye muscle depth (PEMD) -0.8 to 3.7mm.

Reproductive rates

The total number of ewes mated across all sites ewes was 3960. Between 770 and 840 pregnant ewes were generated over the periods defined earlier which enabled between 66 and 77 pregnant ewes to be allocated to each of the two or three replicates of the four ewe condition score treatments at each site (Table 3). The reproductive rate of ewes allocated to each plot/paddock system varied with each research site between 128 to 170% and the incidence of triplets was low at all sites (less than 2%).

Design and allocation of treatments

For the Hamilton site a randomized block design with three replicates of four condition score treatments was used. For the Pigeon Ponds site, an unbalanced randomized block design was used with four condition score treatments replicated twice (allocated to 2 blocks of four plots that were classed as tablelands) while the 2.4 and 3.2 condition score treatments had an additional replicate which was applied to a block comprising of two plots of low lying and undulating aspect. For Mount Barker site, an unbalanced randomized block design was used with four condition score treatments replicated twice (allocated to 2 blocks of four plots that were blocked by exposure to the prevailing winds) while the 2.4 and 3.2 condition score treatments had an additional replicate which was applied to a block comprising of two plots which were the most protected of all plots to the prevailing winds.

Using the above designs the four gestational treatments were applied to either 3 or 2 replicate groups of scanned pregnant ewes at each of the four sites (Table 3). The pregnant ewes were allocated randomly to each treatment using stratification for ewe liveweight and condition score at joining and balancing treatments for parity and sire.

Treatments were applied following pregnancy scanning and were maintained until the end of lambing at which point ewes were aggregated into larger management groups based on their block/replicate structure. While there were slightly different CS targets at each site based on variation in the requirements of the different institutional animal ethics committees the target condition scores of approximately CS 2.4, 2.8, 3.2 and 3.6 at the end of lambing within the treatments applied around day 50 from the start of joining are what are used for descriptive purposes of the treatments throughout the remainder of the paper.

Table 3. Target condition score of ewes at lambing for the four research sites. The number of replicates of each treatment is given in brackets. The table also shows the total number of paddock/plot systems used in each experiment with the total numbers of ewes and their foetuses applied.

Target CS at lambing	Hamilton	Pigeon Ponds	Mount Barker
Treatment targets (and replication)			
Lowest	2.5 (3)	2.4 (3)	2.4 (3)
Med/low	3.0 (3)	2.8 (2)	2.8 (2)
Med/high	3.4 (3)	3.2 (3)	3.2 (3)
Highest	3.8 (3)	3.6 (2)	3.6 (2)
Number of plots and animals			
Total number of paddock/plot systems	12	10	10
Number of ewes allocated per replicate	66	77	75
Total number of ewes	792	770	750
Total number of foetuses scanned and applied	1348	1148	960
Mean reproductive rate of ewes applied to each system (foetuses scanned per ewe pregnant)	1.70	1.49	1.28

Ewe condition score management

The four gestation treatments were a change from their joining CS/allocation CS to the targets of CS 2.4, 2.8, 3.2 and 3.6 at lambing (~day 145). Management from joining to pregnancy scanning aimed to maintain ewe liveweight and CS. The different nutritional treatments were then applied around day 50 from the start of joining and maintained to end of lambing. The four treatments reflect four different liveweight and CS (Jefferies 1961, Russel et al. 1969, van Burgel *et al.* 2011) trajectories from joining and pregnancy scanning (~day 50) to lambing (~day 145). The liveweight trajectory was further defined as the reduction or increase in the conceptus free liveweight estimated using the equations of Wheeler *et al*. (1971).

The gestational condition score treatments were achieved at different sites using two main strategies to manipulate ewe nutrition. This involved restricting the feed on offer (FOO, kg dry matter /ha) or increasing the FOO that was provided to each flock of ewes and supplementing ewes with additional hay or grain as required to increase or decrease liveweight and CS. The FOO that was supplied to the ewes in each pasture paddock/plot was manipulated through various methods including set-stocking, rotational grazing, stocking rate, slower pasture rotations and/or pre-grazing of pastures with additional sheep when required. Table 4 describes the pastures, paddock systems and the grazing management and supplementation used to manipulate ewe nutrition at each experimental site. The CS treatment and replicate structure was maintained from around day 50 to the end of lambing after which ewes and lambs were aggregated into management groups based on the blocks/replicates that maintained the integrity of the experimental design but allowed for easier flock management at a commercial scale.

Pasture management and measurements

Feed on offer (FOO) was assessed using either a rising plate meter or visual estimates. Each method was calibrated by cutting 16 quadrats ranging from high to low levels of dry matter for each of the sown species at the experimental sites. Botanical composition was assessed visually and using botanical composition estimated with the dry-weight rank method (BOTANAL; t'Mannetje and Haydock 1963; Tothill *et al*. 1978). Toe cuts of samples were be sorted into green and dead. Sorted samples were dried at 60°C for 48 hours and percent dry matter calculated. Botanical composition and measurements by NIR of nutritive value were undertaken on an approximately bi-monthly basis during the experimental period, such that key times during the experiment mid-pregnancy, late-pregnancy, lambing and lambing to weaning were measured.

Ewe liveweight and condition score

Ewes were weighed and condition scored at approximately two to three weekly intervals during the study from pre-joining until weaning. Ewes were condition scored (Jefferies 1961, Russel et al. 1969, van Burgel *et al.* 2011) using a single experienced operator for each research site for the duration of the trial. Conceptus free ewe liveweight at day 90 and at lambing were calculated using the equations of Wheeler *et al.* (1971). Liveweight change between joining and day 90 and day 90 and lambing were calculated using conceptus free liveweights by subtracting the earlier measurements from the later measurement so that a liveweight loss over the period would be negative and liveweight gain over the period would be positive.

Table 4. Description of the paddock/plot systems, grazing management and supplementary feeding undertaken at each experimental site.

Site	Hamilton Victoria	Pigeon Ponds Victoria	Mount Barker Western Australia
Paddock/Plot System Structure	48 approximately 1ha paddocks blocked for topography and pasture type.	10 paddocks averaging 9.8ha (7.2-13.3ha) blocked for similar topography and shelter	10 average 10.5ha (9.0-13.2ha) paddocks blocked according to exposure to the prevailing winds.
Approximate Stocking Rate (allocated ewes only)	17.4 ewes/ha	8.3 ewes/ha	7.7 ewes/ha
Grazing Management	Rotational Grazing and pre-grazing	Set-stocking with additional stock added to manipulate FOO	Set-stocking with additional stock added to manipulate FOO
Grain Supplement	Barley: 12.9MJ ME/kg DM,11% crude protein	Oats: 11MJ ME/kg DM	Barley: 13.5 MJ ME/kg DM
Total amount of grain supplement			
CS 2.4	0.39 kg/head	4.8 kg/head	3.2 kg/head
CS 2.8	1.9 kg/head	9.1 kg/head	26.3 kg/head
CS 3.2	24.1 kg/head	21.6 kg/head	28.7 kg/head
CS 3.6	54.8 kg/head	39.5 kg/head	46.9 kg/head
Total amount of pasture hay supplement			
CS 2.4	5.8 kg/head		
CS 2.8	0.63 kg/head		
CS 3.2	0 kg/head		
CS 3.6	1.64 kg/head		

Lambing Management and Measurements

Across all sites ewes were set-stocked within their paddocks/plot systems for the duration of lambing. At the Hamilton site ewes were randomly allocated from within their replicates across the 4 plots (~1ha) within each paddock system, plus an additional 2 Tall Wheatgrass Hedgerow plots (~0.25ha). Ewes and lambs within each replicate were then aggregated after the last ewe gave birth and managed as either replicate cohorts or a single cohort to weaning. At the other two sites ewes and lambs were aggregated when more than 90% of ewes had lambed.

Measurements on ewes and lambs at lambing were derived from those used by the Sheep CRC as described by Brien et al. (2010). Across all sites lambing rounds were conducted daily and both live and dead lambs measured and collected. Lambs were individually tagged at birth, with the birth weight (BWT), lamb status (alive or dead), sex (male or female), type of birth (single, twin, triplet or higher order birth) and date of birth recorded.

The gestation length was calculated for the Pigeon Ponds site using date of lamb birth and the date of artificial insemination for the ewes. Gestation lengths below 130 days or above 170 were removed from the analysis as they were not probable.

Autopsies were undertaken at the Hamilton site to determine cause of death for all dead lambs as per the detailed methodology of Holst (2004). Any observed natural mismothering/adoption/stealing of lambs was not corrected. However, if ewes failed to return to the lamb during the conduct of measurement rounds, short term isolation (48 hours) of the ewe and lamb in a lambing ring to try to encourage ewe/lamb bonding was performed. These interventions were recorded as were all ewe and lamb deaths.

Post-lambing to weaning management

At or near the end of lambing, all differential nutritional management was ceased and all ewes were retained within their gestation management groups/replicates until weaning. These management groups of ewes and their lambs were then provided *ad libitum* access to the volunteer FOO arising for the growing season at all sites with the aim of maximising lamb growth rates from the end of lambing to weaning. The weight and CS of ewes and liveweight of lambs was measured at lamb marking and weaning.

Parasite management of ewes and lambs

Ewes were managed for worm burdens according to the management practices of each of the sites. In general this involved the collection of a bulk worm egg count (WEC) on a 3 to 6 week basis depending on seasonal conditions and the level of WEC detected at each sampling. All ewes or lambs were drenched once their WECs reached threshold levels for drenching based on veterinary advice. Ewes at all sites received a pre-lambing drench and vaccination. Other typical preventative animal health and husbandry practices were implemented according to farm practice at each site.

Statistical Analysis

The experimental unit for the study were the groups of ewes (and their scanned foetuses) assigned to each condition score treatment during pregnancy to the end of lambing. The study had 4 gestational treatments to the end of lambing applied to 2 or 3 replicates depending the experimental site.

Within Site Analysis - All data was initially analysed separately for each site using plot level means and subjecting them to the ANOVA or unbalanced ANOVA procedure to test for the effect of condition score treatment. Plot means for ewe liveweight and CS were calculated separately for all ewes, and those scanned as single or twin bearing ewes. Lamb data was examined by meaning data across all lambs born per plot. Lamb data was also analysed based on plot level means of single, twin and triplet birth type lambs or single and multiple birth type lambs, where the numbers of triplets were low.

For the Hamilton site the blocking structure was block/plot with the ANOVA procedure, while for the Pigeon Ponds and Mount Barker sites an unbalanced ANOVA was used, adjusted for block. Treatment means were compared using a least significant difference (LSD, p=0.05) for sites with a balanced design or the maximum LSD (p=0.05) for sites with an unbalanced design.

Across Site Analysis - The method of restricted maximum likelihood (REML) was used to examine the effect of site and CS treatment and their interaction on lamb birth weight, weaning percentage, marking weight and weaning weight. These analyses utilised plot mean data, as described above, from all experimental sites. The REML procedure was run fitting site, block and plot as random terms and experimental site as a fixed effect, CS treatment and an interaction term for site by treatment interaction was also tested. Where the interaction term was not significant it was dropped from the model to provide the final predicted means. Predicted means for the effect of CS treatment were then compared using predicted LSD (p=0.05) and the largest LSD (LSDmax) has been presented.

Within site individual animal analysis - The method of REML was used for individual analyses to fit progeny birth weight and weaning liveweight data. These analyses were used to examine the effects of ewe liveweight, ewe liveweight change, sires/sire group, birth type, rear type, lamb sex and their interactions. All possible models were examined to define statistical significance of these effects and interactions accepted at $P < 0.05$. The terms used for each analysis and site are provided in the sections below.

For the Hamilton site ewe liveweight at joining, ewe liveweight change at joining until Day 90 of pregnancy, ewe liveweight change from Day 90 of pregnancy until lambing, hedge lambing group, ewe age, birth type or rearing type and sex of progeny were fitted as fixed effects while block, plot, hedge plot, lamb date of birth and sire were fitted as random effects. For the Pigeon Ponds site ewe liveweight at joining, ewe liveweight change at joining until Day 90 of pregnancy, ewe liveweight change from Day 90 of pregnancy until lambing, ewe age, birth type or rearing type, sex of progeny and sire were fitted as fixed effects while block, plot and lamb date of birth were fitted as random effects. For Mount Barker ewe liveweight at joining, ewe liveweight change at joining until Day 90 of pregnancy, ewe liveweight change from Day 90 of pregnancy until lambing, birth type or rearing type, weaning group (for weaning weight only) and sex of progeny were fitted as fixed effects while block, plot and date of birth were fitted as random effects.

For each site estimates of lamb survival were assessed by fitting General Linear Mixed Models (GLMM; Genstat Committee 2008). The approach used a logit transformation and binomial distribution. For Hamilton using additive models, logits were predicted as a function of lamb birth weight (quadratic effect), ewe age, birth type and sex as fixed effects and block, plot and sire as random effects. For Pigeon Pond using additive models, logits were predicted as a function of lamb birth weight (quadratic effect), ewe age, sire, birth type and sex as fixed effects and block and plot as random effects. For Mount Barker using additive models, logits were predicted as a function of lamb birth weight (quadratic effect), birth type and sex as fixed effects and block and plot as random effects. All possible models were examined to define statistical significance of effects and interactions accepted at $P < 0.05$. All statistical analyses were performed using GENSTAT 17th edition (VSN International Ltd, Hemel, Hempstead, UK).

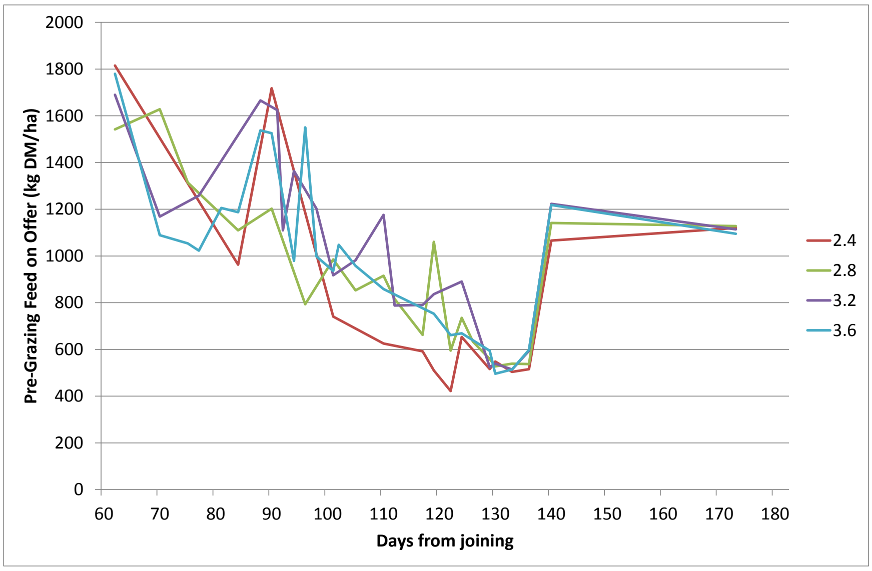
Results

Feed on offer and supplementary feeding

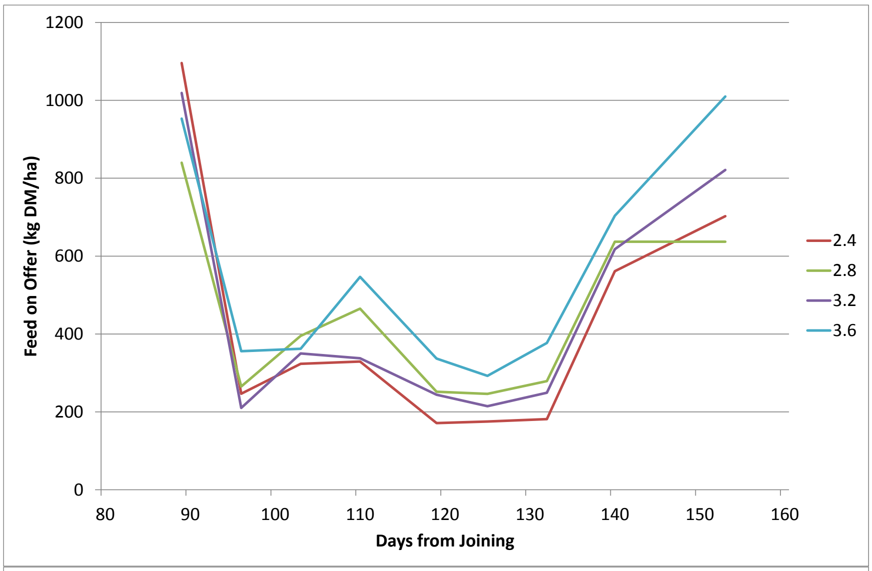
Average feed on offer provided to each treatment group at each experimental site from allocation post-pregnancy scanning to the end of lambing are shown in figure 1. In general terms, higher FOO was offered to the higher CS treatments and lower FOO to the low CS treatments across all sites. However, due to seasonal and paddock constraints these FOO levels were augmented with supplementary feeding at each site to meet the required CS and liveweight gain or loss targets. The FOO data shows that the levels of FOO required to achieve weight loss for the CS 2.4 treatment at all sites was very low, even in late pregnancy (<600 to 800 kg DM/ha).

For the Hamilton site, a portion of ewes from each replicate group had access to the Tall wheatgrass hedgerows at lambing and these plots contained an average FOO of 1602 kg DM/ha (range 1248 to 2370). There was no significant difference in the FOO in plots provided at lambing to any of the treatment groups within the hedgerows. However, the FOO provided in the open plots was lower compared to the hedgerows and on average the lowest CS 2.4 treatment plots had 167kgDM/ha less FOO than the highest CS plots (CS2.4 and 3.8).

Figure 1 The mean feed on offer (FOO, kg DM/ha) for the targeted condition score treatments (CS 2.4 red, 2.8 green, 3.2 purple and 3.6 blue line) from the allocation of ewes to plots to the end of lambing at the Hamilton (a), Pigeon Ponds (b) and Mount Barker (next page) (c) research sites (next page).



(a)



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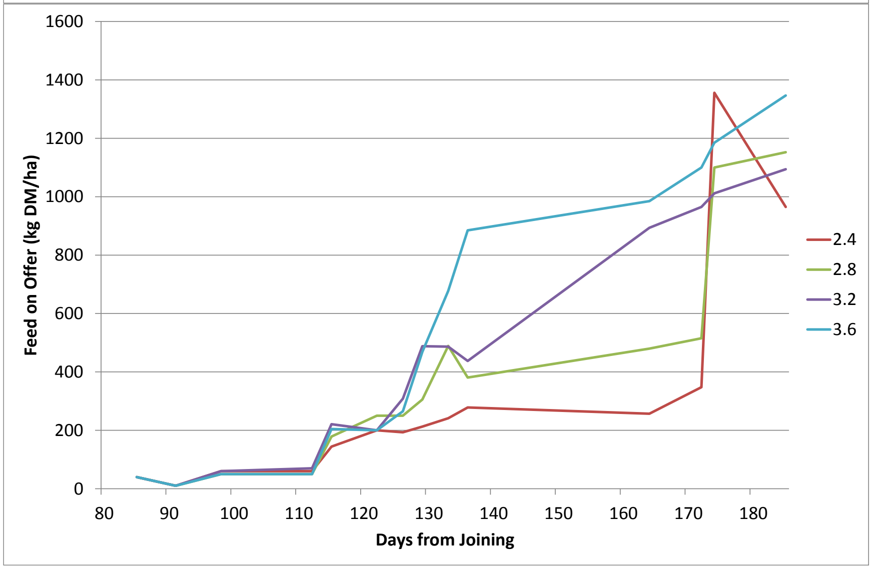


(c)

Ewe liveweight and condition score

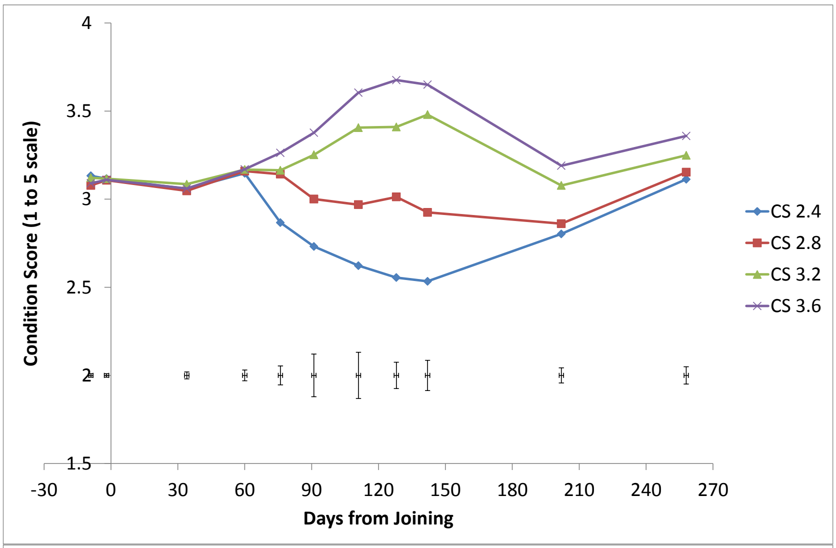
The profiles for the condition score and liveweight and of ewes from joining (~day 0) to weaning (~Day 240 to 260) achieved at the 3 research sites are presented in figure 2 and 3. As would be expected from the experimental design and methodology, condition score and liveweight at joining and allocation to treatments following pregnancy scanning were not significantly different (p>0.05). The CS and liveweight profiles presented demonstrate that the nutritional treatments were successfully imposed at all sites resulting in significant segregation of condition score and liveweight by lambing across all sites. At approximately day 90 the effect of nutritional treatment was either significant or close to significant for all sites.

The average live weight and condition score of maternal ewes at mating varied across sites from 57.8 to 71.7 kg and condition score 3.1 to 3.4. Nutritional treatments commenced between from between 60 and 80 days after the mating with the rams and all sites achieved a range in maternal ewe liveweight and condition score at lambing between extreme treatments of 13.7 to 19.1 kg (average 16.4 kg) in liveweight and 1.1 to 1.5 (average 1.24) in condition score. The average segregation in liveweight at Day 90 between the highest and lowest treatments was 4.2 to 8.1 kg (average 6.0 kg). For CS this difference ranged from 0.15 to 0.67 (average 0.44) of a CS at Day 90. In general, twin-bearing ewes were slightly lower for condition score at lambing than single bearing ewes and the separation in condition score profiles between treatments was slightly greater for twin than the single bearing ewes (data not shown).

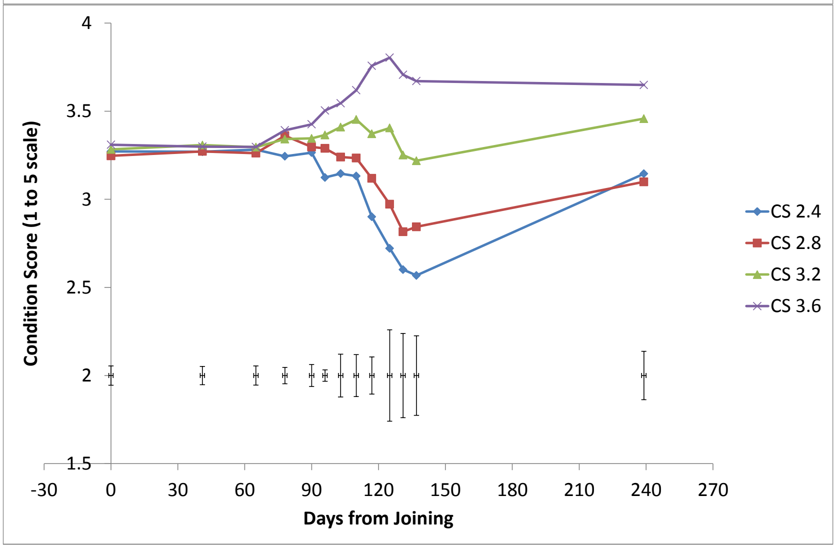
As expected the average values for liveweight adjusted for conceptus and the degree of separation between treatments reflected the raw liveweight values (Table 5). However, the conceptus adjusted data shows that the lowest CS treatment at the Hamilton, Pigeon Ponds and Mount Barker sites lost maternal liveweight (-3.9 to -8.8 kg) from day 0 to lambing. The average change was -7.1 kg across all sites. For the CS 2.8 treatment the average change in maternal weight was -2.1 kg (0.1 kg to -4.1 kg), whilst the CS 3.2 treatment resulted in an average increase in maternal liveweight of 3.8 kg (2.9 kg to 4.7 kg). The highest CS treatment increased maternal liveweight by an average 8.9 kg (7.7 to 10.3 kg).

Following lambing the CS 2.4 treatments increased liveweight and CS compared to their conceptus free liveweight estimates and CS prior to lambing. In contrast, the high CS treatments generally lost both liveweight and condition score from lambing to weaning (Figure 2 and 3). These changes resulted in a convergence of liveweight and CS between CS treatments by weaning even though there were still significant differences in both CS and liveweight between the treatments at weaning.

Figure 2 (next page). The mean condition score (CS) of ewes for the targeted condition score treatments (CS 2.4 blue, 2.8 red, 3.2 green and 3.6 purple line) from the allocation of ewes to plots to weaning at the Hamilton (a), Pigeon Ponds (b) and Mount Barker (c) research sites. Error bars indicate the LSD (5%) for the day of measurement.


4
3.5
3
2.5
2
1.5
Condition Score (1 to 5 scale)
-30
0
30
60
90
120
150
180
210
240
270
Days from Joining
CS 2.4
CS 2.8
CS 3.2
CS 3.6

(a)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Condition Score (1 to 5 scale)
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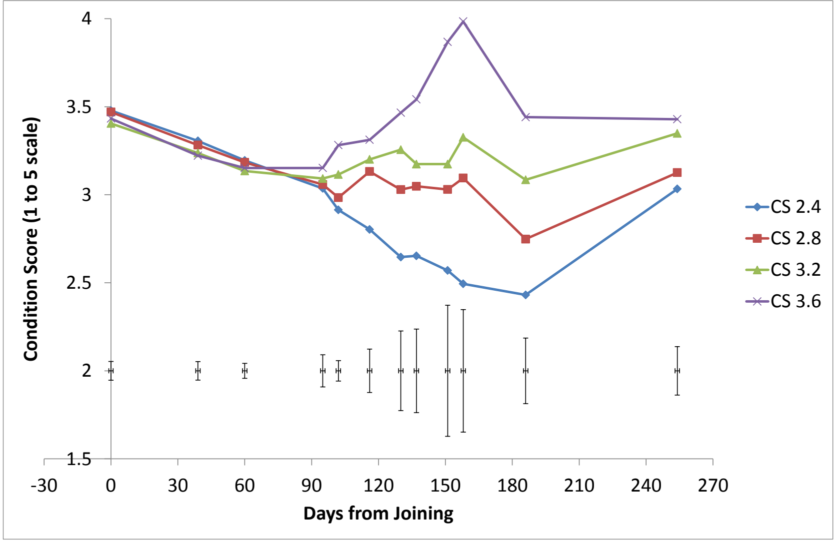
270
Days from Joining
CS 2.4
CS 2.8
CS 3.2
CS 3.6

(b)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Days from Joining
CS 2.4
CS 2.8
CS 3.2
CS 3.6

(c)

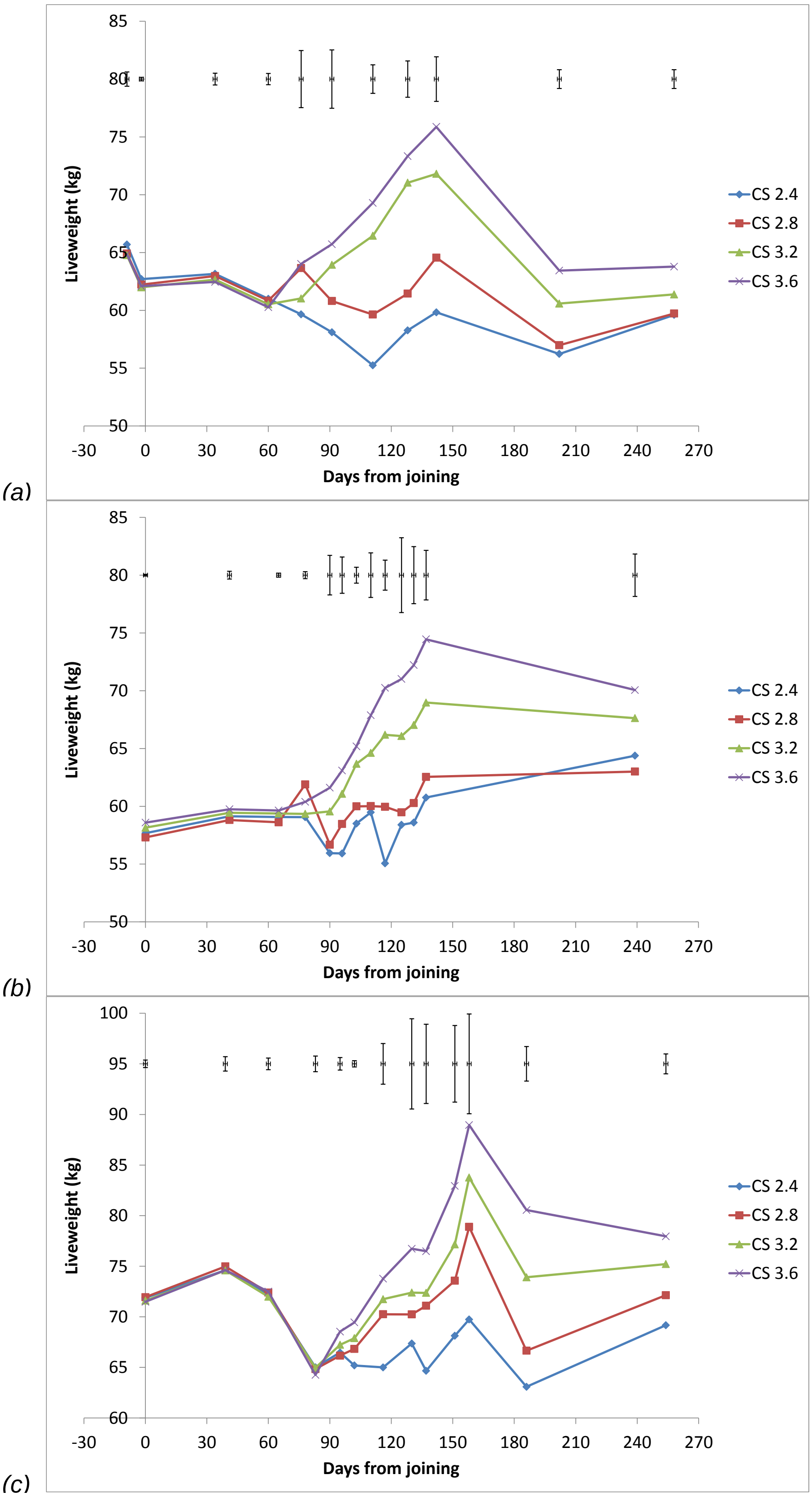

Figure 3. The mean liveweight of ewes for the targeted condition score treatments (CS 2.4 blue, 2.8 red, 3.2 green and 3.6 purple line) from the allocation of ewes to plots to weaning at the Hamilton (a), Pigeon Ponds (b) and Mount Barker (c) research sites. Error bars indicate the LSD (5%) for the day of weighing.

Table 5. The mean ewe live weight (corrected for conceptus; kg) for different nutritional treatments at approximately Day 90 and Day 140 at the three research sites.

	Day 90						Day 140					
Target CS at lambing	2.4	2.8	3.2	3.6	LSD max	P value	2.4	2.8	3.2	3.6	LSD max	P value
Hamilton	57.2	59.8	62.8	65.1	5.27	0.042	53.4	58.1	65.1	70.0	4.10	<.001
Pigeon Ponds	53.7	54.3	57.3	59.3	3.40	0.022	53.7	55.2	61.7	67.1	4.30	0.002
Mount Barker	64.0	65.4	66.5	68.1	0.96	0.001	63.1	71.8	76.4	81.9	8.58	0.011

Across site analysis of birthweight, survival, marking and weaning weight

Across all sites CS treatment had a significant effect on birth weight (P<0.001), lamb survival to marking (P=0.001), lamb weight at marking (P<0.001) and lamb weight at weaning (P<0.001) (Table 6). Birth weight was significantly increased by 0.67 kg (0.64 kg singles and 0.71 kg twins) when ewes were subjected to the highest CS treatment compared to the lowest CS treatment. This trend was also reflected in significant effects (p<0.001) on marking weight (2.3kg all lambs, 2.5kg singles, 2.6kg twins) and weaning weight (2 kg all lambs, 2.7 kg singles, 2.5 kg twins).

Survival to marking for all lambs was improved with increasing CS by 5.5% units from the CS 2.4 to CS 3.8 treatment. However, this trend was largely a function of the survival of twin born lambs which had a 11.1% unit improvement in survival. In contrast, single born lambs achieved similar survival when the CS target was 2.4, 2.8 and 3.2 but survival was reduced at the highest CS treatment (3.6) where there was 6.3% unit reduction in single lamb survival compared to the CS 3.2 treatment (p=0.069).

As expected there was a significant effect of research site (p<0.001, data not shown) on each measured weight trait when the data was analysed across sites for single and twin birth type lambs. Significant interactions between the research site and the CS treatment were also evident for birthweight in multiples (p=0.042), marking weight for singles (p=0.021) and multiples (p=0.049) and weaning weight (p=0.006) in single born lambs. However, the interaction term was not significant for birthweight in singles (p=0.638) or weaning weight in twins (p=0.299). There was no significant site by CS treatment interaction (p>0.05) for survival to marking in singles and twins. The interaction effect became significant where individual sites showed a larger effect due to CS on the measured trait. For example, the Hamilton site showed larger effects on marking weight and weaning weight in single born lambs. However, the level of significance of all the interaction terms was less than that of the main effects for CS treatment and site. In all instances, the mean values for individual sites also showed the same trend as the across site trend due to the condition score treatment.

Table 6. The mean lamb birth weight, survival to marking, marking weight and weaning weights of maternal non-Merino lambs for the main effect of four condition score treatment groups: CS2.4, CS2.8, CS3.2 and CS3.6 when analysed across sites.

	CS2.4	CS2.8	CS3.2	CS3.6	LSDmax	P value
			Birthweight (kg)			
All lambs	4.71	4.93	5.19	5.38	0.156	<0.001
Singles	5.51	5.85	6.08	6.15	0.326	0.001
Multiples	4.37	4.53	4.89	5.08	0.108	<0.001
			Survival to marking (%)			
All lambs	82.8	83.4	89.1	88.3	4.06	0.001
Singles	94.8	92.4	93.3	87.0	5.63	0.069
Multiples	78.1	80.0	87.8	89.2	5.53	<0.001
			Marking Weight (kg)			
All lambs	11.5	12.0	13.3	13.8	0.54	<0.001
Singles	13.8	14.5	16.4	16.3	0.79	<0.001
Multiples	10.3	10.9	12.3	12.9	0.60	<0.001
			Weaning Weight (kg)			
All lambs	28.8	29.3	30.7	30.8	0.76	<0.001
Singles	32.6	33.0	35.7	35.3	0.98	<0.001
Multiples	26.7	27.4	28.8	29.2	0.75	<0.001

Individual Sites Analysis

Lamb birth weight

Lamb birth weights increased with improving ewe nutrition during pregnancy and ewe condition score at lambing (Table 7). With the exception of single lambs at the Mount Barker site, the effect of ewe condition score treatment on birth weight was equally evident in single and twin born lambs. The average difference in birth weight between extreme nutritional treatments was 0.61 kg (range 0.5 to 0.7 kg) for single born lambs and 0.70 kg (range 0.44 to 0.85) for twin born lambs. The effects of ewe condition score on the birth weight of triplet born lambs from maternal ewes was also significant at the Hamilton site and evident at the Pigeon Ponds site (data not shown), but there were limited numbers of triplet born lambs across all sites for Pigeon Ponds and Mount Barker their data are included with the twin data. As expected, twin born lambs were about 1.1 kg lighter than single born lambs (4.8 *vs*. 5.9 kg) although this difference appeared to vary between sites.

Table 7. The mean lamb birth weights (kg) of maternal composite lambs for each of four condition score treatment groups: CS2.4, CS2.8, CS3.2 and CS3.6.

	CS2.4	CS2.8	CS3.2	CS3.6	LSDmax	P value
			Pigeon Ponds			
All lambs	4.76	4.80	5.10	5.21	0.124	P<0.001
Single	5.47	5.69	5.90	6.00	0.274	0.013
Multiple	4.31	4.24	4.71	4.75	0.131	P<0.001
			Hamilton			
All lambs	4.24	4.49	4.89	5.02	0.326	0.004
Single	5.38	5.43	6.13	6.04	0.645	0.056
Twin	4.02	4.29	4.67	4.87	0.285	0.001
Triplet	2.83	3.67	4.08	4.41	0.609	0.005
			Mount Barker			
All lambs	5.18	5.49	5.63	5.98	0.351	0.015
Single	5.68	6.20	6.26	6.32	0.793	0.190
Multiple	4.93	5.14	5.40	5.75	0.231	0.002

Gestation Length

The gestation length of ewes and lambs at the Pigeon Ponds site was shorter for the CS 3.2 and CS 3.6 treatments compared to the CS 2.4 and 2.8 treatments for single born lambs (Table 8). For the twin born lambs only the highest and lowest CS treatments were different.

Table 8. The mean gestation length of maternal composite ewes and their lambs for each of four condition score treatment groups at the Pigeon Ponds site: CS2.4, CS2.8, CS3.2 and CS3.6.

	CS2.4	CS2.8	CS3.2	CS3.6	LSDmax	P value
All lambs	148.4	148.1	147.6	147.0	0.706	0.013
Single	148.5	148.4	147.4	147.2	0.347	<0.001
Multiple	148.3	147.8	147.8	146.8	1.066	0.045

Lamb survival

Only the Hamilton site showed significant increasing trend in lamb survival over all lambs (Table 9). However, for this site the difference was largely driven by the survival of twins which was significantly reduced (22% units) by the lowest CS treatment compared to the highest treatment. Twin lamb survival increased linearly (P<0.01) with increasing ewe condition score at lambing at the Hamilton site. In contrast, the effect on single born lambs was not significant at this site with single lamb survival greater than 90% for all treatments. The Mount Barker site also showed a trend for improved weaning survival of multiple born lambs (p=0.061). The trends in twin lamb survival tended to be in the same direction for Pigeon Ponds site but the effects at this site were not significant. The overall survival of twin or multiple lambs was around 77% across all sites and there was an average 13% unit difference across the range of CS treatments. In contrast, single lamb survival was largely unaffected by the CS treatment with the overall survival of single born lambs from maternal ewes averaging around 92%. However, single lambs did have lower survival at the highest

CS treatment at the WA site and this trend was also evident at the Pigeon Ponds site (Table 9).

Table 9. The mean lamb survival to weaning of maternal composite lambs for each of four condition score treatment groups: CS2.4, CS2.8, CS3.2 and CS3.6.

	CS2.4	CS2.8	CS3.2	CS3.6	LSDmax	P value
			Pigeon Ponds			
All lambs	0.82	0.81	0.85	0.83	0.156	0.835
Singles	0.92	0.93	0.87	0.80	0.222	0.436
Multiples	0.76	0.74	0.85	0.84	0.213	0.403
			Hamilton			
All lambs	0.72	0.79	0.89	0.90	0.060	<0.001
Single	0.91	0.94	0.95	0.94	0.112	0.838
Twin	0.69	0.76	0.89	0.91	0.11	0.008
Triplet	0.41	0.55	0.71	0.80	0.447	0.229
			Mount Barker			
All lambs	0.86	0.84	0.89	0.89	0.533	0.218
Single	0.94	0.89	0.93	0.83	0.062	0.034
Multiple	0.83	0.82	0.87	0.91	0.070	0.061

Causes of Lamb Death

The causes of lamb death presented as percentage of all lambs born at the Hamilton site are presented Table 10 below. The data shows that the low CS treatments had greater percentages of dystocia (c) or hypoxia related deaths than the higher CS treatments. A similar trend in the percentage lambs dying due to starvation mismothering was not quite significant (p=0.094) but the lowest CS treatment had greater starvation and mismothering than the highest CS treatment (p<0.05).

Table 10. The number of lambs assessed in each death category as a percentage of all lambs born for each of the four condition score treatment groups: CS2.4, CS2.8, CS3.2 and CS3.6 at the Hamilton research site.

Death Category	**CS 2.4**	**CS 2.8**	**CS 3.2**	**CS 3.6**	**LSD (5%)**	**p-value**
Dystocia (a)	3.2% (1.021)	1.6% (0.733)	0.9% (0.537)	1.9% (0.785)	(0.5585)	0.303
Dystocia (b)	0.95% (0.56)	1.2% (0.63)	0.4% (0.36)	0.6% (0.43)	(0.849)	0.860
Dystocia (c)	6.2% (1.425)	5.8% (1.383)	0.7% (0.489)	0.7% (0.481)	(0.6265)	0.014
Infection	0.1% (0.186)	0.0% (0.000)	0.4% (0.359)	0.0% (0.000)	(0.5154)	0.348
Premature or dead in utero	0.6% (0.447)	1.4% (0.684)	0.00% (0.000)	0.6% (0.435)	(0.6354)	0.165
Primary Predation	0.4% (0.375)	0.1% (0.187)	0.2% (0.254)	0.4% (0.359)	(0.5246)	0.795
Starvation/Mismothering	9.1% (1.727)	4.1% (1.154)	4.1% (1.155)	2.8% (0.964)	(0.6189)	0.094

Undiagnosed	0.4% (0.375)	0.4% (0.369)	0.2% (0.253)	0.0% (0.000)	(0.4858)	0.294

**Percentages are back-transformed means for all lambs (singles and multiples). All LSD comparisons are made on the angular transformed data presented in brackets.*

Lamb birth weight in relation to survival

Lamb birth weight was strongly related to lamb survival ($p<0.001$) at all sites with a quadratic relationship being the form of the relationship at all sites (Figure 4, Table 11). The shape of the relationship and coefficients for birth weight and birthweight^2 were similar across sites. Another key feature of the analysis was that across all sites single and twin born lambs were equally likely to survive at the same birth weight. Birth type was close to significant for the Hamilton ($p=0.092$) site with the effect on survival of being a twin compared to single was equal to -0.9368 ± 0.3278, when birth type was included in the model. There was also no effect of sex at two of the three sites with only Mount Barker showing a significant effect of sex, where males had lower survival than females at the same birth weight.

At the Hamilton and Pigeon Ponds site a lamb survival of 90% or more was achieved when birth weight was greater than 4kg (Figure 4). This threshold increased to approximately 5 kg for the Mount Barker site. The mean birth weight of single born lambs was greater than these thresholds for all sites and thus survival for singles was generally high. However, all sites did tend to show a tipping point at higher birth weights of 7 to 8 kg and the confidence limit of the prediction was larger in this region. This indicates that there is some increased risk of mortality for heavier weight singles. The average birth weight for twin and multiple born lambs subjected to the lowest CS treatment was 4.0 kg, 4.3kg and 4.9 kg for the Hamilton, Pigeon Ponds and Mount Barker sites respectively (Table 7). Comparing these treatment means with the approximate thresholds for greater than 90% survival it can be seen that a significant population of lambs from the lowest CS treatment would be below the critical weights to optimise survival.

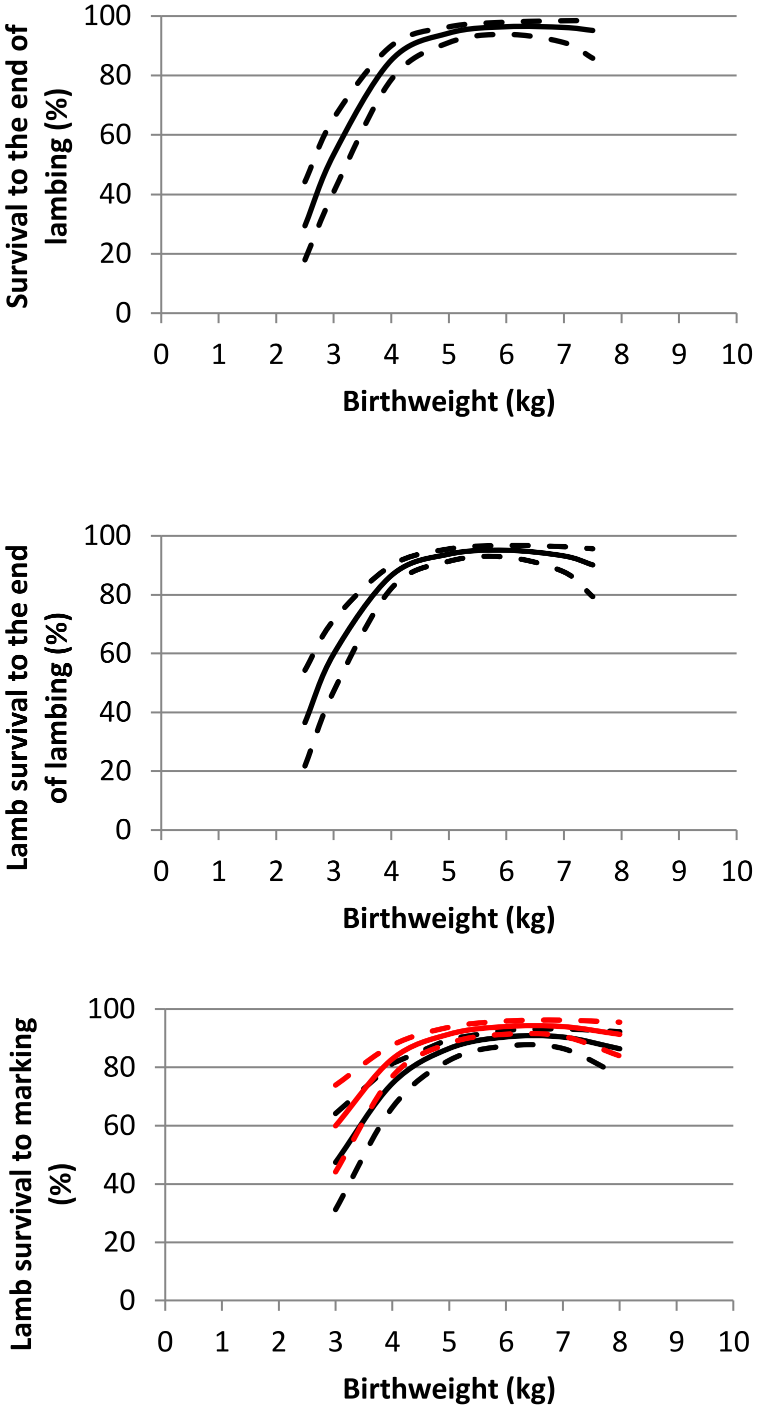

Figure 4. Effect of lamb birth weight on lamb survival to the end of lambing or marking from maternal non-Merino ewes at the Hamilton (top), Pigeon Ponds (middle), and Mount Barker (bottom) sites. The data is combined across birth types for all sites. The effect of sex at the Mount Barker site is indicated by the red line for females and black line for males. The dashed lines represent upper and lower 95% confidence limits.

Table 11. Lamb survival coefficients (±s.e.) of a generalized linear mixed model that predicts lamb survival to end of lambing or marking in terms of lamb birth weight (kg) effects (fixed) after adjustment for blocking effects (random).

		Hamilton	Pigeon Ponds	Mount Barker
Constant		-8.04 ± 1.2368	-7.57 ± 1.390	-5.99 ± 1.353
Birthweight (kg)	kg	3.565 ± 0.5446	3.56 ± 0.569	2.55 ± 0.478
Birthweight Squared (kg^2)	kg^2	-0.2795 ± 0.05896	-0.301 ± 0.0567	-0.197 ± 0.0419
Sex	Male			
	Female			0.507 ± 0.2089

[A] The survival constant is for male progeny.

Lamb growth during lactation

The effects of CS treatment on lamb marking and weaning weights and lamb growth rate from birth to marking and marking to weaning are shown in Tables 12, 13, 14 and 15. The Hamilton and Mount Barker sites both showed significant reductions in growth rate from birth to marking due to the lower CS treatments. Despite a similar trend the effects were not significant at Pigeon Ponds site. The effect was in the order of 25 to 55g/day across all lambs and sites when comparing the highest and lowest CS treatments. Together with the starting differences in birth weight between treatments these differences in growth rate result in differences in the order of 2.3 kg (1.4 kg to 3.23 kg) at marking between CS treatment extremes for all lambs. For single lambs the effect on marking weight was significant at Pigeon Ponds, Hamilton and Mount Barker, whilst for twins the difference was only significant at Mount Barker and Hamilton.

The growth rate from marking to weaning was largely unaffected by CS treatment with only the Hamilton site showing a significant effect for singles lambs of around 28 g/day between the low and high CS treatments. The differences observed in weaning weight were therefore a reflection of the marking weights with very little segregation occurring due to growth rates from marking to weaning. The Hamilton and Mount Barker site both showed significant reductions in weaning weight due to the lower CS treatments and despite a similar trend at Pigeon Ponds the effect at this site was not significant.

As expected the impact of single and twin birth types was highly significant on growth rate, marking and weaning weight. Twin born lambs on average grew 96 g/day slower from birth to marking but this difference was reduced to around 22 g/day from marking to weaning across all sites. Twin lambs were on average 3.6 kg lighter at marking and 5.9 kg lighter at weaning across all sites with some variation between sites.

Table 12. The mean growth rate (g/day) from birth to marking of maternal composite lambs for each of four condition score treatment groups: CS2.4, CS2.8, CS3.2 and CS3.6.

	CS2.4	CS2.8	CS3.2	CS3.6	LSDmax	P value
			Pigeon Ponds			
All lambs	281	273	314	306	94.8	0.557
Singles	358	346	388	367	56.8	0.276
Multiples	227	223	274	269	109.4	0.417
			Hamilton			
All lambs	207	218	254	259	12.5	<.001
Single	264	288	331	337	21.2	<.001
Twin	187	199	239	243	16.8	<.001
Triplet*	160	119	216	216	66.5	0.035
			Mount Barker			
All lambs	344	350	383	399	27.7	0.009
Single	389	404	437	441	71.9	0.196
Multiple	316	322	362	384	48.7	0.033

Table 13. The mean marking weights (kg) of maternal composite lambs for each of four condition score treatment groups: CS2.4, CS2.8, CS3.2 and CS3.6.

	CS2.4	CS2.8	CS3.2	CS3.6	LSDmax	P value
			Pigeon Ponds			
All lambs	9.9	10.0	11.1	11.3	1.91	0.190
Singles	11.9	12.0	13.4	13.1	0.85	0.011
Multiples	8.5	8.6	9.9	10.1	2.22	0.178
			Hamilton			
All lambs	13.9	14.7	17.0	17.2	0.73	<.001
Single	17.6	18.4	21.9	21.4	1.59	0.001
Twin	12.6	13.7	16.1	16.4	0.77	<.001
Triplet*	11.5	9.7	13.9	14.6	3.37	0.044
			Mount Barker			
All lambs	10.6	11.3	12.0	13.0	0.87	0.005
Single	12.1	13.1	14.0	14.5	1.86	0.060
Multiple	9.8	10.3	11.3	12.4	1.01	0.005

Table 14. The mean growth rate (g/day) from marking to weaning of maternal composite lambs for each of four condition score treatment groups: CS2.4, CS2.8, CS3.2 and CS3.6.

	CS2.4	CS2.8	CS3.2	CS3.6	LSDmax	P value
			Pigeon Ponds			
All lambs	297	300.	299.2	300	18.6	0.965
Singles	327	329	335.3	334	17.9	0.505
Multiples	276	279	281	281	16.7	0.788
			Hamilton			
All lambs	165	164	167	168	10.5	0.835
Single	180	186	203	207	11.8	0.003
Twin	159	159	158	160	11.1	0.969
Triplet	124	122	165	145	20.0	0.008
			Mount Barker			
All lambs	327	311	328	312	20.4	0.297
Single	294	288	295	282	10.7	0.381
Multiple	305	296	304	290	7.9	0.067

Table 15. The mean weaning weights (kg) of maternal composite lambs for each of four condition score treatment groups: CS2.4, CS2.8, CS3.2 and CS3.6.

	CS2.4	CS2.8	CS3.2	CS3.6	LSDmax	P value
			Pigeon Ponds			
All lambs	31.5	32.0	32.6	32.9	2.96	0.580
Singles	35.6	35.9	37.5	37.3	2.14	0.097
Multiples	28.5	28.9	30.1	30.4	3.13	0.296
			Hamilton			
All lambs	23.2	24.1	26.4	26.5	0.36	<.001
Single	27.7	28.8	33.3	33.0	1.43	<.001
Twin	21.6	22.7	24.9	25.3	0.69	<.001
Triplet	18.9	16.2	23.6	22.7	4.31	0.021
			Mount Barker			
All lambs	31.4	31.4	32.7	32.6	1.04	0.025
Single	34.5	34.2	36.3	35.6	2.67	0.223
Multiple	29.7	30.0	31.4	31.5	0.56	<0.001

Prediction of birth weight and weaning weight

The coefficients for ewe joining weight effects on birth weight were similar across the Pigeon Ponds and Hamilton sites (0.031 to 0.036) but was smaller for joining weight at Mount Barker (0.013) (Table 16). The coefficients for the effects of ewe liveweight change from joining to Day 90 on birth weight indicate that a 10 kg change in ewe liveweight would result in 0.25 to 0.43 kg difference in birth weight. The coefficients for liveweight change from day 90 to lambing were larger and a 10 kg change in ewe liveweight during this period would result in 0.32 to 0.58 kg difference in birth weight. There was a significant effect of sex with males being heavier across all sites and birth type also reduced lamb birth weight as expected. The effects of sex and birth type were similar in magnitude across sites. Ewe age also influenced the prediction at the Hamilton and Pigeon Ponds site, whilst sire had an effect and interaction effect with birth type at the Pigeon Ponds site.

The effects of joining weight and ewe liveweight change on the prediction of weaning weight reflected the prediction of birth weight with all three factors significant (Table 17). A 10 kg change in ewe liveweight from joining to Day 90 would result in 1.8 to 2.0 kg difference in weaning weight. In contrast the effect of 10 kg change in late pregnancy from day 90 to lambing would result in a 0.7 kg to 1.8 kg change in weaning weight. Joining weight also had a significant influence on weaning weight. Birth type and rear type effects on weaning weight were substantial ranging from -4.7kg to -8.4 kg for twin born and twin reared lambs. Male sex effects were also positive for weaning weight resulting increases of 0.9 to 2.1 kg compared to female counterparts. The age and birth year of the ewe was a significant factor at the Hamilton site for weaning weight. A sire and sire by birth type and rear type interaction was present at the Pigeon Ponds site for weaning weight.

Table 16. Coefficients (± s.e.) that predicts the response in lamb birth weight to ewe joining weight and liveweight (LW) change during pregnancy. All terms in the model were significant (p<0.001).

Model Factor		Hamilton	Pigeon Ponds	Mt Barker
Constant		3.71 ± 0.193	3.53 ± 0.230	5.29 ± 0.303
Ewe LW at Joining (kg)		0.031 ± 0.0031	0.036 ± 0.0038	0.013 ± 0.0044
Ewe LW change day 0 to day 90 (kg)		0.031 ± 0.0061	0.043 ± 0.0077	0.025 ± 0.0077
Ewe LW change day 90 to lambing (kg)		0.046 ± 0.0059	0.058 ± 0.0063	0.032 ± 0.0055
Sex	Male	0.288 ± 0.0385	0.303 ± 0.0430	0.403 ± 0.0601
Ewe Age (Years)	3	0.010 ± 0.0632	0	
	4	0.291 ± 0.0635	-0.041 ± 0.0550	
	5	0.058 ± 0.082	0.127 ± 0.0570	
Birth type	2	-1.41 ± 0.051	-1.34 ± 0.066	-0.76 ± 0.066
	3	-2.64 ± 0.097		-1.13 ± 0.182
Sire	120480		-0.33 ± 0.071	
Birth class T.Sire 120480			0.28 ± 0.090	

[A] The Birth Weight constant is for birth type 1, female progeny, ewe aged 2 yrs and sire 110449.

Table 17. Coefficients (± s.e.) that predict the response in lamb weaning weight to ewe joining weight and liveweight (LW) change during pregnancy. All terms in the model were significant ($p<0.05$).

		Hamilton	Pigeon Ponds	Mt Barker
Constant		20.6 ± 1.09	26.7 ± 1.26	30.2 ± 1.77
Ewe LW at Joining (kg)	Joining	0.15 ± 0.017	0.17 ± 0.020	0.10 ± 0.024
Ewe LW change day 0 to day 90 (kg)	Join-90	0.18 ±0 .034	0.150 ± 0.03	0.19 ± 0.037
Ewe LW change day 90 to lambing (kg)	90-Lamb	0.08 ± 0.032	0.18 ± 0.034	0.07 ± 0.022
Sex	Male	1.0 ± 0.20	1.1 ± 0.24	2.1 ± 0.30
Ewe Age (Years)	3	0.59 ± 0.335		
	4	0.80 ± 0.340		
	5	-0.30 ± 0.447		
Birthtype.reartype	21	-3.5 ± 0.38	-4.5 ± 0.59	-2.8 ± 0.58
	22	-8.4 ± 0.26	-8.4 ± 0.38	-4.7 ± 0.33
	31	-8.3 ± 1.95		
	32	-11.5 ±0.66		
	33	-14.4 ± 0.99		-5.3 ± 0.93
Sire	120480		-1.2 ± 0.39	
Sire.birthtype.reartype	120480.21		-0.04 ± 0.889	
	120480.22		1.25 ± 0.516	

[A] The weaning weight constant is for rear type 11, female progeny, ewe aged 2 yrs and sire 110449.

Discussion

Birth weight

The birth weight of all lambs was significantly improved at all three sites when CS at lambing was increased from the nutritional management applied to ewes from pregnancy scanning to the end of lambing. Across all sites a range in ewe live weight and condition score at lambing of 13.7 to 19.1 kg (average 16.4 kg) and 1.1 to 1.5 of a condition score (average 1.24) resulted in an increased birth weight of about 0.7 kg. The effect on the birth weight for single lambs was significant at two out of three research sites and significant for twins at all three sites. Birth weight was related to liveweight at joining and liveweight change from joining to Day 90 and Day 90 to lambing. Coefficients for the prediction of birth weight from joining liveweight and liveweight change during pregnancy were similar in scale to the results of Paganoni *et al*. (2014) within Merino and Border Leicester Merino ewes and those achieved in Merinos (Oldham et al*.* 2011). Across sites the coefficients were largely consistent particularly for the Hamilton and Pigeon Ponds sites for which the ewes were of similar breeding history. The results at Mount Barker were somewhat different with this site in particular having a lower effect due to joining liveweight. Nevertheless the consistency of the results overall and the coefficients across sites gives some confidence that the impact of maternal liveweight change in non-Merino ewes is similar to that of Merinos and can result in significant changes in lamb birth weight over the range of liveweight change tested in this study.

Lamb Survival

Lamb birth weight is strongly related to lamb survival (Knight *et al*. 1988, Oldham *et al*. 2011, Hinch and Brien 2014) and the results from this study continue to show that relationship across all sites. Single lamb survival was not affected by the lower condition score treatments at any of the research sites which is consistent with the high average birth weight of single lambs (5.4 kg to 6.3 kg) being in the optimum range for survival. In contrast, twin birth type lambs had lower survival at Hamilton and Mount Barker sites for the lower CS treatments, whilst the survival at Pigeon Ponds trended lower but not significantly. These results again reflect the birth weights achieved by the various CS treatments and the proportions of lambs that were lower in birth weight as consequence of the CS treatment. To achieve greater than 90% survival in both single and twin lambs the critical birth weight ranged from around 4.0 kg to 5 kg across the sites.

In contrast to the findings in Merinos (Oldham *et al*. 2011), the effect of birth type, single or twin, was not significant across all sites meaning that the relationship between birth weight and survival and the risk of mortality was not necessarily modified by being born a single or twin in these studies. Therefore for twin bearing ewes achieving critical birth weight for their lambs should alleviate many of the losses associated with twin lambs. In these studies the near maximum lamb survival was achieved for twin bearing ewes when their CS at lambing was 3.2 or greater at which point lamb survival was similar to single born lambs.

Anecdotally, feedback from the Lifetime Ewe Management course participants has indicated that high CS in non-Merino maternal single bearing ewes can lead to higher rates of mortality due to increased birth weight and birthing difficulty. The Mount Barker site showed such an effect for their highest CS treatment (achieving an average CS 4.0 at lambing) where birth weight averaged 6.3kg and survival was consequently reduced to 83% compared to 89% to 94% in the lower CS treatments. This effect was also supported by the across site analysis suggesting an upper limit for CS at lambing and ewe liveweight gain in single bearing ewes. Across sites the highest CS treatment averaged CS 3.6 to 4.0.

Marking and weaning weight

Marking and weaning weight were significantly affected for one out of three sites for single lambs and two out of three sites for twin born lambs, however, trends in the mean values at the Pigeon Ponds site were also present and the lack of significant difference may reflect a lack of precision at this site to discern effects rather than the absence of an impact. For example, the Pigeon Ponds site showed a 1.9 kg range in weaning weight for twins and 1.7 kg range for singles and when marking weight and weaning weight was analysed across all sites the effects of CS treatment were highly significant. Restricted nutrition during mid to late pregnancy significantly depressed weaning weight for singles and twins in this study and the coefficients for liveweight at joining, joining to Day 90 and Day 90 to lambing were all significant. As weaning weight is a pre-cursor and strongly related to slaughter weight these impacts are important as they signify a potential economic impact on the prime lamb producer if birth weight is reduced at lambing.

A key feature of the site results is that the impacts are largely present by lamb marking with the differences in growth rate between marking and weaning contributing little to the impacts on weaning weight. As all sites maintained nutritional treatments to the end of lambing which was 1-2 weeks prior to marking it is clear that the differences are largely a function of both birth weight and possible effects on lactation prior to marking (Banchero *et al.* 2015). It may therefore be possible that high levels of feed on offer during lambing and early lactation could mitigate these liveweight effects.

Prediction of birth weight, survival and weaning weight

The results of this study indicate that it is possible to predict the impacts of ewe liveweight and liveweight change on the birth weight and weaning weight of prime lambs derived from non-Merino ewes. The size of the coefficients would suggest that late pregnancy liveweight gain can be used to offset early pregnancy reductions in foetus weight. However, as most maternal prime lambs systems operate on a lambing time when feed is restricted achieving high CS at joining and allowing a moderate reduction and then maintenance of ewe CS to lambing is likely to optimise use of feed resources, optimise birth weight and increase survival. It is likely that twin bearing ewes will need to reach higher CS or liveweight targets to optimise survival through birth weight increases, whilst singles may be allowed to lose weight provided weaning weight is not reduced to a large degree.

Limitations of the current study

This study was limited to the profiles of ewe liveweight managed in this experiment and the lambing conditions experienced at the time which were generally mild for the year at Pigeon Ponds and Mount Barker. The Hamilton site had higher chill conditions earlier in the lambing period but was also milder than normal in the later part of the lambing period. Some caution should therefore be observed in translating the high level of survival achieved in these studies to commercial farming sites under more challenging environmental conditions.

Additionally ewes were restricted in nutrition until the end of lambing potentially conserving the size of the effects due to birth weight, although results from our second study (Thompson et al. *in press*) indicate limited potential to mitigate gestational birth weight effects through post-lambing feed on offer. Nevertheless FOO levels at lambing for all sites were below those that would normally be recommended (e.g. 600-800kg DM/ha vs. 1000-1200kg DM/ha) and this may have influenced survival particularly in low CS treatments as low FOO has been associated with reduced survival in other studies (Oldham *et al.* 2011).

The experiment also used supplementation of cereal grains (oats, lupins and barley) and hay to achieve CS and liveweight change during the experiment. Barley is known to have beneficial effects on the yield and quality of colostrum and can increase lamb survival (Banchero *et al.* 2007, Hawken *et al.* 2012). It may be that some of the effect on lamb survival seen in higher CS treatments was due to barley feeding effects rather than liveweight change or CS change per se. Most studies where barley feeding has been effective in improving colostrum and lamb survival, the feeding has been conducted in the last two weeks prior to a synchronised lambing. This contrasts, the natural mating used at the Hamilton and Mount Barker sites that results in a greater spread of lambing dates. In addition, the effect of concentrate feeding in late pregnancy on both lamb performance and indirect indicators of lamb colostrum intake has not been consistent in other studies (Kerslake *et al.* 2008). It is worth noting that poor ewe nutrition prior to lambing can reduce colostrum and milk production (see review by Banchero *et al.* 2015) and thus effects on colostrum and milk production will be difficult to disassociate from effects of ewe liveweight change as they are biologically intertwined. So while the mechanisms of ewe liveweight change effects on birth weight and survival in this experiment cannot necessarily be fully attributed to birth weight alone the consistent effect of under-nutrition during mid to late pregnancy in this study are in alignment with previous reviews by Kenyon and Blair (2014) and Rooke *et al.* (2015). In contrast, the improvements for twin lambs in birth weight, weaning weight and lamb survival from improved CS and increased ewe liveweight would appear more consistent in our studies than previous experiments.

In conclusion, manipulating the nutrition of the maternal non-Merino ewes during mid to late pregnancy resulted in predictable impacts on the birth weight of single and multiple lambs. There were minimal effects of low CS at lambing (2.5 to 2.6) on the survival of single born lambs, but possible negative effects of a CS greater than 3.5, where ewe liveweight was markedly increased during pregnancy. However, effects of CS management on weaning weight of single lambs should also be considered when formulating optimum guidelines for singles as weaning weight was improved by the higher CS treatments. Improving CS at lambing increased survival of twins at 2 of the 3 sites and the effect was significant when analysed across all sites. The effect was ‘near-maximum’ with the implementation of the CS 3.2 treatment (3.2 to 3.5 at lambing). Improved ewe condition score at lambing also had positive effects on the weaning weight of multiple born lambs. The coefficients for the effects of joining weight, ewe liveweight change from joining to Day 90 and ewe liveweight change from Day 90 to lambing on birth weight and weaning weight were similar across the research sites indicating some consistency in the response of maternal non-Merino ewes to ewe nutrition during mid to late pregnancy. The relationship for birth weight and survival was also similar across sites. These prediction equations can now be used to model the optimum ewe CS or liveweight profile to optimise production and survival in non-Merino prime lamb production systems.

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References

Behrendt R, van Burgel AJ, Bailey A, Barber P, Curnow M, Gordon DJ, Hocking Edwards JE, Oldham CM and Thompson AN (2011) On-farm paddock-scale comparisons across southern Australia confirm that increasing the nutrition of Merino ewes improves their production and the lifetime performance of their progeny. Animal Production Science 51, 805-812

Banchero GE, Quintans G, Vazquez A, Gigena F, La Manna A, Lindsay DR and Milton JT B. (2007) Effect of supplementation of ewes with barley or maize during the last week of pregnancy on colostrum production. *Animal* 1; 625–630.

Banchero GE, Milton JTB, Lindsay DR, Martin GB and Quintans (2015). Colostrum production in ewes: a review of regulation mechanisms and of energy supply. *Animal* 9:5; 831–837.

Blackshaw P and Ough M (2015) Livestock Farm Monitor Project Victoria 2014/15. Department of Economic Development Jobs, Transport and Resources.

Brien FD, Hebart ML, Smith DH, Hocking Edwards JE, Greeff JC, Hart KW, Refshauge G, Bird-Gardiner TL, Gaunt G, Behrendt R, Robertson MW, Hinch GN, Geenty KG and van der Werf JHJ (2010) Opportunities for genetic improvement of lamb survival, *Animal Production Science* 50; 1017-1025.

Curtis K (2009a) Wool Desk September 2009 ‘Changes in the Australian Sheep Industry’. Department of Agriculture and Food, Western Australia. Issue No. 012. FAO, Food and Agricultural Organisation Statistics. Available at http://faostat.fao.org/ [Verified June 2010].

Curtis K (2009b) Wool Desk Report—June 2009, Flock Demographics and Producer Intentions.

February 2009 National Survey Results. Issue No. 011.

Ferguson MB, Thompson AN, Gordon DJ, Hyder MW, Kearney GA, Oldham CM and B. L. Paganoni (2011) The wool production and reproduction of Merino ewes can be predicted from changes in liveweight during pregnancy and lactation. *Animal Production Science* 51, 763-775.

Greenwood PL, Thompson AN and Ford SP (2010). Postnatal consequences on the maternal environment and growth during prenatal life for productivity of ruminants. In: Greenwood, P.L., Bell, A.W., Vercoe, P.E., Viljoen, G.J. (Eds.), Managing the Prenatal Environment to Enhance Livestock Productivity. Springer, Dordrecht, Heidelberg, London, pp.3–36.

Hawken PAR, Williman M, Milton J, Kelly R, Nowak R and Blache D (2012). Nutritional supplementation during the last week of gestation increased the volume and reduced the viscosity of colostrum produced by twin bearing ewes selected for nervous temperament. *Small Ruminant Research* 105; 308–314.

Hinch GN and Brien F (2014) Lamb survival in Australian flocks: a review. *Animal Production Science* 54; 656–666.

Holst PJ (2004) Lamb autopsy. Notes on a procedure for determining cause of death. (NSW Agriculture).

Jefferies BC (1961) Body condition scoring and its use in management. *Tasmanian Journal of Agriculture* 32; 19–21.

Kenyon PR and Blair HT (2014) Foetal programming in sheep – Effects on production. *Small Ruminant Research* 118; 16–30.

Kerslake JI, Kenyon PR, Morris ST, Stafford KJ, Morel PCH (2008) Effect of concentrate supplement and sward height on twin-bearing ewe body condition and the performance of their offspring. *Australian Journal of Experimental Agriculture* 48; 988–994.

Knight TW, Lynch PR, Hall DRH, Hockey HUP (1988) Identification of factors contributing to the improved lamb survival in Marshall Romney sheep. *New Zealand Journal of Agricultural Research* 31; 259-271.

Masters DG, Stewart CA, Connell PJ (1993) Changes in plasma amino acid patterns and wool growth during late pregnancy and early lactation in the ewe. *Australian Journal of Agricultural Research* 44; 945-57.

Martin P and Phillips P (2011) Australian lamb: Financial performance of slaughter lamb producing farms, 2008–09 to 2010–11, ABARES report prepared for Meat and Livestock Australia, Canberra, June.

Oldham CM, Thompson AN, Ferguson MB, Gordon DJ, Kearney GA and Paganoni BL (2011) The birth weight and survival of Merino lambs can be predicted from the profile of liveweight change of their mothers during pregnancy. *Animal Production Science* 51;776-783.

Paganoni BL, Ferguson MB, Kearney GA and Thompson AN (2014) Increasing weight gain during pregnancy results in similar increases in lamb birth weights and weaning weights in Merino and non-Merino ewes regardless of sire type. *Animal Production Science* 54; 727–735.

Robinson JJ, Ashworth CJ, Rooke JA, Mitchell LM and McEvoy TG (2006) Nutrition and fertility in ruminant livestock. *Animal Feed Science and Technology* 126; 259-276.

Rooke JA, Arnott G, Dwyer CM and Rutherford KMD (2015). The importance of the gestation period for welfare of lambs: maternal stressors and lamb vigour and wellbeing. *The Journal of Agricultural Science* 153; 497-519.

Scales GH, Burton RN, Moss RA (1986) Lamb mortality, birth weight, and nutrition in late pregnancy. *New Zealand Journal of Agricultural Research* 29; 75-82.

't Mannetje L and Haydock KP (1963)-The dry weight rank method for the botanical analysis of pasture. *Journal of the British Grassland Society* 18; 268-275.

Thompson A (2011) Lifetime Wool Special Issue – Forward. *Animal Production Science* 51, i-ii.

Tothill JC, Hargreaves JNG and Jones RM (1978). 'BOTANAL: a comprehensive sampling and computing procedure for estimating pasture yield and composition. 'I. Field Sampling',CSIRO Division of Tropical Crops and Pastures, Brisbane.

Trompf JP, Gordon DJ, Behrendt R, Curnow M, Kildey L, Thompson AN (2011) Participation in Lifetime Ewe Management results in changes in stocking rate, ewe management and reproductive performance on commercial farms. *Animal Production Science* 51; 866–872.

van Burgel AJ, Oldham CM, Behrendt R, Curnow M, Gordon DJ, Thompson AN (2011) The merit of condition score and fat score as alternatives to liveweight for managing the nutrition of ewes. *Animal Production Science* 51; 834–841.

Wheeler JL, Reardon TF, Hedges DA, Rocks RL (1971) The contribution of the conceptus to weight change in pregnant Merino ewes at pasture. *Journal of Agricultural Science* 76; 347–353.

Young JM, Thompson AN, Curnow M and Oldham CM (2011) Whole-farm profit and the optimum maternal liveweight profile of Merino ewe flocks lambing in winter and spring are influenced by the effects of ewe nutrition on the progeny's survival and lifetime wool production. *Animal Production Science* 51; 821–833.

13.4 Appendix 4 – Effects of feed on offer during lambing and lactation on the performance of non-Merino ewes (Experiment 3)

Improving nutrition from late pregnancy until weaning does not fully compensate for the adverse effects of poor ewe nutrition during pregnancy on birth and weaning weight of lambs from non-Merino ewes

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Abstract

Restricting the nutrition of non-Merino ewes during early-mid or late pregnancy consistently reduces the birth weight, survival and weaning weight of lambs, and these impacts on progeny can be predicted from ewe liveweight profile. This paper aimed to validate the prediction equations for birth weight, weaning weight and survival of lambs using liveweight profiles during gestation for non-Merino ewes and test the hypotheses that high levels of feed on offer (FOO) during very late gestation and lactation could mitigate these the adverse effects of poor nutrition during mid and late pregnancy on the birth weight, survival and weaning weight of lambs from non-Merino ewes. Four replicated experiments were conducted in 2015 at research sites in Victoria (Pigeon Ponds and Hamilton), South Australia (Struan) and Western Australia (Mount Barker). Ewes were allocated to two condition score (CS) treatments following pregnancy scanning (~day 50) to reach a target of CS 2.7 or 3.4 at lambing and then allocated to either four or six target FOO treatments until lamb weaning. Across all sites, the actual CS achieved 15 to 20 days prior to lambing were 2.7 and 3.4 and the FOO levels at allocation varied from a low of 620 to 1020 kg DM/ha to a high of 1090 to 2680 kg DM/ha and generally increased during lactation. There were no significant differences between the FOO treatments for lamb birth weight for single or multiple born lambs at any site, possibly because pasture consumption even at the lowest

FOO levels was not sufficiently restricted. There were also no significant differences between the CS or FOO treatments for lamb survival to marking at any site in the current study due to very high birth weights, although actual FOO during lambing was related to survival at one site. Weaning weight was influenced by FOO during lactation. Across the four sites increasing FOO by 1000 kg/ha during lactation (up to 2000 kg/ha) increased weaning weights by 10%, and there were no additional effects of FOO on weaning weights above 2000 kg/ha. The production responses from this study inform economic modelling and the development of liveweight and CS targets at key points in the annual reproduction cycle for best-practice management of non-Merino ewes to increase productivity and profitability.

Introduction

The impact of ewe nutrition before joining or during pregnancy and lactation is known to affect ewe and progeny performance (reviewed by Greenwood *et al*. 2009, Kenyon and Blair 2014; Rooke *et al*. 2015). Knowledge of these production responses to ewe nutrition in Merino ewes (Behrendt *et al.* 2011; Ferguson *et al*. 2011; Hocking-Edwards *et al*. 2011; Oldham *et al*. 2011; Thompson *et al*. 2011a,b), together with whole-farm bioeconomic modelling, have been utilised to develop optimum condition score (CS) profiles and guidelines to manage the nutrition of Merino ewes to improve productivity, profitability and welfare outcomes across multiple environments and production systems (Curnow *et al.* 2011; Young *et al.* 2011). These guidelines for Merino ewes subsequently underpinned the development of the Lifetime Ewe Management training program (Trompf *et al*. 2011) and over 3,000 producers responsible for managing 25% of the National ewe flock have participated in the program. These producers have increased stocking rate by about 10%, increased lamb marking percentages by 7% and decreased ewe mortality by 30% by adopting best practice management of their ewes (Trompf *et al.* 2011; Thompson unpublished data). About 20% of the producers that have participated in Lifetime Ewe Management have managed non-Merino ewes, and whilst they have achieved similar or even greater gains in productivity, feedback from both deliverers and participants is that they lack confidence in both the applicability of the Merino recommendations and how to adjust those targets to maximise the profitability from non-Merino ewes.

The majority of ewes in Australia are pure-bred Merinos, however almost 30% of ewes are non-Merinos which produce about 45% of lamb supply (B. Thomas unpublished data). A recent review suggested that non-Merino ewes have improved production outcomes compared to Merino ewes when managed under identical production conditions (Babiszewski and Hocking Edwards 2013). Blumer *et al*. (2016) reported that despite significant variation among sites, years and ages for liveweight loss and gain, on average non-Merino ewes lost less and gained more liveweight than Merino ewes. This was confirmed by Hocking Edwards *et al*. (*In press*; Experiment 1) and consequently BLM ewes produced lambs that were heavier at birth and weaning and more likely to survive than Merino ewes when managed together. It is also well recognised that the economic value of improving the number of lambs weaned is much greater for non-Merino than Merino ewes (Young *et al.* 2014) and hence understanding the feed requirements and production responses of the non-Merino ewe and her progeny is a pre-requisite for optimising farm profitability. The current management guidelines developed for Merinos may not be directly transferrable to non-Merino ewes and further increases in reproduction efficiency, profitability and lamb supply could be achieved if the nutritional requirements and condition score targets were better tailored to non-Merino ewes.

Across four large experiments, Behrendt *et al*. (Experiment 2) reported that improving ewe nutrition during pregnancy increased lamb birth weights by up to 0.7 kg and the coefficients for the prediction of birth weight from ewe liveweight profile were similar in scale to those achieved in Merinos (Oldham *et al.* 2011; Hocking Edwards *et al.* Experiment 1). Birth weight was significantly related to survival and increasing birth weights improved the survival of twin lambs by 11% across the spectrum of nutritional treatments, whereas the survival of single lambs was fairly insensitive to nutrition except survival was reduced at the highest CS treatment by 6%. Behrendt *at al.* (Experiment 2) also found that restricted nutrition during pregnancy and until the end of lambing depressed weaning weight for singles and twins by 1.7 and 1.9 kg and the coefficients for the prediction of weaning weight from ewe liveweight profile were significant at all sites. The impacts of ewe poor nutrition to the end of lambing on weaning weight, primarily via reduced birth weight and lamb growth to marking, are likely to have a major bearing on the optimum management on non-Merino ewes during pregnancy.There is evidence that short term improvements in ewe nutrition during critical windows of a few weeks during late pregnancy could significantly increase lamb birth weights in non-Merino ewes (Holst *et al*. 1986, 1992; Oddy and Holst 1991), and hence potentially improve survival and weaning weights, although there was no evidence of this in Merinos (Oldham *et al*. 2011). However Oldham *et al.* (2011) did find that improving FOO during lambing increased lamb survival independent of birth weight, presumably be increasing time at the birth site. This paper aimed to validate the prediction equations for birth weight, weaning weight and survival of lambs using liveweight profiles during gestation for non-Merino ewes reported by Hocking-Edwards *et al.* (Experiment 1) and Behrendt *et al*. (Experiment 2), and test the hypotheses that high levels of FOO during late gestation and lactation could mitigate the adverse effects of poor nutrition during mid and late pregnancy on the birth weight, survival and weaning weight of lambs from non-Merino ewes.

Materials and methods

Liveweight change and reproduction were used to assess the performance of non-Merino ewes subjected to low or high condition score treatments during pregnancy and then managed on a range of pastures during late pregnancy and lactation. Carry over effects on reproductive success in the following year were also measured. All experimental work involving animals was carried out under the authority of the Animal Welfare Act of Australia and the experimental schedule received prior approval from the animal ethics committees of Murdoch University (approval number: R2647), South Australian Research and Development Institute (SARDI; Primary Industries and Regions of South Australia Animal Ethics Committee, approval number: (I#1/15), Agriculture Victoria (AgVic; approval number: 2015-01) and Rural Industry Skill Training (approval number" R117).

Experimental sites and design

Four sites were established across Australia on commercial scale properties with two in Victoria (Pigeon Ponds, -37.18, 141.41; Hamilton, -37.45, 142.2), one in South Australia (Struan, -37.10, 140.48), and one in Western Australia (Mount Barker, -34.38, 117.40). Full details of the research sites were provided by Hocking-Edwards *et al.* (Experiment 1) and Behrendt *et al.* (Experiment 2).

A factorial design was applied at all sites with two target ewe condition scores to be achieved at day 140 from the start of joining, and either four or six target FOO treatments applied from Day 140 where the ewes remained on the plots until lamb weaning (Table 1). Condition score targets were achieved through differential feeding from pregnancy scanning through until day 140 from the start of joining. Nutritional management to these targets differed slightly between the sites and included pasture restriction, feed lotting, and/or supplementary feeding.

Pasture management and measurements

Plots at all sites were destocked following summer grazing. Plots were fertilised as required and managed to achieve a FOO targets through grazing deferment and targeted grazing by other livestock based on estimates of FOO, pasture growth rates and estimates of intake (Thompson *et al.* 1994). FOO was estimated visually at 2-4 weekly intervals during the preparation period. At Day 140, lamb marking and weaning FOO was estimated and calibrated by one or two observers using the method described in full by Ferguson *et al.* (2011). At each of these sampling dates botanical composition was also assessed and samples collected for measurement of nutritive value using the techniques described by Behrendt *et al.* (Experiment 2). Due to the set stocking rate design of the experiment, FOO was not fixed throughout the grazing period but varied with pasture growth rate and grazing pressure. At the Struan site FOO levels in all plots decreased substantially between the end of lambing and marking and consequently ewes needed to be supplemented in two of the three replicates from marking to until weaning.

Experimental sheep

At both sites in Victoria the ewes were maternal composites, based on Coopworth breeding. In South Australia the ewes were Border Leicester X Merino ewes, and in Western Australia the ewes were Greeline X Border Leicester. Ewes were mixed age adults except at the site in Western Australia where all ewes were 2012 born (3 years old). Around 1000 ewes at each site were naturally mated using syndicates and pregnancy scanned to identify ewes that conceived in the first 14-21 days of joining. At each site these ewes were then allocated to one of two groups which were balanced for liveweight, condition score, age and sire (if known) before being differentially fed to achieve significant differences in condition score and liveweight between the two nutritional treatment groups by Day 140 from the start of joining. Both single and multiple bearing ewes were included in the experiment with the aim of at least 30 ewes per plot except at Hamilton where a more detailed FOO treatment was applied with 10 ewes per plot. Key management points and dates for each site are described in Table 2.

Ewe liveweight and condition score

Condition score was assessed by the same trained operator at each site using the technique described by Jeffries (1961). All ewes had their liveweight and condition score recorded at joining, post joining, and pregnancy scanning and approximately monthly outside of these management points up until Day 140 from the start of joining when they were weighed and condition scored, side-branded, and allocated to the plots. Ewe liveweight and CS was then assessed again at marking and weaning and at the following joining. For the analysis, liveweights collected during pregnancy were adjusted for conceptus weight (Wheeler 1971).

Table 1. Factorial designs and sheep numbers for the four sites across Australia examining the effect of condition score (CS) pre-lambing and Feed On Offer (FOO; kg DM/ha) from late gestation to weaning on the productivity on non-Merino ewes and their progeny.

	Pigeon Ponds				Hamilton				Struan				Mount Barker			
Treatment	CS	FOO	Reps (n)	Ewes (n)	CS	FOO	Reps (n)	Ewes (n)	CS	FOO	Reps (n)	Ewes (n)	CS	FOO	Reps (n)	Ewes (n)
	2.6			420	2.7			240	2.6			384	2.6			350
		500	3	126		500	4	40		500	3	96		500	3	105
		1000	2	84		1000	4	40		1000	3	96		1000	2	70
		1500	3	126		1500	4	40		1500	3	96		1500	3	105
		2000	2	84		2000	4	40		2000	3	96		2000	2	70
						2500	4	40								
						3000	4	40								
	3.4			420	3.7			240	3.5			384	3.4			350
		500	3	126		500	4	40		500	3	96		500	3	105
		1000	2	84		1000	4	40		1000	3	96		1000	2	70
		1500	3	126		1500	4	40		1500	3	96		1500	3	105
		2000	2	84		2000	4	40		2000	3	96		2000	2	70
						2500	4	40								
						3000	4	40								

Table 2. Key management points and sheep numbers for the four sites across Australia examining effect of condition score (CS) pre-lambing and Feed On Offer (FOO; kg DM/ha) from late gestation to weaning on the productivity on non-Merino ewes and their progeny

Site	Pigeon Ponds	Hamilton	Struan	Mount Barker
Ewe type	Maternal composites	Maternal composites	Border Leicester x Merino	Greeline x Border Leicester
Joining date	1-Feb-15	19-Mar-15	27-Jan-15	29-Jan-15
Number ewes joined	1150	949	970	1370
Number ewes allocated to CS treatments	850	548	792	725
Last weight before lambing (Day 140)	19-Jun-15	6-Aug-15	17-Jun-15	26-Jun-15
Number of ewes allocated to FOO treatments	700	480	768	694
Average date of lambing	2-Jul-15	20-Aug-15	7-Jul-15	16-Jul-15
Date of weaning	27-Aug-15	17-Nov-15	24-Sep-15	9-Oct-15
Joining date for carryover reproduction	20-Feb-16	3-Feb-16	4-Jan-16	26-Jan-16
Number ewes scanned for carryover reproduction	588	411	679	666

Reproductive measurements

Lambing rounds were performed twice daily at each site so that birth data was collected for most ewes. Every lamb (dead and alive) was double tagged with a numbered electronic identification tag and a visual tag and identified to a ewe. Birth date, birth weight, birth type, sex and survival were recorded, and death date if known. Unidentified lambs were tagged and spray marked for later identification where possible. Marking was conducted by contractors at all sites in the fortnight following the completion of lambing and lambs were weaned at ~12 weeks of age. Lambs were weighed at both marking and weaning. Following weaning in 2015, ewes were managed as one mob or in randomised split mobs under similar conditions throughout joining (naturally mated) until pregnancy scanning the following year in order to measure the effects of the treatment group on carryover reproductive rates.

Statistical analysis

Genstat (Genstat committee 2008) was used to analyse data, with ANOVA applied to test the differences between the treatment means for the nutritional groups (high, low) and the FOO groups (600, 900, 1200, 1800), and the interaction, with a blocking structure of plot within FOO replicate. While the FOO targets were not exactly met at each site, the above targets are used for descriptive purposes for the rest of this paper. Dependant variable means tested with ANOVA were: ewe liveweight and condition score throughout the experiment including joining liveweight in the following year, lamb birth weight and lamb survival, and lamb marking and weaning weights.

The effects of ewe liveweight and liveweight change (Day 0 weight, liveweight change early pregnancy [0-90], and liveweight change late pregnancy [90-140]) on lamb birth weight, lamb survival, and lamb marking and weaning weights were also analysed using REML, with nutrition group, FOO group, lamb sex and lamb birth type included as fixed effects, and ewe liveweight and liveweight change included as covariates. There was variation in composition and pasture quality at some sites and percentage legume and or percentage green was included as a covariate in the liveweight analyses for these sites. All interactions were investigated to second order and removed if not significant (P>0.05) using stepwise regression.

In addition to the above site analyses, a cross site analysis was conducted to investigate general effects of condition score and FOO with lamb birth weight, marking and weaning weights, and survival as dependent variables in a REML analysis. Fixed effects tested were site (Pigeon Ponds, Hamilton, Struan and Mount Barker), condition score treatment and FOO treatment. Block and plot were included as random terms to account for replication. In a separate model FOO was also tested as a covariate within FOO treatment.

Results

Ewe condition score and feed on offer treatments

The average liveweight and CS of the ewes at the start of joining was 61 kg and CS 3.6 at the Hamilton site, 63 kg and CS 3.7 at the Pigeon Ponds site, 76 kg and CS 3.6 at the Mount Barker site and 65 kg and CS 3.2 at the Struan site. At joining multiple bearing ewes were significantly heavier than those ewes bearing singles but the differences in CS were not significant.

Ewes were managed differentially from pregnancy scanning and a significant difference in ewe liveweight change from pregnancy scanning to Day 140 from the start of joining was achieved between the high and low CS treatments (Fig. 1). On average, at allocation to FOO treatments there was a difference of 10 kg (60.8 *vs.* 70.8 kg) and 0.80 of a CS (2.6 *vs.* 3.4) between the high and low CS treatments. The average liveweight and CS of the ewes in the high and low CS treatments at allocation to FOO treatments for individual sites was 68 *vs*. 58 kg and CS 3.5 *vs*. 3.0 at the Hamilton site, 65 *vs*. 56 kg and CS 3.3 *vs*. 2.6 at the Pigeon Ponds site, 82 *vs*. 71 kg and CS 3.4 *vs*. 2.6 at the Mount Barker site and 68 *vs*. 58 kg and CS 3.3 *vs*. 2.6 at the Struan site.

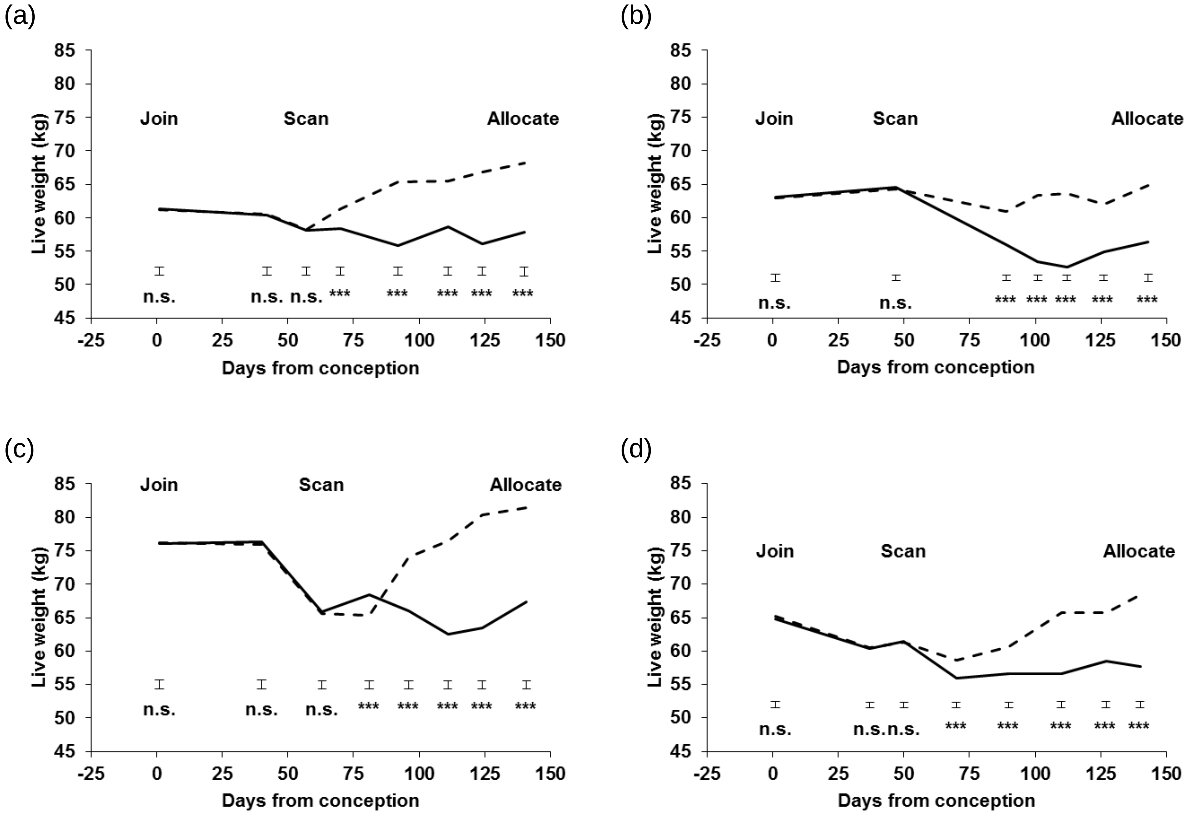

Figure 1. The ewe liveweight profile for the high (dashed line) and the low (solid line) condition score treatments at Hamilton (a), Pigeon Ponds (b), Mount Barker (c) and Struan (d). Error bars represent the least significant difference at the 5% level and the level of significance is indicated below the errors bars (n.s = not significant;* P<0.05; ** P<0.01; *** P<0.001).

At allocation to FOO treatments a wide range of FOO levels were generated across the four sites and the changes in FOO until weaning are shown in Fig. 2. The average FOO at allocation to FOO treatnments, during lambing and during lactation at each site is summarised in Table 3.

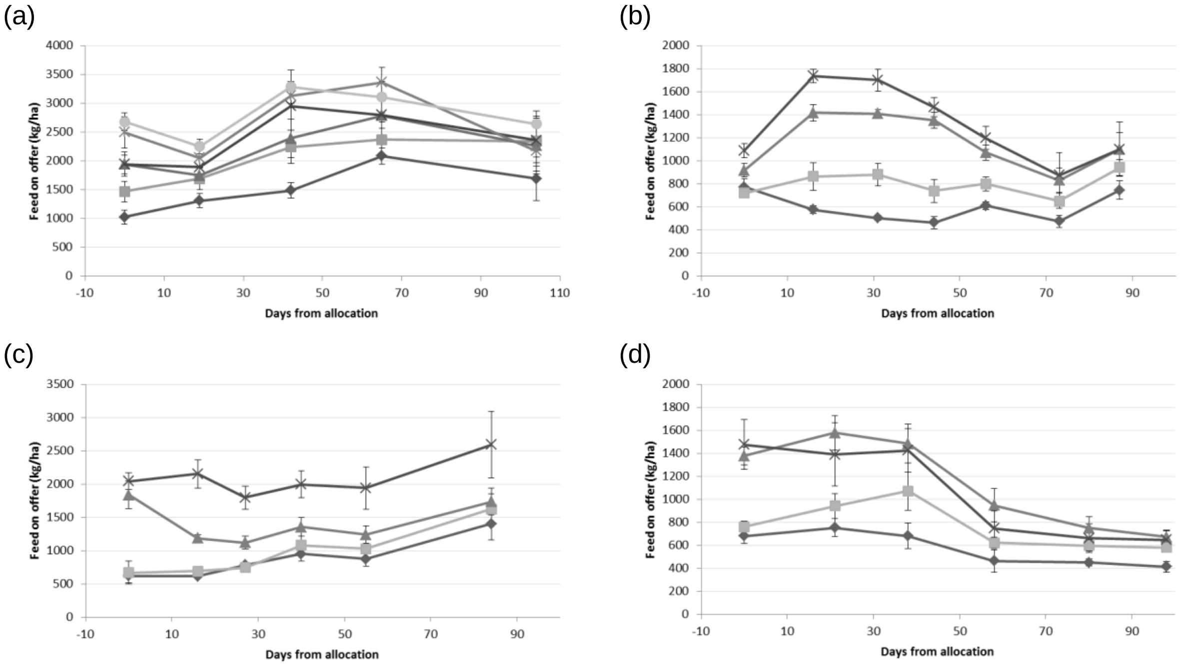

Figure 2. Average Feed On Offer (FOO; ± SEM) for different treatments between allocation to plots at day 140 from the start of joining and weaning at Hamilton (a), Pigeon Ponds (b), Mount Barker (c) and Struan (d). Target FOO treatments are represented by diamonds (500 kg DM/ha), squares (1000 kg DM/ha), triangles (1500 kg DM/ha) and crosses (2000 kg DM/ha). The additional lines at thew Hamilton site represent higher FOO treatments (2500 and 3000 kg DM/ha).

Table 4. Plot means for actual feed on offer at treatment allocation, during lambing and during lactation for the feed on offer (FOO) treatments at each site.

FOO treatment	Feed on offer (kg DM/ha)		
	Allocation	Lambing	Lactation
	Hamilton		
500	1023	1165	1641
1000	1468	1579	2159
1500	1942	1844	2296
2000	1939	1915	2499
2500	2496	2274	2679
3000	2679	2465	2820
P-value	P<0.001	P<0.001	P<0.001
	Pigeon Ponds		
500	774	618	563
1000	722	822	814
1500	919	1248	1197
2000	1090	1508	1345
P-value	P<0.001	P<0.001	P<0.001
	Mount Barker		
500	620	618	927
1000	670	681	1035
1500	1838	1512	1328
2000	2045	2099	2096
P-value	P<0.001	P<0.001	P<0.01
	Struan		
500	681	754	575
1000	763	942	763
1500	1377	1578	1135
2000	1475	1388	1058
P-value	P<0.01	P<0.01	P<0.001

Treatment effects on ewe liveweight and condition score at marking and weaning

At marking, the ewes from the Low CS treatment had significantly lower liveweight and CS than ewes from the High CS treatment across all sites (Table 4). The difference in ewe liveweight between CS treatments ranged from 3.1 kg at Struan to 6.9 kg at Pigeon Ponds, which corresponded to a difference in CS of 0.16 at Struan and 0.55 at Pigeon Ponds. At Struan, there was a significant difference between CS treatments for single-bearing ewes (P<0.05) but not multiple-bearing ewes.

Across all sites the average difference in liveweight and CS at weaning between ewes in the low and high CS treatments was reduced to 4.6 kg (65.2 *vs*. 9.8 kg) and 0.30 of a CS (2.8 *vs.* 3.1). Ewes from the low CS treatment had significantly lower liveweight and CS that those from the high CS treatment at all sites except Mount Barker.

Table 4. Plot means of ewe liveweight and condition score at marking and weaning for the condition score (CS) treatments at each site.

CS treatment	Hamilton		Pigeon Ponds		Mount Barker		Struan	
	single	multiple	single	multiple	single	multiple	single	multiple
				Ewe liveweight at marking				
high	75.1	74.2	68.3	66.8	81.6	77.0	62.2	62.7
low	70.1	69.8	60.7	61.4	74.6	70.6	59.2	60.3
l.s.d	2.31	2.98	2.25	2.69	4.08	2.20	3.09	2.57
P-value	P<0.001	P<0.01	P<0.001	P<0.001	P<0.01	P<0.01	P<0.05	P=0.07
				Ewe condition score at marking				
high	3.47	3.25	3.27	2.97	3.38	2.99	2.76	2.56
low	3.23	3.03	2.71	2.46	2.87	2.49	2.56	2.42
l.s.d	0.086	0.095	0.154	0.084	0.296	0.345	0.133	0.189
P-value	P<0.001	P<0.001	P<0.001	P<0.001	P<0.01	P<0.01	P<0.01	n.s.
				Ewe liveweight at weaning				
high	79.5	78.3	69.3	67.0	81.9	78.1	57.6	57.7
low	74.9	73.6	60.3	59.6	79.4	74.1	54.0	54.5
l.s.d	2.90	3.62	2.28	2.58	6.04	6.88	1.61	1.98
P-value	P<0.01	P<0.05	P<0.001	P<0.001	n.s.	n.s.	P<0.001	P<0.01
				Ewe condition score at weaning				
high	3.82	3.61	3.29	2.92	3.60	3.23	2.67	2.51
low	3.58	3.37	2.62	2.38	3.37	2.94	2.47	2.31
l.s.d	0.134	0.139	0.206	0.149	0.610	0.664	0.097	0.127
P-value	P<0.001	P<0.01	P<0.001	P<0.001	n.s.	n.s.	P<0.001	P<0.01

There was a significant effect of FOO treatment on ewe liv eweight and CS at lamb marking at some sites (Table 5). At Pigeon Ponds, ewes grazing the lowest FOO treatment were approximately 12 kg lighter (P<0.001) and 0.7 CS lower (P<0.001) than those grazing the highest FOO treatment. At Struan, there was an 8 kg differences in ewe liveweight between the highest and lowest FOO treatment (P<0.01) but there was no significant effect on CS. There were no significant differences in ewe liveweight or CS across the FOO treatments at the Hamilton or Mount Barker sites.

By weaning the differences between FOO treatments for ewe livweight and CS was most evident at Pigeon Ponds. At Pigeon Ponds ewes were nearly 15 kg lighter (P<0.001) when grazing the low FOO treatment and about 1 CS lower (P<0.001) than those grazing the highest FOO treatment. At Struan ewes from the low FOO treatment were generally significantly lighter than those from the high FOO treatment, but there were no significant differences in CS between FOO treatments for either single or multiple-bearing ewes at Struan. The differences in ewe liveweight and CS between the FOO treatments at the Hamilton or Mount Barker sites were not significant. Across all four sites, the differences in ewe liveweight and CS at weaning between the 500 and 2000 kg/ha FOO treatments was 4.8 kg (65.0 *vs*. 69.8 kg) and 0.3 CS (3.1 *vs*. 2.8).

Table 5. Plot means of ewe liveweight and condition score at marking and weaning for the feed on offer (FOO) treatments at each site.

FOO treatment	Ewe liveweight (kg)				Ewe condition score			
	Single		Multiple		Single		Multiple	
	Marking	Weaning	Marking	Weaning	Marking	Weaning	Marking	Weaning
Hamilton								
500	71.0	77.2	69.8	76.8	3.35	3.72	3.02	3.39
1000	71.3	76.9	72.3	76.1	3.35	3.76	3.15	3.48
1500	72.3	75.3	73.3	76.0	3.26	3.53	3.15	3.56
2000	72.2	78.0	71.3	76.2	3.42	3.75	3.18	3.57
2500	73.6	77.1	73.5	77.1	3.35	3.66	3.2	3.46
3000	75.4	78.6	71.7	73.6	3.36	3.79	3.12	3.49
l.s.d	4.00	5.03	5.17	6.27	0.149	0.232	0.164	0.241
P-value	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Pigeon Ponds								
500	56.5	55.9	57.2	55.9	2.56	2.38	2.40	2.17
1000	63.0	61.9	61.4	59.3	2.76	2.64	2.52	2.43
1500	69.3	70.5	69.8	68.9	3.29	3.35	2.95	2.96
2000	70.8	72.5	68.8	70.3	3.42	3.53	3.01	3.13
l.s.d	2.91	2.94	3.47	3.33	0.243	0.326	0.133	0.236
P-value	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001
Mount Barker								
500	76.1	79.7	72.6	76.7	3.08	3.36	2.78	3.08
1000	79.7	83.6	75.2	77.9	3.20	3.78	2.72	3.29
1500	77.3	78.5	72.8	73.8	3.04	3.32	2.65	2.92
2000	80.9	82.3	75.6	77.0	3.25	3.63	2.82	3.13
l.s.d	6.46	9.54	3.47	10.88	0.468	0.965	0.545	1.02
P-value	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Struan								
500	57.4	53.3	57.3	54.5	2.60	2.46	2.45	2.39
1000	59.1	55.8	59.8	55.1	2.61	2.59	2.42	2.35
1500	63.2	56.8	63.0	56.8	2.78	2.66	2.49	2.38
2000	64.4	57.2	65.8	58.1	2.66	2.58	2.60	2.51
l.s.d	3.68	2.27	3.65	2.86	0.188	0.136	0.255	0.18
P-value	P<0.01	P<0.01	P<0.001	P=0.06	n.s.	P=0.05	n.s.	n.s.

Treatment effects on lamb birth weight, marking weight and weaning weight

The birth weight of single born lambs was not significantly different between ewe CS treatments at any of the sites. At Hamilton, Pigeon Ponds and Mount Barker birth weights were significantly lower for twin born lambs born to ewes in the low CS treatment than those born to ewes in the high condition score group, but this treatment effect was reversed at the Struan site (Table 6). A combined analysis across all four sites indicated that the effects of CS treatment on birth weights of twin lambs was significant, being 5.18 and 5.31 kg for the low and high CS treatments respectively (P<0.01).

The period between allocation to FOO treatments and date of birth had a significant effect on lambs birth weights (20 g/day; P<0.001), and this period was longer for low than high CS ewes (19.0 *vs*. 17.5 days; P<0.001).

The effects of CS treatment on lamb weights at marking and weaning varied between sites, although the CS treatment x site interaction was not significant in a combined analysis (Table 6). At Hamilton significant differences in lamb weights at marking and weaning were found between the CS groups, however only in lambs born as multiples. The opposite was the case at Struan and only the weight of single lambs was significantly affected by CS treatment. At Pigeon Ponds, both single and twin born lambs from ewes in the high condition score group were heavier at marking and at weaning than those born to ewes in the low condition score group. The effects of CS treatment on lamb weights at Mount Barker were similar in magnitude to Pigeon Ponds, however the effect was only significant for twin lambs at marking. A combined analysis across all four sites indicated that the effects of CS treatment on lamb weights was significant, being 18.0 and 18.9 kg for singles (P<0.01) and 14.4 and 15.6 kg for twins (P<0.001) at marking and 31.3 and 32.6 kg for singles (P<0.05) and 25.9 and 27.6 kg for twins (P<0.001) at weaning for the low and high CS treatments respectively (P<0.01).

Table 6. Plot means of lamb birth weight, lamb marking weight and lamb weaning weight for the condition score treatments at each site.

Treatment	Birth weight (kg)		Marking weight (kg)		Weaning weight (kg)	
	Single	Multiple	Single	Multiple	Single	Multiple
			Hamilton			
high	6.31	5.24	20.4	17.1	37.5	33.0
low	6.14	5.01	20.0	15.5	37.5	30.8
l.s.d	0.213	0.15	1.01	0.68	1.69	1.39
P value	n.s.	P<0.01	n.s.	P<0.001	n.s.	P<0.01
			Pigeon Ponds			
high	5.74	5.20	17.3	14.2	26.2	21.7
low	5.85	5.05	16.0	12.9	23.7	19.7
l.s.d	0.254	0.153	0.94	0.67	1.37	1.13
P value	n.s.	P=0.05	P<0.01	P<0.001	P<0.01	P<0.001
			Mount Barker			
high	6.31	5.60	20.8	16.9	39.2	33.4
low	6.20	5.33	19.5	15.8	37.2	32.2
l.s.d	0.428	0.134	1.52	1.15	3.66	3.28
P value	n.s.	P<0.001	P=0.10	P=0.05	n.s.	n.s.
			Struan			
high	6.47	5.14	17.0	13.3	28.3	22.4
low	6.27	5.32	15.4	12.8	26.0	21.6
l.s.d	0.206	0.183	0.99	1.18	0.97	1.59
P value	P=0.06	P<0.05	P<0.01	n.s.	P<0.001	n.s.

There were no significant differences in birth weight of single or multiple born lambs between the FOO treatments at any site (Table 7) and the condition score x FOO treatment interaction on lamb birth weight was not significant at any site. There were also no significant effects of FOO treatments on lamb weights at marking or weaning at the Hamilton or Mount Barker sites. At Pigeon Ponds, single and twin born lambs were in the higher FOO treatments were heavier at marking and weaning that those in the lowest FOO treatment. At Struan, at weaning there was a significant different between the FOO treatment groups, again for single lambs only so that lambs on the high FOO treatment plots were 2.6 kg heavier than those born in the low FOO treatment.

Table 7. Plot means of lamb birth weight, lamb marking weight and lamb weaning weight for the feed on offer (FOO) treatments at each site.

Treatment	Birth weight		Marking weight		Weaning weight	
	Single	Multiple	Single	Multiple	Single	Multiple
Hamilton						
500	6.28	5.01	20.7	15.9	39.6	32.5
1000	6.45	5.12	20.5	16.0	37.5	32.3
1500	6.09	5.21	19.4	15.8	36.0	30.6
2000	6.14	5.14	19.7	16.6	37.4	33.1
2500	6.13	5.26	19.6	17.1	36.0	31.8
3000	6.28	5.02	21.4	16.2	38.7	31.0
l.s.d (max)	0.368	0.259	1.76	1.17	2.92	2.41
P value	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Pigeon Ponds						
500	5.81	5.03	15.5	12.2	22.4	18.0
1000	5.75	5.24	16.3	13.1	24.2	19.9
1500	5.87	5.06	17.7	14.6	27.2	22.5
2000	5.69	5.24	17.1	14.5	26.1	22.9
l.s.d (max)	0.402	0.243	1.36	1.07	2.16	1.78
P value	n.s.	n.s.	$P<0.01$	$P<0.001$	$P<0.001$	$P<0.001$
Mount Barker						
500	6.17	5.43	20.0	15.8	38.1	32.8
1000	6.32	5.52	20.7	17.3	39.8	34.8
1500	6.08	5.43	19.3	16.0	37.2	31.5
2000	6.59	5.53	20.9	16.6	38.3	33.0
l.s.d (max)	0.677	0.212	2.40	1.83	5.80	5.18
P value	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Struan						
500	6.25	5.10	15.5	12.4	25.6	20.6
1000	6.46	5.31	16.1	13.3	26.7	21.6
1500	6.39	5.26	16.6	13.1	28.1	22.6
2000	6.39	5.26	16.6	13.6	28.2	23.2
l.s.d (max)	0.291	0.262	1.40	1.67	1.38	2.28
P value	n.s.	n.s.	n.s.	n.s.	$P<0.01$	n.s.

At Struan, there was a significant interaction between CS treatment and FOO treatment associated with lamb growth to marking in single born lambs leading to differences in marking weight. Single lambs born to low condition score ewes grew faster if they were born on the high FOO plots, so that these lambs were 2.9 kg heavier than those born on low FOO plots (P<0.05; l.s.d 1.987 kg) while single lambs born to high condition score ewes were not found to be different. This effect was reversed between marking and weaning so that by weaning the interaction was no longer found to be significant. There was a trend (P=0.054) for a positive association between FOO and growth rates birth to weaning for twins born to high condition score ewes however this did not result in differences being found for weaning weight.

Lamb birth weight could be predicted by ewe joining weight, liveweight change during pregnancy (Day 0 to 90 and Day 90 to 140), lamb birth type, lamb sex and also the number of days the ewe was on the FOO treatment plot before lambing (period). Coefficients for all sites are shown in Table 8. A combined analysis across all sites indicated that a 10 kg increase in ewe liveweight at joining was associated with a 0.20 kg increase in lamb birth weight. Similarly, the coefficients for the effects of ewe liveweight change from joining to Day 90 on birth weight indicate that a 10 kg change in ewe liveweight would result in 0.21 kg difference in birth weight. The coefficients for liveweight change from day 90 to lambing indicated that a 10 kg change in ewe liveweight during this period result in 0.31 kg difference in birth weight, except for Pigeon Ponds where the effect was much greater. The largest effect on lamb birth weight was birth type with twin-born lambs being approximately 1.0 kg lighter than single-born lambs and triplet lambs being approximately 2.0 kg lighter than single-born lambs. FOO, botanical composition or pasture quality at lambing did not explain any additional variation in lamb birth weight at any site.

Table 8. Coefficients (± s.e.) of REML linear model that predicts lamb birth weight (kg) in terms of ewe liveweight (LW; kg) and liveweight change, birth type (single, twin, triplet), progeny sex and period (days on Feed on Offer treatment prior to lambing) after adjustment for blocking effects (random). All terms included are significant (P<0.05).

	Hamilton	Pigeon Ponds	Mount Barker	Struan
Constant*	4.57 ± 0.300	3.73 ± 0.250	4.72 ± 0.285	4.34 ± 0.258
Ewe LW at joining	0.02 ± 0.005	0.03 ± 0.004	0.02 ± 0.003	0.02 ± 0.004
Ewe LW change Day 0-90	0.02 ± 0.005	0.03 ± 0.006	0.03 ± 0.004	0.02 ± 0.008
Ewe LW change Day 90-140	0.03 ± 0.011	0.09 ± 0.010	0.03 ± 0.007	0.04 ± 0.006
Birth class twin	-1.21 ± 0.006	-1.02 ± 0.065	-0.81 ± 0.072	-1.34 ± 0.059
Birth class triplet	-	-2.45 ± 0.191	-1.80 ± 0.094	-2.12 ± 0.164
Male	0.37 ± 0.057	0.31 ± 0.048	0.38 ± 0.053	0.44 ± 0.050
Period**	0.02 ± 0.006	0.016 ± 0.006*	0.014 ± 0.006	0.02 ± 0.003

^{A} Birth weight constant is for single born, female progeny. * P = 0.06.

Lamb weaning weights could be predicted by ewe joining weight and liveweight change during pregnancy (Day 0 to 90 and Day 90 to 140), lamb birth and rearing type, lamb sex, dam age and also the number of days the ewe was on the FOO treatment plot before lambing (period) (Table 9). The effect of ewe joining weight effects on weaning weight were similar across all sites. The combined anlaysis indicated that a 10 kg increase in ewe liveweight at joining was associated with a 1.4 kg increase in lamb weaning weight. Similarly, the combined coefficients for the effects of ewe liveweight change from joining to Day 90 and Day 90 to Day 140 on weaning weight indicate that a 10 kg change in ewe liveweight during either period would result in 1.5 kg or 1.2 kg difference in weaning weight.

Table 9. Coefficients (± s.e.) of REML linear model that predicts lamb weaning weight (kg) in terms of ewe liveweight (LW; kg), birth and rear class, progeny sex, Feed on Offer (FOO kg/ha), percentage green pasture and clover and period (days on Feed on Offer treatment prior to lambing) after adjustment for blocking effects (random).

	Hamilton	Pigeon Ponds	Mount Barker	Struan
Constant[A]	27.12 ± 2.269	14.90 ± 1.290	32.90 ± 2.000	-1.11 ± 9.476
Ewe LW at joining	0.21 ± 0.026	0.15 ± 0.016	0.12 ± 0.019	0.14 ± 0.017
Ewe LW change Day 0-90	0.13 ± 0.047	0.18 ± 0.028	0.14 ± 0.035	0.15 ± 0.033
Ewe LW change Day 90-140	0.20 ± 0.066	0.24 ± 0.039	0.09 ± 0.038	0.13 ± 0.025
Birth class 21	-3.32 ± 0.817	-6.77 ± 0.769	-2.77 ± 0.615	-2.19 ± 0.485
Birth class 22	-6.46 ± 0.370	-5.22 ± 0.248	-5.74 ± 0.372	-7.25 ± 0.261
Birth class 31	-	-2.33 ± 1.882	-6.70 ± 1.437	-
Birth class 32	-	-5.82 ± 1.918	-9.27 ± 0.698	-9.26 ± 0.763
Birth class 33	-	-12.55 ± 1.159	-10.30 ± 0.670	-
Ewe birth year 2008 (7 yr)	-	-	-	-1.70 ± 0.248
Ewe birth year 2009 (6 yr)	-1.37 ± 0.475	-	-	-1.71 ± 0.300
Ewe birth year 2010 (5 yr)	-0.94 ± 0.495	-	-	-
Ewe birth year 2011 (4 yr)	-0.59 ± 0.532	-	-	-
Male	n.s.	0.99 ± 0.178	2.01 ± 0.281	0.84 ± 0.207
Average FOO[B]	0.0005 ± 0.0006	0.0061 ± 0.0009	-	0.0041 ± 0.0013
Percentage green[C]	-	-	-	0.22 ± 0.088
Percentage clover[D]	-	-	0.09 ± 0.014	-
Period	-0.29 ± 0.034	-0.32 ± 0.013	-0.31 ± 0.014	-0.24 ± 0.013

[A] Weaning weight constant is for single born, single raised, female progeny. At sites where age of dam was significant, the constant is for 3 year old ewes; [B] Average FOO from birth to weaning; [C] Percentage green at Struan ranged between 85% and 100%; and [D] Percentage clover at Mount Barker ranged.

Birth type and rear type effects on weaning weight were significant at all sites (Table 9), and on average twin born and reared lambs and triplet born reared lambs were 6.9 kg and 10.7 kg lighter than single born and reared lambs. Male lambs were heavier at weaning than female lambs, except for the Hamilton site, and the average differences was 1.4 kg. The age and birth year of the ewe were also significant factors at the Hamilton and Struan sites for weaning weight, and period on FOO treatments was negatively related to weaning weight at all sites at these lambs were younger at weaning.

The effects of FOO during lactation on lamb weaning weights varied between sites, but the combined analysis indicated that on average weaning weight increased curvilinearly ($P < 0.001$) with increasing FOO during lactation. About 30% of the variation in liveweight change between individual progeny was explained by average FOO during lactation. The relationships between FOO and progeny weaning weight differed between progeny sex and rearing type, but none of the interactions between FOO during lactation and progeny sex or rearing type were significant (all $P > 0.05$) for progeny weaning weight. The FOO needed to achieve progeny growth rates in excess of 90% of the maximum (achieved at 2000 kg DM/ha FOO) was 750 kg DM/ha for single born and reared lambs and 950 kg DM/ha for twin born and reared lambs.

At the Struan site there was an effect of percentage green at allocation, so that across the range of percentage green (80 to 100%) there was a 4.2 kg increase in weaning weight, and at the Mount Barker site a 10% increase in the proportion of clover was associated with a 0.90 kg increase in weaning weight. However, in the combined analysis no additional variance in weaning weights of progeny was explained by including these assessments of pasture quality.

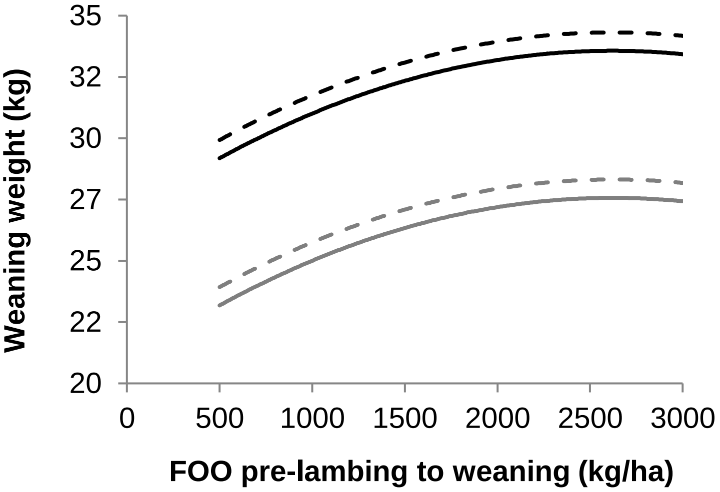

Figure 2. Effect of average feed on offer during lactation on predicted weaning weight of lambs from maternal ewes across four research sites. The data represent single born and reared (black) or twin born and reared (grey) lambs from ewes that maintained liveweight during late pregnancy (solid line) or gained 6 kg during late pregnancy (dashed line).

Lamb survival

At the plot level there were no significant differences between the CS or FOO treatments for lamb survival to marking at any site. This was also the case when all data was combined into a single analysis across sites. Lamb survival was related to lamb birth weight at all sites. At Pigeon Ponds and Mount Barker lamb survival was also significantly associated with birth type. Single and twin born lambs were not significantly different however triplet survival was lower even at similar birth weights. There was very few triplet lambs born at the Hamilton site and on average the birth weight versus survival responses were similar for the single and twin born lambs. There was no significant effect of sex of lamb on survival at Pigeon Ponds, Mount Barker or Hamilton. However at the Struan site, lamb survival was different for males and females, and a significant interaction was found between sex and lamb birth type so that survival for female lambs born as triplets was higher than that of singles and twins (which were not different), while for male lambs, survival was highest for single born lambs and lowest for triplet born lambs. The overall relationship between birth weight and survival from the combined analysis is shown in Fig 2.

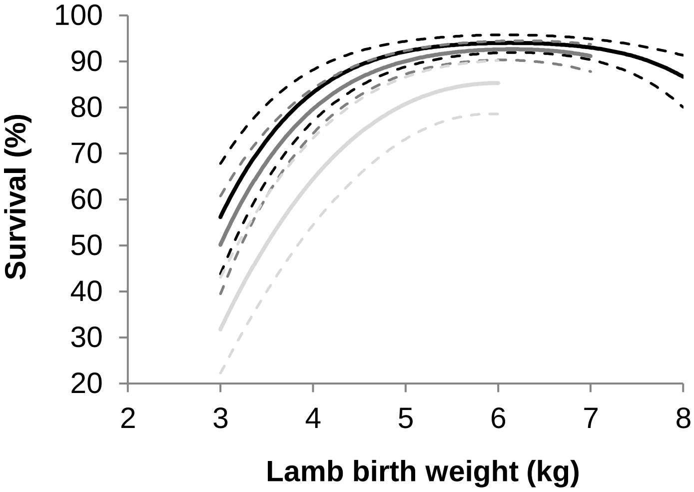

Figure 3. Effect of lamb birth weighy on survival to marking of lambs from maternal ewes across four research sites. The data represent single (black), twin (dark grey) and triplet (light grey) lambs. The dashed lines are the upper and lower limits of confidence (at 95%).

At the Hamilton site, despite no effects at the plot levels between target FOO levels and lamb survival, lamb survival at the individual level was related to actual FOO (Fig. 4). Lamb survival increased ($P<0.05$) as the FOO at lambing increased and the effect was independent of birth weight. At the average birthweight of singles and twins, it was predicted that survival increased by about 5% when FOO increased from 1000 to 2000 kg DM per ha at lambing. This response was not evident at any of the other sites.

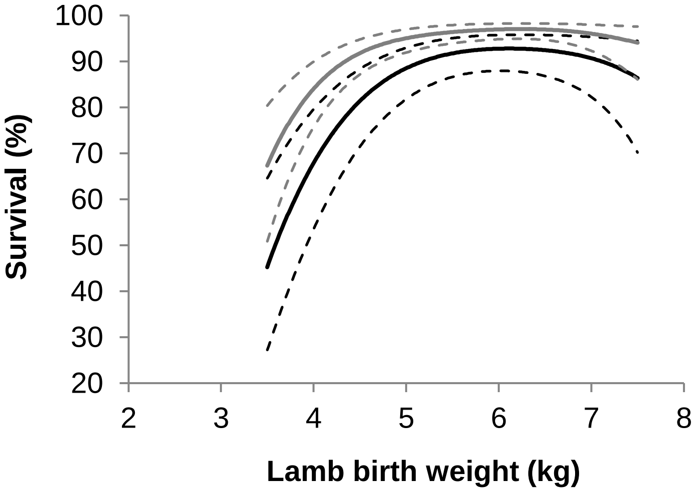

Figure 4. Survival predicted using birth weight for lambs born at the Hamilton site. The black line represents lambs born on when low feed on offer (900 kg DM/ha) and the grey line represents lambs born on when high feed on offer (2400 kg DM/ha). The

data is for single and twin lambs combined and the dashed lines are the upper and lower limits of confidence (at 95%).

Discussion

Increasing the liveweight of non-Merino ewes at joining and their liveweight gain during pregnancy increased lamb birth weights. Across all sites a 10 kg increase in ewe liveweight at joining increased lamb birth weight by 0.20 kg and a 10 kg gain in ewe liveweight during early/mid or late pregnancy increased birth weight by 0.21 kg and 0.33 kg, respectively. On average the birth weight responses to ewe liveweight and liveweight change were of a similar magnitude to that reported using the same ewe genotypes at these sites in the year prior by Hocking-Edwards *et al.* (Experiment 1) and Behrendt *et al.* (Experiment 2) and for other non-Merino (Paganoni *et al.* 2014) and Merino ewes (Oldham *et al*. 2011; Paganoni *et al.* 2014). This overall consistency in the coefficients across studies gives some confidence that the impact of maternal liveweight change on lamb birth weight in non-Merino ewes is similar to that of Merinos, and that these impacts on birth weight could be used in bio-economic modelling to develop optimum liveweight profiles for non-Merino ewes in different environments as undertaken for Merinos (Young *et al.* 2011). However, as non-Merino ewes appear to have the capacity to lose less or gain more weight and condition than Merino ewes under similar grazing conditions (Babiszewski and Hocking-Edwards 2013; Blumer *et al*. 2016; Hocking-Edwards *et al. in press*), the absolute impacts on birth weight of changes in nutritional management may differ for non-Merino and Merino ewes depending on the specific nutritional conditions.

The changes in liveweight of non-Merino ewes during both early-mid and late pregnancy influenced birth weights, and there was no evidence that maternal nutrition during late pregnancy had more predictable impacts on lamb birth weights than nutrition during early-mid pregnancy. This differs to the reviews by Greenwood *et al.* (2009), Kenyon and Blair (2014) and Rooke *et al.* (2015) that suggested that the effect on lamb birth weight of maternal under-nutrition in early to mid-pregnancy appear to be more variable. For all sites the effects of liveweight change in late pregnancy on lamb birth weights were greater that the effects of liveweight change in early and mid-pregnancy, which was consistent with Behrendt *et al.* (*in press*). These findings also confirm those of Taplin and Everitt (1964), Oldham *et al*. (2011) and Paganoni *et al.* (2014) that the effects of poor nutrition in early and mid-pregnancy can be completely overcome by improving nutrition during late pregnancy regardless of ewe breed. This indicates that varying liveweight at lambing will have variable effects on lamb birth weights, depending on the pattern of liveweight change during pregnancy.

The birth weight responses to ewe liveweight change in early-mid or late pregnancy varied between individual sites within year, and from comparing to the data reported by Behrendt *et al.* (Experiment 1), the responses also varied albeit to a lesser extent between years within some sites. In general, ewes at the Pigeon Ponds and Hamilton sites were more responsive within each experiment, but the coefficients to predict birth weight from liveweight change during early-mid and late pregnancy also varied between each experiment at these sites whereas this was not the case at Struan or Mount Barker. The precise reasons for these differences are unknown but are likely to be related to interactions between the genetic base of the ewes and other factors. It is well recognised that ewes differ widely in their responsiveness to nutrition in terms of impacts on foetal (Vonnahme *et al*. 2006) and lamb weight (Ferguson 2012), and further work is needed to identify indicator traits for more resilient flocks as this will influence their optimum liveweight profiles. The variation in coefficients between sites and years may also be related to whether the ewes were gaining or losing maternal weight during the different stages of pregnancy, as it appears that the impact of nutrition above maintenance requirements is more variable (Kenyon and Blair 2014; Rooke *et al.* 2015). Bioeconomic modelling is required to determine if these variations in the coefficients to predict birth weight influence the optimum liveweight and CS profile of Maternal ewes.

There were no significant differences between the FOO treatments for lamb birth weight for single or multiple born lambs at any site. This indicates that manipulating the amount of FOO during the 15 to 20 day period immediately prior to lambing did not significantly influence lamb birth weight and therefore our hypothesis was rejected. Oldham *et al.* (2011) also found no evidence that short term improvements in ewe nutrition during critical windows prior to Day 140 of pregnancy influenced birth weights in Merinos, but there is some evidence that of a few weeks during very late pregnancy could increase lamb birth weights in non-Merino ewes (Holst *et al*. 1986, 1992; Oddy and Holst 1991). The most likely explanation is that potential intake and or relative Intake-Quantity were far greater than expected, such that intake of pastures from the lowest FOO levels during this period which varied from 620 to 1165 kg DM/ha did not differ significantly from that achieved at the higher FOO levels which exceeded 1500 kg DM/ha. It is also possible that any growth differential of the foetus associated with higher FOO levels was not sufficiently large such that its impacts over 15 to 20 days did not result in measurable impacts on lamb birth weights. There was no significant condition score x FOO treatment interaction on lamb birth weight at any site, however the across site analysis provides some evidence that the birth weight of twin lambs from ewes in the low CS treatment did compensate at higher FOO levels. The effects of higher levels of FOO in very late pregnancy to improve birth weights requires further investigation and maybe more relevant to earlier lambing flocks where FOO levels would be lower than the current study unless pastures were deferred.

A lack of impact of ewe CS treatments on birth weights of single lambs, and a much smaller effects of ewe CS at lambing on birth weights of twin lambs compared to the earlier study reported by Behrendt *et al.* (Experiment 1), may also suggest that lambs from low CS ewes did compensate in very late pregnancy regardless of FOO level. In that study a difference in ewe liveweight and CS between extreme treatments of 14.8 kg and 1.1 of a CS changed the birth weight of singles by 0.43 kg and twins by 0.64 kg, whereas in the current study a difference of 9.8 kg and 0.7 of a CS only changed the birth weight of twin lambs by 0.14 kg. The smaller differences in lamb birth weights in the current study can also be attributed partly to a greater proportion of the differences in liveweight at Day 140 of pregnancy being generated in early-mid pregnancy and a lower response in birth weight per kg change in ewe liveweight than the earlier study. Despite this, it is clear that the impacts of adverse nutrition prior to day 140 on lamb birth weights cannot be to totally eliminated by providing higher levels of feed on offer levels during lambing.

Lamb survival was related to lamb birth weight at all sites and the effect of birth type was not significant across all sites indicating that the risk of mortality for singles was not necessarily modified by being born a single or twin in these studies. The shape of the birth weight versus survival responses at each site was remarkable consistent between this study and that reported by Behrendt *et al.* (Experiment 1), and the absence of a birth type effects was consistent with that reported for non-Merino ewes by Paganoni *et al.* (2014) and our own metanalysis (Thompson *et al*., unpublished data) but differs to what occurs in Merinos (Oldham *et al.* 2011). At the plot level there were no significant differences between the CS or FOO treatments for lamb survival to marking at any site in the current study, whereas Behrendt *et al.* (*Experiemnt 1*) reported a linear improvement in survival of multiple born lambs with increasing CS at lambing. A lack of effect of treatments on lamb survival in the current study compared to the earlier study is entirely explained by differences in birth weight. There were minimal effects of treatments on birth weight and even the lightest twins in the current study were heavier than the heaviest twins from the similar ewes the year prior. At the average birth weights at each site in the current study the average rates of survival were 94% for singles and 90% for twins. Further exploration of data is required to determine when nutritional interventions will influence survival, but due to their higher birth weights it is highly likely that survival of lambs from non-Merino ewes will be less sensitive to nutritional conditions.

The effects of CS treatments on lamb weights at marking and weaning varied between sites, but the combined analysis across all four sites indicated single and multiple born lambs from ewes in the low CS groups were 1 to 2 kg lighter at marking and weaning than those from the high CS group. Across all sites a 10 kg increase in ewe liveweight at joining increased lamb weaning weight by 1.4 kg and similarly a 10 kg gain in ewe liveweight during early/mid or late pregnancy also increased weaning weight by 1.2 to 1.5 kg. The amount of FOO during lactation had a larger impact on lamb growth and weaning weight than liveweight change of the ewe during pregnancy, which is consistent with the findings of Coop (1972), Gibb and Treacher (1982) and Thompson *et al.* (2011). The FOO needed to achieve progeny growth rates in excess of 90% of the maximum (achieved at 2000 kg DM/ha FOO) was 750 kg DM/ha for single born and reared lambs and 950 kg DM/ha for twin born and reared lambs. These FOO levels are much lower that those reported by Thompson *et al.* (2011) for Merinos. Futher work is needed to determine if the optimum use of pasture is during late pregnancy or lactation.

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References

Babiszewski E and J. E. Hocking Edwards (2013). Potential industry impact: management of non-Merino ewes. B.LSM.0039, North Sydney.

Behrendt R, van Burgel AJ, Bailey A, Barber P, Curnow M, Gordon DJ, Hocking Edwards JE, Oldham CM and Thompson AN (2011) On-farm paddock-scale comparisons across southern Australia confirm that increasing the nutrition of Merino ewes improves their production and the lifetime performance of their progeny. *Animal Production Science* 51; 805-812.

Behrendt R, Hocking-Edwards JE, Gordon D, Hyder M, Babiszewski E , Kelly M, Cameron F, Byron J, Raeside M , Kearney G and Thompson AN (2017). Reducing maternal nutrition from mid-pregnancy to the end of lambing of non-Merino ewes results in predictable decreases in birth weight and weaning weight. *Animal Production* Science (in preparation).

Blumer SE, Gardner GE, Ferguson MB and Thompson AN (2016) Environmental and genetic factors influence the live weight of adult Merino and Border Leicester-Merino ewes across multiple sites and years. *Animal Production Science* 56 (4); 775-788.

Coop IE, Clark, VR, Claro D (1972) Nutrition of the ewe in early lactation. 1. Lamb growth rate. *New Zealand Journal of Agricultural Research* 15, 203-208.

Curnow M, Oldham CM, Whale JK, Gordon DJ, Rose IJ, Behrendt R, Thompson AN (2011) Successful adoption of new guidelines for the nutritional management of ewes is dependent on the development of appropriate tools and information. *Animal Production Science* 51; 851-856.

Ferguson MB, Thompson AN, Gordon DJ, Hyder MW, Kearney GA, Oldham CM and B. L. Paganoni (2011) The wool production and reproduction of Merino ewes can be predicted from changes in liveweight during pregnancy and lactation. *Animal Production Science* 51; 763-775.

Gibb MJ, Treacher TT (1980) The effect of ewe body condition at lambing on the performance of ewes and their lambs at pasture. *Journal of Agricultural Science, Cambridge* 95, 631-640.

Greenwood PL, Thompson AN and Ford SP (2010). Postnatal consequences on the maternal environment and growth during prenatal life for productivity of ruminants. In: Greenwood, P.L., Bell, A.W., Vercoe, P.E., Viljoen, G.J. (Eds.), Managing the Prenatal Environment to Enhance Livestock Productivity. Springer, Dordrecht, Heidelberg, London, pp.3–36.

Hocking Edwards JE, Copping KJ, Thompson AN (2011) Managing nutrition of twin bearing ewes during pregnancy using Lifetimewool recommendations increases production of twin lambs. *Animal Production Science* 51; 813-820.

Hocking Edwards JE, Babiszewski E, Behrendt R, Gordon D and Thompson AN (2017). Crossbred ewes gain more weight and are fatter than Merino ewes but similar coefficients predict lamb birth weight and survival. *Animal Production Science* (in preparation).

Host PJ, Allan CJ and Gilmour AR (1991). Effect of a restricted diet during mid-pregnancy of ewes on uterine and foetal growth and lamb birth weights. *Australian Journal of Agricultural Research.*

Jefferies BC (1961) Body condition scoring and its use in management. *Tasmanian Journal of Agriculture* 32; 19–21.

Kenyon PR and Blair HT (2014) Foetal programming in sheep – Effects on production. *Small Ruminant Research* 118; 16–30.

Oddy VH and Holst PJ (1991). Maternal foetal adaptation to mid pregnancy feed restriction in single bearing ewes. *Australian Journal of Agricultural Research* 42; 969-978.

Oldham CM, Thompson AN, Ferguson MB, Gordon DJ, Kearney GA and Paganoni BL (2011) The birth weight and survival of Merino lambs can be predicted from the profile of liveweight change of their mothers during pregnancy. *Animal Production Science* 51; 776-783.

Paganoni BL, Ferguson MB, Kearney GA, Thompson AN (2014) Increasing weight gain during pregnancy results in similar increases in lamb birth weights and weaning weights in Merino and non-Merino ewes regardless of sire type. *Animal Production Science* 54; 727–735.

Rooke JA, Arnott G, Dwyer CM and Rutherford KMD (2015). The importance of the gestation period for welfare of lambs: maternal stressors and lamb vigour and wellbeing. *The Journal of Agricultural Science* 153; 497-519.

Taplin DE and Everitt GC (1964) The influence of prenatal nutrition on postnatal performance of Merino lambs. *Proceedings of the Australian Society of Animal Production* 5; 72–81.

Thompson AN, Doyle PT, Grimm M (1994) Effects of differential grazing of annual pastures in spring on sheep and wool production. *Australian Journal of Agricultural Research* 45; 367-89.

Thompson AN, Ferguson MB, Campbell A, Gordon DJ, Kearney GA, Oldham CM, Paganoni BL (2011) Improving the nutrition of Merino ewes during pregnancy and lactation increases weaning weight and survival of progeny but does not affect their mature size. *Animal Production Science* 51; 784-793.

Thompson AN, Ferguson MB, Gordon DJ, Kearney GA, Oldham CM, Paganoni BL (2011). Improving the nutrition of Merino ewes during pregnancy increases the fleece weight and reduces the fibre diameter of their progeny's wool during their lifetime and these effects can be predicted from the ewe's liveweight profile. *Animal Production Science* 51; 794-804.

Trompf JP, Gordon DJ, Behrendt R, Curnow M, Kildey L, Thompson AN (2011) Participation in Lifetime Ewe Management results in changes in stocking rate, ewe management and reproductive performance on commercial farms. Animal Production Science 51; 866–872.

Vonnahme K A, Hess BW, Nijland NJ, Nathanielsz PW and Ford SP (2006) Placentomal differentiation may compensate for maternal nutrient restriction in ewes adapted to harsh range conditions. *Journal of Animal Sci*ence 84; 3451–3459.

Wheeler JL, Reardon TF, Hedges DA, Rocks RL (1971) The contribution of the conceptus to weight change in pregnant Merino ewes at pasture. *Journal of Agricultural Science* 76, 347–353.

Young JM, Thompson AN, Curnow M and Oldham CM (2011) Whole-farm profit and the optimum maternal liveweight profile of Merino ewe flocks lambing in winter and spring are influenced by the effects of ewe nutrition on the progeny's survival and lifetime wool production. *Animal Production Science* 51; 821–833.

Young JM, Trompf J, Thompson AN (2014) The critical control points for increasing reproductive performance can be used to inform research priorities. *Animal Production Science* 54(6); 645-655.

Young JM, Thompson AN, Curnow M, Oldham CM and Behrendt R (2016) Economic value of pregnancy scanning and optimum management of dry, single and twin bearing Merino ewes. *Animal Production Science* 56 (4); 669-678.

13.5 Appendix 5 – Bioeconomic modelling and preliminary guidelines using the research site coefficients

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Executive Summary

Following the preliminary analysis to develop guidelines for Maternal producers using the INF coefficients relating ewe liveweight profile to lamb birth weights, survival and growth, 'Lifetime Maternals' was established to refine relationships and enable improved guidelines to be developed. This report presents the economic analysis done using the coefficients generated from the 2014 sites of the 'Lifetime Maternals' project. The Hamilton version of MIDAS was used as the modelling tool for this project because it represents the whole flock and it includes a powerful feed budgeting module that optimises animal and pasture management across the whole farm. MIDAS calculates the profitability of the whole flock based on the productivity of each class of stock, commodity prices and the farm carrying capacity calculated in the detailed feed budget. This makes MIDAS an efficient tool to examine different nutrition strategies for a flock.

The optimum profile identified for single and twin bearing ewes is not impacted by the different coefficient sets generated at the different sites and the impact of the different coefficients sets on the triplet and dry ewe patterns are minor. The optimum patterns identified were for the ewes to join at 60-kg, maintain live weight in early pregnancy, twins to gain 6-kg in late pregnancy, singles to gain 3-kg in late pregnancy, triplets to lose 3-kg in late pregnancy and the dry's to either maintain or gain 3kg. There was little difference in the results for the different coefficient sets and this indicates that the optimal management is not varying with the different genotypes that have been evaluated at the research sites. However, the lack of difference in the optimal management of the triplet bearing ewes using the Pigeon Ponds coefficients requires further investigation because the result is unexpected. There is a difference between the model equations and the measured liveweight change at different FOO and supplement levels. This along with the difference in the optimum profiles when the post weaning recovery of the ewes is adjusted indicates that the feed budgeting equations need to be examined for the maternal breeds. The variation is expected to be associated with the estimation of feed intake because this is the component of the equations that is least robust.

The analysis could also be improved with the inclusion of information about the impact of FOO levels at lambing and during lactation on lamb survival and weaning weights. This information should be available after the statistical analysis of the 2015 research results which included treatments on FOO levels during these periods. FOO levels might be important if high FOO during lambing can increase survival at low birth weight, because that would mean deferring pasture till lambing could compensate for weight loss prior to lambing. A similar effect could also occur if FOO during lactation can increase weaning weight and allow greater weight loss during pregnancy. Another question of practical significance that

needs investigating is whether ewes should be mated heavier if seasonal conditions offer opportunity for ewes to gain more weight in the post weaning period. That is, is the current optimum to join at 60-kg due to it being more profitable to utilise extra feed to run more ewes rather than have the ewes gain more weight or is it due to the post weaning cost of recovering the weight lost during the feed limited period of the year. The economic analysis will be expanded to cover other regions when the final coefficients are available after the results from the 2015 research year are completed.

Background

Based on demand from maternal producers following the success of the Lifetime Ewe Management (LTEM) training course an analysis to determine nutritional guidelines for Maternal breeds was carried out (Young 2014) using production coefficients derived from the statistical analysis of the Sheep CRC Information Nucleus flocks (INF) (Paganoni *et al.* 2014). The optimum profile identified in that analysis was: (1) Aim for CS 3 at joining; (ii) Maintain weight to mid-pregnancy and (iii) Gain weight in late pregnancy. However, there were questions over the robustness of these conclusions for four reasons:

The analysis was based on a dataset in which the variation in ewe liveweight profile was generated from ewes that were run together on a common nutritional treatment at each site. The ewes had all been managed with the aim of following the LTEM guidelines and the lack of nutritional treatments across the groups meant there was no rigor in the analysis.

It was expected from the Lifetimewool trial that FOO during lactation would affect weaning weight and weaning weight was a major driver of the profitability of the maternal sheep systems. Measurements of FOO at lambing and during lactation were not available in the INF dataset.

The conclusion from the analysis was to have single bearing ewes gaining weight in late pregnancy. Anecdotally, this would be expected to be associated with high levels of dystocia but this wasn’t born out in the INF dataset. This needed further investigation to determine if it is realistic.

The optimum pattern was to maintain or gain weight from joining to lambing and this was partly affected by the feed cost associated with the ewes gaining weight post weaning. This highlights the question whether the feed budgeting relationships used in MIDAS accurately reflect the maternal breeds.

Therefore, a research programme similar to Lifetimewool but targeted to maternal breeds commenced in 2014 to be a source of the biological relationships required to develop a more robust set of management guidelines.

Methods

A research trial is being carried out at four sites across Australia (Hamilton, Pigeon Ponds, Struan and WA) to collect the information necessary to develop coefficients relating ewe liveweight and condition score profile prior to joining and during pregnancy on lamb birth weight, survival and weaning weight. To date the measurements from 2014 have been statistically analysed and coefficients have been generated for each research site. This economic analysis was carried out using the Hamilton version of the MIDAS model (Young *et al.* 2011). Only one region has been completed to date and further regions will be included when the final relationships are available after the 2015 research data is analysed.

Assumptions about progeny production

For this analysis the birth weight, survival and weaning weight of the progeny was adjusted based on the liveweight profile of the ewes. The adjustments have been based on coefficients derived from the statistical analysis of each research site (Gavin Kearney *pers. comm.*). A summary of the coefficients developed across all sites are provided in Table 1, 2 and 3. The coefficients were derived from the maternal live weight and changes in maternal live weight during pregnancy, the correction to conceptus free liveweight was based on the Wheeler (1971) equation.

Table 1. Coefficients fitted in the statistical model that explains progeny birth weight from Ewe liveweight (LW) at joining (kg) and LW change (kg) during pregnancy. Cells with a grey highlight did not include a coefficient from the statistical analysis. The birth weight of the triplet born lambs at Pigeon Ponds was assumed to be the same as the twin born lambs.

	Site	Hamilton	Pigeon Ponds	SA	WA
Constant		3.7	3.527	3.596	5.166
LW	Joining	0.03088	0.03617	0.03871	0.01287
LWC	Join-90	0.03065	0.04288	0.02663	0.02475
	90-Lamb	0.04712	0.05762	0.03736	0.032
Sex	Male	0.2885	0.3028	0.3243	0.4033
EweAge	2	0	0		
	3	-0.00033	0		
	4	0.28297	-0.04117		
	5	0.04375	0.12742		
	6	0	0		
	7				
Birth type	1	0	0	0	0
	2	-1.414	-1.341	-1.416	-0.761
	3	-2.628	-1.341	-2.305	-1.127

Table 2. Coefficients fitted in the statistical model that explains lamb survival from birth weight and birth type. Equation for survival: Survival = 100 / (1 + EXP(-y)) where y = value predicted using above coefficients.

	Site	Hamilton	Pigeon Ponds	SA	WA
Constant		-7.457	-7.574	-4.928	-5.994
Sex	Male				0
	Female				0.5068
Birth type	1	0		0	
	2	-0.9368		-0.957	
	3	-0.9591		-0.8643	
Birth wt	kg	3.828	3.56	2.761	2.553
	kg^2	-0.325	-0.3008	-0.2318	-0.1967

Table 3. Coefficients fitted in the statistical model that explains weaning weight from Ewe liveweight (LW) at joining (kg) and LW change (kg) during pregnancy and lactation. BT.RT cells with a grey highlight didn't include a coefficient from the statistical analysis but a zero value was not sensible. The Pigeon Ponds value is based on the value from twins. The WA values are based on scaling the BT.RT 33 value.

	Site	Hamilton	Pigeon Ponds	SA	WA
Constant		21.78	26.06	13.16	30.24
LW	Joining	0.1437	0.1784	0.2482	0.0996
LWC	Join-90	0.1793	0.1528	0.1733	0.1949
	90-Lamb	0.07047	0.1821	0.115	0.0689
	(90-L)^2				
	L-W		0.09216	-0.04837	
	(L-W)^2		-0.008553	-0.01131	
Sex	Male	1.0225	1.1539	0.8737	0
	Female	0	0	0	-2.117
BT.RT	11	0	0	0	0
	21	-3.5	-4.392	-3.279	-2.785
	22	-8.225	-8.349	-7.244	-4.69
	31	-7.893	-4.392	-4.894	-3.168
	32	-11.645	-8.349	-8.244	-4.773
	33	-14.105	-8.349	-7.405	-5.353
Cycle	1st			1.6463	
	2nd			0	
Year	2009			0	
	2010			1.6494	
	2011			1.0854	
Sire	110449		0		
	120480		-1.1454		
Sire.BT	120480.Twin				
Sire.BTRT	120480.21		0.0428		
	120480.22		1.2736		

* The adjusted constant for Pigeon Ponds is based on assuming half of the animals are from the first sire and half from the second sire. For SA it is assumed that two thirds of the progeny are concieved in the first cycle and one third in the second cycle and that they are evenly spread across the 3 years.

A comparison of the survival coefficients shows some variation between the sets of coefficient from the different sites. The WA & Pigeon Ponds sites are generally more responsive to birth weight, however, all sites have a similar maximum survival levels (Figures 1, 2 and 3).

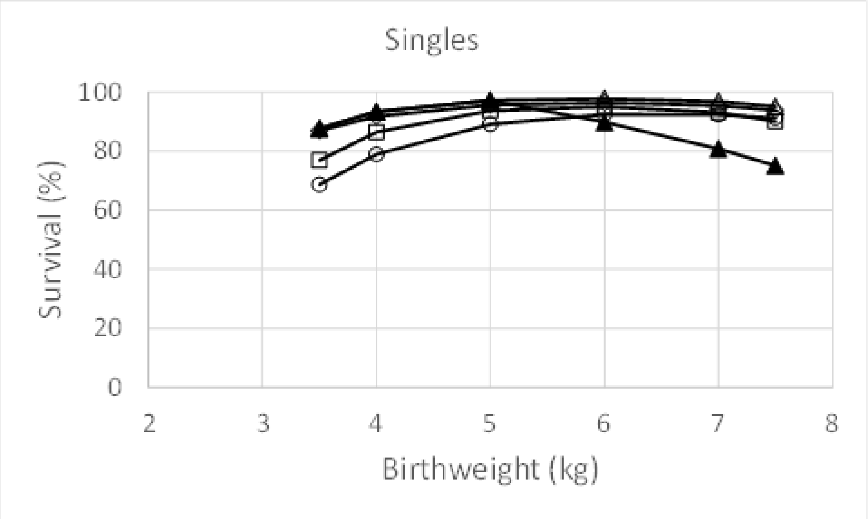


Figure 1. Relationship between birth weight and survival for single born lambs for each of the research site coefficient sets (∆ Hamilton, ▲ Hamilton with dystocia adjustment, □ Pigeon Ponds, ◊ SA, ○ WA).

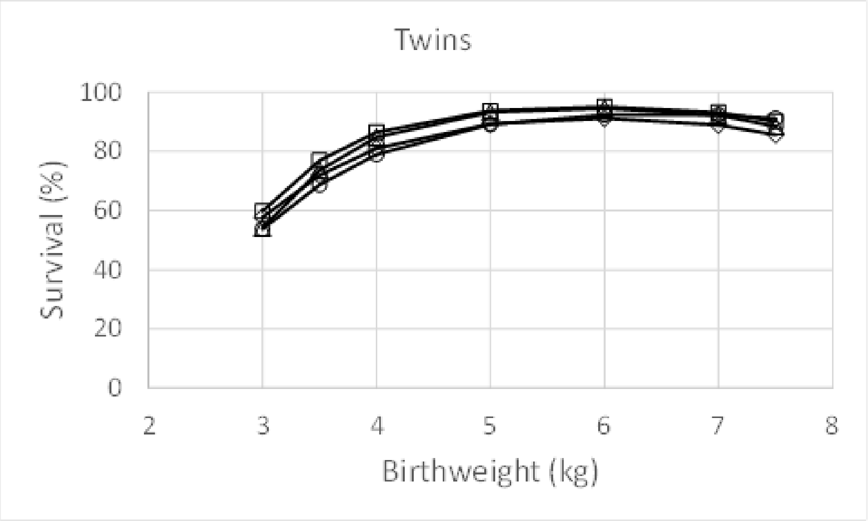


Figure 2. Relationship between birth weight and survival for twin born lambs for each of the research site coefficient sets (∆ Hamilton, □ Pigeon Ponds, ◊ SA, ○ WA).

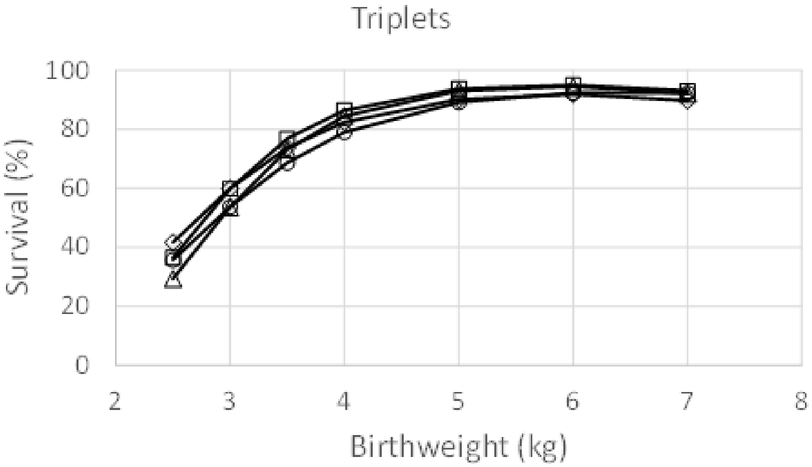


Figure 3. Relationship between birth weight and survival for triplet born lambs for each of the research site coefficient sets (∆ Hamilton, □ Pigeon Ponds, ◊ SA, ○ WA).

MIDAS

The Hamilton EverGraze version of MIDAS (Young *et al.* 2004a) has been used to calculate the profitability for a range of nutrition profiles for reproducing ewes in the Hamilton district of Victoria. MIDAS is a computer model used to assess the impact of change in a farming system. It describes the biological relationships of a representative farm. This information is used to estimate the profitability of particular enterprises or management strategies. MIDAS was selected as the modelling tool for the economic component of this project because it represents the whole flock and it includes a powerful feed budgeting module that optimises animal and pasture management across the whole farm. This makes MIDAS an efficient tool to examine different nutrition strategies for a flock.

MIDAS calculates the profitability of the whole flock based on the productivity of each class of stock, commodity prices and the farm carrying capacity calculated in the detailed feed budget. Being an optimizing model it calculates the optimum stocking rate and optimum rate of grain feeding that will maximize profitability while achieving the targets specified for the ewes. The model also accounts for the change in ewe energy requirements that result from increasing lambing percentage and the number of ewes pregnant or lactating with singles, twins or triplets when ewe nutrition is altered. Account is also taken of the weaning weight of singles, twin and triplet born lambs and the amount of feeding required to get each rear class to a saleable weight.

The feed budgeting module in MIDAS is based on the energy requirement and intake capacity equations of the Australian Feeding Standards (SCA 1990), these are also the basis of the GrazFeed model. The feed year is divided into 10 periods and the feed budget is calculated in MJ of ME required per day for each period. With different targets for ewe nutrition the metabolisable energy (ME) requirement for the ewes can vary for each of the 10 periods. The model then calculates whether the most profitable way to achieve the required nutrition for the flock is by adjusting stocking rate, adjusting grain feeding or adjusting the grazing management of pastures and varying the severity of grazing at different times of the year to alter the pasture production profile.

MIDAS is a steady state model, so an implicit assumption is that any management change has been applied for sufficient time for the impact to have permeated the entire flock. Also, the sheep of one age group must finish the year at the same weight as the next age group started the year. Therefore the optimum profile cannot lose weight over the course of the year unless the ewes are losing weight over their lifetime.

The supplementary feeding rates identified as the most profitable are much higher than are practiced by farmers. A major part of the reason for the difference is that MIDAS works on an average season and doesn't consider variation between seasons. To represent this lower profit expectation and reduce the level of supplementary feeding back to commercial reality, the cost of supplement has been artificially increased. The cost added was calculated on a cost of 5.1c/MJ of ME.

The model farm

The following section outlines the main assumptions underpinning this analysis and the management of the property for the 'standard' ewe nutrition strategy.

Land management units - The model represents a 'typical' farm in the Hamilton region in south west Victoria. The total area of the farm is 1000ha and is comprised of 3 land management units (LMUs; Table 4).

Table 4. Description and area of each Land Management Unit on the model farm.

Land Management Unit	Area (ha)	Description
Ridges	200	Well drained gravely soils at tops of hills.
Mid slopes	600	Moderately drained loams in the mid slopes
Flats	200	Clay soils in lower slopes that are often waterlogged.

Animal production system - The analysis is based on a maternal ewe genotype that is purchased as an 18 month old animal and all ewes are mated to a terminal sire. Lambing is July/August and shearing in March. All offspring are sold as finished lambs in December at 4.5 months of age. The average production for the genotype is outlined in Table 5. All ewes are scanned and separated into groups based on their litter size. Each group can then be offered differential nutrition.

Table 5. Summary of production assumptions for the sheep flock. The values represent the ewe flock averages (2, 3, 4, 5 and 6 year old) for ewes that are joined at 60kg liveweight and maintained through to lambing.

Standard reference weight (kg)	60
Fleece weight (clean kg/hd)	2.5
Mean fibre diameter (μm)	27
Scanning rate (%)	158
Weaning rate (%)	142

Pasture production - The pasture production is based on a highly productive perennial ryegrass and sub-clover stand typical of pastures on farms in the top 20% of the monitor farm project. This pasture is grown on all land management units. The growth rate of the pasture has been based on simulations using the GrassGro model with climate data from the Hamilton weather station (Steve Clark *pers comm.*).

Farm management

Table 6. Production and management parameters for the ‘standard’ ewe nutrition profile (Join at 60-kg and maintain to lambing).

Profit ($/ha)	644
Number of ewes	10,642
Stocking rate (DSE/WGH)*	20.7
Supplementary feeding (kg DSE)	28
Supplementary feeding (t)	558
Flock structure (% ewes)	100
Sale age of CFA ewes	6.5
But in age of you ewes	2
Scanning (%)	146
Lambing (%)	133
Pasture growth (t/ha)	10.6
Pasture utilization (%)	53
Time of lambing	19 Jul-22 Aug

* Stocking rate calculated using DSE ratings as outlined in the Farm Monitor Project, Dec 2001

The liveweight profiles - Twenty four different liveweight profiles have been evaluated in this analysis for the dry, single, twin and triplet bearing ewes. Two of the 24 patterns evaluated for the dry’s differ from the equivalent pattern evaluated for the reproducing ewes during late pregnancy. The profiles examined vary in the amount of liveweight lost from joining through to mid pregnancy and then the amount of liveweight change from mid pregnancy to lambing (Figure 4). There are 3 alternate rates of liveweight loss to mid pregnancy (no loss, lose 3-kg and lose 6-kg) and 4 levels of liveweight change to lambing. For the reproducing ewes the 4 levels are gain 6-kg, gain 3-kg, maintain and lose 3-kg. For the dry ewes the 4 levels are gain 3-kg, maintain, lose 3-kg and lose 6-kg. The selection of the 24 patterns allows comparison of the effects on profitability of varying condition at joining, varying rate of loss of condition after joining and the rate of gain in condition prior to lambing. Each nutrition strategy examined has a similar pattern that varies in one of the above factors. This pairing of patterns allows the cost or benefit of varying the CS targets of ewes at different times of the reproductive cycle.

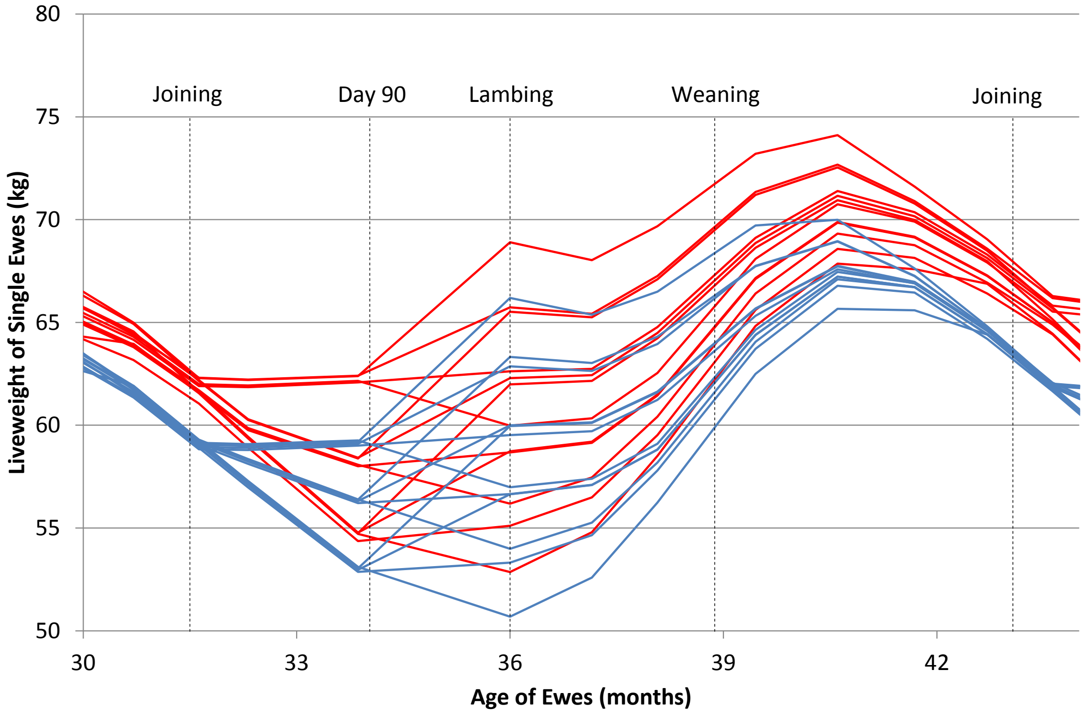


Figure 4. The 24 nutrition profiles examined in MIDAS.

For each profile the energy demands and the resulting production of the ewes was simulated using the MIDAS simulation spread sheet. The production levels of the progeny were adjusted as described in the previous section. Table 10 outlines the calculated energy demand of the ewes and tables 7, 8 and 9 are the estimated change in ewe and progeny production for each of the different profiles.

Starting and finishing at a lower condition requires less energy for the entire year. Comparing the 'Join at 60-kg, maintain to lambing' with 'Join at 63-kg, maintain to lambing' the lower LW pattern requires 0.42 MJ/d, 0.45 MJ/d, 0.81 MJ/d and 0.47 MJ/d less during the periods joining to day 90, day 90 to lambing, lambing to weaning and weaning to next joining respectively. This is a reduction in the total energy requirement of 192 MJ for the year. Losing condition after joining reduces the energy requirement during that period but increases it in a later period depending on when the condition is regained (either before lambing or from lambing to next joining). Losing 3-kg and regaining it before lambing requires approximately 3 7MJ more energy than maintaining weight through the entire period because of the metabolic inefficiency of losing and then gaining condition – that is, gaining weight requires more energy than losing weight generates. However, losing 3-kg and not regaining it until after lambing requires approximately 49 MJ less energy than maintaining through to lambing. This reduction in energy requirement is because the inefficiency described above is outweighed by the saving in maintenance requirement because the animal is lighter for an extended period.

Starting and finishing at a lower (or higher) condition score also affects number of lambs conceived, progeny survival and ewe wool production. The number of lambs conceived is proportional to condition at joining and ewe wool cut is closely correlated to energy intake so nutrition targets that require more energy produce more wool. Progeny birth weight, survival and weaning weight are closely related to condition of the ewes at lambing, the higher the condition the higher the production. Each of these progeny measures are fine-tuned depending on whether condition was lost and then regained from joining to lambing or maintained throughout (see Table 2.7, 2.8 & 2.9).

Table 7. Scanning percentage and weaning percentage for ewes that follow each of the 24 different profiles. Values are calculated for each of the coefficient sets. Note: Scanning percentage is not altered by the research coefficients.

LW profile	Scan %	Weaning Percentage			
		Hamilton (%)	Pigeon Ponds (%)	SA (%)	WA (%)
63,0,+6	152.3	142.0	144.5	139.5	139.1
63,0,+3	152.2	140.9	144.2	139.3	138.9
63,0,0	151.6	139.1	143.0	138.2	137.8
63,0,-3	151.2	137.1	141.7	137.1	136.7
63,-3,+6	151.5	140.7	143.5	138.6	138.0
63,-3,+3	151.5	139.4	143.1	138.2	137.8
63,-3,0	150.4	136.4	140.7	136.2	135.8
63,-3,-3	150.2	134.2	139.1	134.9	134.7
63,-6,+6	150.5	138.8	141.9	137.1	136.5
63,-6,+3	150.4	137.1	141.0	136.4	136.0
63,-6,0	149.4	133.5	138.0	134.0	133.7
63,-6,-3	149.6	130.9	136.0	132.5	132.3
60,0,+6	146.2	136.2	138.5	133.9	133.6
60,0,+3	146.2	135.1	138.1	133.5	133.2
60,0,0	146.0	133.3	137.0	132.5	132.4
60,0,-3	146.2	131.5	135.8	131.7	131.6
60,-3,+6	146.4	135.5	138.2	133.6	133.2
60,-3,+3	146.2	134.1	137.4	132.9	132.7
60,-3,0	146.0	131.7	135.7	131.5	131.4
60,-3,-3	146.0	129.3	133.9	130.1	130.1
60,-6,+6	146.1	134.0	136.9	132.5	132.0
60,-6,+3	146.0	132.3	136.0	131.7	131.5
60,-6,0	145.7	129.0	133.3	129.6	129.6
60,-6,-3	145.9	125.9	130.7	127.7	127.7

Table 8. Birthweight and survival of single, twin and triple lambs born to ewes following each of the 24 different profiles. Values are calculated for each of the coefficient sets.

LW profile	Hamilton BW/Survival			Pigeon Ponds BW/Survival			SA BW/Survival			WA BW/Survival		
	Single (kg/%)	Twins (kg/%)	Triplets (kg/%)	Single (kg/%)	Twins (kg/%)	Triplets (kg/%)	Single (kg/%)	Twins (kg/%)	Triplets (kg/%)	Single (kg/%)	Twins (kg/%)	Triplets (kg/%)
63,0,+6	6.2 / 97.8	4.8 / 91.9	3.5 / 73.6	6.3 / 94.8	5.0 / 93.6	6.3 / 94.8	6.4 / 96.2	5.0 / 89.3	4.1 / 83.8	6.0 / 92.3	5.2 / 90.2	4.8 / 88.2
63,0,+3	6.0 / 97.8	4.6 / 91.0	3.4 / 69.0	6.2 / 94.9	4.8 / 92.9	6.2 / 94.9	6.3 / 96.3	4.9 / 88.8	4.0 / 82.4	5.9 / 92.2	5.1 / 89.7	4.7 / 87.5
63,0,0	5.9 / 97.8	4.5 / 90.0	3.3 / 64.0	6.0 / 95.0	4.7 / 92.1	6.0 / 95.0	6.2 / 96.3	4.8 / 88.2	3.9 / 80.8	5.8 / 92.0	5.0 / 89.3	4.7 / 86.8
63,0,-3	5.8 / 97.8	4.4 / 88.9	3.1 / 59.3	5.8 / 95.0	4.5 / 91.2	5.8 / 95.0	6.1 / 96.4	4.7 / 87.6	3.8 / 79.3	5.7 / 91.8	4.9 / 88.8	4.6 / 86.1
63,-3,+6	6.1 / 97.8	4.7 / 91.4	3.4 / 70.8	6.2 / 94.9	4.9 / 93.2	6.2 / 94.9	6.3 / 96.3	4.9 / 88.9	4.0 / 82.8	5.9 / 92.2	5.1 / 89.9	4.8 / 87.7
63,-3,+3	5.9 / 97.8	4.5 / 90.4	3.3 / 65.7	6.0 / 95.0	4.7 / 92.3	6.0 / 95.0	6.2 / 96.3	4.8 / 88.3	3.9 / 81.2	5.8 / 92.0	5.0 / 89.3	4.7 / 86.9
63,-3,0	5.8 / 97.8	4.4 / 88.9	3.1 / 59.4	5.8 / 95.0	4.5 / 91.1	5.8 / 95.0	6.1 / 96.4	4.7 / 87.6	3.8 / 79.1	5.7 / 91.8	4.9 / 88.7	4.6 / 86.0
63,-3,-3	5.7 / 97.8	4.2 / 87.8	3.0 / 54.7	5.7 / 95.0	4.4 / 90.1	5.7 / 95.0	6.0 / 96.4	4.6 / 87.0	3.7 / 77.7	5.6 / 91.6	4.9 / 88.3	4.5 / 85.3
63,-6,+6	6.0 / 97.8	4.6 / 90.7	3.3 / 67.3	6.1 / 95.0	4.7 / 92.5	6.1 / 95.0	6.3 / 96.3	4.8 / 88.5	3.9 / 81.5	5.8 / 92.1	5.1 / 89.5	4.7 / 87.1
63,-6,+3	5.8 / 97.8	4.4 / 89.4	3.2 / 61.5	5.9 / 95.0	4.5 / 91.5	5.9 / 95.0	6.1 / 96.4	4.7 / 87.8	3.8 / 79.7	5.7 / 91.9	5.0 / 88.9	4.6 / 86.2
63,-6,0	5.7 / 97.8	4.2 / 87.8	3.0 / 54.9	5.7 / 95.0	4.3 / 90.0	5.7 / 95.0	6.0 / 96.4	4.6 / 86.9	3.7 / 77.5	5.6 / 91.6	4.8 / 88.2	4.5 / 85.2
63,-6,-3	5.5 / 97.7	4.1 / 86.5	2.9 / 49.8	5.5 / 94.8	4.2 / 88.8	5.6 / 94.8	5.9 / 96.4	4.5 / 86.3	3.6 / 75.9	5.5 / 91.4	4.8 / 87.7	4.4 / 84.4
60,0,+6	6.1 / 97.8	4.7 / 91.5	3.5 / 71.5	6.2 / 94.9	4.9 / 93.4	6.3 / 94.9	6.3 / 96.3	4.9 / 88.9	4.0 / 82.7	5.9 / 92.3	5.2 / 90.1	4.8 / 88.0
60,0,+3	5.9 / 97.8	4.5 / 90.5	3.3 / 66.4	6.1 / 95.0	4.7 / 92.6	6.1 / 95.0	6.2 / 96.3	4.8 / 88.3	3.9 / 81.0	5.8 / 92.1	5.1 / 89.6	4.7 / 87.3
60,0,0	5.8 / 97.8	4.4 / 89.2	3.2 / 60.5	5.9 / 95.0	4.5 / 91.5	5.9 / 95.0	6.1 / 96.4	4.7 / 87.6	3.8 / 79.1	5.7 / 91.9	5.0 / 89.0	4.6 / 86.4
60,0,-3	5.7 / 97.8	4.3 / 88.1	3.1 / 55.6	5.7 / 95.0	4.4 / 90.5	5.7 / 95.0	6.0 / 96.4	4.6 / 87.0	3.7 / 77.6	5.7 / 91.7	4.9 / 88.5	4.5 / 85.7
60,-3,+6	6.0 / 97.8	4.6 / 91.0	3.4 / 68.6	6.1 / 95.0	4.8 / 92.9	6.1 / 95.0	6.3 / 96.3	4.8 / 88.5	4.0 / 81.7	5.9 / 92.2	5.1 / 89.7	4.7 / 87.5
60,-3,+3	5.9 / 97.8	4.4 / 89.8	3.2 / 63.0	5.9 / 95.0	4.6 / 91.9	5.9 / 95.0	6.1 / 96.4	4.7 / 87.8	3.8 / 79.9	5.8 / 92.0	5.0 / 89.2	4.6 / 86.7
60,-3,0	5.7 / 97.8	4.3 / 88.3	3.1 / 56.7	5.8 / 95.0	4.4 / 90.6	5.8 / 95.0	6.0 / 96.4	4.6 / 87.0	3.7 / 77.8	5.7 / 91.8	4.9 / 88.6	4.5 / 85.8
60,-3,-3	5.6 / 97.8	4.2 / 86.9	3.0 / 51.3	5.6 / 94.9	4.3 / 89.4	5.6 / 94.9	5.9 / 96.4	4.5 / 86.3	3.6 / 76.1	5.6 / 91.5	4.8 / 88.0	4.5 / 85.0
60,-6,+6	5.9 / 97.8	4.5 / 90.2	3.3 / 64.8	6.0 / 95.0	4.6 / 92.1	6.0 / 95.0	6.2 / 96.4	4.8 / 88.0	3.9 / 80.3	5.8 / 92.0	5.0 / 89.3	4.7 / 86.8
60,-6,+3	5.7 / 97.8	4.3 / 88.8	3.1 / 58.8	5.8 / 95.0	4.5 / 90.9	5.8 / 95.0	6.0 / 96.4	4.6 / 87.3	3.7 / 78.4	5.7 / 91.8	4.9 / 88.7	4.6 / 86.0
60,-6,0	5.6 / 97.8	4.2 / 87.1	3.0 / 52.1	5.6 / 94.9	4.3 / 89.4	5.6 / 94.9	5.9 / 96.4	4.5 / 86.4	3.6 / 76.1	5.6 / 91.5	4.8 / 88.0	4.5 / 85.0
60,-6,-3	5.5 / 97.7	4.1 / 85.5	2.9 / 46.6	5.5 / 94.7	4.1 / 87.9	5.5 / 94.8	5.8 / 96.4	4.4 / 85.6	3.5 / 74.3	5.5 / 91.3	4.7 / 87.4	4.4 / 84.1

Table 9. Average weaning weight and proportion of single, twin and triple born lambs at weaning from ewes following each of the 24 different profiles. Values are calculated for each of the coefficient sets. Weaning weight is average of the rear types for the multiple born animals.

LW profile	Hamilton WWt/Proportion			Pigeon Ponds WWt/Proportion			SA WWt/Proportion			WA WWt/Proportion		
	Single (kg/%)	Twins (kg/%)	Triplets (kg/%)	Single (kg/%)	Twins (kg/%)	Triplets (kg/%)	Single (kg/%)	Twins (kg/%)	Triplets (kg/%)	Single (kg/%)	Twins (kg/%)	Triplets (kg/%)
63,0,+6	33.4 / 33	25.9 / 64	20.4 / 3	40.5 / 30	32.8 / 64	32.8 / 5	33.1 / 34	26.6 / 62	26.5 / 4	37.2 / 33	33.2 / 63	32.5 / 4
63,0,+3	33.0 / 34	25.5 / 64	20.1 / 2	40.0 / 31	32.3 / 64	32.3 / 5	32.6 / 35	26.1 / 61	26.1 / 4	37.0 / 33	32.9 / 62	32.2 / 4
63,0,0	32.6 / 35	25.2 / 63	19.8 / 2	39.4 / 32	31.8 / 63	31.8 / 5	32.0 / 36	25.6 / 61	25.6 / 4	36.7 / 34	32.7 / 62	32.0 / 4
63,0,-3	32.2 / 37	24.9 / 62	19.5 / 2	38.9 / 33	31.3 / 62	31.3 / 5	31.5 / 37	25.1 / 60	25.1 / 3	36.5 / 35	32.5 / 61	31.8 / 4
63,-3,+6	32.7 / 34	25.2 / 64	19.7 / 2	40.1 / 31	32.4 / 64	32.4 / 5	32.3 / 35	25.9 / 61	25.8 / 4	36.6 / 34	32.5 / 62	31.8 / 4
63,-3,+3	32.3 / 35	24.8 / 63	19.4 / 2	39.4 / 32	31.8 / 63	31.8 / 5	31.8 / 36	25.4 / 61	25.3 / 4	36.3 / 34	32.2 / 62	31.6 / 4
63,-3,0	31.8 / 37	24.4 / 62	19.0 / 1	38.7 / 33	31.2 / 61	31.2 / 5	31.1 / 37	24.7 / 60	24.7 / 3	36.0 / 35	31.9 / 61	31.3 / 4
63,-3,-3	31.4 / 38	24.1 / 61	18.7 / 1	38.2 / 34	30.8 / 61	30.8 / 5	30.5 / 38	24.1 / 59	24.0 / 3	35.8 / 36	31.8 / 61	31.1 / 4
63,-6,+6	32.0 / 35	24.5 / 63	19.1 / 2	39.5 / 32	31.9 / 63	31.9 / 5	31.6 / 36	25.1 / 60	25.1 / 3	35.9 / 34	31.8 / 61	31.2 / 4
63,-6,+3	31.5 / 36	24.1 / 62	18.7 / 2	38.9 / 33	31.3 / 62	31.3 / 5	30.9 / 37	24.5 / 60	24.5 / 3	35.6 / 35	31.6 / 61	30.9 / 4
63,-6,0	31.0 / 39	23.6 / 60	18.2 / 1	38.1 / 35	30.6 / 60	30.7 / 5	30.1 / 38	23.7 / 59	23.6 / 3	35.3 / 36	31.3 / 60	30.7 / 4
63,-6,-3	30.6 / 40	23.3 / 59	17.9 / 1	37.5 / 36	30.2 / 59	30.2 / 5	29.5 / 39	23.2 / 58	23.0 / 3	35.1 / 36	31.1 / 60	30.4 / 4
60,0,+6	33.1 / 36	25.4 / 62	20.0 / 2	40.1 / 34	32.4 / 62	32.3 / 5	32.5 / 38	25.9 / 59	25.9 / 3	37.0 / 36	32.9 / 60	32.2 / 4
60,0,+3	32.6 / 37	25.1 / 61	19.7 / 2	39.5 / 34	31.9 / 61	31.8 / 5	32.0 / 39	25.4 / 58	25.4 / 3	36.8 / 36	32.6 / 60	32.0 / 4
60,0,0	32.2 / 39	24.7 / 60	19.3 / 1	38.9 / 35	31.3 / 60	31.3 / 5	31.5 / 39	24.9 / 58	24.9 / 3	36.5 / 37	32.4 / 59	31.7 / 4
60,0,-3	31.9 / 40	24.4 / 59	19.0 / 1	38.4 / 36	30.8 / 59	30.9 / 5	31.0 / 40	24.4 / 57	24.4 / 3	36.3 / 37	32.2 / 59	31.5 / 4
60,-3,+6	32.5 / 37	24.9 / 61	19.4 / 2	39.7 / 34	32.0 / 61	32.0 / 5	31.9 / 38	25.3 / 59	25.3 / 3	36.5 / 36	32.3 / 60	31.7 / 4
60,-3,+3	32.0 / 38	24.5 / 60	19.1 / 2	39.1 / 35	31.4 / 60	31.4 / 5	31.4 / 39	24.8 / 58	24.8 / 3	36.2 / 37	32.1 / 60	31.4 / 4
60,-3,0	31.6 / 40	24.1 / 59	18.7 / 1	38.4 / 36	30.9 / 59	30.9 / 5	30.7 / 40	24.2 / 57	24.2 / 3	35.9 / 37	31.8 / 59	31.1 / 4
60,-3,-3	31.1 / 41	23.8 / 58	18.4 / 1	37.8 / 37	30.4 / 58	30.4 / 5	30.0 / 40	23.6 / 57	23.5 / 3	35.7 / 38	31.6 / 59	30.9 / 3
60,-6,+6	31.8 / 38	24.2 / 61	18.8 / 2	39.2 / 35	31.5 / 61	31.5 / 5	31.2 / 39	24.6 / 58	24.6 / 3	35.8 / 37	31.7 / 60	31.0 / 4
60,-6,+3	31.3 / 39	23.8 / 59	18.4 / 1	38.5 / 36	30.9 / 60	30.9 / 5	30.6 / 40	24.0 / 58	24.0 / 3	35.5 / 37	31.4 / 59	30.8 / 4
60,-6,0	30.8 / 41	23.4 / 58	18.0 / 1	37.8 / 37	30.3 / 58	30.3 / 5	29.7 / 41	23.2 / 57	23.2 / 3	35.3 / 38	31.2 / 59	30.5 / 3
60,-6,-3	30.3 / 43	23.0 / 57	17.6 / 1	37.2 / 38	29.8 / 57	29.8 / 5	29.1 / 41	22.6 / 56	22.6 / 2	35.0 / 38	31.0 / 58	30.3 / 3

Table 10. ME required (MJ/day) by dry, single, twin and triplet bearing ewes through the reproductive cycle for different profiles.

LW profile	ME Required Drys				ME Required Singles				ME Required Twins				ME Required Triplet			
	Join-D90	D90-Lamb	Lamb-Wean	Wean-Join	Join-D90	D90-Lamb	Lamb-Wean	Wean-Join	Join-D90	D90-Lamb	Lamb-Wean	Wean-Join	Join-D90	D90-Lamb	Lamb-Wean	Wean-Join
63,0,+6					11.1	18.3	22.7	12.7	11.2	18.7	26.2	13.0	11.2	18.9	28.9	13.3
63,0,+3	10.8	13.3	14.2	12.8	11.0	16.0	22.8	12.9	11.0	16.5	26.3	13.3	11.0	16.9	29.0	13.6
63,0,0	10.6	10.5	12.0	12.9	10.8	13.6	22.8	13.3	10.9	14.3	26.3	13.7	10.9	14.6	29.0	13.9
63,0,-3	10.5	9.0	12.3	13.2	10.7	12.2	22.9	13.7	10.8	12.9	26.4	14.0	10.8	13.2	29.1	14.2
63,0,-6	10.4	8.2	14.1	12.6												
63,-3,+6					9.5	18.3	22.8	12.9	9.5	18.7	26.3	13.3	9.5	18.9	29.0	13.6
63,-3,+3	9.1	12.8	12.0	12.9	9.3	15.9	22.8	13.3	9.4	16.5	26.3	13.7	9.4	16.8	29.0	13.9
63,-3,0	8.9	10.0	12.3	13.2	9.1	13.2	22.9	13.7	9.2	13.8	26.4	14.0	9.2	14.2	29.1	14.2
63,-3,-3	8.8	8.6	12.7	13.3	9.0	11.8	23.7	13.7	9.1	12.4	27.2	14.1	9.1	12.7	29.8	14.3
63,-3,-6	8.7	7.3	14.2	12.8												
63,-6,+6	7.4	6.7	12.0	12.9	8.2	17.9	22.8	13.3	8.2	18.4	26.3	13.7	8.3	18.6	29.0	13.9
63,-6,+3	7.8	12.1	12.3	13.2	8.0	15.5	22.9	13.7	8.1	16.1	26.4	14.0	8.1	16.4	29.1	14.2
63,-6,0	7.6	9.5	12.7	13.3	7.9	12.7	23.7	13.7	7.9	13.4	27.2	14.1	7.9	13.7	29.8	14.3
63,-6,-3	7.5	8.1	13.9	13.4	7.8	11.3	24.3	13.9	7.8	12.0	27.6	14.2	7.8	12.3	30.5	14.3
63,-6,-6	7.4	6.7	12.0	12.9												
60,0,+6	10.0	7.3	14.2	12.8	10.7	18.3	21.9	11.9	10.8	18.7	25.9	12.2	10.8	18.9	28.5	12.6
60,0,+3	10.4	12.8	11.2	12.0	10.6	15.9	22.0	12.4	10.6	16.5	26.0	12.7	10.6	16.8	28.6	13.0
60,0,0	10.2	10.0	11.2	12.4	10.4	13.2	22.0	12.8	10.4	13.8	26.0	13.1	10.5	14.2	28.6	13.4
60,0,-3	10.1	8.6	11.5	12.9	10.3	11.8	22.2	13.4	10.3	12.4	26.2	13.6	10.4	12.7	28.8	13.8
60,0,-6	10.0	7.3	14.2	12.8												
60,-3,+6					9.5	17.9	21.9	12.3	9.6	18.4	26.0	12.7	9.6	18.6	28.6	13.0
60,-3,+3	9.1	12.1	11.2	12.3	9.4	15.5	22.0	12.8	9.4	16.1	26.0	13.0	9.4	16.4	28.6	13.3
60,-3,0	9.0	9.5	11.5	12.9	9.2	12.7	22.2	13.4	9.2	13.4	26.2	13.6	9.2	13.7	28.8	13.8
60,-3,-3	8.9	8.1	13.1	13.0	9.1	11.3	23.4	13.5	9.1	12.0	26.8	13.8	9.1	12.3	29.5	14.0
60,-3,-6	8.8	6.7	14.2	13.1												
60,-6,+6					8.2	17.4	22.0	12.8	8.2	17.9	26.0	13.0	8.2	18.1	28.6	13.3
60,-6,+3	7.8	11.6	11.5	12.9	8.0	15.0	22.2	13.4	8.1	15.6	26.2	13.6	8.1	16.0	28.8	13.8
60,-6,0	7.6	9.0	13.2	13.0	7.8	12.2	23.5	13.5	7.9	12.9	27.0	13.8	7.9	13.3	29.7	14.0
60,-6,-3	7.5	7.7	13.8	13.2	7.7	10.9	24.0	13.7	7.8	11.5	27.6	13.9	7.8	11.8	30.3	14.1
60,-6,-6	7.4	6.3	14.6	13.3												

Standard Prices, Production and Sensitivity Analysis - The prices used in this analysis are summarised in Table 11.

Table 11. Standard price and production levels assumed in this analysis.

	Standard
Wool price (cents/kg clean sweep the board; 30 um)	600
Meat price	
- Lamb ($/kg DW)	5.00
- Ewe hoggets ($/hd net)	105
- CFW ewes ($/hd net)	85
-	
Grain price	
- Barley ($/t fed out)	275

Proportion of dry, single, twin and triplet bearing ewes - Scanning data from Cashmore for 2007 onwards was used to relate the proportion of dry, single, twin and triplet bearing ewes to the scanning percentage. This database includes 11,000 ewe lambs, 8,000 ewe hoggets and 4,000 2.5 year olds and older animals up to 6yo. The data available was the proportion of ewes scanned dry, single, twin or triplet by age group by Sire ASBV for NLW. All the data points were analysed together because there was no indication that age or Sire ASBV for NLW altered the relationship. A multiple regression analysis related the proportion of ewes of each birth type to scanning percentage, (scanning percentage)^2, (scanning percentage)^3 and the inverse of scanning percentage. The coefficients are in Table 12. The range of scanning percentage in the data was from 45% up to 171% so this is the range that the equations are valid over, however sensible results are achieved up to 195% scanning, although at this level the equations may be underestimating the proportion of triplet bearing ewes.

For use in the MIDAS model the proportion of single bearing ewes was calculated from the estimated proportions of dry, twin and triplets, rather than using the equation. This was to ensure that the proportion of ewes always added to 100%. Also, a 2 further constraints were added when using the derived coefficients; 1) the proportion of triplet bearing ewes was constrained to a minimum of 0 (the estimated proportion was less than zero if scanning percentage was at or below 45%); 2) the proportion of dry ewes was constrained to minimum of 4% (based on the data and this came into effect with scanning % above 165%). The data points and the fitted values as used in MIDAS are in Figure 5.

Table 12. Multiple regression coefficients relating proportion of dry, single, twin and triplet bearing ewes to the scanning percentage.

	Dry	Single	Twin	Triplet
Constant	14.9831	-12.438	2.5274	-1.711
Scan %	-0.1631	1.214	$-2.875\text{x}10^{-3}$	0.0685
$(\text{Scan }\%)^2$		$-5.869\text{x}10^{-3}$	$2.216\text{x}10^{-3}$	$-8.74\text{x}10^{-4}$
$(\text{Scan }\%)^3$				$4.105\text{x}10^{-6}$
1 / Scan %	2588.2			

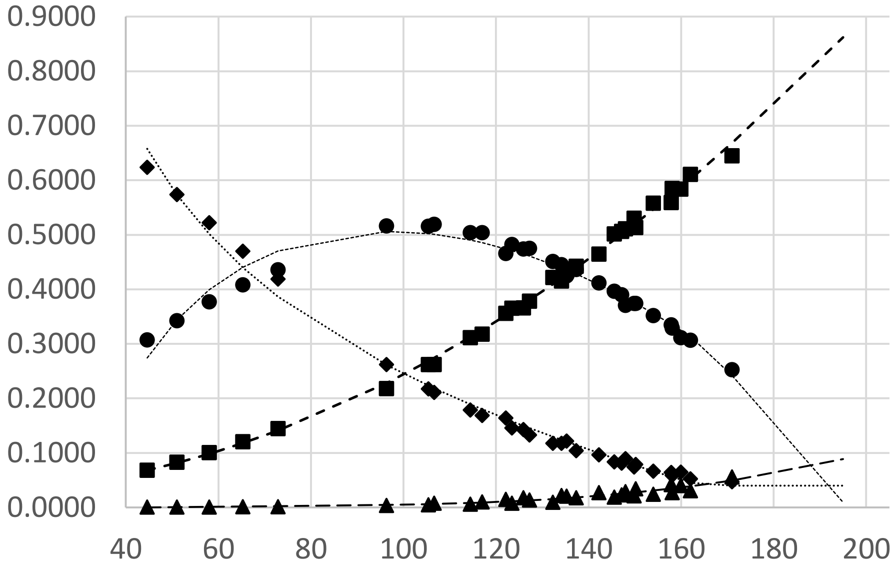


Figure 5. Data points used for the multiple regression (◊ Dry, ● single, ■ twin and ▲ triplet) and the fitted relationship (dashed lines).

Evaluation of feed budget equations - The Pigeon Ponds and WA sites have recorded FOO and supplement fed, and this information has been related to live weight change of single and twin bearing ewes during pregnancy. A linear model was fitted to describe LWC from FOO and supplement offered. A comparison has been made between this fitted model and the MIDAS simulation that is the basis of the MIDAS feed budget.

The MIDAS simulation was set up for 60-kg standard reference weight single and twin bearing ewes at 50-kg, 60-kg and 70-kg at day 85 of pregnancy and run through to day 150 of pregnancy. The FOO levels investigated were 100, 350 and 600 kg/ha and supplement fed was 0, 500 and 1000 g/hd/d. The MIDAS pasture was 11.7 MJ of ME/kg. The results of these 18 runs were compared with the WA linear model (day 65-110 and day 97-139) and the Pigeon Ponds model (day 90-140 and day 110-140).

The Analysis - Twenty four different liveweight patterns were evaluated for each of the Litter size groups (Dry, Single, Twin and Triplets). It was not computationally possible to evaluate all the combinations of LW patterns for the 4 groups so an alternative was selected based on the expectation that the optimum profile for one litter size group will be unaffected by the nutrition offered to the other litter size groups.

Determination of the optimum liveweight patterns was done in two steps. The first step involved identification of the optimum pattern for each of the dry, single, twin and triplet bearing ewes assuming pregnancy status could be identified at day 0. Farm profitability was calculated when the twin bearing ewes followed each of the 24 profiles while the dry, single and triplet bearing ewes maintained from joining to lambing. Once the optimum was identified the process was repeated for single bearing ewes with the twins at the optimum and dry and triplets being maintained. This was repeated for dry and triplets. The order twin, single, dry then triplet was because the majority of ewes were twins followed by single, dry and triplets. For each coefficient set, the single and twin bearing ewes (>85% of the flock) had the same optimum pattern of liveweight change during early pregnancy so for these classes of stock the simplification about scanning at day 0 was unimportant. However, the dry and triplets had different optimal early pregnancy profiles. Given that this is not currently technically feasible further runs were carried out for the second step to identify the optimal late pregnancy nutrition profiles for drys and triplets, given the ewes had to be run in common till scanning.

Results and Discussion

The Optimum nutrition targets - The optimum pattern for single and twin bearing ewes, which comprise greater than 85% of the flock, was the same for all the coefficient sets (Table 1). The optimum for each was joining at 60-kg and maintaining weight in early pregnancy. The singles followed this with slow weight gain in late pregnancy (+3 kg/hd or 50 g/hd/d) and the twins faster weight gain (+6 kg/hd or 100 g/hd/d). The profiles are consistent with the twin ewes lambing in slightly better condition that the single bearing ewes. If the triplet ewes were identified in mid-pregnancy then the optimal management with all the coefficient sets was to lose 3-kg in late pregnancy. If the triplets could be identified at day 0 then the optimal management was to lose 6-kg in early pregnancy and a further 3-kg in late pregnancy. This result is consistent with the finding from the previous analysis using the INF coefficients, but it is counter intuitive because it also occurs in the Pigeon Ponds coefficient set in which the triplet coefficients were set at the same as the twin coefficients (due to lack of information). In this case it would be expected that the optimal triplet management would be similar to the twins. This needs further work to identify the reasoning or whether it is an error in the modelling.

If the dry ewes were identified in mid pregnancy then the optimal management varied depending on the coefficient set. The optimum for Hamilton, SA and WA was for the dry ewes to maintain during late pregnancy, whereas for Pigeon Ponds the optimum was to gain 3-kg. These differences between the coefficient sets only affected profitability of the dry ewes by between $2 and $4 per dry ewe. For the three sites, gaining 3-kg in late pregnancy was about $2/dry ewe less profitable (Table 13) and for Pigeon Ponds maintaining weight in late pregnancy was $4/dry ewe less profitable.

Table 13. Optimum liveweight profiles for dry, single, twin and triplet bearing ewes. Extra results for triplets and drys that have a different optimum profile if the animals could be identified at day 0 rather in mid pregnancy.

	Class	Unit	Hamilton	Pigeon Ponds	SA	WA
Join wt	All	kg	60	60	60	60
LWC early pregnancy	All	kg	0	0	0	0
LWC late pregnancy	Single	kg	+3	+3	+3	+3
	Twin	kg	+6	+6	+6	+6
	Triplet	kg	-3	-3	-3	-3
	Dry	kg	0	+3	0	0
LWC early & late pregnancy if scanned at day 0	Triplet	Kg kg	-6 -3	-6 -3	-6 -3	-6 -3
	Dry	kg kg	-6 -3	0 +3	-6 -3	-6 -3

If the feed to the ewes was varied so that they deviated from the above targets then profitability was reduced (Table 14) and the impacts are similar across the coefficient sets. Management in early pregnancy appears less important than management in late pregnancy and prior to joining. During late pregnancy management of the drys is least critical followed by triplets, and singles and twins are similar. Joining the ewes 3-kg heavier reduces profitability by about $10/ewe and this is a similar magnitude to the cost of having the single and twin bearing ewes under-achieve the late pregnancy targets.

Table 14. Difference in profit per ewe ($/ewe of that class) if there is deviation from the LW targets for different classes of ewes.

		Class	Unit	Hamilton	Pigeon Ponds	SA	WA
Join weight	+	All	kg	-9.76	-9.32	-8.87	-9.09
Early pregnancy	+	All	kg	-5.05	n/a	n/a	n/a
Late pregnancy	+	Single	kg	-12.07	-11.43	-11.79	-5.20
	-	Single	kg	-8.60	-9.99	-9.01	-12.59
	+	Twin	kg				
	-	Twin	kg kg	-10.01	-11.40	-9.59	-8.45
	+	Triplet	kg kg	-5.09	-5.40	-4.75	-6.75
	-	Triplet					
	+	Dry		-2.01	-8.38	-1.79	-1.68
	-	Dry			-3.72		

n/a: Early pregnancy alternatives not evaluated for these coefficient sets

Model feed equations vs experiment - Comparing the relationship between ewe LWC and FOO at different supplement levels (Fig. 6) shows that the MIDAS levels are generally below the values measured in the trials except with higher FOO and low supplementary feeding. The WA site is generally more responsive to increasing FOO than the Pigeon Ponds site and the slope of the MIDAS relationship is curvilinear and within the range measured.

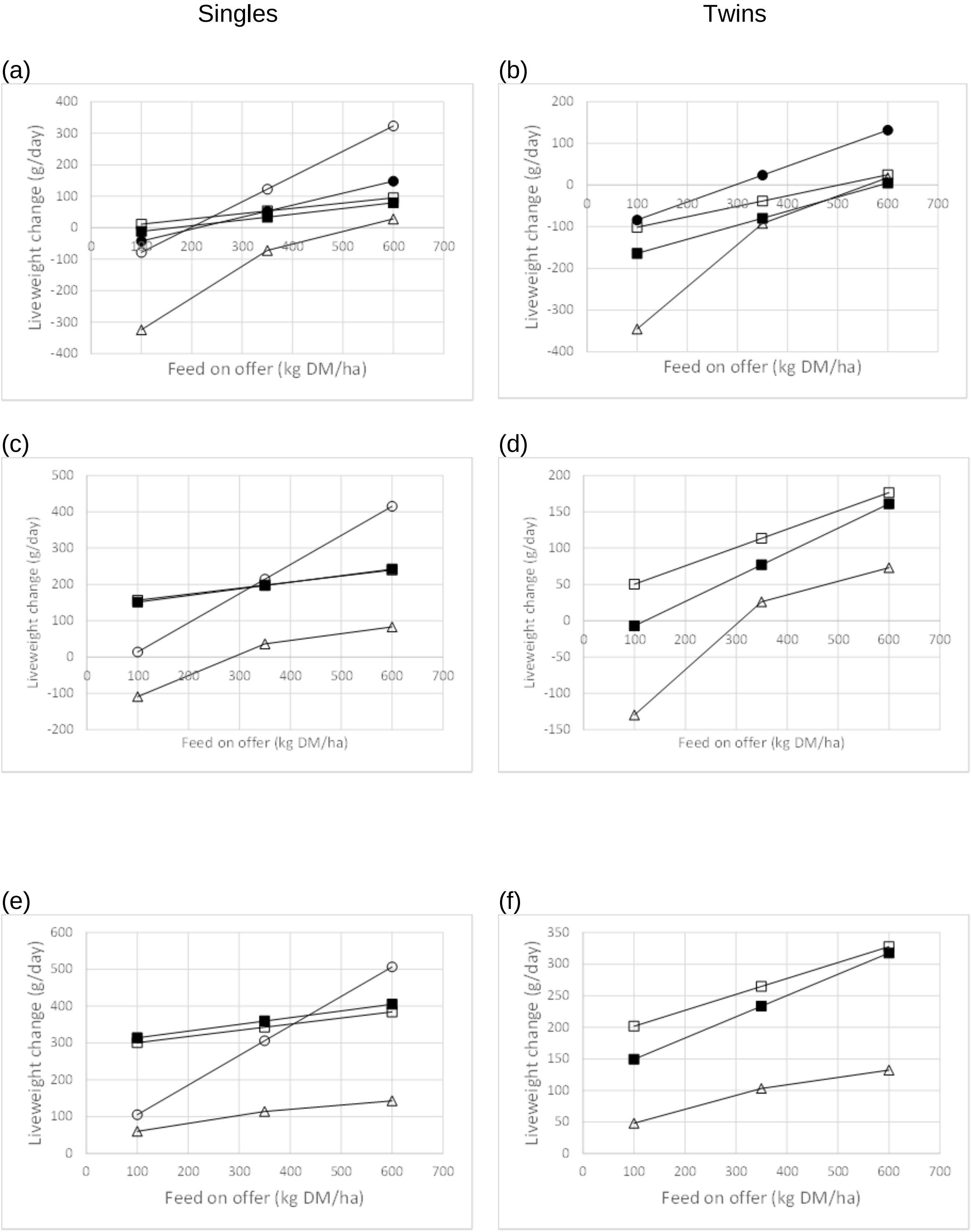
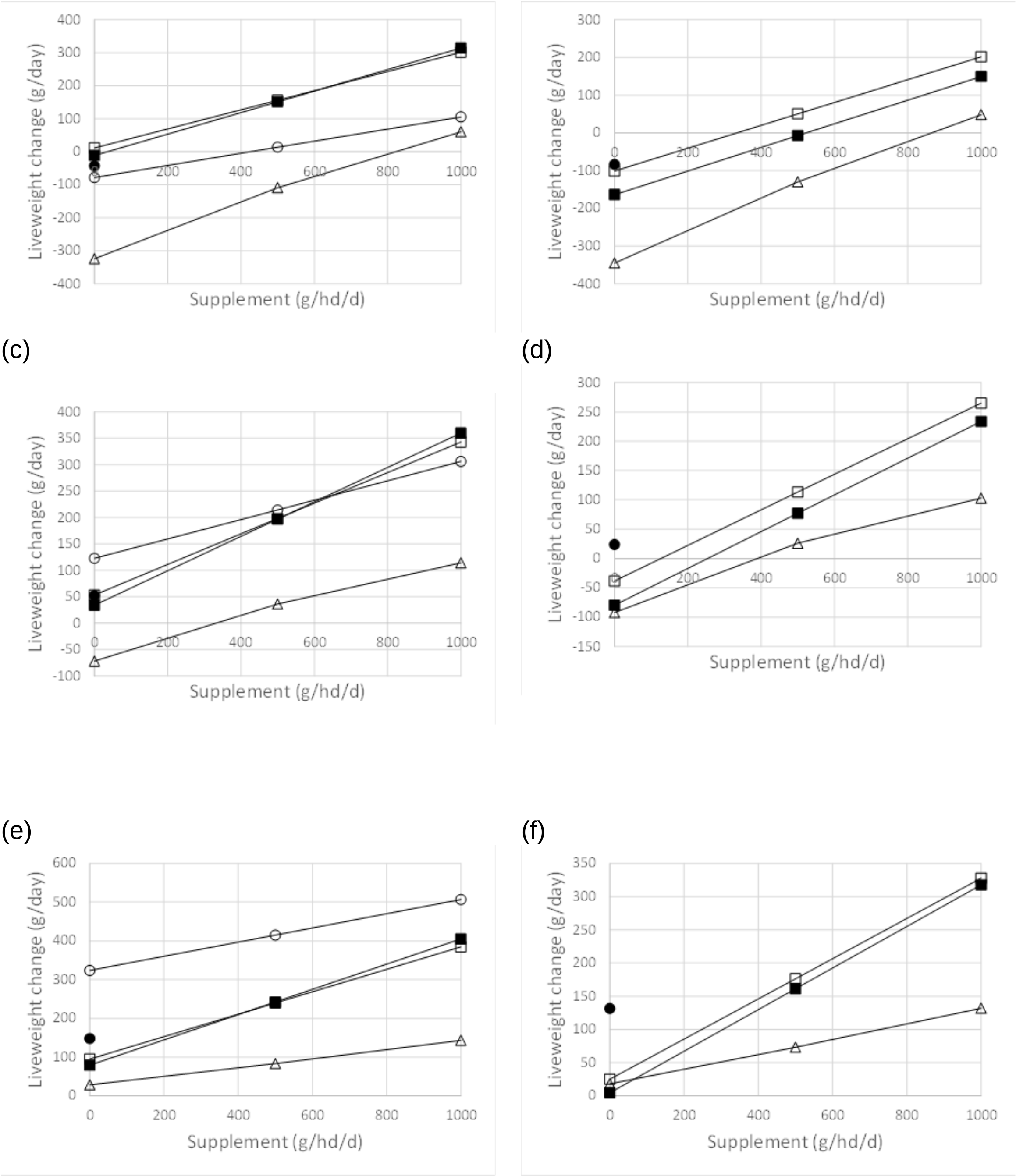


Figure 6 a-f: Liveweight change of single (a, c, e) and twin (b, d, f) ewes and the impact of varying FOO levels when fed 0 (a,b), 500g/hd/d (c,d) or 1000g/hd/d (e,f) of supplement (☐ Pigeon Ponds day 90-140,■ Pigeon Ponds day 110-140,O WA day 64-110,● WA day 97-139,Δ MIDAS day 85-150)

Comparing the relationship between ewe LWC and supplement offered at different FOO levels (Fig. 7) shows that the change in LWC with increasing supplement offered is lower at the WA site compared with Pigeon Ponds. The MIDAS calculations although at a lower level has a slope within the range of the Pigeon Ponds and WA sites. The variation in the slope between the different sites could be associated with different substitution rates of supplement for pasture due to different pasture characteristics.


Singles

Twins

(a)

(b)

(c)

(d)

(e)

(f)

Figure 7 a-f: Liveweight change of single (a, c, e) and twin (b, d, f) ewes and the impact of varying supplement levels when running on 100kg/ha (a,b), 350kg/ha (c,d) or 600kg/ha (e,f) of FOO (☐ Pigeon Ponds day 90-140,■ Pigeon Ponds day 110-140,O WA day 64-110,● WA day 97-139,Δ MIDAS day 85-150)

Sensitivity Analysis on the biology - These above results, based on the preliminary coefficients from the research sites are not as some industry experts expected. Their observation had been that the good maternal operators had their ewes gaining maximum weight post weaning so that the ewes were in CS 3.5+ at joining. They then allowed the ewes to drop during pregnancy to lamb in C2.7. They considered this to be the optimal pattern because the ewes were gaining weight during a period when feed supply was plentiful and they were losing weight in autumn and early winter when feed supply is limiting. This matching of ewe liveweight profile to feed supply was achieved while achieving high levels of single and twin lamb survival. There are several possible explanations why the model results don't agree with the expert opinion:

(a) The experts are wrong.
(b) As indicated in the previous section, the feed budget equations in the model do not allow weight gain post weaning as rapidly as occurs in the paddock and therefore the calculations are showing the patterns that lose condition during pregnancy are penalised in the post weaning period. To test the importance of this possible reason for the divergence of the results, the model was run assuming ewes from all live weight patterns only have to gain the same amount of condition in the post weaning period.
(c) Higher live weight at joining is not optimal because at higher live weight more triplet lambs are conceived and these lambs are not profitable. Triplet lambs appear to be unprofitable because the ewes have a higher death rate, the lambs have high death rates and the lambs are much lighter at weaning. The Pigeon Ponds coefficient set tests the importance of this mechanism because in the Pigeon Ponds dataset there were insufficient triplet progeny to fit coefficients and for this coefficient set it was assumed the triplets were like twins.
(d) Experts consider that lamb deaths due to dystocia will be high if ewes follow the optimum pattern identified in the modelling. The lamb survival equations don't reflect large reductions in survival due to larger lambs and therefore the threat of dystocia is only a minor factor in the selection of the optimum patterns in this analysis. To test the importance of dystocia on the selection of the optimum patterns the survival relationships for single born lambs was altered to reflect increased deaths above 5kg (See Figure 2.1).

The sensitivity analysis on dystocia using the Hamilton coefficients altered the results very little. The optimum profile for singles during pregnancy was not affected (Table 14) although the cost of gaining weight during pregnancy was increased from $12/single ewe up to $14/single ewe (Table 15) and the cost of gaining less weight was reduced from $9/single ewe down to $7/single ewe. The reduction in profit from joining the ewes at heavier weights was not affected. This indicates that unless the impact of dystocia is more extreme than the level examined in the sensitivity analysis then the threat of dystocia wouldn't be a rational reason to feed single bearing ewe less during pregnancy.

Table 14. Optimum liveweight profiles for dry, single, twin and triplet bearing ewes using Hamilton coefficients with adjustment for Dystocia and Post weaning weight gain. Extra results for Triplets and drys that have a different optimum profile if the animals could be identified at day 0 rather in mid pregnancy.

	Class	Unit	Hamilton	Dystocia	Post wean
Join wt	All	kg	60	60	60
LWC early pregnancy	All	kg	0	0	-6
LWC late pregnancy	Single	kg	+3	+3	0
	Twin	kg	+6	+6	+6
	Triplet	kg	-3	-3	-3
	Dry	kg	0	+3	+3

The sensitivity analysis on the post weaning weight gain of the ewes did impact the optimum patterns and the cost of missing the targets. The optimum management during early pregnancy, instead of being to maintain weight, was to lose 6-kg. In late pregnancy it was optimal for the twins to gain 6-kg, the singles to maintain weight (although this was a very similar profitability to gaining 3-kg), the dry ewes to gain 3-kg and the triplets to lose a further 3-kg. The cost of joining at heavier weights was reduced to $2/ewe and the cost of missing the other targets was also generally reduced. This indicates that examination of the feed budgeting equations warrants further investigation because it is likely they are affecting the optimum profiles identified in the analysis.

Table 15. Difference in profit per ewe ($/ewe of that class) if LW targets for ewes are missed with the standard Hamilton coefficients and the coefficients adjusted for the dystocia & post wean sensitivity analysis.

		Class	Unit	Hamilton	Dystocia	Post wean
Join weight	+	All	kg	-9.76	-9.92	-1.69
Early pregnancy	+	All	kg	-5.05		
Late pregnancy	+	Single	kg	-12.07	-14.16	-0.15
	-	Single	kg	-8.60	-7.27	-2.89
	+	Twin	kg			
	-	Twin	kg kg	-10.01	-10.11	-2.51
	+	Triplet	kg kg	-5.09	-10.89	-0.85
	-	Triplet				
	+	Dry		-2.01	-3.61	-7.69
	-	Dry			-0.06	-0.29

n/a: Early pregnancy alternatives not evaluated for these coefficient sets

Conclusions

The optimum profile identified for single and twin bearing ewes is not impacted by the different coefficient sets and the impact of the different coefficients sets on the triplet and dry patterns are minor. The optimum patterns identified were for the ewes to join at 60kg, maintain weight in early pregnancy, twins to gain 6-kg in late pregnancy, singles to gain 3-kg in late pregnancy, triplets to lose 3-kg in late pregnancy and the drys to either maintain or gain 3-kg. There was little difference in the results for the different coefficient sets and this indicates that the optimal management is not varying with the different genotypes that have been evaluated at the research sites. However, the lack of difference in the optimal management of the triplet bearing ewes using the Pigeon Ponds coefficient set requires further investigation because the result is unexpected.

There is a difference between the model equations and the measured live weight change at different FOO and supplement levels. This along with the difference in the optimum profiles when the post weaning recovery of the ewes is adjusted indicates that the feed budgeting equations need to be examined for the maternal breeds. The variation is expected to be associated with the estimation of feed intake because this is the component of the equations that is least robust. The analysis could also be improved with the inclusion of information about the impact of FOO levels at lambing and during lactation on lamb survival and weaning weights. This information should be available after the statistical analysis of the 2015 research results which included treatments on FOO levels during these periods. FOO levels might be important if high FOO during lambing can increase survival at low birth weight, because that would mean deferring pasture till lambing could compensate for weight loss prior to lambing. A similar effect could also occur if FOO during lactation can increase weaning weight and allow greater weight loss during pregnancy. Another question of practical significance that needs investigating is whether ewes should be mated heavier if seasonal conditions offer opportunity for ewes to gain more weight in the post weaning period. That is, is the current optimum to join at 60kg due to it being more profitable to utilise extra feed to run more ewes rather than have the ewes gain more weight or is it due to the post weaning cost of recovering the weight lost during the feed limited period of the year. The economic analysis will be expanded to cover other regions when the final coefficients are available after the results from the 2015 research year are completed.

References

Paganoni BL, Ferguson MB, Kearney G, Thompson AN (2014) Increasing weight gain during pregnancy results in similar increases in lamb birth weights and weaning weights in Merino and non-Merino ewes regardless of sire type. *Animal Production Science* 54(6); 727-735.

Standing Committee on Agriculture (1990). Feed standards for Australian Livestock – Ruminants. CSIRO Publishing.

Young JM, Bathgate AD, Saul G and Clark S (2004a). MIDAS Insights on Profitably utilising Perennial Plants in Hamilton, Victoria. Report to EverGraze project. CRC for Management of Dryland Salinity using Perennial Plants. August 2004.

Young JM, Thompson AN Oldham CM and Curnow M (2011) Whole-farm profit and the optimum maternal liveweight profile of Merino ewe flocks lambing in winter and spring are influenced by the effects of ewe nutrition on the progeny’s survival and lifetime wool production. *Animal Production Science* 51(9); 821-833.

Young JM (2014). Nutritional guidelines for maternal ewes, an estimation using INF coefficients. Report to Murdoch University.

13.6 Appendix 6 - Maternal genotypes and Predictions of Intake & Energy Requirements

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Background

A major main aim of the project "Lifetime Maternals - development of management guidelines for non-Merino ewes" is to produce guidelines on the optimal nutritional management of non-Merino ewes focussing on the pregnancy and lactation periods. These guidelines would follow a similar format to the guidelines developed for Merino ewes (Young *et al.* 2011) that are part of the Lifetime Ewe Management training course and would include target levels for ewe LW (or CS) at joining and changes during early and late pregnancy and during lactation.

The analysis required to develop these guidelines includes 2 major components:

1. The change in production of the ewe and the progeny when nutrition is altered during pregnancy and lactation. Production changes include: birth weight, weaning weight and lamb survival. This has been examined in plot level grazing trials and the changes in production have been related to the ewe LW profile. There are four trial sites around the country providing the data on changes in production with varying nutrition and these have a similar design to the Lifetime Wool project. The treatments include ewes following different nutrition profiles from mid-pregnancy so that they lamb at low or high LW/CS.

2. The quantity of feed required to follow different ewe LW profiles. The approach was to use the MIDAS model to do the wholefarm feed budget for the different ewe profiles and optimise stocking rate and supplementary feeding. The MIDAS model feed budget is based on the intake and energy requirement equations as outlined in Feeding Standards for Australian Livestock and the SheepExplorer spread sheet.

The modelling approach has not been successful because the feed budgeting for these non-Merino genotypes is not replicating the measured performance of the ewes in the research trials. Specifically, the high rates of liveweight gain measured in the trials can't be feasibly achieved in the feed budget. This seems to indicate that either predicted intake is too low or the predicted energy requirements for maintenance or weight gain are too high.

Approach

The project team has collated experimental data to help quantify the problem. It has been divided into three levels based on the comparisons that can be made:

1. Compare actual versus predicted intake for trials in which feed was offered ad-libitum and intake was measured.
2. Compare actual versus predicted LWC for trials in which LWC was measured and quantity of feed consumed was measured (or estimated).
3. Compare actual vs predicted LWC for trials in which FOO and supplementary feeding have been measured.

Although the prediction of both energy requirements and voluntary feed intake include many parameters the above provides an indication if the errors are associated with errors in predicting intake or errors associated with estimating energy requirements.

Table 1. The data sets available for each component. See Appendix 1 for details of each data set.

Component	Data sets
1. Actual vs predicted intake	Hamilton feed shed Leemings, straw fed in a feed lot
2. Actual vs predicted LWC (known intake)	Hamilton feed shed Leemings, straw fed in a feed lot Struan, fed grain on a bare paddock.
3. Actual vs predicted LWC (on pasture)	Struan 2015

Note: Other data (Leemings 2014, Slades 2014) is available for component 3 but this hasn't been analysed in GrazFeed.

The analysis examining the data for components 1 and 2 was done using Sheep Explorer. Component 3 was done with GrazFeed (5.0.3).

Results

Component 1 - Actual vs predicted intake

In all four situations examined the equations under estimated feed intake (Table 2). The underestimation was approximately 25% for three of the four but was much higher (48%) for the adults in the feed shed. The underestimation of intake for the straw diet indicates that it is not just associated with estimation of intake on a pelleted diet.

Table 2. Component 1, actual vs predicted intake.

Site	Ttmnt	Diet	Actual Intake (kg/hd/d)	Predicted Intake	Error (P-A)/A
Hamilton Feed shed	Hoggets	Pellets	2.05	1.47	-28%
	Adults	Pellets	2.68	1.38	-48%
Leemings	Singles	Straw	~1.0	0.76	-24%
	Twins	Straw	~1.0	0.77	-23%

Component 2 - Actual vs predicted LWC (known intake)

The errors in prediction of liveweight change when intake is known are not consistent for the six measurements (Table 3). There were situations in which the equations predicted more weight gain, less weight gain, more weight loss and also less weight loss. The largest discrepancy was for the twin ewes at the Leeming site where the error was 81 g/hd/d, in all other situations the error was less than 40g/hd/d.

Table 3. Component 2, actual vs predicted LWC with known intake.

Site	Ttmnt	Diet	Actual LWC (g/hd/d)	Predicted LWC (g/hd/d)	Error (P-A) (g/hd/d)
Hamilton Feed shed	Hoggets	Pellets	120	136	+16
	Adults	Pellets	239	208	-29
Leemings	Singles	Straw	-114	-117	-3
	Twins	Straw	-72	-153	-81
Struan	CS High	Barley	-7	+32	+39
	CS Low	Barley	-77	-90	-13

The six points were also plotted on a graph of Predicted vs Actual (Fig. 2). There is variation around the y=x line but the fitted line has a slope of 1.03 and an R^2 of 0.92. There is no indication of a systematic error.

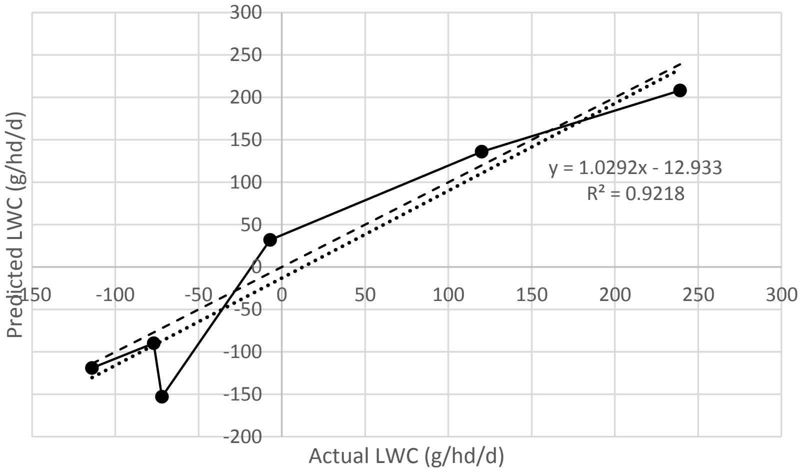

Figure 2. Predicted LWC vs Actual LWC with y=x (dashed) and fitted line (dotted).

There are a range of potential sources of error in the data and some sensitivity analysis was carried out on the inputs for each of the data sets.

Table 4. Sensitivity of predicted LWC (g/hd/d) to inputs.

Input	Variation	Impact on predicted LWC for each data set Hamilton	Leeming	Struan
M/D (MJ of ME/kg)	+/- 0.5	+/- 30	+/- 17	+/- 10
Age (yr)	+/- 1	+/- 2	+/- 8	+/- 3
SRW (kg)	+/- 5	-/+ 0	-/+ 3	-/+ 0.5
CF LW (kg)	+/- 5	-/+ 6	-/+ 17	-/+ 6
Day of Year (d)	+/- 60	-/+ 20	+/-0	+ 2
Day of Preg (d)	+/- 10	-	-/+ 13	-/+ 3

The impact of the errors varies between sites, but the Diet M/D has the largest impact at all sites. Day of the year has a major influence at Hamilton where there was significant weight gain occurring. At Leeming's the day of pregnancy has a major influence and the trial measurements span a 96 day window from day 40 to day 136 of pregnancy. Using the average day of pregnancy will be leading to some error in the predictions.

The two largest discrepancies between the actual and predicted (-81 g/hd/d at the Leeming site and +39g/hd/d at Struan) are unlikely to be accounted for in errors associated with data measurements at the site, whereas, for the other treatments the variation between actual and predicted are within the errors associated with measuring the data.

Component 3 - Actual vs predicted LWC (on pasture)

Grazfeed is over predicting liveweight change in early pregnancy (Fig. 3), ie Grazfeed predicted less LW loss or more LW gain than actual. During this time, the twins and singles were in the same plots. Between day 70 and 110, Grazfeed is under predicting liveweight change across all treatments, ie ewes had a greater increase in liveweight than Grazfeed predicted. Finally between Day 110 and 140, Grazfeed was under predicting liveweight change by 190 g/hd/d in the low twins, 60 g/d in the high twins, 20 g/d in the low singles and over predicted LWC in the high singles by 40 g/hd/d.

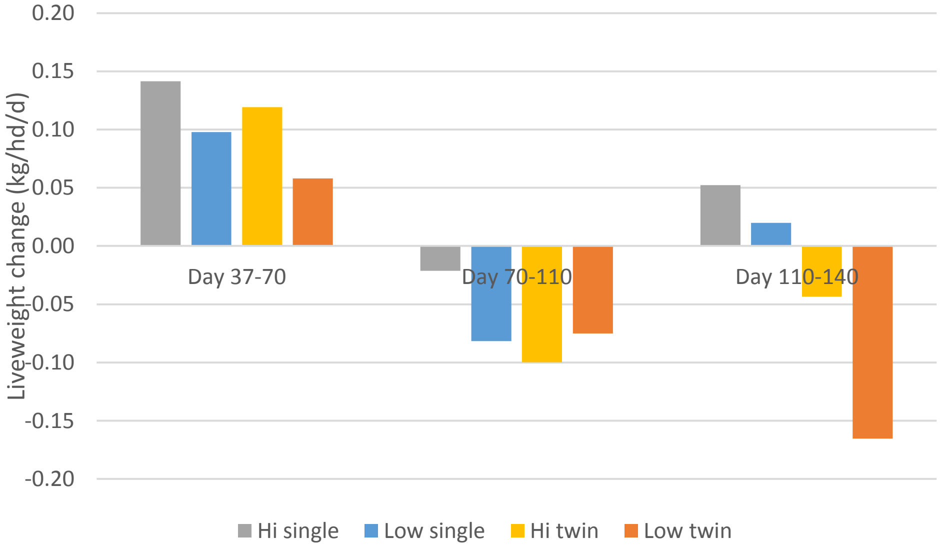

Figure 3. GrazFeed predicted LW change - Measured LW change for maternal ewes in each of the 4 treatments at Struan in 2015.

Two variables were checked in a sensitivity analysis. The impact of doing the calculations using conceptus free weight (Fig. 4) and adjusting the lambing date through Grazfeed where average lambing date was day 160 from rams in (7th July) (Fig. 5). In each case the corrections only make a small difference to the discrepancy between predicted and actual.

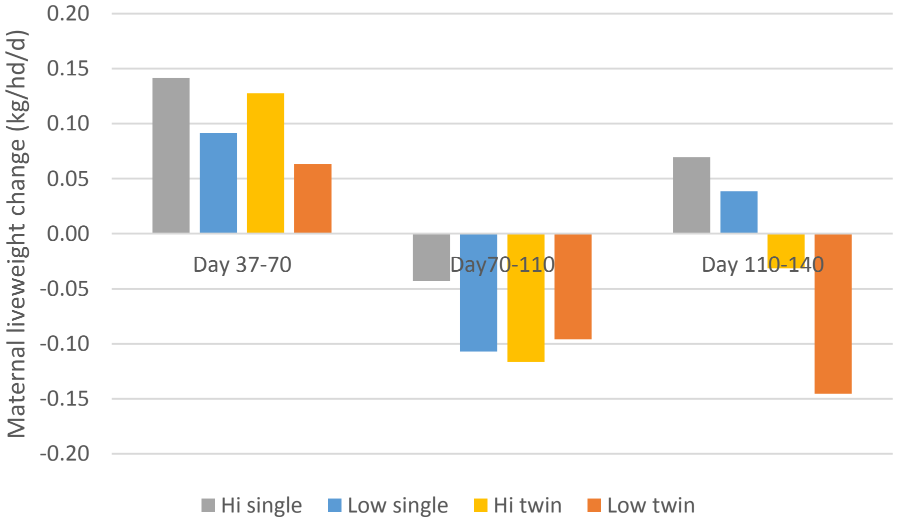

Figure 4. GrazFeed predicted LW change - Measured LW change for maternal ewes using conceptus free weight.

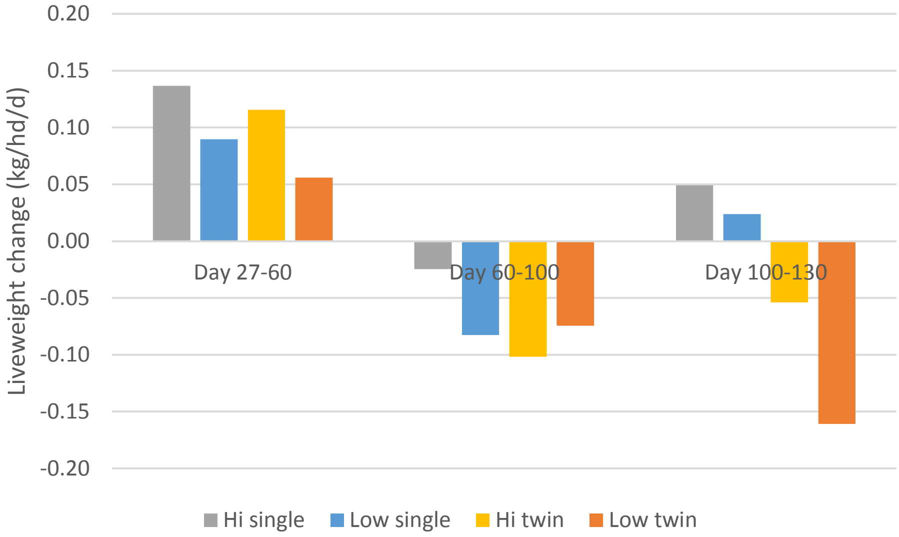

Figure 5. GrazFeed predicted LW change - Measured LW change for maternal using an average lambing date of 160 days after rams in.

The 12 points were also plotted on a graph of Predicted vs Actual (Fig. 6). In early pregnancy, grazing dry feed with supplement, the predictions consistently under estimated LW loss (or LW gain was predicted when the animals were actually losing weight). In the mid pregnancy period which spanned over the break of the season the predictions consistently underestimated LW gain. In the late pregnancy period some treatments the LWC was over estimated and others it was underestimated.

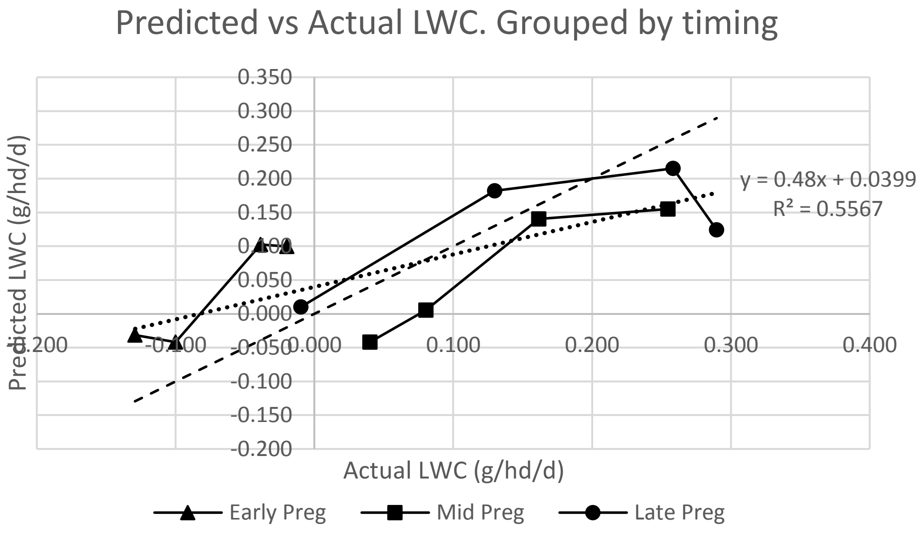

Figure 6. Predicted LWC vs Actual LWC with y=x (dashed) and fitted line (dotted).

It is noticeable that the predicted values change less than the actual values with the slope of the regression line fitted being 0.48. This could indicate that either

1. The energy required to gain weight or the energy made available when losing weight is less than predicted.
2. Intake is under estimated on good feed and overestimated on poor feed.

Conclusions

The predictions of LWC of ewes grazing pasture ranged from an overestimation of 150g/hd/d to an underestimation of 150 g/hd/d. This is a substantial range and this level of difference would lead to significant changes in nutritional management on-farm. The source of the error is unclear with some data suggesting the error is associated with estimation of potential intake and other data suggesting it could be associated with estimation of the energy content of a kilogram change in liveweight.

The predictions of intake against the measured data were between 25 and 50% lower for the four treatments that had measured intake with ad-lib feed available. The underestimation was consistent across the four data points. This indicates (from very limited data) that there could be a systematic error in the estimation of potential intake capacity.

The error in the estimation of LWC when intake was known was within the variation in measurement of the data for 4 of the 6 treatments and the error did not appear to be systematic. This indicates that the errors in the energy requirement calculations are small. Errors in the prediction of the ewe LWC when grazing pasture are substantial. A regression of the predicted LWC against actual indicates that the variation in predicted change is about half of the variation in the actual change. Insufficient measurements have been made to determine the source of the error.

Appendix 1. Details for Components 1 and 2 (treatment group averages)

Site	Genotype	Status	Ttmnt	Age	SRW (kg)	Ave CF LW (kg)	Diet	M/D MJ / kg	DOMD %	Date
Hamilton	Maternal	Dry	Hogget	538 days	65 (est)	54	Pellet	9.5	60	4 Feb
Feed shed	composite	Dry	Adult	859 days	65 (est)	67	Pellet	9.5	60	21 Dec
Leemings	Maternal	Mid preg (day 88)	Single – Low CS	2.5 yo	60.6	57.4	Straw	6.1		10 May
	composite	Mid preg (day 85)	Twins – Low CS	2.5 yo	61.8	62.3	Straw	6.1		10 May
Struan	BL/M	Early preg (day 53)	CS High	2.5 yo	62.7	59.9	Barley	11.7		20 Mar
		Early preg (day 50)	CS Low	2.5 yo	60.5	57.9	Barley	11.7		20 Mar

CF = Conceptus Free

Appendix 2. Details for Component 3 (Data source: Struan 2015)

Pasture	Clover	15%
	Grasses	Temperate
	Steepness of land	Level
	Mean DMD herbage	75% green 45% dry
	Weather effects	None
Supplement	Barley	
	DM	89%
	DMD	90%
	ME	13.7MJ ME
	CP	12%
Ewes	Breed	Border leicester x Merino
	Mature weight	62kg
	GFW	4.0kg
	Fleece Yield (clean)	70%
	Ave. age	48 months
	Wool length	2cm
Rams	Breed	Dorset/ Suffolk
	Mature weight	80kg

CS treatment	Start Date	Day pregnancy	FOO Single	FOO Twin	Grain Single	Grain Twin
2.5	5th March	37	100	100	450	450
	19th March	51	100	100	450	450
	10th April	73	100	100	450	450
	20th April	83	100	100	400	500
	28th April	90	0	0	500	600
	6th May	98	150	150	200	500
	19th May	111	200	500	200	500
	8th June	131	400	400	250	200
	18th June	141	400	400	250	200
3.6	5th March	37	100	100	900	900
	19th March	51	100	100	900	900
	10th April	73	100	100	900	900
	20th April	83	100	100	1000	1250
	28th April	90	0	0	1100	1000
	6th May	98	150	100	950	1000
	19th May	111	200	500	950	1000
	8th June	131	450	400	1100	1000
	18th June	141	450	400	1100	1000

- Day of pregnancy is based on days since rams in (27/1/15), and rams remained in the mobs (6 mating groups) for 37 days (5/3/15).
- At day 37, mating groups were boxed and split into two groups (high CS target, and low CS target) balanced for weight, CS, age and mating group.
- The high CS mob were managed to achieve a target CS 3.5 by day 140, while the low CS mob were managed to achieve a target CS 2.6 by day 140.
- All ewes within mobs were run together until scanning on day 83 (20th April) when twins and singles were separated.
- Average lamb date was 7/7/15, at day 160 from rams in.
- Break of season occurred at approx. day 90.

13.7 Appendix 7 - Analysis of the Components of the energy and intake equations

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Executive Summary

During the analysis carried out to determine the optimum liveweight profiles for maternal ewes it was concluded that the equations used to predict energy requirements and intake capacity of the maternal ewes didn’t represent the liveweight measurements taken in the trials and didn’t align with anecdotal observations of the performance of the maternal breeds in the paddock. It was also concluded that the discrepancy was affecting the optimum patterns identified. Following this analysis actual and predicted intake and liveweight change was compared for a number of experiments that measured feed supply and liveweight change of maternal ewes. Two animal house and two feedlot trials were available that included measurement of ad-lib intake, these showed that the equations were underestimating intake. In addition to the errors in intake the predictions of liveweight change from the known level of ME intake included errors of 30-50g/hd/d. Other trials that included measurement of liveweight of animals grazing pasture showed errors of up to 150g/hd/d between actual and predicted with the predictions both over and under estimating reality. This indicates that the errors are not just associated with the estimation of intake and is likely to be associated with error in estimating maintenance requirement and energy use efficiency.

The analysis described in this report is designed to complement the previous analyses and determine the importance of each component of the intake and energy equations in determining the optimum nutrition profiles for maternal ewes. The equations have a number of components that could be in error and each has a different impact on the LW gain or LW loss through the year. These components include potential intake, impact of relative condition on intake, impact of low availability on intake, impact of low digestibility on intake, maintenance requirement, efficiency of energy use for maintenance, efficiency of use of energy for weight gain and energy value of a kilogram of weight gain/loss. The impact of each component of the equations on LW change was quantified for four scenarios with different pasture feed supply and different animal LW. The scenarios approximated spring, summer, autumn and winter. There were 2 phases to the analysis; the first phase involved quantifying the effect of a change in the equation component on the liveweight performance of the animals. In the second phase the impact on the optimal liveweight patterns and the magnitude of the effect on profitability was quantified.

Each of the components has a different impact on the LWC of the ewes in each production scenario. Increasing potential intake increases the LWG or reduces LWL in each of the production scenarios, the biggest gain is in spring and the smallest gain in autumn. Reducing the impact of relative condition on intake only has a small effect on LW in the scenarios examined and when the animals are heavy (beginning of summer) increasing the effect of relative condition on intake increases LW loss and in the periods when the ewes are light there is a slight increase in the LW gain. Relative Intake-Quantity has its largest effect during winter when FOO is low but quality is high. Relative Intake-Quality improves the LW performance of the animals during summer and autumn when the feed quality is poor. Reducing maintenance requirement has a similar effect as increasing potential intake and increases LWG or reduces LWL in all periods of the year; however it has relatively more effect during autumn and less in spring. Increasing efficiency of energy use for maintenance has a similar impact to reducing maintenance requirement, which is expected because that is the major mode of action. Increasing efficiency of energy use for weight gain only affects the spring period when the animals are gaining weight. Reducing the energy content of weight gain/loss results in an increase in LW gain during spring and an increase in LW loss during autumn.

In all cases the variation in LW change (which had a maximum of 37 g/hd/d) is less than the discrepancies observed in the trials (up to 160 g/hd/d). This indicates that the magnitude of the sensitivity analysis on the components was conservative, however, larger changes led to unrealistic combinations of stocking rate and supplementary feeding from the optimised farm. This means that the calculated changes in profit are an underestimate of the changes expected and also suggests that the differences observed may be due to a combination of the components acting in tandem.

The optimum profile with the standard equations is joining at 60kg and maintaining in early pregnancy then in late pregnancy; singles gain 3kg, twins gain 6kg, triplets lose 3kg and drys maintain. In all cases varying a component of the equations leads to a change in the optimum profile for at least one class of ewes. Increasing potential intake or reducing the energy content of weight gain/loss both lead to the optimum profile involving losing weight in early pregnancy and more weight gain in late pregnancy for singles and triplets. A common change for the other components was allowing the dry ewes to lose weight in late pregnancy because the changes to the equations made it easier for the ewes to gain weight in the post weaning period.

When the optimum profile from the ‘standard equations’ model was run in the models with varying equation components then profit was reduced by between $0.10 and $7.71 /ewe for a 50g/hd/d change in ewe LW change. These profit values are likely to be an underestimate because the discrepancies between the equations and experimental observations were up to 160 g/hd/d. The components that had the largest impacts were potential intake, Relative Intake-Quantity, maintenance requirement, efficiency for maintenance and energy content of gain. Even where changing the components of the equations is only having a small effect on the optimum LW profile there is often an effect on the cost of not achieving the optimum. For example, increasing potential intake reduces the cost of mating at 63kg from $11.09 per ewe down to $3.58 per ewe, and increasing Kg reduces the cost of single ewes gaining 6kg in late pregnancy from $11.05/single ewe down to $1.63/single ewe.

In summary, the components identified in this analysis as being important to the calculation of the optimum profiles are potential intake, relative intake associated with quantity of feed on offer, energy required for maintenance, the efficiency of energy use for maintenance and the energy content of the weight gain and loss. This is an extensive list, so unfortunately this analysis and the other calculations have not narrowed down the list of traits that need to be quantified for maternals as it appears that both intake and energy requirements are important to determining the optimum profiles for maternal ewes.

Background

During the analysis carried out to determine the optimum liveweight profiles for maternal ewes it was concluded that the equations used to predict energy requirements and intake capacity of the maternal ewes didn't represent the liveweight measurements taken in the trials and didn't align with anecdotal observations of the performance of the maternal breeds in the paddock. It was also concluded that the discrepancy was affecting the optimum patterns identified. Subsequent analysis comparing 2 equation scenarios showed that the optimum profile was different for each scenario and the variation in profit between those optima was significant.

To evaluate the potential sources of variation a number of experiments that measured feed supply and liveweight change of maternal ewes were collated and the experimental measurements were compared with the equation predictions. This comparison was documented in a discussion paper in May 2016. There was only a limited number of observations against which to evaluate the equations, especially with respect to the level of intake. Two animal house and two feedlot trials were available that included measurement of intake, these showed that the equations were underestimating intake. In addition to the errors in intake the predictions of liveweight change from the known level of ME intake included errors of 30-50g/hd/d. Other trials that included measurement of liveweight of animals grazing pasture showed errors of up to 150g/hd/d between actual and predicted with the predictions both over and under estimating reality. This indicates that the errors are not just associated with the estimation of intake and is likely to be associated with error in estimating maintenance requirement and energy use efficiency.

This analysis is designed to complement the analysis described above and determine the importance of each component of the intake and energy equations in determining the optimum nutrition profiles for maternal ewes. The equations have a number of components that could be in error and each has a different impact on the LW gain or LW loss through the year. These components include:

1. Potential intake (PI): the amount an animal will eat if the feed is abundant and high quality. A genotype with a higher PI would be observed to have a higher drive to eat through the entire year. PI is estimated as 2.8% of the LW of the animal for animal at their SRW and in CS 3. This estimate is then scaled for the size of the animal relative to the SRW, the condition of the animal and the quality and quantity of pasture that is available. In this analysis PI was increased by 10%.

2. Relative Condition (RC): RC is the weight of the animal relative to its frame size. Fatter animals consume less feed and thinner animals consume more. A genotype that is more sensitive to RC would be observed as having a higher drive to eat when it is thin and less drive to eat when it is in good condition.

   RC = LW / Normal weight (N), where N is the weight of animal if it was in CS 3

   RC scalar = 2RC (1.5 - RC)

   In this analysis the difference of the RC scalar from 1 was scaled up by 25%.

3. Relative Intake Quantity (RIqn): Animals consume less when there is less feed on offer. An animal that is less sensitive to RIqn would be observed to have a greater drive to eat when feed availability is low, this would likely involve more hours spent grazing each day.

   $$RIqn = (1-e^{-1.5FOO}) (1+0.6e^{-1.4FOO2})$$

   In this analysis the difference of RIqn from 1 was reduced by 25%.

4. Relative Intake Quality (RIql): Animals consume less when the available feed is less digestible. An animal that is less sensitive to RIql would be observed to have a greater drive to eat when feed quality is low, this would likely involve more hours spent grazing each day but unlike RIQn it would only be observed during autumn and not winter. The anecdotal observation of 'sucking the moss off gravel stones' would describe this parameter.

   $RIql = 1-1.7(0.8-DMD)$ where DMD is Dry matter digestibility

   In this analysis the difference of RIql from 1 was scaled by 25%.

5. Maintenance requirement (MR): the amount of energy that the animal requires to maintain weight if it is in a thermos neutral environment and doesn't have to do excessive exercise.

   $MR = \frac{0.26\ LW^{0.75}e^{0.03Age}}{Km} + 0.09\ MEI$ where MEI = total ME intake.

   In this analysis MR was scaled down by 10%.

6. Efficiency of energy use for maintenance (Km): The efficiency with which energy consumed or energy liberated from weight loss is used for maintenance. Km is estimated from the M/D of the diet using the following equation.

   $$Km = 0.5 + 0.02\ M/D$$

   In this analysis the difference of Km from 1 was scaled by 10%.

Changes in MR and Km would be observed as generally more robust sheep achieving better LW gains than expected from the feed available.

7. Efficiency of energy use for weight gain (Kg): The efficiency with which energy surplus to maintenance, heat production and exercise is converted into body stores. High Kg would be observed as animals that gain weight easily.

   Kg, like Km is estimated from the M/D of the diet

   $$Km = 0.043\ M/D$$

   In this analysis the difference of Kg from 1 was scaled by 10%.

8. Energy value of LW gain (EVG): The amount of energy in a kilogram of weight gain or weight loss. Reducing EVG would be observed as animals that gain weight easily but unlike high Kg the animals would also lose weight quickly.

   If energy balance is positive: $LWG = (Balance * Kg) / EVG$

   If energy balance is negative: $LWL = Balance / (Km * EVG)$

   In this analysis EVG was scaled down by 10%.

Methods

There was two phases to the analysis; the first phase involved quantifying the effect of a change in the equation component on the liveweight performance of the animals. In the second phase the impact on the optimal liveweight patterns and the magnitude of the effect on profitability was quantified.

For phase 1 the impact of each component of the equations on LW change was quantified for 4 scenarios with different pasture feed supply and different animal LW. The scenarios approximated spring, summer, autumn & winter. The spring scenario is on green pasture with high FOO, high quality and light sheep (coming out of winter). Summer is on dry pasture with high FOO, lower digestibility and heavy sheep. Autumn is on dry pasture with low FOO, low digestibility and lighter sheep. Winter is on green pasture with low FOO, high digestibility and light sheep (Table 1). For these 4 production scenarios the impact on LWC was quantified for each of the components of the equations

Table 1. The 4 scenarios used to demonstrate the impact of each component of the equations.

Scenario	FOO (kg/ha)	DMD (%)	Supplement Offered g/hd/d	Ewe LW (kg)	LWC Std eqns (g/hg/d)
Spring	2610	75	0	57.3	148
Summer	3040	60	200	66.6	-8
Autumn	650	50	370	64.3	-96
Winter	467	77	0	55.2	7

The second phase was carried out using the MIDAS model and followed the method outlined in the 5th Milestone report. The LW profiles and the Hamilton production coefficients were used as described. The optimum profile was determined for each equation set and then the optimum profile for the standard equations was evaluated with each of the other equations to provide the magnitude of the error if an extension programme based on the incorrect profiles was carried out.

Results and Discussion

Each of the components has a different impact on the LWC of the ewes in each production scenario (Table 2).These different responses could be compared with anecdotal evidence to decide if one of the components describes what farmers are observing better than the others. Increasing PI increases the LWG or reduces LWL in each of the production scenarios, a 10% increase in PI increases the LWC by between 10 and 33 g/hd/d. The biggest gain is in spring and the smallest gain in autumn which is in line with the level of intake. Reducing the impact of RC on intake only has a small effect on LW in the scenarios examined because the animals are close to CS 3 and at this condition the change in intake is small. When the animals are heavy (beginning of summer) then increasing the effect of RC on intake increases LW loss and in the periods when the ewes are light there is a slight increase in the LW gain. RIQn has its largest effect during winter when FOO is low but quality is high. RIQl has a similar effect on improving the LW performance of the animals during summer and autumn when the feed quality is poor. Reducing MR has a similar effect as increasing PI and increases LWG or reduces LWL in all periods of the year, however it has relatively more effect during autumn and less in spring. Increasing Km has a similar impact to reducing MR, which is expected because that is the major mode of action. Increasing Kg only affects the spring period when the animals are gaining weight. Reducing EVG reduces the amount of energy required to gain a kilogram and it also reduces the energy made available when animals are losing weight therefore the impact is an increase in the rate of LW gain in spring and an increase in the LW loss in autumn in proportion to the change in EVG.

In all cases the variation in LW change (up to a maximum of 37 g/hd/d) is less than the discrepancies observed in the trials (up to 160 g/hd/d). This indicates that the magnitude of the sensitivity analysis on the components was conservative, however, larger changes led to unrealistic combinations of stocking rate and supplementary feeding from the optimised farm (Table 3). This means that the calculated changes in profit are an underestimate of the changes expected and it also suggests that the differences observed may be due to a combination of the components acting in tandem.

Table 2. Impact on LW change (g/hd/d) from altering each component of the equations for the 4 production scenarios.

Production Scenario	Std	PI	RC	RI Qn	RI Ql	MR	Km	Kg	EVG
Spring	148	181	151	150	151	161	154	165	185
Summer	-8	8	-17	-7	6	9	4	-8	-10
Autumn	-96	-86	-98	-91	-80	-67	-82	-96	-120
Winter	7	29	10	31	7	19	13	7	8
Max impact on LWC		33	9	25	16	29	14	17	37

Altering the components of the equations increases farm profitability (Table 3). The increase in profitability is achieved by increasing the optimum stocking rate and reducing the level of grain feeding required. In most cases this is achieved by increasing the quantity of pasture that is consumed per hectare which is possible because the animals can be offered a poorer quality diet and still achieve the target LW pattern.

Table 3: Production levels and profitability of the farm when the components of the equations are altered. Expressed at the level of actual level of adjustment.

	Std	PI	RC	RI Qn	RI Ql	MR	Km	Kg	EVG
Profit ($/ha)	785	1119	996	820	852	1070	1094	968	1161
Stocking Rate (DSE/ha)	18.91	19.35	19.05	18.45	19.06	20.13	20.05	19.14	20.54
Supp feeding (kg/DSE)	22.33	2.32	9.17	18.47	18.37	9.12	7.34	11.46	3.77
Pasture consumed (kg/ha)	5550	6228	5894	5505	5673	5921	5835	5724	6184

The optimum profile with the standard equations is as described in the milestone report, joining at 60kg and maintaining in early pregnancy then in late pregnancy singles gain 3kg, twins gain 6kg, triplets lose 3kg and drys maintain (Table 4). In all cases varying a component of the equations leads to a change in the optimum profile for at least one class of ewes. Increasing PI or reducing EVG both lead to the optimum profile involving losing weight in early pregnancy and more weight gain in late pregnancy for singles and triplets. A common change for the other components was allowing the dry ewes to lose weight in late pregnancy because the changes to the equations made it easier for the ewes to gain weight in the post weaning period.

Table 4. Optimum LW profile for Single bearing, twin bearing, triplet bearing and dry ewes. Note: All ewes follow the same profile until mid pregnancy.

	Std	PI	RC	RI Qn	RI Ql	MR	Km	Kg	EVG
Join Wt	60	60	60	60	60	60	60	60	60
Early Preg	0	-3	0	0	0	0	0	0	-3
Late Preg									
Single	+3	+6	+3	+6	+3	+6	+6	+3	+6
Twin	+6	+6	+6	+6	+6	+6	+6	+6	+6
Trip	-3	+6	-3	-3	-3	-3	-3	-3	0
Dry	0	+3	-6	-6	-6	-6	-6	+3	-6

If the optimum profile from the ‘standard equations’ model is run in the models with varying equation components then profit is reduced by between $0.10 and $7.71 /ewe for a 50g/hd/d change in ewe LW change (Table 5) and the components that have the largest impacts are PI, RIQn, MR, Km and EVG. RC, RIQl and Kg only have a small impact. The discrepancies between the equations and experimental observations are up to 150 g/hd/d therefore the impact on the variation in profit due to altering the components of the equation could be larger than reported in Table 5.

Table 5. Reduction in profit ($/ewe) if the optimum profile identified with the standard equations is run with varying components in the equations. Note: The values are scaled so that each component is at the level where it would alter LW change by 50 g/hd/d.

PI	RC	RI Qn	RI Ql	MR	Km	Kg	EVG
3.13	0.68	3.85	0.10	3.31	7.71	0.39	2.58

Even where changing the components of the equations is only having a small effect on the optimum LW profile there is often an effect on the cost of not achieving the optimum (Table 6). For example, increasing PI reduces the cost of mating at 63kg from $11.09 per ewe down to $3.58 per ewe, and increasing Kg reduces the cost of single ewes gaining 6kg in late pregnancy from $11.05/single ewe down to $1.63/single ewe.

Table 6: Change in profit if a sub optimal pattern is followed. Bold entries indicate the pattern that is optimal for the standard equations.

	Std	PI	RC	RI Qn	RI Ql	MR	Km	Kg	EVG
Joining weight									
63kg	-11.09	-3.58	-4.11	-12.06	-11.07	-8.65	-7.51	-6.56	-2.43
60kg	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Early Pregnancy									
Maintain	**0.00**	**-1.98**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**-0.97**
Lose 3kg	-4.73	0.00	-6.73	-4.60	-4.93	-3.93	-3.41	-1.63	0.00
Lose 6 kg	-6.98	-3.02	-12.02	-8.43	-7.12	-6.88	-5.95	-2.78	-0.01
Late Pregnancy									
Singles									
Gain 6kg	-11.05	-3.32	-6.06	0.00	-10.25	0.00	0.00	-1.63	-5.75
Gain 3kg	**0.00**	**0.00**	**0.00**	**-1.25**	**0.00**	**-3.05**	**-3.85**	**0.00**	**-1.84**
Maintain	-8.55	-0.42	-9.55	-12.39	-8.25	-11.75	-12.63	-6.85	0.00
Lose 3kg	-18.43	-7.02	-17.44	-21.02	-16.65	-17.95	-18.75	-12.05	-2.61
Twins									
Gain 6kg	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Gain 3kg	-6.68	-0.45	-7.55	-8.86	-6.26	-6.87	-6.84	-5.95	-0.64
Maintain	-16.26	-8.06	-18.09	-19.09	-16.41	-14.69	-14.73	-12.68	-3.65
Lose 3kg	-24.31	-12.98	-25.33	-25.99	-23.35	-19.59	-19.43	-17.24	-7.64
Triplets									
Gain 6kg	-30.54	0.00	-22.36	-63.77	-18.28	-35.20	-25.03	-17.16	0.00
Gain 3kg	-17.09	-0.90	-14.96	-41.15	-12.07	-17.30	-16.32	-11.38	-2.25
Maintain	-4.93	-2.00	-5.70	-14.87	-4.96	-6.44	-6.46	-4.57	-4.98
Lose 3kg	**0.00**	**-2.65**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**-6.53**
Dry ewes									
Gain 6kg	-4.05	-3.54	-2.15	-38.84	-4.99	-20.92	-18.90	0.00	-2.09
Gain 3kg	**0.00**	**-0.38**	**-1.73**	**-16.13**	**-0.49**	**-9.39**	**-7.55**	**-0.80**	**0.00**
Maintain	-2.34	0.00	-3.42	-10.43	-2.63	-5.35	-3.95	-3.08	-0.16
Lose 3kg	-0.11	-0.77	0.00	0.00	0.00	0.00	0.00	-1.97	-1.00

Conclusions

The analysis of the experimental data showed that intake was being consistently under estimated and this analysis shows that potential intake has a large effect on the optimum LW profile for maternal ewes. This makes potential intake a high priority for further investigation. The other components identified in this analysis as being important to the calculation of the optimum profiles are relative intake associated with quantity of feed on offer, energy required for maintenance and the efficiency of energy use for maintenance and the energy content of the weight gain and loss. Unfortunately this analysis and the other calculations have not narrowed down the list of traits that need to be quantified for maternals as it appears that both intake and energy requirements are important to determining the optimum profiles for maternal ewes.

References

Milestone Report #5. Project B.LSM.0064. Report to MLA. Sept 2015

Young JM (unpub). Maternal genotypes and Predictions of Intake and Energy Requirements. Discussion Paper for Project B.LSM.0064. May 2016