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Lifetime maternals – Phase II: Feeding Standards for maternal Ewes

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Abstract

Current Australian nutritional standards and condition score guidelines may not be optimal for the management of maternal composite ewes. The performance of maternal type ewes is different to the performance expected according to guidelines established for the management of Merino ewes in Australian farming systems. Two intensive feeding experiments, one using automated feeders (Hamilton) and the second a standard animal house set up with individual pens (Katanning) have been conducted to determine the potential intake, energy requirements for maintenance, efficiency of energy use of weight gain, or loss, for maternal composite ewes. The first experiment also examined maternal type ewes in comparison to Merino responses, and the second experiment examined the effects of composition with a condition score overlay. A third experiment measured the intake of twin bearing maternal type ewes at pasture over a range of available food on offer (from 400kg/ha through to *ad libitum*).

Data from the 3 experiments were used to alter the feeding standards equations to improve the representation of maternal ewes. These updated equations were then used within the MIDAS whole farm model to develop optimum liveweight and condition score profiles that would maximise profitability for a sheep enterprise with a maternal type ewe base. The targets for maternal type ewes are different to the targets developed for Merino ewes. The optimum is to join in condition score 4 or more and lose condition during pregnancy. If lambing early the optimum is to lose condition in both early and late pregnancy whereas for later lambing the optimum is to lose condition in early pregnancy and maintain condition in late pregnancy. The rate loss of condition during pregnancy is limited to the level that can be lost without increasing ewe mortality.

Executive summary

Current Australian nutritional standards and condition score guidelines may not be optimal for the management of maternal composite ewes. The performance of maternal type ewes is different to the performance expected according to guidelines established for the management of Merino ewes in Australian farming systems. Two intensive feeding experiments, one using automated feeders (Hamilton) and the second a standard animal house set up with individual pens (Katanning) have been conducted to determine the potential intake, energy requirements for maintenance, efficiency of energy use of weight gain, or loss, for maternal composite ewes. The first experiment also examined maternal type ewes in comparison to Merino responses, and the second experiment examined the effects of composition with a condition score overlay.

The feed intake and liveweight change of maternal composite and Merino ewes were significantly affected by feeding treatment. At Hamilton, the liveweight change between treatments was linearly related to feed intake on an individual animal basis and based on treatment means. At Katanning, this relationship was curvilinear so that conversion of feed energy to liveweight was slightly more efficient for ewes experiencing liveweight loss. At Hamilton, estimates of the maintenance requirements varied from 0.494 to 0.599 MJ/kg BW0.75 for the maternal composite ewes and 0.457 to 0.582 MJ/kg BW0.75 for the Merino ewes, subject to the model and measurements used. There appeared to be little difference in the maintenance requirements per kilogram of metabolic bodyweight for maternal composite and Merino ewes and this result was similar for ewes at high and low condition scores measured at Katanning. Maintenance requirements were lower at Katanning (0.330 MJ/kg BW0.75) although this likely reflects differences in "confinement" (ie group housing versus individual pens). Measured maximum *ad libitum* intake was similar based on percentage of liveweight basis, but all sheep in both experiments achieved intake levels higher than predicted using current industry standards.

The grazing trial conducted in South Australia measured intake of twin-bearing ewes in late pregnancy on four levels of feed on offer: 400, 700, 1000 kg DM/ha and *ad libitum*. Intake estimated from pasture disappearance rate was positively correlated with target FOO level ($P<0.0001$) and pasture height ($P=0.007$), with ewes on *ad libitum* treatment consuming 870g DM/day more than those on 400kg DM/ha treatment. Time spent grazing measured using a tri-axial motion detecting accelerometer had a significant negative relationship with FOO. When intake was predicted using lifetime ewe management feed budgets there was a large discrepancy with observed intakes, indicating that current industry standard feed budgeting resources may be under estimating the actual intake of non-Merino ewes in late pregnancy. The definition of more accurate feed requirements and feed on offer targets for non-Merino ewes will allow for increased precision of management, and optimisation of stocking rate and pasture utilisation.

Data from the 3 trial sites in this project were used to alter the feeding standards equations to improve the representation of maternal ewes. The changes made to the feeding standards equations to improve them for use with maternal ewes were:

1. Increase potential intake by 25%
2. Alter the relationship between FOO and intake capacity
3. Reduce the effect of relative condition on intake

4. Changed liveweight per unit of CS change to 15kg/CS.

To make these changes to the equations in the feeding standards this project examined the intake capacity of maternal ewes grazing pasture and assessed the energetics of maternal ewes in the animal house on a pelleted diet. From the analysis of the results of the experiments it was concluded that the prediction of maintenance requirement and efficiency of use of energy was within experimental error and there was insufficient evidence to indicate a need for alteration. However, results from the DXA scans showed that some animals had a higher protein content and lower fat content than expected and when the animals gained weight that more protein and less fat was deposited. Furthermore, the maternal ewes ate more than was predicted and did not reduce intake when body condition score increased above 3 as predicted using current equations. On pasture with high FOO they consumed 25% more feed than was predicted, although when FOO was low (200 kg/ha) the increase was about 35%.

The optimum is to join in condition score of 3.8 to 4.2 and lose condition (up to 1.3 CS) during pregnancy to lamb at CS 3.0 to 3.1 for singles and CS 3.3 to 3.7 for multiple bearing ewes. If lambing early the optimum is to lose condition in both early and late pregnancy whereas for later lambing the optimum is to lose condition in early pregnancy and maintain condition in late pregnancy. The maximum rate of loss of condition during pregnancy is limited to the level that can be lost without increasing ewe mortality.

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1 Background

The development of optimum condition score profiles for Merino ewes and their adoption via programs such as Lifetime Ewe Management and Bred Well Fed Well have resulted in widespread improvements for productivity, profitability and welfare across the sheep industry. The 'Measure-to-manage' principles have also been adopted by prime lamb producers with non-Merino ewes, however there has also 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 much 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 expected if the nutritional requirements and condition score targets promoted to industry were better tailored to non-Merino ewes. The overarching aim of the 'Lifetime maternals' project was therefore to use a combination of experimentation and bioeconomic modelling to develop ewe liveweight and condition score (CS) profiles to maximise whole farm profit for non-Merino ewes.

Several large-scale grazing experiments involving 500 to 1300 ewes were conducted across four research sites in 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 when managed together. Ewes were managed to achieve one of four target condition scores at lambing varying from 2.5 to 3.6 and the effects on ewe and lamb production were quantified. This same design but using non-Merino ewes only was also implemented at sites in Hamilton and Pigeon Ponds in Victoria and Mount Barker in Western Australia. In these experiments the treatments continued through until the end of lambing, so ewes in lower CS prior to lambing also 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 2.6 or 3.4 at the start of lambing and then allocated to a range of FOO treatments varying from 600-800 kg DM/ha to more than 2000 kg DM/ha until lamb weaning.

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 up to 15 kg and more than one CS at lambing the differences in liveweight and CS at the following joining were minimal across a range of seasons and environments. The carryover effects on reproduction the following year were variable but across the four sites the reproductive rate of ewes poorly fed during the previous pregnancy was only reduced by about 5% depending on seasonal conditions which was much less than observed in similar experiments with Merino ewes.

In 2014 when treatments were maintained until the end of lambing, across all sites the lower CS treatments reduced lamb weights by 0.6 kg at birth, 1.9 kg at marking and 1.6 kg at weaning. The treatment effects were similar for single and twin born lambs and the impacts on weaning weights were largely present by lamb marking. 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 0.30 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 1.0 kg. In these experiments the effects of ewe liveweight change during early-mid and late pregnancy on lamb birth weight and weaning weight were similar in magnitude and relative importance to that observed in Merinos. 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. There were limited triplets born at the research sites, however together with the metanalysis, 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 condition score from 2.7 to 3.3, as even the lightest single lambs still weighed about 5.5 kg. However on average the survival of single lambs was reduced by 7% in ewes fed to achieve CS 3.7 through to the end of lambing (89% compared to 82%), due to increased risk of birth injury and dystocia. Increasing ewe CS at lambing from 2.5 to 3.6 and especially up to CS 3.2 improved the survival of multiple born lambs by 17% and weaning rate from twin bearing ewes from 135% to 169%.

In 2015, when ewes in CS 2.7 or 3.3 at about day 135 of pregnancy were allocated to varying FOO until weaning, ewe CS treatments had no significant effects birth weights of single lambs and less than expected impacts on the birth weight of twin lambs. There were also no significant differences in birth weights between the FOO treatments at any site. The lack of effect of the FOO treatments 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 over the 2-3 week period prior to lambing 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. At this stage the precise reasons for the birth weight responses to CS and FOO treatments are therefore not known. 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 in part reflected the ewes being 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. Surprisingly average FOO during lactation had negligible if any effect on weaning weight at three of the four sites, and hence higher levels of FOO during lambing and lactation could not mitigate the adverse effects of poor nutrition during pregnancy. Only at one site was the effect of FOO during lactation of practical significance, probably because FOO levels were as low as 560 kg during all of lactation, and the adverse impacts of low CS at Day 140 of pregnancy on weaning weight was mitigated by having an extra 330 to 420 kg DM/ha on offer during lactation.

The results imply that CS targets at lambing of 2.7 for single-bearing ewes and at least 3.2 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 nutrition from the point of lambing until weaning does not fully counteract the adverse effects of poor nutrition during pregnancy on weaning weight of lambs from non-Merino ewes, and these impacts on weaning weights are likely to have an economic impact on lamb production systems. Overall, the project has shown that the liveweight 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 or CS profiles for non-Merino ewe flocks.

An analysis to develop these target liveweight and CS profiles was undertaken using the coefficients generated from the 2014 experiments and the Hamilton version of MIDAS. 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 (ie CS 3), 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. However, the optimum profiles did vary significantly when the feed budget equations were adjusted to represent alternative explanations for the differences observed between the 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.

Further 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. 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. 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 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. 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. These traits need to be quantified for non-Merino ewes to enable optimum profiles for non-Merino ewes to be developed and extended to industry.

2 Project objectives

2.1 Lifetime Ewe Maternals

2.1.1 Animal house experiments

Conducted two animal house experiments to determine the potential intake, energy requirements for maintenance, efficiency of energy use for maintenance and the energy content of weight gain, or loss, for maternal ewes varying in condition score and compared responses to Merinos and current Australian Feeding Standards for Ruminants.

2.1.2 Grazing experiment

Conducted an intensive grazing experiment to quantity relative feed intake associated with quantity of feed on offer and develop revised feed-on-offer targets for late pregnancy to achieve condition score targets at lambing.

2.1.3 Whole farm modelling

Utilised new understanding of the intake and energy equations to allow more accurate whole-farm economic modelling to be completed to determine the economic optimum liveweight and condition score profile for maternal ewes in three different regions.

2.1.4 Extension

Integrated and refined nutritional requirements for maternal ewes established and delivered for incorporation into existing and new training programs such as BredWell FedWell, Profitable Grazing Systems and Lifetime Ewe Management.

3 Animal house experiments

3.1 Hamilton

The degree to which maternal composite ewes have higher feed intake or feed efficiency than those predicted using current Australian nutritional standards has significant implications for modelling the most profitable management targets for condition score in a prime lamb enterprise and for managing ewe nutrition during pregnancy. An intensive feedlot experiment using automatic feeders to restrict feed intake to different levels of maintenance requirement (MR) was conducted using 126 maternal composite and 20 Merino non-pregnant ewes.

Six treatments were applied to the maternal ewes (within 7 pens of 18 ewes) reflecting different percentages of estimated MR (40%, 60%, 80%, 100%, 140%, 180%) that would result in liveweight loss or gain of approximately -150 g/day, -100 g/day, -50 g/day, 0 g/day and 50 g/day and 100 g/day respectively for a non-pregnant 60 kg maternal composite ewe. Four treatment levels were also applied to Merino ewes (in one pen of 20 ewes) at 60%, 80%, 100%, and 140% of MR. Ewes were adapted to the feed intake facility for 19 days prior to the start of the restricted feeding period. A 9 mm sheep starter/conditioner pellet with an average metabolisable energy of 10.3 MJ/kg DM, crude protein of 12.3% and neutral detergent fibre content of 39.5% were fed through 2 automatic feeders in 7 pens of maternal composite ewes and one pen of Merino ewes. The "as fed" amount of feed controlled by the automatic feeder was calculated for each individual sheep based on their liveweight, condition score and estimated standard reference weight using current Australian nutritional standards for sheep. During restricted feeding the automated feed system was programmed to deliver ~100 g per meal to each ewe until she reached or exceeded her treatment level of feeding each day (within 24 hours). Liveweight measurements were undertaken 3 times per week and condition score once per week. A 24 hour fasted liveweight and measurement of body composition by dual-x-ray absorptiometry were undertaken on each pen of sheep 10 to 2 days and 8 to 2 days before the start and end of the restricted feeding period respectively. An ultrasound scan of C-fat and eye muscle depth was taken in conjunction with a liveweight measurement at 4 days prior to the start of the restricted feeding period and at the end of the restricted feeding period.

The average *ad libitum* intake during the 19 day adaption was 2.24 kg/day for the maternal composite ewes and 1.51 kg/day for the Merino ewes. After 42 days of restricted feeding the mean feed intake per day of both groups of sheep were significantly affected by the feeding treatment (maternal ewes $P < 0.001$, Merino ewes $P = 0.001$). This resulted in a significant difference in liveweight change between treatments ($P < 0.001$). Maternal composite ewes in the lowest feeding treatment lost 8.7 kg liveweight (209 g/day) and Merino ewes lost 7.5 kg (179 g/day). The highest feeding treatment increased liveweight by 2.3kg (54g/day) in both the maternal composite and Merino ewes. Liveweight, fasted liveweight change and changes in estimates of total, fat and lean tissue mass derived by dual-x-ray absorptiometry were linearly related to mean feed intake per day on an individual animal basis and across experimental treatments. Estimates of the maintenance requirements varied from 0.494 to 0.599 MJ/kg BW0.75 for the maternal composite ewes and 0.457 to 0.582 MJ/kg BW0.75 for the Merino ewes, subject to the model and liveweight or tissue mass measurements used. There appeared to be little difference in the maintenance requirements per kilogram of metabolic bodyweight for maternal composite and Merino ewes and all estimates were higher than those predicted using current industry formulae for housed sheep. The achieved maximum *ad libitum* feed intake for the ration fed in this experiment of 3.3 and 2.4 kg DM/day, representing 4.1% and 4.4% (DM basis) of liveweight for maternal Composite and Merino ewes respectively, are higher than current industry programs or standards would predict.

The results reported will be combined with the results from the South Australian Research and Development Institute (SARDI) and Murdoch University experiments for further analysis and modelling. This will inform the development of industry recommendations and training packages for producers on the energy requirements to manage liveweight and condition score of maternal composites ewes.

3.2 Katanning

The performance of maternal type ewes is different to the performance expected according to guidelines established for the management of Merino ewes in Australian farming systems. An experiment to intensively measure intake and liveweight change at Katanning in Western Australia was conducted, with an additional overlay to examine the effects of varying condition score on feed intake and liveweight efficiency.

Two hundred ewes were fed in a feed lot for 6 weeks to achieve a significant difference in condition score using hay and a commercially produced 9mm pellet. One hundred and sixty ewes were then selected and managed in individual pens and after a 7 day acclimation period, the ewes were fed at one of six levels within CS treatment, continuing with the same commercial pellet. The treatments were applied and adjusted to the individual sheep level by liveweight. The levels tested were: 40%, 60%, 80%, 100%, 140% and 180% of maintenance for ewes in confinement. The ewes were fed daily in the morning after any refusals had been weighed and removed. The ewes had liveweight measurements collected 3 times weekly and were condition scored once per week. Following the period of restricted feeding, ewes were allowed to consume *ad libitum* after a 5 day adjustment period allowing the low feeding groups to catch up with the higher groups, with *ad libitum* feeding measured over 14 days. On three occasions, the ewes were measured for ultrasound fat and muscle at the C site before being fasted (feed 24H, and water 12H) and having body composition measured using Dual Xray Absorptiometry (DXA).

Condition score treatment created a significant difference in condition between the two groups on entry to the feed intake shed (CS3.32 versus CS2.55). Significant differences in intake and liveweight change were achieved during restricted feeding and these changes were still significant during *ad libitum* feeding. Condition score treatment did not have a significant effect on liveweight change during the restricted period, however during the *ad libitum* period, ewes in the low CS group gained significantly more liveweight than ewes in the high CS group despite eating at approximately the same proportion of feed to liveweight (~3% of liveweight). The ultrasound and DXA results show that the ewes in the LOW CS group gained more lean tissue than ewes in the HIGH CS group, and this was similar across the range of previous feeding treatments so that as level of previous feeding increased, lean tissue gain has decreased.

During restricted feeding the mean feed intake per day and the resulting liveweight change were significantly affected by feeding treatment ($P < 0.001$). Ewes in the lowest feeding treatment (40% of maintenance) lost 153 g/day. Ewes in the highest feeding treatment (180% of maintenance) gained 116 g/day. Ewes at 100% of maintenance achieved close to liveweight maintenance (-16 g/day). However this entailed maintenance of fat tissue (1.1 g/day) at the cost of lean tissue (-24.7 g/day). This means that the maintenance of whole body energy stores will be associated with a small degree of liveweight loss.

Liveweight, fasted liveweight change and changes in estimates of total, fat and lean tissue mass derived by dual-x-ray absorptiometry had essentially linear relationships with feed intake with some curvilinearity evident at the highest feeding levels. Estimates of maintenance requirements per kilogram of metabolic liveweight ($LW^{0.75}$) was 0.330MJ of ME/KG per day. Maintenance of fat tissue was achieved at 0.317 MJ of ME/KG per day and maintenance of lean tissue at 0.354 MJ of ME/KG per day. Maintenance requirements were slightly lower than current industry recommendations, however this may be due to the definition of "confinement" varying from group pens to individual pens. Maximum intake was considerably higher than current industry understanding with maximum intakes (measured as a 5 day average) at 4.2 - 4.4% of final liveweight, which may contribute towards accounting for greater liveweight gains observed in paddock fed sheep.

4 Grazing experiment

4.1 Struan

A significant proportion of total Australian lamb supply is produced from non-Merino or Merino-cross ewes, such as Border Leicester x Merino (BLM). Management guidelines for Australian sheep production systems have been based on the outcomes of research from Merino ewes. However, previous studies have shown that Merino and non-Merino ewes generally perform differently when managed together, suggesting that management guidelines developed for Merinos may not be directly transferrable to other breeds of sheep.

Analysis of outcomes from MLA funded 'B.LSM.0064: Lifetime Maternals – development of management guidelines for non-Merino ewes' showed condition score targets at lambing of 2.7 for single ewes and 3.3 for multiple-bearing non-Merino maternal ewes are likely to achieve near-maximum lamb survival and weaning rates. However, in that study ewes maintained or lost less weight on much lower feed-on-offer (FOO) levels than estimated using current feeding standards, contradicting the current recommendations for FOO levels during pregnancy to achieve target condition score at lambing. Defining more accurate FOO targets to meet these condition score targets, especially during late pregnancy and at lambing, are prerequisites for precise management of ewe nutrition to optimise stocking rates and feed utilisation.
The aim of this study was thus to conduct an intensive grazing experiment during late pregnancy to determine the intake of ewes on four different levels of FOO: 400, 700, 1000 kg DM/ha and ad lib. It is acknowledged that intake of grazing animals at pasture is inherently difficult to measure, and as such several methods were utilised within the current study to estimate intake, including pasture disappearance rates over the trial period and accumulation of CO_2, as well as novel sensor technology to estimate time spent grazing.

The study was conducted at Struan Research Centre, near Naracoorte in south east of South Australia. Twin bearing Border Leicester x Merino ewes were selected for the trial, and allocated to one of the four feed treatments at 129 days after rams were introduced, stratified for liveweight, condition score and age. Ewes were placed onto a 0.15ha plot (acclimatisation sub-plot) of their allocated feeding treatment in groups of 9 to allow ewes to become accustomed to their treatment feeding level. After grazing the acclimatization plot for a period of three days, ewes had intake measures recorded by gas accumulation, and were then introduced to an adjacent trial sub-plot for a further three days of grazing during which pasture and sensor measures of intake were recorded. Ewes had a final gas accumulation measure taken after three days of grazing the trial plot prior to completion of their experimental measures.

There was a significant difference between all treatments in the actual FOO on entry into and exit from both the acclimatisation and trial plots. Actual FOO into the trial period ranged from 519 kg DM/ha in the 400 FOO target to 1325 kg DM/ha in the ad lib. target treatment. Likewise, there was a positive relationship between FOO targets and pasture height, with pasture in the ad lib. treatment 3.2cm taller than pasture in the 400kg DM/ha treatment. This range in FOO and pasture heights reflected a significant correlation between observed intake and FOO on entry into trial plots, with ewes on higher FOO targets consuming more pasture ($P<0.0001$). The positive relationship between intake and FOO was supported by sensor measures that showed a significant negative relationship between time spent grazing and FOO ($P<0.05$), time spent grazing and intake ($P<0.05$) and a positive relationship between time spent ruminating and FOO ($P=0.0001$).

At 400kg DM/ha FOO, observed intake was consistent with intake predicted using Grazfeed animal management software, however at 700 kg DM/ha FOO, Grazfeed predicted intake was significantly lower than observed intake when actual ewe liveweight was used ($P<0.01$). From 1000 to 1500kg DM/ha FOO, observed intake was significantly greater than Grazfeed predicted intake estimated using ewe standard reference weight ($P<0.01$) which was greater than intake estimated using the actual 84kg ewe liveweight ($P<0.001$). This indicates that at lower levels of FOO, Grazfeed is more accurate in predicting intake than at higher levels of FOO. Conversely, when intake was compared with lifetime ewe management feed budgeting predictions, observed intake was consistently higher than predicted across the entire 400 – 1500 kg DM/ha range of FOO levels examined in this study, with the greatest discrepancies occurring at low levels of FOO. This discrepancy between predicted and observed intake supports the hypothesis that intake of pasture by twin-bearing crossbred ewes in late pregnancy is greater than that predicted by models used for feeding guidelines by Australian lamb producers. In particular, lifetime ewe predictions of intake at low FOO are significantly underestimating potential intake. Results of this trial will be used in conjunction with results from the Murdoch University and DEDJTR research trials in economic modelling to refine FOO targets for non-Merino ewes.

5 Whole farm modelling

There has been a demand from industry for nutrition guidelines for Maternal breeds following on from the success of the Lifetimewool (LTW) research programme and the Lifetime Ewe Management (LTEM) extension programme that developed guidelines for the nutrition of Merino ewes at joining and, during pregnancy and lactation. It has been hypothesised by people working with Maternal sheep that the optimum management for maternal ewes will be different than that required for a Merino ewe. This was supported by a survey of producers and consultants that showed that many producers didn't believe that the Merino guidelines are relevant for their flocks.

There are several reasons that the Merino guidelines may not be correct for maternal breeds. Firstly, the wool produced by Merino progeny is more valuable than the wool produced by progeny of maternal breeds. Young *et al.* (2011) showed that about one third of the value of improved management of the nutrition profile of Merino ewes occurs through improvements in the value of wool produced by the progeny. Secondly, Maternals are bigger, have higher reproductive rates and lamb survival and the prime lamb is ideally turned off in the shortest time possible (around 5-6 months of age) which increases the importance of weaning weight. Thirdly, the progeny of maternal breeds are more resilient and have lower death rates. The argument therefore is that the optimum profile for maternal ewes may include greater weight loss than the profile for Merino ewes.

Project B.LSM.0064 "Lifetime Maternals - development of management guidelines for non-Merino ewes" quantified the production response of maternal ewes and their progeny to varying nutrition during pregnancy and lactation. That project developed a range of coefficients that related lamb birth weight, weaning weight and number of lambs conceived to ewe LW profile and lamb survival to lamb birth weight. However, the project was unable to draw conclusions about nutritional guidelines from the modelling carried out because the feed budgeting for maternal genotypes using the equations and parameters from the Australian Feeding Standards did not replicate the measured performance of the ewes in the research trials. Specifically, the high rates of liveweight gain measured in the experiments could not be feasibly achieved in the feed budgets using current prediction equations.

There were 3 components of the current project:

1. Animal research measuring intake, liveweight change and body composition
2. Re-calibrate the equation from the feeding standards to reflect intake and energetics of maternal ewes
3. Economic modelling to develop guidelines for maternal ewes

This report covers components 2 and 3 of the overall project.

The animal research in the current project involved 3 sites in total. The first site (Struan, SA) measured intake on pasture of pregnant Border Leicester Merino (BLM) ewes with varying levels of feed on offer (FOO). The other 2 sites (Hamilton, Victoria & Katanning, WA) measured maternal composite ewes under intensive feeding conditions with close control and measurement of feed intake and measurement of liveweight and body composition (using DXA scanning).

The project examined the intake capacity of maternal ewes grazing pasture and assessed the energetics of maternal ewes in the animal house on a pelleted diet. From the analysis of the results of the experiments it was concluded that the prediction of maintenance requirement and efficiency of use of energy was within experimental error and there was insufficient evidence to indicate a need for alteration. However, the maternal ewes ate more than was predicted and did not reduce intake when body condition score increased above 3 as predicted using current equations. On pasture with high FOO they consumed 25% more feed than was predicted, although when FOO was low (400 kg/ha) the increase was only about 10%.

Energy Value of Gain which is directly related to the composition of the gain was directly estimated as the slope of the relationship between the change in energy retained from the DXA scans and change in fasted liveweight. The discrepancy between the measured EVG (Hamilton 25.3 MJ/kg, Katanning 14.1 MJ/kg) and predicted EVG (26.4 MJ/kg) is less than 5% for the Vic ewes, however, for the WA ewes the discrepancy is more than 45%. Estimation of EVG was also attempted by calibrating the predictions against the actual measurement of LWC, FOO and supplementary feeding made in B.LSM.0064. Using this approach the estimated EVG was 17.4 MJ/kg.

Further research is recommended to better quantify the relationship between live DXA scans and the proportions of chemical fat and protein and their energy content in maternal sheep because there is limited experimental evidence for correcting the DXA information to remove bias. It is also necessary for producers to accurately feed budget so that they can follow the guidelines.

Another finding from the project was that maternal ewes gain about 15kg for each 1 unit increase in CS. This compares with the equivalent value for Merinos determined in the LifetimeWool experiments of 9.2 kg/CS. This adjusted figure was used to convert the LW profiles calculated in the modelling to CS profiles.

Based on the experimental results 4 changes made to the feeding standards equations to improve them for use with maternal ewes were:

1. Increase potential intake by 25%
2. Alter the relationship between FOO and intake capacity
3. Reduce the effect of relative condition on intake
4. Changed liveweight per unit of CS change to 15kg/CS

To optimise the LW patterns it was necessary to include relationships between ewe mortality and, rate of LW loss during pregnancy and CS of ewes at lambing. These relationships are to account for the risks of pregnancy toxaemia, hypocalcaemia, dystocia and getting caste at lambing. There is little data on which to base these relationships and therefore it is recommended that further research is carried out to define the relationship between rate of weight loss during pregnancy and the risk of pregnancy toxaemia and hypocalcaemia, and ewe CS at lambing and the risk of dystocia

The economic analysis described in this report was carried out using 2 regional versions of the MIDAS models. The Hamilton version included lambing in autumn, winter and spring and the Great Southern version included lambing in autumn and winter. In both regional versions ewe replacements were purchased at 18 months, mated to a terminal sire and all progeny were sold as finished lamb between 4.5 and 5.5 months of age.

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 achieve saleable weights within each rear class.

The analysis was carried out in 3 sections:

1. Determination of the optimum LW profile for ewes and the effect of altering prices and grazing intensity, genotype assumptions and inclusion of the ewe mortality safety margin.

2. Evaluation of the cost of missing targets at different stages of the reproductive cycle.

3. Evaluation of the sensitivity of profit to the joining CS and the impact on the optimum management during pregnancy.

The optimum LW pattern was generated starting with a standard feed supply. From this feed profile, variations in feed supply were generated that would alter the LW profile of the ewes by about 50 g/hd/d (equivalent to 1.5 kg/hd/month or 0.1 CS/month). The feed supply variations were then divided into 4 periods that aligned with: Joining to scanning; Scanning to lambing; Lambing to weaning and Weaning to joining. These levels of variation were used to alter the standard feed supply pattern and create a new pattern for testing.

For each pattern tested, ewe and progeny production was adjusted using the relationships developed in project B.LSM.0064 and farm profitability was estimated using the MIDAS model. The next nutrition level was selected using a converging algorithm based on maximising farm profit. This algorithm selected the optimum profile to within 0.1 CS at each time point.

Project L.LSM.0008 has developed guidelines for maternal ewes that are different to the targets developed for Merino ewes that are being extended through the LTEM ewe program and they are better than the best profile that could have been developed in the absence of this project. The increase in profit compared with the LTEM profile is between $7 and $11/ewe and the improvement compared with the previous best bet is between $2 and $8/ewe.

The optimum is to join in condition score of 3.8 to 4.2 and lose condition (up to 1 CS) during pregnancy to lamb at CS 3.0 to 3.1 for singles and CS 3.3 to 3.7 for multiple bearing ewes. If lambing early the optimum is to lose condition in both early and late pregnancy whereas for later lambing the optimum is to lose condition in early pregnancy and maintain condition in late pregnancy. The maximum rate of loss of condition during pregnancy is limited to the level that can be lost without increasing ewe mortality.

For early lambing the optimum CS at joining is the level that the ewes volunteer, without supplementary feeding, however, peak CS needs to be managed so that the target lambing CS can be achieved without excessive LW loss during early and late pregnancy. For later lambing the LW loss from the peak is managed with supplementary feeding to achieve the joining CS that allows the lambing target to be achieved without excessive LW loss.

If ewes volunteer a higher or lower CS at joining, then the optimum loss of CS during pregnancy is altered. Heavier ewes at joining lose more condition during pregnancy and the CS target at lambing is not altered markedly. In all cases the optimum CS at lambing for singles is about CS 3 and between CS 3.3 and 3.7 for multiples.

The price of supplementary lupin grain was tested in the range $235/t up to $465/t and the price of meat was tested in the range $4.30 to $8.60/kg for lamb, over these ranges there was no change of practical significance to the optimum CS profile. Therefore, the guideline profiles are robust in respect of market conditions.

6 Extension tools

Results are now available for integration into extension messages regarding best practice for optimum ewe and lamb performance, as well as the condition score profiles that will maximise farm profit when utilising non-Merino ewes. As well, there are results that will assist in informing further work examining maintenance requirements, intake at pasture, liveweight and whole body energy change.

While there are some components that require further work and interpretation, the coefficients for the reproductive performance of non-Merino ewes and lambs are robust across regions and replicates and are available for delivering to producers via workshops such as Lifetime Ewe Management, and BredWell FedWell.

7 Conclusions/recommendations

Experimental work conducted during phase I of Lifetime Maternals (B.LSM.0064) showed that CS targets of 2.7 for single bearing and at least 3.2 for twin bearing ewes achieved near maximal lamb survival and weaning rates in maternal type ewes across a range of genotypes and environments. However in addition to survival, conception rates and lamb weaning weight are significant drivers of profitability in sheep enterprises based on maternal genetics. The ability of maternal type sheep to maximise production at pasture is also a significant contributor to profitability in both finisher and store production enterprises.

Whole farm modelling utilising results from phase I in combination with new information generated during phase II has demonstrated that lambing CS is the key target to maximise profit, and this target is CS 3.0 – 3.1 for single bearing ewes and CS 3.3 - 3.5 for twin bearing ewes. These targets are robust to changes in environment, time of lambing, stocking rate, condition score at joining, and grain and meat prices. As reported previously the uptake of pregnancy scanning is still critically low (20-25% of non-Merino ewes currently scanned for multiple births), and this will contribute to negative outcomes for animal welfare outcomes and for farm profitability. Further work is required within the industry to clearly demonstrate the value of pregnancy scanning, and to improve producer awareness and confidence in this practice as a management tool.

Survival of ewes and lambs is clearly defined by pregnancy status with dystocia in over conditioned single bearing ewes contributing to both ewe and lamb mortality, while under conditioned twin bearing ewes produce lambs that are susceptible to the starvation/mismothering/exposure complex and are themselves more susceptible to pregnancy toxaemia and hypocalcaemia. Further work is currently underway to define best practice management protocols for ewes who conceive triplets (L.LSM.0013). The impact of the rate of LW loss during pregnancy and CS at lambing on maternal ewe mortality is important for these guidelines. It is an area with little data and a safety margin has been included in the guidelines developed. Therefore, further research is recommended to define the relationship between rate of weight loss during pregnancy and the risk of pregnancy toxaemia and hypocalcaemia, and ewe CS at lambing and the risk of dystocia.

Producers using maternal type ewes have previously attempted to improve management outcomes using the targets developed as part of Lifetime Ewe Management, and this has been somewhat effective. The new modelling shows that continuing to use Merino targets for maternal type sheep will penalise profit by $7-11 per ewe. Considerable work has been undertaken as part of phase II and it has been demonstrated that maternal type sheep can eat significantly more pasture than predicted, particularly at low levels of food on offer. However, it may be that intake estimates for Merino sheep also require updating. Additionally, there was a considerable range in the results from the phase II experiments for maintenance requirement, between Merino and maternal ewes, between animal house set ups, and between artificial and pasture feeding of maternal type ewes. While the error between these measurements was not large enough to support a change to recommendations for maintenance, further work is required to assess maintenance requirements with accuracy (eg calorimetry). In the meantime, the ability of maternal sheep to achieve high throughputs of pasture and pelleted diets suggests there may be scope to develop cheaper supplementary feeding options for these ewes, such as low energy pellets.

During the recalibration process for whole farm modelling, 1) the energy value of gain and 2) the impact of relative condition on potential intake were two components highlighted as being the least robust. However, both of these components have the potential to significantly impact the guidelines and profitability. Differences in both the relative condition on intake, and energy value of gain were considerable between the animal house experiments and there are a number of plausible reasons (experimental design, genotype, starting maturity/leanness/fatness/body composition). Therefore it is recommended that these are areas requiring further data collection to support accurate estimation of these parameters in economic analysis.

8 Lifetime Maternals - key messages

- Whole farm profit is sensitive to stocking rate and to changes in condition of non-Merino ewes during the year.
- Adoption of the optimum condition score profile is achievable independent of whole farm stocking rate.
- The optimum condition score targets for maternal ewe flocks (finished lambs at 45-50kg on pasture) are different to the optimum targets for Merino flocks. Using the Merino targets for maternal flocks reduces profit by $7-11/ewe.
    - *One condition score unit for maternal type sheep is equal to 15kg, or ~25% of liveweight, however there will be variation due to differences in breeding, sheep size and body composition between flocks.*
- Condition score at lambing is the key target because it influences ewe survival and the birthweight, survival and weaning weight of lambs. The lambing condition score target is largely

unaffected by region, time of lambing, stocking rate, condition score at joining, and grain and meat prices.

- Single bearing ewes should be lambed at condition score 3.0 to 3.1. Multiple bearing ewes should be lambed at condition score 3.3 to 3.5.
  - *Flocks that are not scanned will need to manage the tradeoff between single and twin bearing ewe productivity as neither optimum target can be achieved.*
- Condition score at joining can be as volunteered from stocking rate and seasonal conditions provided the lambing target can be achieved.
  - *The flock average should be no higher than CS 4.2.*
  - *For flocks joining after peak liveweight, supplementary feeding at joining to reduce liveweight loss below CS 3.8-4.2 is profitable.*
- Ewes can lose the difference during pregnancy, managing the trade-off between excessive weight loss causing mortality through pregnancy toxaemia and insufficient weight loss leading to heavy ewes at lambing with increased risk of dystocia.
  - *Prior to pregnancy scanning ewes can lose up to CS 0.7.*
  - *Single bearing ewes can lose a further CS 0.6 through mid to late pregnancy.*
  - *Multiple bearing ewes should be maintained through mid to late pregnancy.*
- Maternal type ewes have a potential intake 25% higher than current estimates so that increased FOO intake allows ewe recovery during lactation and post weaning, and ewes return to joining in higher condition.

9 Appendix

9.1 Hamilton experiment (draft paper)

9.1.1 An assessment of the maintenance energy requirements of group housed Maternal Composite and Merino ewes using automated feeders.

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9.1.2 Abstract

The degree to which non-Merino Maternal Composite ewes have higher feed intake or feed efficiency than those predicted using current Australian nutritional standards has significant implications for modelling the most profitable management targets for condition score in a prime lamb enterprise and for managing the nutrition of ewes during pregnancy in flock situations. However, most of the data that underpins current feeding standards has been collected from sheep that have been individually housed and fed. The ability to express social interactions and feeding behaviours could therefore be important considerations in assessing the maintenance of sheep in group housed situations. An intensive feedlot experiment using automatic feeders to restrict feed intake to different levels of maintenance energy requirement (MR) was conducted using 126 Maternal composite and 20 Merino non-pregnant ewes. Six treatments were applied to the Maternal ewes (18 ewes per pen) reflecting different percentages of estimated MR (40%, 60%, 80%, 100%, 140%, 180%) that would result in liveweight loss or gain of approximately -150 g/day, -100 g/day, -50 g/day, 0 g/day and 50 g/day and 100 g/day for a non-pregnant 60 kg Maternal composite ewe. The 4 treatment levels were also applied to Merino ewes (20 ewes per pen) at 60%, 80%, 100%, and 140% of MR. Ewes were adapted to the feed intake facility for 19 days prior to the start of the restricted feeding period. A 9mm sheep starter/conditioner pellet manufactured by Johnson's Premium Stockfeeds with an average metabolisable energy, crude protein and neutral detergent fibre content of 10.3 MJ/kg DM, crude protein of 12.3% and of 39.5% respectively, were fed through 2 automatic feeders in 7 pens of Maternal ewes and one pen of Merino ewes. The "as fed" amount of feed controlled by the automatic feeder was calculated for each individual sheep based on their liveweight, condition score and estimated standard reference weight using current Australian nutritional standards for sheep. During restricted feeding the automated feed system was programmed to deliver 100 g per meal to each ewe until she reached or exceeded her treatment level of feeding each day (within 24 hours). Liveweight measurements were undertaken 3 times per week and condition score once per week. A 24 hour fasted liveweight, ultrasound scan of C-fat and eye muscle depth and measurement of body composition by dual-x-ray absorptiometry was conducted near the start and end of the restricted feeding period. The average *ad libitum* intake during the 19 day adaption was 2.24 kg/day for the maternal ewes and 1.51 kg/day for the Merino ewes. After 42 days of restricted feeding the mean feed intake per day of both breeds of sheep were significantly affected by the feeding treatment (Maternal ewes $P < 0.001$, Merino ewes $P = 0.001$). This resulted in a significant difference in liveweight change between treatments ($P < 0.001$). Maternal ewes in the lowest feeding treatment lost 8.7 kg liveweight (209 g/day) and Merino ewes lost 7.5 kg (179 g/day). Liveweight, fasted liveweight change and changes in estimates of total, fat and lean tissue mass derived by dual-x-ray absorptiometry were linearly related to mean feed intake per day on an individual animal basis and across experimental treatments. Estimates of the maintenance requirements varied from 0.494 to 0.599 MJ/kg $BW^{0.75}$ for the Maternal Composite ewes and 0.457 to 0.582 MJ/kg $BW^{0.75}$ for the Merino ewes, subject to the model and liveweight or tissue mass measurements used. There appeared to be little difference in the maintenance requirements per kilogram of metabolic bodyweight for Maternal Composite and Merino ewes and all estimates were higher than those predicted using current industry formulae for

housed sheep. Finally, the achieved maximum *ad libitum* feed intake for the ration fed in this study of 3.3 and 2.4 kg DM/day, representing 4.1% and 4.4% (DM basis) of liveweight for Maternal Composite and Merino ewes respectively, were much higher than predictions based on current standards.

9.1.3 Introduction

The implementation of genetic evaluation (Brown *et al.* 2007) in the Australian Sheep Industry has allowed Terminal sire breeds, Border Leicester and Coopworth sheep breeds to achieve substantial improvements in productivity since 2000 (Swan *et al.* 2009). In contrast, the progress for Merino sheep has been consistent but slower. The prime lamb industry, has in particular achieved genetic progress in growth rate, carcass weight, leanness, muscling and reproduction and there has been additional focus on body composition related traits such as lean meat yield and intramuscular fat (Pethick *et al.* 2006). Given the well-established genetic correlations between a number of these traits and liveweight (Safari *et al.* 2005) it is expected that genetic improvements will lead to some genetic gains in mature liveweight of sheep. In addition, increased emphasis on reproduction is likely to lead to associated increases in mature size (Snowder 2002). Mature size and liveweight are related to feed intake and are fundamental variables used to calculate the nutritional requirements of sheep (CSIRO 1990, Freer *et al.* 1997). Estimates for the heritability of feed intake at pasture have been moderate for crossbred ewes but low to moderate for Merinos (Fogarty *et al.* 2006, Fogarty *et al.* 2009, Lee *et al.* 1995, Lee *et al.* 2001) and thus selection for reduced feed intake should be possible but needs to account for ewe liveweight to avoid correlated changes in mature size and growth. The genetic changes in the Australian sheep flock therefore infer that the feed intake and energy efficiency of both non-merino and Merino sheep may have changed substantially over the last 20-30 years and thus feeding guidelines based on the feeding standards developed over 20 years ago (CSIRO 1990) may not accurately predict the requirements of modern non-merino or Merino sheep.

A review by Babiszewski and Hocking Edwards (2013) showed substantial range in the estimates for the maintenance energy requirements across several breeds of sheep. An estimate for mature Merino wethers 552 kj ME/kgBW0.75/day (Young and Corbett 1968) was compared to an estimate of 290 for mature non-pregnant dry ewes (Ball *et al.* 1995, Ball *et al.* 1998). In addition studies where Merino ewes have been managed together with crossbred sheep under the same pasture conditions, the crossbred ewes have gained more liveweight and condition score (Holst *et al.* 1992, Hocking Edwards *et al.* 2018, Babiszewski and Hocking Edwards, 2013). These differences could be attributed to differences in the maintenance requirements, efficiency of liveweight gain or loss in response to pasture conditions, or differences in feed intake and the drive to eat. Recent studies on maternal ewe feed efficiency (Muir pers. comm.) have shown high levels of feed intake in mature adults (mean 2.68kg DM/day) on pellets of low to moderate nutritive value (9.6MJ ME/kg DM, 9.8% crude protein) that are substantially greater than would be predicted from current nutritional standards and software(Freer *et al.* 1997). Interestingly these 3 year old sheep also had a liveweight growth of 239g/day during the test period, changing CS by 0.5 and resulting in relatively equal changes in muscle and fat depth. This data suggests that Maternal sheep may have a higher feed intake and be more dynamic in their mobilization and accretion of both muscle and fat than we would typically expect for mature sheep. This observation is also supported by the marked changes in fat depth and muscle depth that occur in maternal and crossbred ewes in response to nutritional management and during lactation (Behrendt 2014) and the observations that ewes were able to maintain liveweight at much lower feed on offer than expected (Thompson 2016).

The degree to which non-Merino ewes have higher feed intake or feed efficiency than those predicted using current nutritional standards has a significant implications for modelling the most profitable management targets for CS in a prime lamb enterprise. Using the incorrect energy or intake equations and subsequently misidentifying the optimum ewe liveweight or condition score profile reduced farm profit by between $25,000 and $75,000 for a 1,000 head ewe flock ($2.58 and $7.71/ewe/year) for a 50 g/head/day change in ewe liveweight change. The impacts on farm profitability maybe far greater than this because the discrepancies between experimental and predicted ewe liveweight change have been up to 160 g/head/day (Thompson 2016). Assessing the maintenance requirements of modern Maternal Composite and Merino sheep could therefore be important for assessing the suitability of current nutritional standards for the estimation of the energy requirements of adult ewes.

The maintenance energy requirements of sheep have been typically estimated using calorimetry, feeding trials and comparative slaughter techniques (Corbett and Ball 2002). These methods rely significantly on the measurement of feed intake during the studies and immediately prior to key measures of liveweight, fasting metabolism or body composition. In nearly, all cases these feed intake measures require the individual housing and measurement of feed intake in sheep to provide the necessary precision to estimate energy intake. However, sheep are a flocking species and require social interactions for normal behaviour and isolation from the flock can be stressful. The development of feeding system that could individually control sheep intake in a group housed situation would allow estimation of intake and energy experiments without impinging on the group interactions of sheep. In this experiment we have examined the potential maximum intake of commercially available pellet ration and estimated the energy requirements for maintenance and efficiency of energy use for weight gain, or loss, in mature (4 year old) non-pregnant maternal composite ewes compared the responses in a similar age cohort Merino ewes and those that would be predicted using current Australian Feeding Standards for Ruminants (CSIRO 1990, Freer *et al.* 1997).

9.1.4 Methodology

9.1.4.1 Animal Ethics

This experiment was undertaken using the automated feed intake facility at Department of Economic Development, Jobs, Transport and Resources (DEDJTR) Hamilton, Victoria. Prior to conducting the experiment, Animal Ethics approval was obtained from the DEDJTR Agricultural Research & Extension Animal Ethics Committee (AEC Proposal #2017-04).

9.1.4.2 Animals and pre-experimental adaptation

One hundred and sixty five Maternal composite and one hundred and twenty eight Merino (adult, yellow tag, 2013 born) ewes were sourced from the DEDJTR Hamilton Research flock and were not mated during autumn 2017. The Maternal composite ewes had some pedigree and performance records and had been previously tested for feed efficiency (residual feed intake) under *ad libitum* feeding conditions in the feed intake facility (Muir *pers. comm.*). These sheep were well adapted to feeding in the feed intake facility. The Merino ewes were completely naïve to the feed intake facility. All ewes were shorn (21/09/2017), vaccinated, treated for internal and external parasites prior to entry into the feeding facility.

All sheep were initially adapted to the pelleted diet under paddock conditions through on the ground trail feeding and daily increments in the amount of pellets offered before being given *ad libitum* access to the pellets via Paton lick feeders whilst at pasture. This adaptation occurred over a two week period and was staged to occur prior to feed lot entry for the Merino and Maternal sheep.

The Merino ewes underwent a 3 week pre-experimental adaptation and training to use the automatic feeders during which their level of feeder use and feed intake was recorded and assessed. The adaptation period was undertaken with rear access gates and feeder access flaps open on the automated feeders. During this period, 14 Merino ewes from the 128 were identified as not using the feeders at all and another 17 were sporadically accessing the feeders. All Merino ewes were provided some access to pellets in troughs at approximately 0.5 kg/head per day during the adaptation period. At the completion of this adaptation period all Merino ewes were then allowed to graze at pasture with *ad libitum* access to pellets via lick feeders for 10 days. During this period, the Maternal ewes also began their pellet adaptation and were subsequently given full access to pellets via the lick feeders.

Two hundred and forty non-pregnant ewes (114 Merino ewes and 126 non-Merino Maternal composite) were then subsequently selected and allocated to 10 pens, with each pen comprising 50 percent Merino ewes and 50 percent Maternal ewes. The Merino ewes had been selected on the basis of previous feeder use and measured feed intake during their earlier pre-experimental adaptation period. For the Maternal ewes the heaviest and lightest sheep at the extremes of liveweight and condition score were removed from the study. All sheep were then allowed *ad libitum* access to pellets through the automatic feeders with 1 kg of pellets available in the feed pan. Feeder use and feed intake were recorded. A small quantity of pellets were also fed in troughs to ensure all sheep had access to some feed even if they were not using the feeders.

In this round of the pre-experimental adaptation, the feeder access flaps and gates were engaged and by the end of the first week only 38 of the remaining 114 Merinos were feeding (and some of these not consistently). This compared with 100% of the Maternal ewes feeding regularly. Adaptation to using the gates and flaps were critical to the implementation of the restricted feeding and the decision was made to concentrate the experiment on the Maternal ewes in the experiment and only use those Merinos that were well adapted to feeding. Sheep were then allocated to a experimental design that segregated the two breeds of sheep.

9.1.4.3 Experimental design

One hundred and twenty six Maternal ewes were randomly allocated to 6 treatments following stratification for the estimated standard reference weight of each ewe. The standard reference weight (SRW) of each individual ewe was estimated using their liveweight measured on the 23/10/17 and adjusted for their condition score (Jefferies 1961) on the basis that 1 condition score was equivalent to 15% of liveweight of each ewe (CSIRO 1990, Freer *et al.* 1997). The Maternal ewes were applied to 7 pens such that each pen contained 3 replicate ewes per treatment for a total of 18 ewes per pen. The remaining 20 Merino ewes that were feeding consistently using gates and feeder access flaps were allocated using the same procedure except that they were applied to 4 treatments in one pen so that each treatment had 5 replicate ewes.

The six treatments applied to the Maternal ewes reflected different percentages of estimated maintenance requirements (MR; 40%, 60%, 80%, 100%, 140%, 180%) that would result in liveweight loss or gain of approximately -150 g/day, -100 g/day, -50 g/day, 0 g/day and 50 g/day and 100 g/day for a 60 kg Maternal non-Merino ewe. The 4 treatment levels applied to the Merino ewes was 60%, 80%, 100%, and 140% of MR.

Feeding and feed intake restriction

Feeding and feed intake restriction was performed in the automated feed intake facility at DEDJTR, Hamilton. Each feeding treatment was calculated based on the individual liveweight, condition score and estimated SRW of the animal at the start of the restricted feeding period, based on a prediction of their maintenance requirement. The maintenance requirement and level of feeding required for each treatment was calculated using the "ME_Required" spreadsheet program, CSIRO 2012 (http://www.grazplan.csiro.au/?q=node/18) for each individual ewe and adjusted to an "as fed" amount using the dry matter percentage of the ration. The final amount of feed set as the "as fed" target per day was rounded to the nearest 100 g.

The experiment was conducted using a 9mm sheep starter/conditioner pellet manufactured by Johnson's Premium Stockfeeds. The manufactured pellet was delivered in two consignments. Representative sub-samples of the pellets from each consignment were tested through two commercial feed testing laboratories prior to the experiment. The average metabolisable energy, crude protein and neutral detergent fibre content of the pellets were 10.3 MJ/kg DM, 12.3% and 39.5%, respectively. The average dry matter content of the pellets was 89.9%. The pellet was manufactured from the following ingredients; 10% almond hulls, 42% barley, 35% cereal straw, 11% clover hay, 1% Compass Lamb Premix and 1% Urea.

The experiment comprised 4 periods, with differing daily feed allocations and meal sizes, as follows;

Pre-restriction adaptation, under *ad libitum* feeding (1 kg on offer in feed pan) - 23/10/2017 to 11/11/2017 ~ 19 days

Restricted feeding treatments (100 g meal size) – 11/11/2017 to 22/12/2017 ~ 41 days.

Post-restriction adaptation (~1.4 kg/day allowance, with 200 g meal size) - 22/12/2017 to 26/12/2017 ~ 5 days.

Post-restriction *ad libitum* feeding (1 kg on offer in feed pan) – 27/12/2017 to 12/01/2018 ~ 16 days.

All feeding events, meal sizes, feed intake and the time of each feed event were recorded using the automated feeders in each pen (Muir *et al.* 2018). Each pen contained two automatic feeders.

During the restricted feeding period, the automated feed system was programmed to deliver 100 g per meal to each ewe until they reached or exceeded their treatment level of feeding each day (within 24 hours). A ewe was able to access up to one more meal than allocated, if the total consumption was still less than their allocated feed amount on any given day. The feeding system therefore only had the precision to restrict feeding within 0.1 kg of the targeted level of feeding. This means that where animals had a calculated feed requirement between even multiples of 0.1 kg that some level of over-feeding or under feeding will have occurred to a greater degree, than if the feeding level was a direct multiple of 0.1 kg.

The number of meals per day for any ewe was set by the level of feeding such that a ewe allocated 1.0 kg of feed would need to have at least 10 meals in 24 hours to consume her entire feed allocation for the day. This means that meal size and the frequency of feeding events within each day will be confounded with level of feeding. The range in feeding level treatments was set such that the number of meals for an average weight sheep was within the normal range of the number meals observed in sheep under *ad libitum* feeding conditions (Muir pers. comm.). However, as animals became heavier during the adaptation period the feed intake required became greater. This meant that to consume the allocated level of maintenance requirement, the number meals required per day also became greater.

For example, a 60 kg ewe allocated 1.6 kg to consume for 180% maintenance will need to consume 16 meals of 0.1 kg sized meals. This means that total intake may be constrained where the number of meals per day required exceeds the behavioural drive or time available for the ewe to access the feeder. For this reason, potential voluntary intake was also assessed for animals at the end of the restricted feeding period using a 1 kg allowance for maximum meal size under *ad libitum* feeding conditions.

At the end of the 42 day restricted feeding period, a 16 day test period was applied to measure the *ad libitum* feed intake of all sheep in the experiment. This was slightly shorter than the optimum time indicated by Macleay *et al.* (2016). To reduce potential issues from acidosis and other digestive disturbances from sudden increases/changes in intake due to gorging by ewes on previously low rates of feeding a 5 day period of restricted feeding to an amount 1.4 kg, using a 200 g meal size was included prior to the *ad libitum* test period. Following this short intermediate adaptation phase the ewes were given *ad libitum* access to 1 kg of feed in the feeders and the total intake was not restricted. All feeding events, meal sizes, feed intake and time of feed event were recorded using the automated feeders in each pen. Samples of the pellets from each feeder were taken on a weekly basis and bulked to provide 2 samples per week for testing of feed nutritive value by near-infrared spectroscopy (NIR).

9.1.4.4 Animal Measurements, samples and management

Liveweight, condition score, C-fat and eye muscle depth

Liveweight (LWT) was measured 3 times per week on Monday, Wednesday and Friday, whilst condition score (CS) was assessed by the same experienced technical officer on a weekly basis (Wednesdays). An ultrasound measurement of C-fat (CFAT) and eye muscle depth (EMD) was taken at the start and end of the restricted feeding period using a Sheep Genetics accredited livestock scanner.

Dual-X-ray Absorptiometry (DXA)

The change in the amount of fat and lean tissue in the body of each ewe was assessed by Dual-X-ray absorptiometry (QDR Series X-Ray Bone Densitometer, Model: Discovery A, Hologic Inc., Bedford, MA, USA) with scans conducted near the start and end of the restricted feeding period. A fasted liveweight (FLWT, 24 hour feed curfew and 12 hour water curfew) was conducted in conjunction with the DXA measurement as animals need to be weighed for anaesthesia and sheep were required curfew prior to sedation for the DXA scanning procedure. The analysis to predict live animal body composition in terms of total tissue mass (TTM), lean tissue mass (LTM), fat tissue mass (FTM) and bone mineral content (BMC) was undertaken by the same procedure as described in Hunter *et al.* 2011, except that the body of the sheep was placed into the right arm region instead of the left. The left and right arm regions are equivalent in terms of analysis as they share the same algorithms (pers. comm. Hologic) and the arm regions have been shown to be the most precise and repeatable in pigs (Suster *et al.* 2003, Suster *et al.* 2006). The head was placed into the head region but was excluded from the analysis of body composition as it contained both interference from ear tags and the pulse oximeter that was used to monitor the pulse rate and blood oxygen saturation of the sheep during the sedation and DXA scanning. The data output from the Hologic software was used for statistical analysis presented in this report.

9.1.4.5 Housing and Weather Observations

Animals were housed in the DEDJTR Hamilton feed intake facility within 8 pens that had full time access to water. All pens had a dirt floor and all housing was under the shed roof line. However the shed has open sides to the east, west and south and only the northern side is partially protected from wind by another enclosed shed. Temperature and humidity were measured using six Tiny tag data loggers (https://www.geminidataloggers.com/) placed in three locations at about 2m above ground centred over the eastern and western bank of 5 pens under the shed roof line. Wind speed and direction were obtained from recorded observations at a height of 2m at the DEDJTR Hamilton farm weather station located approximately 2.5km from the feed intake facility.

9.1.4.6 Statistical Analysis

For feed intake, every recorded meal event during the adaption, the 42 day restricted feeding period and the post-restriction feeding periods were used to calculate the sum of feed consumed per day for each individual sheep. During the restricted feeding period some meal events required calculation due to erroneous weight of feed consumed recorded. This was done for each pen using a spline approach, as described in Verbyla, Cullis,Kenward, and Welham (1999). The spline approach was used instead of a parametric form to allow a more ‘flexible’ construction of the intake response curves over the duration time in the feeder, because an exponential-type increase was not always suited to the data. Within the model, feeder effects were tested, both linear and curvature (spline) effects, along with animal nested within feeder fitted as random effects.

Analysis of variance (ANOVA) was conducted separately for the Maternal composite and Merino ewe data, on ewe liveweight, condition score and body composition data at the start and end of the experiment. ANOVA was also undertaken on feed intake data to examine feed intake on individual dates and by using the mean value per day across the duration of the adaptation, restricted feeding, post-restriction periods and a period near the end of *ad libitum* feeding, where feed intake had stabilised to a maximum level for both breeds of sheep. The latter was analysed to obtain an estimate of the possible maximum potential intake for ewes in the study. This feed intake value was also analysed as a percentage of the liveweight at the start of the *ad libitum* feeding period (27/12/2017). The success of the feeding system in manipulating and controlling feed intake during the restricted feeding period was examined by analysing the linear relationship between the desired “as fed” feed allowance and the values of feed intake that were achieved and measured for individual sheep.

CS and SRW change were calculated for the 42 day period from the start of restricted (10/11/2017) feeding to the 21 December 2017 and analysed by ANOVA. Liveweight gain or loss per day (g/day) for the restricted feeding period was estimated for each individual sheep via regression of each liveweight measurement against the day of measurement to obtain the slope of the linear regression. The intercept was used as the starting liveweight for further analyses. For the Maternal ewe data, pen was used as a blocking term and the percentage of MR as the treatment term in all ANOVAs. The same data was analysed separately for Merino ewes using a ANOVA (without blocking) for the treatment effect of the percentage of MR. Least significant differences were calculated (P = 0.05) and used to compare treatment means.

To estimate the maintenance requirements of Merino and Maternal ewes, the gain or loss in measured liveweight or DXA tissue mass (g/day) was analysed by REML against the mean feed intake (g/day) for the days of feeding between each measure near the start and finish of the restricted feeding period. The individual data of each sheep was used fitting pen as the random term in the analysis of Maternal composite ewe data. The inclusion of the starting metabolic liveweight (liveweight$^{0.75}$) for each individual sheep was also evaluated in the model and included when significant (P < 0.05). For each model, the maintenance value for the mean feed intake was predicted for the point at which there was zero liveweight or tissue mass change per day. The upper and lower 95% confidence limits for each estimate of maintenance were then calculated. This data was converted to a figure of metabolisable energy in megajoules for each kilogram of metabolic body weight using the dry matter and mean metabolisable energy content of the ration fed and the mean metabolic liveweight of the ewes for the liveweight or tissue mass measure used.

All statistical analyses were performed using GENSTAT 17th edition (VSN International Ltd, Hemel, Hempstead, UK).

9.1.5 Results

9.1.5.1 Weather

The mean, maximum and minimum temperature and relative humidity for the restricted and *ad libitum* feeding periods of the study are shown in Figure 1. The average wind speed and wind direction is also shown. The mean maximum temperature was 28.7 C and the mean minimum 11.3 with daily mean temperatures averaging 18.5C during the study period. Relative humidity averaged 56.4% during the study period. The data indicated that temperatures were mostly in the thermoneutral zone (9°C to 32°C) for dry adult sheep in good condition, that started the restricted feeding period at 51 days after shearing, with a fleece depth of approximately 20-30mm. (Alexander 1974, CSIRO 1990 and Yufeng *et al.* 2017). The average wind speed at sheep height was generally low to moderate (Figure 2) averaging 7.8 km/hr for the period. The wind speed at sheep height and in the shed is likely to have been lower than measured at 2m due to shelter at the site and adjustments required for sheep height, when determining the effect of wind chill (Mount and Brown 1983). The wind direction was primarily from the East South East, South and South East. The other major wind directions ranged from the South West through to North West and North with similar number of days experiencing these wind conditions.

9.1.5.2 Restricted feeding system performance

During restricted feeding the mean measured feed intake per day of all individual ewes was highly correlated (r=0.95, P < 0.001) to the "as fed" allowance entered for each individual animal into the feeder system. A simple linear model was able to explain 90.2% of the variation in the relationship between the "as fed" allowance and the measured feed intake (P < 0.001, Figure 3). Accounting for pen group (blocks) in the model increased the variance explained to 91.5%, with pen group being a significant factor (P < 0.001). Breed of sheep was confounded with the pen group. However, the

Merino pen estimate of 67.1 ± 39.6 was not significantly different (*P* = 0.093) compared to reference level (Pen 1) and was of intermediate size in the range of parameter estimates for other pens containing only Maternal Composite ewes (Range; 4.3 ± 40.7 for Pen 2, *P* = 0.916 to 162.7 ± 40.1 for Pen 4, *P* < 0.001). The addition of the interaction between pen and the "as fed" feeding level to the linear model explained 91.9% of the variation in measured intake but the change in variance accounted was not significant (*P* = 0.060).

9.1.5.3 Feed intake

Table 1 and Table 2 show the allocated mean "as fed" amount of pellets programmed into the automatic feeders for each treatment, following rounding to 0.1 kg of feed for each individual sheep for the Maternal composite and Merino ewes. Also shown in Table 1 and Table 2 is the mean feed intake in g/day during the restricted feeding period. The mean *ad libitum* intake for the same sheep during the 19 day period of adaption is shown for comparison as is the mean intake during the post-restriction feeding periods.

All MR feeding treatments had similar mean feed intake per day during the adaptation period. The Maternal composite ewes consumed around 2.2 kg/day of pellets and the Merino ewes around 1.5 kg during this period. This period of feeding included fasting periods during curfew for the first round of DXA scanning.

During the restricted feeding period, there was a significant effect (*P* < 0.001) of the feeding treatment (percentage of MR) on the measured individual feed intake of both Maternal and Merino ewes (Table 1 and Table 2). However, ewes fed 40% and 60% of MR tended to consume greater than the "as fed" allocation, whilst ewes fed 140% and 180% of MR consumed less than the "as fed" ration allocation (Table 1 and Table 2, Figure 3).

At the end of restricted feeding all ewes were allowed access to 1400 g/day of feed with 200 g meal size, as process of changing the ewes from the low restricted intake to high intake under *ad libitum* feeding. During this period the prior percentage of MR feeding treatment affected the daily intake of the Maternal composite ewes (*P* < 0.001) with ewes fed lower percentages of MR voluntarily consuming less of the allowance when set to 1400 g/day. No such effect was observed for the Merino ewes.

There was no significant effect of percentage of MR feeding treatment on the average post-restriction *ad libitum* feeding intake. The average daily intake of Maternal Composite ewes during this period was approximately 3.4 kg/day, whilst the Merino ewes consumed around 2.6 kg/day under *ad libitum* feeding. However, the intake of the ewes changed dramatically following the switch to an *ad libitum* feeding allowance, despite the post-restriction adaptation to a common level of feeding. On the 27/11/2017 the ewes were switched to *ad libitum* feeding and gorged themselves before substantially reducing feed intake on the 28/11/2017. For the Maternal Composite ewes due significant differences in feed intake over these two days based on their prior feeding treatment. Ewes fed lower percentages of MR gorged themselves less than those that had received greater than maintenance feeding and also had higher feed intake the day after gorging.

Both Maternal ewes and Merino ewes then gradually increased intake reaching a stable maximum feed intake similar to that of the gorged intake on 27/11/2017 at around 5-9 days after the start of *ad libitum* feeding. A period of 5 days between 6/1/2018 and 10/1/2018 that was stable for intake was used to estimate the maximum average *ad libitum* intake. There was no effect of prior feeding level on the maximum average *ad libitum* intake. The average maximum intake across treatments under *ad libitum* feeding for Maternal Composite ewes and Merino ewes was 3.7 and 2.7 kg respectively, representing 4.6% and 4.9% of their liveweight at the start of the *ad libitum* feeding period on 27/11/2017.

9.1.5.4 Liveweight and condition score

Liveweight and condition score was similar across all feeding treatments at the start of the adaptation period and the restricted feeding period (Table 3 and Table 4). Maternal Composite ewes weighed 76.3 kg and were in CS 3.6 at the start of adaptation period, whilst Merino ewes weighed 56.8 kg and were in CS 3.2. The estimated SRW of the Maternal Composite ewes was 72.3 kg at the start of the restricted feeding period whilst the SRW for the Merino ewes was estimated at 53.1 kg.

The liveweight and condition score of Maternal Composite ewes increased during the adaptation feeding period with a liveweight gain of 7.3 kg and 0.46 of a CS on average. There was little change in the liveweight (-1.3 kg) or CS (0.12) of the Merino ewes during the adaption period under *ad libitum* feeding conditions.

The restricted feeding period resulted in weight loss for all the maintenance and lower feeding treatments for both breeds of ewes and these changes haven been to some degree reflected in a reduced CS, particularly for the Maternal Composite ewes. The lowest treatment (40% MR) in the maternal ewes lost 10.8 kg between weigh dates or 8.8 kg based on the linear estimate of weight loss for the period. Merino ewes lost 6.7 kg between weigh dates or 7.5 kg based on the linear estimate at 60% MR. For Maternal ewes, the highest treatment (180%) gained 2.3 kg, whilst the highest treatment (140% MR) in the Merinos gained 2.3 kg based on the linear estimates of weight gain.

The calculated weight gain or loss per day was significantly affected by the treatment and linearly related to the percentage of MR fed for both maternal ewes and Merino ewes ($P < 0.001$, Table 3 and Table 4). In addition, the liveweight ($P < 0.001$) and CS ($P < 0.001$) were different at the end of restriction between treatments in the Maternal ewes but these differences were not significant in the Merino ewes due to the smaller number of replicate ewes. The changes in both LWT and CS influenced the changes in estimated SRW and as reported in Table 2 and Table 3 was significantly affected by treatment in both the Maternal and Merino ewes ($P < 0.001$, $P = 0.008$).

At the end of the *ad libitum* feeding period Maternal composite ewes that had received the highest feeding treatments (140% and 180% MR) maintained an advantage in liveweight ($P = 0.014$) and CS ($P = 0.053$) over the ewes that had received 40% of MR during the restricted feeding period. This effect of prior feeding treatment was only evident for CS in the Merino ewes ($P = 0.047$).

9.1.5.5 Ultrasound muscle and Fat depth

The liveweight, C-fat and eye muscle depth at ultrasound scanning before the start of restricted feeding and at the end of restricted feeding are shown in Table 5 for Maternal composite ewes and Table 6 for Merino ewes. Eye muscle depth (average 36.5mm) and C-fat (average 6.7mm) were greater in Maternal Composite ewes than Merino ewes (27.7mm and 3.7mm).

Restricted feeding resulted in significant changes in C-fat and eye muscle depth for Maternal Composite ewes ($P < 0.001$) but the changes for Merinos were not significant despite the significant liveweight change at scanning (*P* < 0.001). The changes in eye muscle depth were negative for all MR treatments in both Maternal Composite ewes and Merino ewes. In contrast, fat depth increased with feeding levels above 100% MR in the Maternal Composite ewes and Merino ewes.

The change in fat depth for Maternal Composite ewes were curvilinear, with linear (*P* < 0.001) and quadratic components (*P* = 0.034) across the range of treatments. In contrast, the changes in eye muscle depth were linear (*P* < 0.001) with no evidence of a curve in the response (*P* = 0.631). The change in liveweight between ultrasound scanning showed both a linear response (*P* < 0.001) with some evidence of curvature (*P* = 0.005) at the high levels of feeding (140% and 180% MR) consistent with the change in fat depth. However, examination of the relationships with individual animal data, based on actual intake indicate that these curvilinear relationships were not present and were a function of the treatment structure, whereby some individual animals that had consumed lower amounts of feed at the higher MR treatment were reducing the change in fat depth and liveweight for those treatments.

9.1.5.6 Dual x-ray absorptiometry (DXA) body composition

Across all sheep the fasted liveweight undertaken immediately prior to each DXA scan near the start and end of the restricted feeding period was highly correlated (r = 0.985, 0.997, P < 0.001) to the total tissue mass (TTM) of the DXA scan, which excluded the head region of the scan. The 24 hour fasted liveweight of the Maternal ewes was on average 11.8 kg lower than the weight of the Maternal ewes at the start of restriction. For Merino ewes, the difference in fasted liveweight to the starting liveweight was 5.5 kg on average. The Maternal ewes contained 23.8% DXA tissue fat and the Merinos 20.6% DXA tissue fat prior to the start of the restricted feeding. The restricted feeding period resulted in significant changes in the fasted liveweight and the total, fat and lean tissue mass determined by DXA for both Maternal and Merino ewes (Table 7 and Table 8). For all the changes in fasted liveweight and the total, fat and lean tissue mass in both Maternal and Merino the relationship was significantly linear (P < 0.001) with limited evidence of curvilinear effects. For the Maternal Composite ewes only the change in DXA fat tissue mass showed significant quadratic components (P < 0.001). For Merinos, only the pre-DXA liveweight change showed significant quadratic (P = 0.006) to the relationship. However, examination of the relationships with individual animal data, based on actual intake indicate that these curvilinear relationships were not present and were a function of the treatment structure, whereby some individual animals that had consumed lower amounts of feed at the higher MR treatment were reducing the change in fat tissue weight for those treatments.

The DXA data shows that fat tissue mass was retained or increased at lower levels of feeding than lean tissue mass. The Maternal Composite ewes lost more weight as lean than fat at levels of feeding below maintenance but gained more fat than lean tissue at feeding levels above maintenance. The Merino ewes did not increase weight of lean tissue at any of the feeding levels tested.

9.1.5.7 Relationship between feed intake and liveweight gain/loss

All changes in liveweight or tissue mass of Maternal and Merino ewes were linearly related (*P* < 0.001) to the measured feed intake on an individual animal basis (Table 9 andTable 10, Figure 4,Figure 5, Figure 6 andFigure 7) irrespective of whether the measure used was full liveweight measured during the restricted feeding period, fasted liveweight measured prior to each DXA scan or the DXA derived estimates of total, fat or lean tissue mass. The coefficients for model terms, their significance and the percentage of variance accounted for by the models for each liveweight or tissue mass measured against the measured feed intake are presented in Table 9 andTable 10.

For the Maternal composite ewes the coefficients for mean feed intake representing the efficiency of feed or energy use for weight gain or loss were similar across all measures of liveweight or total tissue mass with models accounting for 61.7 to 73.9% of the variance in liveweight or DXA tissue mass change per day.

For the Merino ewes the efficiency of feed or energy use for liveweight gain or loss varied more between models using different liveweight measures (Table 10). The variance accounted for by the models was high 76.7 to 85.7%.

It is not possible to directly compare the Merino and Maternal performance and relationships with feed intake within the ANOVA structure for the experimental design because Merinos were confined to a different pen. However, a preliminary examination using REML to test for a breed interaction within the combined data for both Merino and Maternal composite using models 1 to 6 from Table 9 andTable 10, indicates that the coefficient for mean feed intake were only significantly different between breeds for the measures of liveweight taken during restriction ($P = 0.033$) and the liveweight measured at ultrasound scanning ($P < 0.050$).

9.1.5.8 Estimation of maintenance requirements

The estimates of maintenance requirements in terms of the feed or energy required to maintain liveweight or tissue mass are presented in Table 11 for Maternal Composite ewes and Table 12 for Merino ewes. The results show a range in the estimates of maintenance intake per day of 167 and 200g for Maternal Composite ewes and Merino ewes respectively. This translates to a range in ME estimates of 0.1 and 0.13 MJ/day/kgBW$^{0.75}$ for Maternal composite ewes and Merino ewes respectively. The 95% confidence limits overlap significantly across the estimates of maintenance for both breeds of sheep for each the models used.

For both breeds of sheep greater daily feed intake or metabolisable energy is required to maintain the weight of lean tissue than the weight of fat tissue when assessed using DXA. This indicates that for both breeds maintenance of liveweight would result in a loss of lean tissue and small a small gain or maintenance of fat tissue, although this is less clear for the Merino data. For Maternal ewes, when there was total tissue loss there was increased loss of lean tissue compared to fat tissue and when there is tissue gain, there was increased gain in the weight of lean compared to the gain in fat. Merinos followed the same pattern during tissue loss but as the experiment did not increase total or lean tissue mass markedly at the highest treatment (140% MR) and higher intake levels were not evaluated, it is not clear if the same relationship is present for Merinos at levels of intake greater than 140% of MR.

It is not possible to directly compare the Merino and Maternal estimates for maintenance within the design structure as Merinos were confined to a different pen in the experimental design. However, taking into consideration the estimates of maintenance ME requirements on a metabolic weight basis and the confidence limits the requirements of both breeds of sheep appear to have been similar in this study.

9.1.6 Discussion

The automatic feeders were successfully able to apply different levels of feeding to both Maternal and Merino ewes. These feeding levels were aimed at different levels of maintenance requirements for both the Maternal and Merino ewes. The automatic feeding system on average overfed pellets to those ewes allocated lower than maintenance feed allowances and under-fed ewes at feeding levels above the 100% MR treatment. The over-feeding and under-feeding was possibly due to a number of factors. Some sheep were able to consume more or less than their allowance when accessing the feeders due to initial issues with feeder flaps being pushed open allowing access to the feed pan. The pushing open of the feeder flaps resulted in interference with accurate measurement of intake by the scales, however, this issue was confined to the first half of the restricted feeding period after which the installation of stronger actuators to open and close the feeder flaps resolved the issue. From that point in time the control of feeding and feeding measures was much more stable. Another, reason for some overfeeding is that it is also implicit in the design of the feeding system with ewes able to consume meals in ~100 g amounts meaning that once they are close to their allowance threshold another meal of 100 g could exceed the as fed allowance. Other issues that are likely to have affected these intake results are that all ewes at lower levels of allowance were able to consume proportionally more of their ration per meal due to the 0.1 kg meal size setting and sheep that had larger allowance may not have been sufficiently driven to consume the required number of meals to meet their allowance per day.

Despite these issues the treatment level of feeding was highly linearly related to the observed feed intake and induced significant changes in both mean feed intake per day and liveweight for both Maternal and Merino ewes across the percentage of MR treatment feeding levels. The lowest and highest feeding levels diverged significantly for liveweight and liveweight change in both the Maternal and Merino ewes. CS also diverged but only for the Maternal Composite ewes. It can be concluded that the automated feeding system was significantly able to control feed intake of the ewes and that the changes in liveweight and body composition were linearly related to the feeding treatment.

Sheep that were fed higher and lower amounts of the ration changed body composition as demonstrated by both the ultrasound scanning measures of eye muscle and C-fat depth but also DXA measures of fat and lean tissue. Both fat and muscle were lost at low levels of feed intake, whilst gains in both fat and muscle were apparent in the Maternal Composite ewes at the highest levels of feed intake. All changes in tissue mass were linear and this result was consistent with the linear response based on liveweight measures. This result contrasts with the current methods for estimating liveweight gain or loss based on feed/energy intake that have assume different efficiencies of energy use for weight gain and loss (CSIRO 1990, Freer *et al.* 1997). The linear response for both weight gain and loss in our study indicates that the efficiency of energy use for maintenance (km) is not different to the efficiency of energy use for gain (kg) for the adult Maternal Composite ewes. When the slope of the relationship for liveweight gain or loss versus predicted feed intake for the ewes in this study are examined, using the "ME_Required" spreadsheet program, CSIRO 2012 (http://www.grazplan.csiro.au/?q=node/18), in comparison to those achieved in this study it suggests that industry may be currently under-estimating the degree of weight gain and over estimating the amount of weight loss for maternal ewes at different levels of feed intake.

There were differences in the liveweight gain or tissue mass achieved across treatments when compared on the basis of liveweight measured three times per week, fasted liveweight prior to DXA scanning or using DXA derived tissue mass estimates. However, all measurement methods appeared to show similar maintenance requirements for both the Maternal and Merino ewes. The estimates for maintenance varied from 0.494 to 0.599 MJ/kg $BW^{0.75}$ for the Maternal ewes and 0.457 to 0.582 MJ/kg $BW^{0.75}$ for the Merino ewes respectively. These estimates of maintenance are higher than the 0.425MJ/kg $BW^{0.75}$ average of studies reviewed Babiszewski and Hocking Edwards (2013) but are within the range of values quoted for adult animals. The variation in estimates between those reliant on liveweight during the restricted feeding period and those using fasted liveweight measures or DXA total tissue mass are mostly likely due to differences in how changes in gut fill contribute to the measures.

It is not possible to directly compare the Merino and Maternal estimates maintenance statistically as Merinos were confined to a different pen in the experimental design. However, taking into consideration the estimates of maintenance ME requirements on a metabolic weight basis and the confidence limits the requirements of both breeds of sheep appear to have been similar in this study. This suggests that current feeding guidelines for maintenance feeding of Merinos may be suitable for Maternal composites. However, coefficients for mean intake per day for Merinos based on changes in liveweight during restriction or between ultrasound scans were different to those of the Maternal Composite ewes indicating possible differences in the efficiency of energy use for gain or loss. However caution is required as other measures using fasted liveweight or DXA tissue mass were not different. These differences may have occurred due to differences in gut fill between the ewes given their adaptation levels of feeding and also due to differences in degree of fatness at the start of the experiment.

The average feed intake requirements and metabolisable energy requirements for maintenance predicted by the "ME_Required" spreadsheet program, CSIRO 2012 (http://www.grazplan.csiro.au/?q=node/18) for the ration fed in the study, was 1.0 kg/day and 0.8 kg/day and 9.7 and 7.1 MJ/day, for the Maternal and Merino ewes respectively. These ME values are around 0.360 MJ/day/kg $BW^{0.75}$ for the sheep used in this study. Therefore for both the Maternal Composite ewes and Merino ewes our estimates for maintenance appear 30-40% higher than those that would be predicted by current feeding standards (that underpin programs such as Grazfeed). It is not clear why this difference has occurred. It may be due to the higher condition of the ewes entering the experiment or because ewes were evaluated in a group housed situation under more open environmental conditions with some exposure to wind and night time temperatures. Further analysis taking into account weather conditions during the study may be able to determine if this gap is narrowed by accounting for heat loss due to chill.

Finally, the achieved feed intake for the ration fed in this study of 3.3 and 2.4 kg DM/day, representing 4.1% and 4.4% of liveweight (DM basis), for Maternal Composite and Merino ewes respectively, are much higher than current industry programs (such as Grazfeed) or current nutritional standards (CSIRO 1990) would predict as a potential intake. This may be due to the physical presentation of the ration in a pellet which is easily consumed.

The experiment has demonstrated the successful use of automatic feeding for evaluating maintenance requirements for sheep. However, problems with implementing the feeding system with Merinos in the current study mean that the estimates derived for Merinos were less robust and require further research to confirm possible differences with Maternal sheep in terms of energy use for weight gain or loss.

Another significant issue is the large difference in maintenance estimates compared to those estimated using the "ME_Required" spreadsheet program, CSIRO 2012 (http://www.grazplan.csiro.au/?q=node/18) at the beginning of the study. Further work is required to determine the reasons for the differences and it is suggested that a calorimetric approach is required to validate both our study findings and to determine whether the differences in maintenance estimates are real or due to environmental and behavioural variation between feeding systems. In addition, the large differences in estimates of potential intake require further investigation to determine if these intake levels can be replicated for non-pregnant ewes grazing at pasture rather than pellets and also if they can be replicated across a range of digestibility levels.

The results from this study indicate that industry may be under estimating the maintenance requirements of group housed sheep, where social interactions increase the energy expenditure of sheep in seeking food and performing group behaviours. In addition the linear response for both weight gain and loss indicates that the efficiency of energy use for maintenance (km) is not different to the efficiency of energy use for gain (kg) for the adult Maternal Composite ewes in this study. This suggests that industry may be currently under-estimating the degree of weight gain and over estimating the amount of weight loss for maternal ewes at different levels of feed intake. It is likely that there also differences for Merino ewes which require further verification. Finally, our results indicate that industry are most likely under predicting the level of pellets that can be consumed by mature non-pregnant ewes under *ad libitum* feeding and this has implications for whether maintenance can be achieved in mature ewes fed rations with lower nutritive content. Subject to the cost and nutritive value of ingredients savings in feed costs for maintenance feeding may be realised, if the intake capacity of sheep can be exploited.

9.1.7 Conclusions

The automatic feeding system successfully restricted feed intake to values that were highly correlated to the 'as fed' allowances entered into the feeding system. The experiment created the significant linear changes in liveweight and body composition that would be expected for the different levels of controlled feed intake. This data has then been used to provide estimates maintenance requirements for maternal ewes that were similar to those of Merino ewes but were collectively 30%-40% greater than those predicted for housed non-pregnant sheep using the "ME_Required" spreadsheet program, CSIRO (2012). The efficiency of energy use for weight gain and loss were also slightly different to those assumed in the program and under current feeding standards. Finally the measured maximum feed intake for the ration fed during the experiment was much greater than would be predicted using current feeding standards. The reasons for these differences require further research.

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9.1.10 Figures and Tables

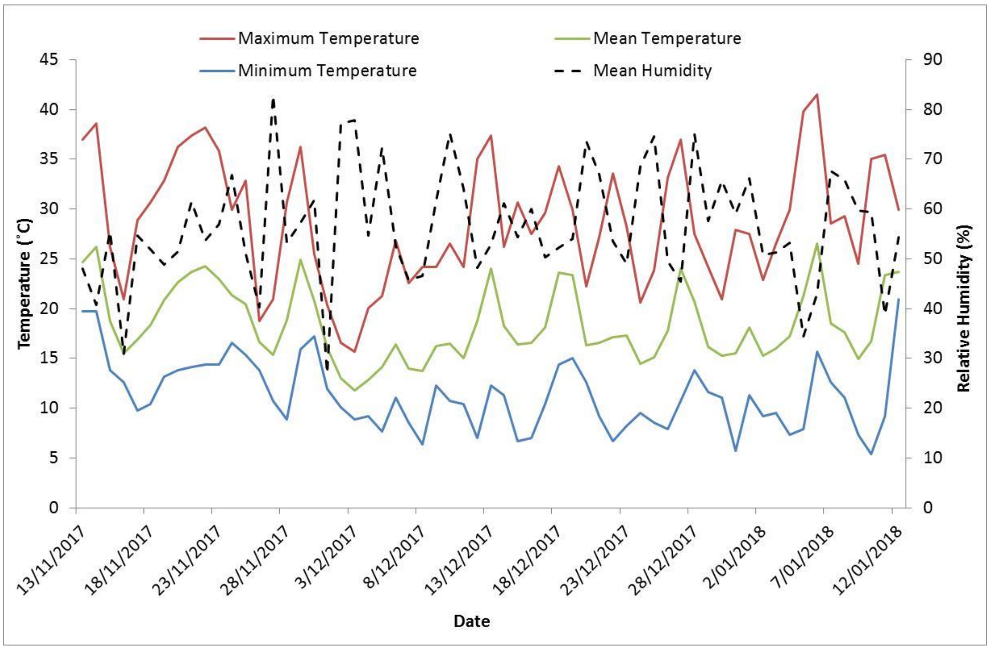

Figure 1. The mean, maximum and minimum temperature and relative humidity during the restricted and ad libitum feeding periods of the study.

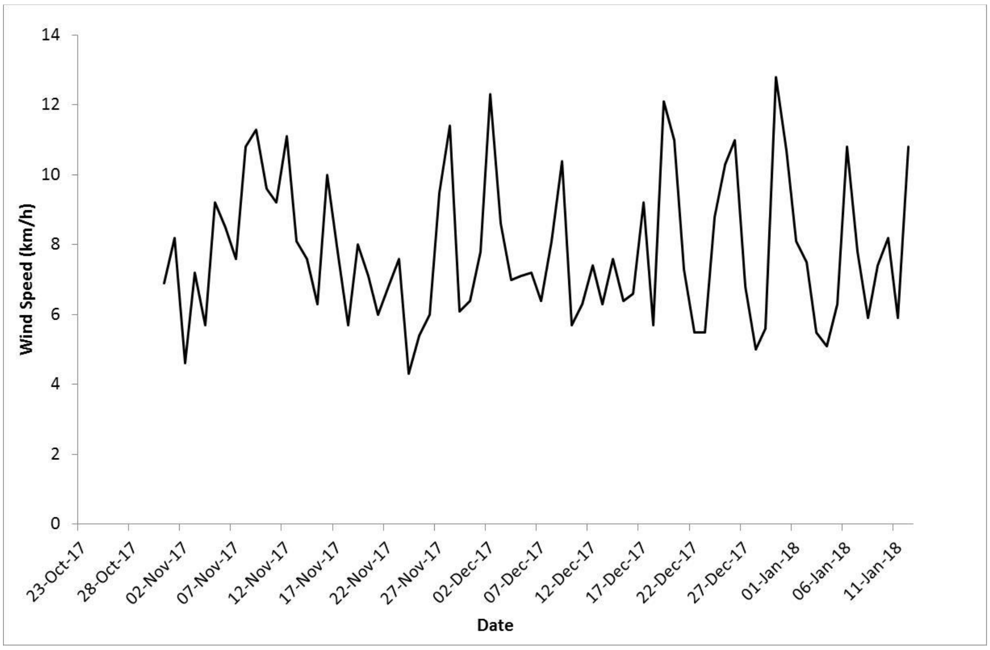

Figure 2. The mean daily wind speed (km/hr) during the adaptation, restricted and ad libitum feeding periods of the study.

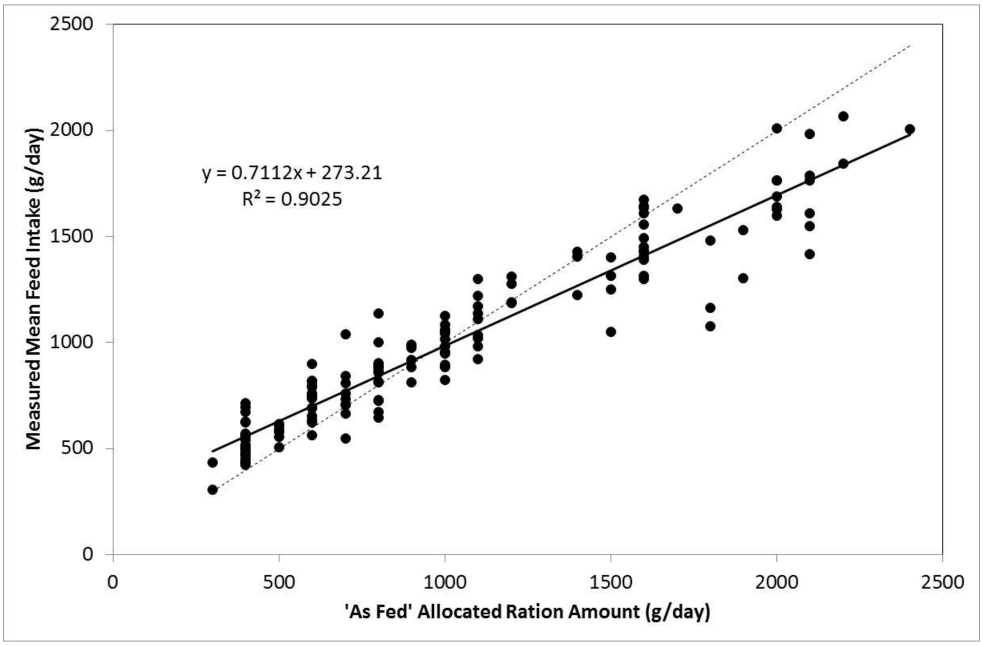

Figure 3. The individual mean daily measured feed intake (g/day) of Maternal and Merino ewes fed using automatic feeders programmed to restrict feed intake to an allocated amount of pellets ('As fed' g/day). The solid line indicates the fitted linear relationship for the data collected and the dashed line the theoretical relationship (1:1), if there was absolute control of feed intake. (*The mean values were calculated for the restricted feeding period only).*

Table 1. The measured feed intake (g/day) during adaptation, restricted feeding, ad libitum feeding periods and the periods between DXA scans and ultrasound scanning for adult Maternal composite ewes. The allocated "as fed" level of feeding programmed into the automatic feeders for the restricted feeding period is shown. The restricted feeding treatments were based on a percentage of maintenance requirement for each individual ewe.

Parameter	40%	60%	80%	100%	140%	180%	LSD (5%)	*P*-value
Adaptation *ad libitum* intake (g/day)	2144	2215	2233	2337	2269	2259	237.9	0.723
As fed treatment (g/day)	391	600	814	1052	1557	2029	48.2	< 0.001
Restricted intake 41 days (g/day)	515	733	842	1051	1430	1651	92.7	< 0.001
Restricted intake 42 days (g/day)[A]	549	771	872	1081	1457	1667	92.9	< 0.001
Post-restriction adaptation intake (g/day)	1346	1430	1451	1446	1522	1544	57.2	< 0.001
Post-restriction *ad libitum* intake (g/day)[B]	3229	3550	3415	3414	3335	3297	292.2	0.337

Intake 27/12/2018 (g)	3182	3736	3846	3782	3978	4167	448.0	0.001
Intake 28/12/2018 (g)	2049	1699	1856	1435	1502	1233	476.7	0.013
Maximum Post-restriction *ad libitum* intake (g/day)	3466	3892	3749	3748	3562	3632	360.7	0.229
Maximum post-restriction *ad libitum* intake as percentage of liveweight on 27/11/2017 (%)	4.5	4.9	4.7	4.6	4.2	4.5	0.46	0.055
Ultrasound scanning Period mean Intake (g/day)	807	1021	1127	1324	1669	1862	109.0	< 0.001
DXA scanning period mean intake (g/day)	1025	1239	1298	1504	1800	1938	126.5	< 0.001

[A] Includes the intake for the first day of feeding on the weigh date associated with the start of restricted feeding but it should be noted that feed restrictions did not take effect until 6.00pm that evening.

[B] Excludes the half day of data prior to the final weight due to a feeder outage resulting in lower than normal intake.

Table 2. The measured feed intake (g/day) during adaptation, restricted feeding, ad libitum feeding periods and the periods between DXA scans and ultrasound scanning for adult Merino ewes. The allocated "as fed" level of feeding programmed into the automatic feeders for the restricted feeding period is shown. The restricted feeding treatments were based on a percentage of maintenance requirement for each individual ewe.

Parameter	60%	80%	100%	140%	LSD (5%)	*P*-value
Adaptation *ad libitum* intake (g/day)	1416	1679	1500	1447	501.2	0.691
As fed treatment (g/day)	440	600	780	1120	137.4	< 0.001
Restricted intake 41 days (g/day)	555	696	814	1091	186.0	< 0.001
Restricted intake 42 days (g/day)[A]	571	707	825	1102	200.8	< 0.001
Post-restriction adaptation intake (g/day)	1354	1478	1428	1426	189.4	0.595
Post-restriction *ad libitum* intake (g/day)[B]	2456	2627	2788	2376	535.7	0.395
Intake 27/12/2017 (g)	2571	2798	2745	2581	1044.1	0.953
Intake 28/12/2017 (g)	1976	1575	2080	2039	707.8	0.431
Maximum Post-restriction *ad libitum* intake (g/day)	2527	2754	2929	2539	516.9	0.328
Maximum post-restriction *ad libitum* intake as percentage of liveweight on 27/11/2017 (%)	4.8	5.1	5.2	4.3	0.74	0.103
Ultrasound scanning Period mean Intake (g/day)	673	791	894	1165	219.1	0.002
DXA scanning period mean intake (g/day)	632	751	880	1153	219.9	< 0.001

[A] Includes the intake for the first day of feeding on the weigh date associated with the start of restricted feeding but it should be noted that feed restrictions did not take effect until 6.00pm that evening.

[B] Excludes the half day of data prior to the final weight due to a feeder outage resulting in lower than normal intake.

Table 3. Liveweight (LWT) and condition score (CS) measurements for Maternal ewes at the start of the adaptation period, the restricted feeding period and following ad libitum feeding at the end of the experiment for each percentage of maintenance feeding treatment. The standard reference weight (SRW) and gain or loss in LWT, CS and SRW are shown for the period of restricted feeding.

Parameter	40%	60%	80%	100%	140%	180%	LSD (5%)	*P*-value
Adaptation								
LWT at start of adaptation (kg)	76.2	76.0	76.2	76.1	77.3	75.8	3.82	0.979
CS at start of adaptation	3.60	3.6	3.5	3.5	3.7	3.5	0.25	0.562
Restricted Feeding								
LWT at start of restriction (kg)	83.5	82.7	83.4	84.4	85.2	82.3	4.0	0.730
LWT at start of restriction (intercept) (kg)[A]	79.2	78.9	79.9	80.6	83.0	79.5	4.22	0.423
LWT at start of restriction (intercept)$^{0.75}$ (kg)[A]	26.5	26.5	26.7	26.9	27.5	26.6	1.06	0.422
CS at start of restriction	4.1	4.0	4.0	4.1	4.2	4.0	0.21	0.164
SRW at start of restriction (kg)	72.2	72.5	72.4	73.0	72.0	71.9	3.51	0.990
LWT at end of restriction (kg)	72.5	75.0	77.2	79.6	86.4	83.0	4.63	< 0.001
CS at end of restriction	3.4	3.6	3.6	3.8	4.0	3.9	0.28	< 0.001
SRW (kg) at end of restriction	68.1	69.2	70.9	71.4	74.9	73.0	4.08	0.018
LWT change during restriction (kg)[B]	-10.8	-8.2	-6.2	-4.8	1.2	0.7	2.16	< 0.001
Weight gain or loss (g/day)[A]	-209	-141	-127	-73	16	54	42.1	< 0.001
CS gain or Loss	-0.6	-0.4	-0.4	-0.3	-0.2	-0.1	0.20	< 0.001
SRW change (kg)	-3.9	-3.3	-1.5	-1.7	2.8	1.2	2.37	< 0.001
Post-Restriction Feeding – ad libitum								
Liveweight at the end of *ad libitum* feeding (kg)	86.0	89.0	88.3	89.9	94.8	91.0	4.78	0.014
CS at the end of *ad libitum* feeding	4.1	4.1	4.1	4.3	4.4	4.3	0.24	0.053

[A] Intercept and weight loss or gain calculated from the linear relationship of liveweight against day of measurement for all weigh dates in the restricted feeding period.

[B] Change calculated based on the start and finish from the individual weigh dates.

Table 4. Liveweight (LWT) and condition score (CS) measurements for Merino ewes at the start of the adaptation period, the restricted feeding period and following ad libitum feeding at the end of the experiment for each percentage of maintenance feeding treatment. The standard reference weight (SRW) and gain or loss in LWT, CS and SRW are calculated for the period of restricted feeding.

Parameter	60%	80%	100%	140%	LSD (5%)	*P*-value
Adaptation						
LWT at start of adaptation (kg)	56.8	57.1	56.8	56.6	11.18	1.000
CS at start of adaptation	3.2	3.2	3.2	3.1	0.51	0.993
Restricted Feeding						
LWT at start of restriction (kg)	55.1	54.7	56.2	56.0	12.83	0.993
LWT at start of restriction (intercept) (kg)[A]	52.5	54.4	54.8	54.1	12.93	0.982
LWT at start of restriction (intercept)$^{0.75}$ (kg)[A]	19.5	20.0	20.1	19.9	3.5	0.984
CS at start of restriction	3.3	3.3	3.3	3.4	0.45	0.955
SRW at start of restriction (kg)	52.5	52.6	54.1	53.0	11.42	0.990
LWT at end of restriction (kg)	48.4	51.2	54.6	60.3	12.62	0.258
CS at end of restriction	2.8	3.0	3.1	3.4	0.48	0.137
SRW (kg) at end of restriction	49.7	51.0	53.9	56.9	9.8	0.443
LWT change during restriction(kg)[B]	-6.70	-3.50	-1.60	4.30	2.515	< 0.001
Weight gain or loss (g/day)[A]	-179	-129	-63	55	53.7	< 0.001
CS gain or Loss	-0.5	-0.3	-0.2	0.02	0.33	0.031
SRW change (kg)	-2.8	-1.7	-0.3	3.9	3.67	0.008
Post-Restriction Feeding – ad libitum						
Liveweight at the end of *ad libitum*	59.2	61.4	62.3	62.4	13.76	0.956
CS at the end of *ad libitum*	3.3	3.6	3.5	3.7	0.24	0.047

[A] Intercept and weight loss or gain calculated from the linear relationship of liveweight against day of measurement for all weigh dates in the restricted feeding period.

[B] Change calculated based on the start and finish from the individual weigh dates.

Table 5. Liveweight, C-fat and eye muscle depth for Maternal Composite ewes at the start and end of the restricted feeding period for each percentage of maintenance feeding treatment. The change in these parameters over the period is also shown.

Parameter	40%	60%	80%	100%	140%	180%	LSD (5%)	*P*-value
Starting liveweight at Scanning (kg)	79.6	79.6	79.7	80.9	82.1	79.1	3.86	0.652
Starting Liveweight at Scanning$^{0.75}$ (kg)	26.6	26.6	26.7	27.0	27.3	26.5	0.97	0.646
Starting C-fat depth (mm)	6.9	6.4	6.6	6.6	7.1	6.6	0.96	0.728
Starting eye muscle depth (mm)	36.9	36.0	36.7	36.5	36.8	36.1	1.29	0.699
End liveweight at Scanning (kg)	70.8	73.5	75.1	78.3	84.0	81.7	4.27	< 0.001
End C-fat depth (mm)	5.8	5.7	6.2	6.8	7.9	7.4	0.96	< 0.001
End eye muscle depth (mm)	34.1	34.1	34.3	35.2	35.6	35.6	1.26	0.031
Change in liveweight at scanning (kg)	-8.8	-6.1	-4.6	-2.6	2.0	2.7	1.61	< 0.001
Change in liveweight at scanning (g/day)	-191	-133	-100	-57	42	59	35.0	<.001
Change in C-fat depth (mm)	-1.0	-0.7	-0.4	0.3	0.8	0.8	0.58	< 0.001
Change in eye muscle depth (mm)	-2.8	-2.0	-2.3	-1.3	-1.2	-0.5	1.03	< 0.001

Table 6. Liveweight, C-fat and eye muscle depth for Merino ewes at the start and end of the restricted feeding period for each percentage of maintenance feeding treatment. The change in these parameters over the period is also shown.

Parameter	60%	80%	100%	140%	LSD (5%)	*P*-value
Starting Liveweight at Scanning (kg)	57.8	57.3	58.5	57.0	13.10	0.995
Starting Liveweight at Scanning$^{0.75}$ (kg)	20.94	20.79	21.08	20.70	3.524	0.996
Starting C fat depth (mm)	3.3	3.8	3.8	3.7	1.58	0.892
Starting Eye muscle depth (mm)	28.2	27.6	28.0	27.0	3.73	0.908
End Liveweight at Scanning (kg)	47.8	49.8	54.2	56.6	12.68	0.462
End C fat depth (mm)	3.2	4.0	3.7	4.2	1.67	0.620
End Eye muscle depth (mm)	26.0	25.6	26.4	26.8	3.54	0.900
Change in Liveweight at Scanning (kg)	-10.0	-7.5	-4.3	-0.4	2.65	< 0.001
Change in Liveweight at Scanning (g/day)	-217	-163	-94	-9	57.6	< 0.001
Change in C fat depth (mm)	-0.1	0.2	-0.1	0.5	0.69	0.235
Change in Eye muscle depth (mm)	-2.2	-2.0	-1.6	-0.2	2.24	0.265

Table 7. The fasted liveweight (FLWT), total tissue mass (TTM), bone mineral content (BMC), lean issue mass (LTM), fat tissue mass (FTM) and percentage fat of adult Maternal composite ewes scanned by dual-X-ray absorptiometry (DXA) excluding the head region at the start and finish of restricted feeding. The DXA data are the mean values of raw output from the DXA and are unadjusted to the chemical body composition of sheep.

Parameter	40%	60%	80%	100%	140%	180%	LSD (5%)	*P*-value
DXA Scan at Start								
FLWT at DXA (kg)	72.5	71.7	71.6	71.7	73.5	70.7	3.52	0.735
FLWT at DXA$^{0.75}$ (kg)	24.9	24.6	24.6	24.6	25.1	24.4	0.91	0.718
TTM (kg)	69.9	69.5	69.4	70.0	71.2	68.7	3.47	0.811
BMC (kg)	1.2	1.3	1.2	1.2	1.3	1.2	0.07	0.699
LTM (kg)	51.8	52.4	51.2	52.0	52.5	51.4	2.48	0.891
FTM (kg)	16.9	15.8	17.0	16.8	17.5	16.1	1.90	0.542
Percentage Fat (%)	24.1	22.6	24.3	23.8	24.5	23.3	2.03	0.439
Percentage Lean (%)	74.1	75.6	73.9	74.4	73.7	74.9	2.02	0.441
DXA Scan at Finish								
FLWT at DXA (kg)	67.5	68.2	70.0	71.6	75.5	74.3	4.16	< 0.001
TTM (kg)	64.5	66.1	67.3	69.1	73.1	72.0	4.09	< 0.001
BMC (kg)	1.4	1.4	1.3	1.3	1.4	1.3	0.09	0.791
LTM (kg)	47.5	49.2	48.9	49.9	52.1	52.2	2.88	0.007
FTM (kg)	15.7	15.6	17.1	17.9	19.6	18.4	2.05	< 0.001
Percentage Fat (%)	24.2	23.4	25.3	25.8	26.8	25.5	2.14	0.038
Percentage Lean (%)	73.7	74.6	72.7	72.3	71.4	72.7	2.12	0.063
Change in DXA Scan Parameters								
FLWT at DXA (kg)	-5.1	-3.5	-1.7	-0.2	2.0	3.6	1.90	< 0.001
FLWT at DXA (g/day)	-113	-77	-38	-4	44	81	41.6	< 0.001
TTM (kg)	-5.6	-3.4	-2.1	-0.9	1.9	3.3	1.63	< 0.001
TTM(g/day)	-123	-74	-48	-21	42	73	35.7	< 0.001
BMC (kg)	0.1	0.1	0.1	0.1	0.1	0.1	0.04	0.895
LTM (kg)	-4.4	-3.2	-2.4	-2.1	-0.3	0.8	1.31	< 0.001

LTM (g/day)	-96	-72	-53	-48	-8	19	29.0	< 0.001
FTM (kg)	-1.3	-0.2	0.2	1.2	2.2	2.3	0.65	< 0.001
FTM (g/day)	-29	-5	3	25	48	52	14.3	< 0.001
Percentage Fat (%)	-0.1	0.8	1.0	2.0	2.3	2.2	0.74	< 0.001
Percentage Lean (%)	-0.3	-1.1	-1.2	-2.1	-2.4	-2.2	0.75	< 0.001

Table 8. The fasted liveweight (FLWT), total tissue mass (TTM), bone mineral content (BMC), lean issue mass (LTM), fat tissue mass (FTM) and percentage fat of adult Merino ewes scanned by dual-X-ray absorptiometry (DXA) excluding the head region at the start and finish of the restricted feeding period. The DXA data are the means of raw output from the DXA and are unadjusted to the chemical body composition of sheep.

Parameter	60%	80%	100%	140%	LSD (5%)	*P*-value
DXA Scan at Start						
FLWT at DXA (kg)	49.4	50.1	51.5	49.2	11.59	0.974
FLWT at DXA$^{0.75}$ (kg)	18.6	18.8	19.2	18.5	3.23	0.978
TTM (kg)	46.8	48.0	49.2	47.2	10.53	0.962
BMC (kg)	0.9	0.9	0.9	0.9	0.20	0.985
LTM (kg)	36.7	36.8	38.3	35.9	7.12	0.905
FTM (kg)	9.2	10.3	10.0	10.4	4.06	0.928
Percentage Fat (%)	19.5	21.2	20.1	21.6	5.01	0.800
Percentage Lean (%)	78.5	76.9	78.1	76.5	4.97	0.805
DXA Scan at Finish						
FLWT at DXA (kg)	43.7	45.7	47.4	50.6	11.97	0.665
TTM (kg)	40.3	43.1	44.7	47.3	11.38	0.630
BMC (kg)	1.0	1.0	0.9	0.9	0.22	0.960
LTM (kg)	31.2	32.5	34.5	35.4	7.34	0.629
FTM (kg)	8.1	9.6	9.3	10.9	4.49	0.625
Percentage Fat (%)	19.8	22.1	20.4	22.6	5.61	0.686
Percentage Lean (%)	77.8	75.7	77.5	75.4	5.51	0.725
Change in DXA Scan Parameters						
FLWT at DXA (kg)	-5.7	-4.4	-4.1	1.4	1.34	< 0.001
FLWT at DXA (g/day)	-136	-105	-98	33	31.8	< 0.001
TTM (kg)	-6.5	-4.9	-4.5	0.14	1.58	< 0.001
TTM (g/day)	-155	-117	-107	3	37.7	< 0.001
BMC (kg)	0.1	0.1	0.0	0.0	0.06	0.500
LTM (kg)	-5.4	-4.3	-3.9	-0.5	1.30	< 0.001

LTM (g/day)	-129	-103	-92	-11	31.0	< 0.001
FTM (kg)	-1.1	-0.7	-0.7	0.6	0.72	0.001
FTM(g/day)	-27	-16	-16	13	17.2	0.001
Percentage Fat (%)	0.3	0.9	0.3	1.0	1.27	0.544
Percentage Lean (%)	-0.7	-1.2	-0.6	-1.1	1.28	0.662

Table 9. The coefficients (± s.e.) and R^2 for the fitted linear relationships between the gain or loss per day for different measures of liveweight and dual x-ray absorptiometry (DXA) tissue mass measured near the start and end of restricted feeding and the mean feed intake per day of Maternal Composite ewes fed from automatic feeders. (P < 0.05, **P < 0.01, ***P < 0.001, n.s. not significant, P>0.05).*

Model	Liveweight or Tissue Mass Parameter	Constant	Mean Intake (g/day)	Starting $Liveweight^{0.75}$ (kg)	R^2 (%)
1	Daily gain or loss in liveweight during restricted feeding (g/day)	-35.61 ± 104.227	0.2212 ± 0.01653 ***	-10.46 ± 4.018 *	61.7
2	Daily loss or gain in ultrasound scanning liveweight (g/day)	-65.61 ± 90.208	0.2291 ± 0.01319 ***	-11.06 ± 3.434 **	73.9
3	Change in Pre-DXA Fasted Liveweight (g/day)	-312.3 ± 22.13	0.2004 ± 0.01335 ***		66.8
4	Change in DXA Total Tissue Mass (TTM; g/day)	-312.2 ± 19.52	0.1957 ± 0.01143 ***		72.6
5	Change in DXA Fat Tissue Mass (FTM; g/day)	-111.6 ± 8.35	0.08666 ± 0.004064 ***		81.0
6	Change in DXA Lean Tissue Mass (LTM; g/day)	-203.0 ± 16.34	0.1092 ± 0.01045 ***		48.7

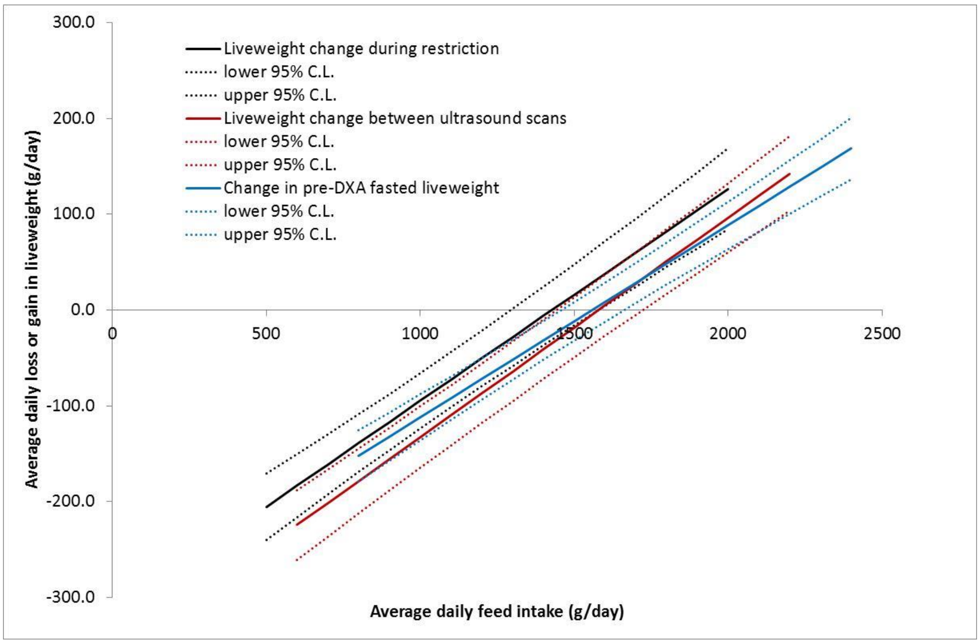

Figure 4. The fitted linear relationships (solid lines) between daily liveweight gain or loss (based on different measures of liveweight taken near the start and end of restricted feeding) and the measured feed intake per day of Maternal Composite ewes fed from automatic feeders. The dotted lines indicate the lower and upper 95% confidence limits.

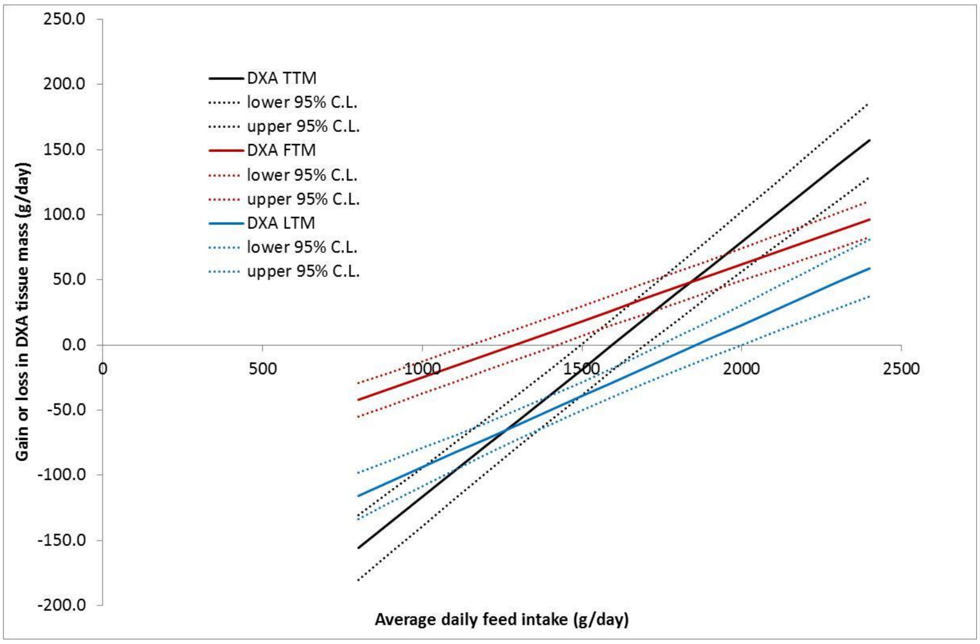

Figure 5. The fitted linear relationships (solid lines) between daily gain or loss in total tissue mass (TTM), fat tissue mass (FTM) or lean tissue mass (LTM) measured by dual x-ray absorptiometry (DXA) and the measured feed intake per day of Maternal Composite ewes fed from automatic feeders. The dotted lines indicate the lower and upper 95% confidence limits.

*Table 10. The coefficients (± s.e.) and R^2 for the fitted linear relationships between the gain or loss per day for different measures of liveweight and dual x-ray absorptiometry (DXA) tissue mass measured near the start and end of restricted feeding and the mean feed intake per day of Merino ewes fed from automatic feeders. (*P < 0.05, **P < 0.01, ***P < 0.001, n.s. not significant, P > 0.05).*

Model	Liveweight or Tissue Mass Parameter	Constant	Mean Intake (g/day)	Starting Liveweight$^{0.75}$ (kg)	R^2 (%)
1	Daily gain or loss in liveweight during restricted feeding (g/day)	-70.5 ± 80.1	0.4401 ± 0.0475 ***	-25.29 ± 4.75 ***	81.5
2	Daily loss or gain in ultrasound scanning liveweight (g/day)	-29.9 ± 74.6	0.389 ± 0.041 ***	-23.62 ± 4.06 ***	82.5
3	Change in Pre-DXA Fasted Liveweight (g/day)	-11.3 ± 66.9	0.2959 ± 0.037 ***	-16.91 ± 4.15 ***	76.5
4	Change in DXA Total Tissue Mass (TTM; g/day)	-107.2 ± 49	0.287 ± 0.0271 ***	-12.34 ± 3.04 ***	85.7
5	Change in DXA Fat Tissue Mass (FTM; g/day)	-69.31 ± 7.58	0.06803 ± 0.00854 ***		76.7
6	Change in DXA Lean Tissue Mass (LTM; g/day)	-55.2 ± 45.7	0.2132 ± 0.0253 ***	-11.21 ± 2.84 **	78.5

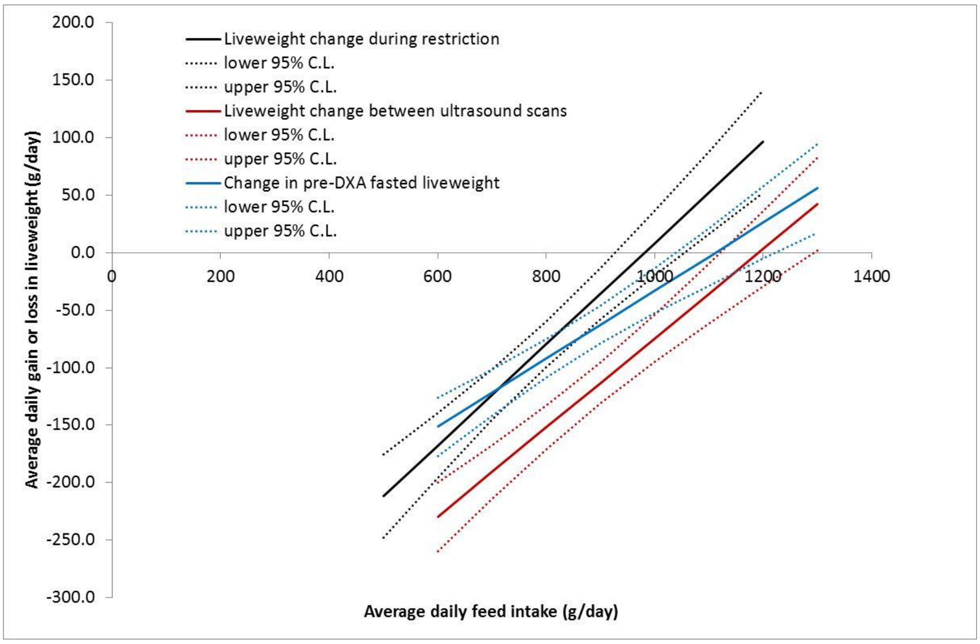

Figure 6. The fitted linear relationships (solid lines) between daily liveweight gain or loss (based on different measures of liveweight taken near the start and end of restricted feeding) and the measured feed intake per day of Merino ewes fed from automatic feeders. The dotted lines indicate the lower and upper 95% confidence limits.

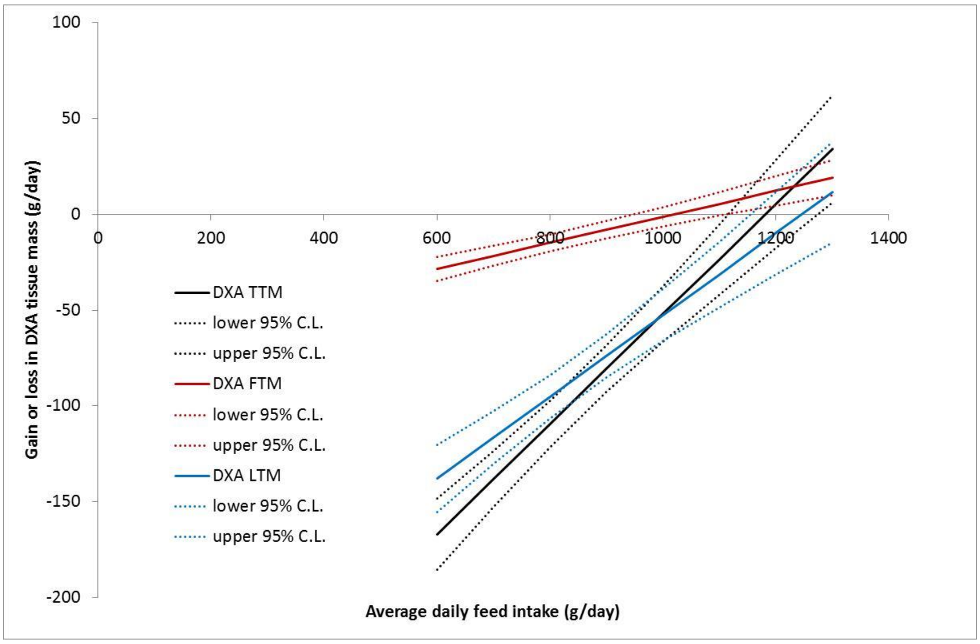

Figure 7. The fitted linear relationships (solid lines) between daily gain and loss in total tissue mass (TTM), fat tissue mass (FTM) or lean tissue mass (LTM) measured by dual x-ray absorptiometry (DXA) and the measured feed intake per day of Maternal Composite ewes fed from automatic feeders. The dotted lines indicate the lower and upper 95% confidence limits.

Table 11. The predicted feed intake and metabolisable energy per kg of metabolic body weight (kg$^{0.75}$) required to maintain liveweight, total tissue mass, fat tissue mass and lean tissue mass in Maternal Composite ewes according to models 1 to 6 shown in Table 9. Lower and upper 95% confidence limits (CL) provided for each estimate.

Model	Predicted maintenance feed intake (g/day, as fed)	Lower 95% CL	Upper 95% CL	Predicted maintenance metabolisable energy requirement (MJ/day/kg BW$^{0.75}$)	Lower 95% CL	Upper 95% CL
1	1428	1294	1579	0.494	0.447	0.546
2	1579	1443	1722	0.546	0.499	0.595
3	1559	1458	1663	0.586	0.548	0.625
4	1595	1495	1699	0.599	0.562	0.638
5	1288	1150	1422	0.484	0.432	0.534
6	1859	1748	2000	0.699	0.657	0.752

* maintenance was defined as the feed intake at which there was zero change in liveweight, total tissue mass, fat tissue mass or lean tissue mass over the feeding period described by each model shown in Table 9.

Table 12. The predicted feed intake and metabolisable energy per kg of metabolic body weight ($BW^{0.75}$) required to maintain liveweight, total tissue mass, fat tissue mass and lean tissue mass in Merino ewes according to models 1 to 6 shown in Table 10. Lower and upper 95% confidence limits (CL) provided for each estimate.*

Model	Predicted maintenance feed intake (g/day, as fed)	Lower 95% CL	Upper 95% CL	Predicted maintenance metabolisable energy requirement (MJ/day/kg $BW^{0.75}$)	Lower 95% CL	Upper 95% CL
1	981	928	1054	0.457	0.433	0.491
2	1191	1121	1293	0.528	0.497	0.573
3	1111	1039	1223	0.548	0.512	0.603
4	1181	1115	1274	0.582	0.550	0.628
5	1019	950	1113	0.502	0.468	0.549
6	1246	1155	outside range	0.614	0.569	outside range

*maintenance was defined as the feed intake at which there was zero change in liveweight, total tissue mass, fat tissue mass or lean tissue mass over the feeding period described by each model shown in Table 10.

9.1.11 Hamilton data

Hamilton LTM2 Data.xlsx

9.2 Katanning experiment (detail)

9.2.1 Maternal type sheep have greater than estimated *ad libitum* intake, and at low condition score deposit feed energy preferentially into lean tissue.

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9.2.2 Abstract

The performance of Maternal type ewes is different to the performance expected according to guidelines established for the management of Merino ewes in Australian farming systems. An experiment to intensively measure intake and liveweight change at Katanning in Western Australia was conducted. Condition score treatments created a significant difference in condition between the two groups on entry to the feed intake shed (CS3.32 versus CS2.55). Significant differences in intake and liveweight change were achieved during restricted feeding and these changes were still significant during *ad libitum* feeding. During restricted feeding the mean feed intake per day and the resulting liveweight change were significantly affected by feeding treatment ($P < 0.001$). Ewes in the lowest feeding treatment (40% of maintenance) lost 153 g/day. Ewes in the highest feeding treatment (180% of maintenance) gained 116 g/day. Ewes at 100% of maintenance achieved close to liveweight maintenance (-16 g/day). However this entailed maintenance of fat tissue (1.1 g/day) at the cost of lean tissue (-24.7 g/day). This means that the maintenance of whole body energy stores will be associated with a small degree of liveweight loss.

Liveweight, fasted liveweight change and changes in estimates of total, fat and lean tissue mass derived by dual-x-ray absorptiometry had essentially linear relationships with feed intake with some curvilinearity evident at the highest feeding levels. Estimates of maintenance requirements per kilogram of metabolic liveweight ($LW^{0.75}$) was 0.330MJ of ME/KG per day. Maintenance of fat tissue was achieved at 0.317 MJ of ME/KG per day and maintenance of lean tissue at 0.354 MJ of ME/KG per day. Maintenance requirements were slightly lower than current industry recommendations however this may be due to the definition of "confinement" varying from group pens to individual pens. Maximum intake was considerably higher than current industry understanding with maximum intakes (measured as a 5 day average) at 4.2 - 4.4% of final liveweight, which may contribute towards accounting for greater liveweight gains observed in paddock fed sheep.

9.2.3 Methodology

9.2.3.1 Animal Ethics

Experiment work was undertaken using a single pen facility set up at the Katanning research facility (Department of Primary Industries and Regional Development [DPIRD], Western Australia). All experimental work involving animals was approved by the Murdoch University and DPIRD Animal Ethics Committees (AEC Proposal R3002/17 and 17-6-14 respectively).

9.2.3.2 Animals and pre-experimental adaptation

Two hundred 2014 drop dry Maternal composite ewes (Greeline) were purchased from Glenridge, Mount Barker in December 2017. The ewes were shorn in late December and in January 2018 were transported to Murdoch University (Perth, Western Australia) and managed in a feedlot. On arrival the ewes were fitted with EID tags, treated for internal parasites, and weighed and condition scored.

The ewes were then split amongst 6 pens so that each group was balanced for liveweight and condition score. For the next week the ewes were fed *ad libitum* hay and gradually introduced to a pelleted diet (Morgan Feed Supplies, Toodyay; 10MJ of ME/kg dry matter, 12% protein). Then for the next two weeks the ewes in 3 groups were fed 475g/head per day while the ewes in the other three groups were fed 225g/head per day so that they began to lose condition. For the following 3 weeks, the ewes were fed the pelleted feed on an individual pen basis so that the first 3 groups continued to maintain average liveweight (CS treatment HIGH), and the ewes in the second 3 groups continued to lose condition (CS treatment LOW). The condition score targets were CS3.5 for the HIGH ewes and CS2.5 for the LOW ewes. At the conclusion of this introductory period, all ewes less than CS2.3 or more than CS4.3 were removed from the experiment, and the remaining ewes (n=188) were fasted overnight, weighed, and transported to the Katanning research facility.

One hundred and sixty ewes (80 from each CS treatment group) were allocated to one of six feeding groups so that each feeding group was balanced for liveweight and condition score (within condition score treatment). The feeding groups were as follows: 40%, 60%, 80%, 100%, 140%, and 180% of maintenance (Table 13) and were designed to achieve a range in liveweight change of between approximately -150g/head per day and +100g/head per day for a 60kg ewe. More ewes were allocated to the low CS and low feeding groups in anticipation of some ewes having to be removed. The single pen set up was broken into 9 blocks (BLOCK) to facilitate further measurements, and ewes were randomly allocated into pens within each block so that each block was balanced for CS treatments, feeding treatments, and liveweight and CS.

Insert table 13 here

9.2.3.3 Feeding and intake restriction

The experiment was conducted using a 9 mm sheep starter/conditioner pellet (Morgan Feed Supplies, Toodyay). The manufactured pellet was delivered in one consignment and stored undercover onsite. Sub samples collected daily were pooled and submitted for independent analysis by two feed testing laboratories. The analysed metabolisable energy, crude protein and neutral detergent fibre content of the pellets were 10.6MJ/kg DM, 10.4% and 36%, respectively. The average DM of the pellets was 91.5%. The pellet was manufactured from the following ingredients; lupins, barley, wheat, cereal straw, lime, salt, molasses, vitamin/trace mineral premix, Vitamin E, lasalocid sodium, Yea-sacc. Ewes were fed in one meal each morning. Any refusals were measured before a new meal was provided.

For the first week and up until DXA scanning, the ewes were fed at maintenance estimated for each ewe individually according to her liveweight using the Lifetime Ewe Management guidelines for ewes in confinement. At DXA scanning the ewes within each block were fasted and this fasting liveweight was used to establish the maintenance requirement for each ewe which was then adjusted as per the allocated feeding treatment. The feeding quantity for each ewe was set at this level for the following 35 days (rounded to 50g).

After this restricted feeding period, the ewes were transitioned towards an *ad libitum* diet (21 days). Ewes on the 40% (of maintenance) diet received 60%. On the second day these ewes, plus the ewes already on 60% received 80%. On the third day these ewes, plus the ewes already on 80% received 100%. This continued until all ewes were being provided with 180% (on day five). After this, ewes were given 180% of requirements plus 1kg, and from then on, 125% of their maximum meal size. Given the time required to gradually increase meal sizes, *ad libitum* feeding was measured over 14 days.

9.2.3.4 Animal Measurements, samples and management

Composition measures (ultrasound, Dual X-ray Absorptiometry [DXA], and blood sampling for leptin) were collected at the start of the restricted feeding period, at the end of the restricted feeding period, and at the end of the *ad libitum* feeding period. Liveweight (LWT) was measured 3 times per week on Monday, Wednesday and Friday, while CS was assessed by the same experienced technical officer on a weekly basis (each Monday). An industry accredited ultrasound scanning operator measured C site fat and muscle on the Friday immediately preceding each week of DXA measurement.

DXA was used to assess changes in body composition (proportions of fat and lean tissue). The equipment used was a QDR series Horizon A Dual energy X-ray Absorptiometry machine (Hologic Inc. Bedford, MA, USA). Ewes were scanned by BLOCK. On the day prior to DXA measurement, each ewe had a 9mL blood sample collected via jugular venipuncture into a heparinised blood tube. Blood samples were centrifuged and the plasma harvested and stored at -20°C. The ewes were then fed at either their restricted level or a meal restricted to 100% of maintenance (for the final scan) before commencing a 24 hour fast including 12 hours off water. On the morning of scanning a fasting liveweight and a condition score was collected for all ewes as a group, and each ewe was weighed again individually immediately prior to sedation for the DXA procedure. Predictions of total tissue mass, lean tissue mass, fat tissue mass and bone mineral content were estimated using the onboard Hologic software adapted from human analysis with all tissue placed within the arm region as previously described by (Dunshea et al). Estimates for the head region were excluded from the analysis due to interference in this section from EID tags and the pulse oximeter used to monitor sedation.

A mid-side sampling crate (a tipping crush) was used to restrain the ewes for sedation, and at this time a 100cm2 mid-side wool sample was collected for analysis of wool quality (initial sample), and wool growth during the feeding period.

9.2.3.5 Housing and Weather Observations

Ewes were housed in a modular single pen facility set up in a shed with a raised and slatted wooden floor designed for holding sheep. Each pen was *0.87 x 1.20m* and fitted with an automatic water nipple. All construction was open railings to allow clear vision of other ewes in the shed. The shed was closed on three sides (north, west, south) although gaps allowed cross ventilation, and open to the east so the shed was fully naturally lit and ventilated. Another shed was positioned to the east which blocked strong winds from the east. Weather data was collected from the weather station onsite at the research facility located approximately 1.4km from the animal house.

9.2.3.6 Statistical Analysis

For feed intake, the daily intake for each period was calculated for individual animals. This was a set amount for the restricted period (RESTRICT), and then the average daily intake including adaptation for the *ad libitum* period (ADLIBALL), all days not including adaptation (ADLIB) as well as subsets using the last 14 days of the *ad libitum* period (ADLIB14), the final 5 days of the *ad libitum* period (ADLIB5), and maximum intake. ADLIB14, ADLIB5 and maximum intake were also analysed as a percentage of fasting liveweight. Daily liveweight change (DLWC) was calculated using a linear function over time to account for error associated with weighing and the intercept of this function was used as the starting liveweight where this was included in models (SLW). Liveweight change was also assessed as the difference between fasting liveweights (FDLWC). Liveweight measures were also assessed in all models as metabolic liveweight ($LW^{0.75}$).

The proc mixed procedure was used to predict treatment means for intake and liveweight change during the two feeding periods, as well as ewe fasting liveweights, CS and body composition data (fat mass, lean mass, total mass and percentage body fat, and ultrasound measurements – fat and eye muscle depth at the C site) at the start, middle, and end of the experiment. CS treatment (HIGH, LOW) and feeding treatment (Level 1, 2, 3, 4, 5, and 6 – representing 40%, 60%, 80%, 100%, 140% and 180% of maintenance respectively) and the interaction were included in the models as fixed effects and BLOCK was included as a random term.

Measures of daily energy change during each period were then analysed using general linear models: liveweight change (derived from the linear relationship), liveweight change (derived from fasting liveweights), total tissue mass, lean tissue mass and fat tissue mass. Daily energy change was also analysed as the change in whole body energy, where 1g of lean tissue has an energy value of 5.31kJ and 1g of fat tissue has an energy value of 33.4kJ. The dependent variables were modelled against average intake for the appropriate period (restricted or *ad libitum*), and fasting liveweight$^{0.75}$ and condition score collected at the start of the period tested. Block was included as a random term. For the *ad libitum* feeding analysis, [previous] feeding level was also included as a covariate.

All statistical analyses were performed using SAS (SAS 2002). All models tested interactions to the first order (where necessary) and terms were removed in a stepwise fashion if not significant (P>0.05).

9.2.4 Results

9.2.4.1 Weather

The maximum and minimum temperature and relative humidity for the restricted and *ad libitum* feeding periods of the experiment are shown in Figure 8. The average wind speed is shown in Figure 9. The mean maximum temperature was 25.1^{o}C and the mean minimum 12.7^{o}C and relative humidity averaged 51.3% during the experimental period. While the wind speed could be quite high, the ewes in the single pen facility were largely protected from the strongest prevailing winds due to the closed off western wall.

9.2.4.2 Condition score treatment

Condition score differences were achieved following differential feeding in the feedlot prior to allocation to the animal house, with a significant difference of CS0.8 between the LOW and HIGH treatment groups (CS2.55 ±0.02 and CS3.32 ±0.03 respectively).

9.2.4.3 Feed intake

The feeding treatments during restriction were successful in delivering a range of intakes (

Table 14) that drove significant differences in condition score and liveweight (

Table 14). Feeding level during restriction was significantly different between the CS treatment groups by 54g (P<0.001;

Table 14). Feeding level was also significantly different between the 6 feeding treatments (P<0.001;

Table 14), so that ewes in the lowest treatment group (40%) were eating 262g per head per day, and ewes in the highest group (180%) were eating 1176g per head per day. During the following period (ad libitum), intake was still significantly associated with the condition score treatment (P<0.001;

Table 14) so that intake for ewes in the HIGH condition core treatment group ate 2079g (± 35g) per head per day and ewes in the low CS treatment group ate 1914g (± 34g) per head per day. Feeding treatment also had a significant association with ad libitum consumption (P<0.001;

Table 14) so that ewes in the lowest treatment group (40%) were eating 1868g (± 53g) per head per day, and ewes in the highest group (180%) were eating 2277g (± 62g) per head per day. If the last 14 days of ad libitum consumption were used as the dependent variable, there were still significant differences between the condition score and feeding treatment groups (

Table 14). There was a trend for low CS ewes to have higher intake as a percentage of the fasting liveweight collected at the start of the ad libitum period (P=0.09;

Table 14), and the maximum intake could be as high as 5.5% (±13g) of the fasting liveweight on a single day for low CS ewes, significantly higher than the high CS ewes (5.1% ±14g; P<0.01;

Table 14).

Insert table 14 here

9.2.4.4 Condition score, liveweight and liveweight change

The difference between the condition score treatment groups closed during the acclimation period so that the difference at the beginning of restricted feeding was 0.5CS (CS3.14 ±0.04 for the high CS group and CS2.62 ±0.04 for the low CS group). This difference was similar at the end of the restricted feeding period. There was a significant interaction between feeding treatment and condition score treatment associated with the change in CS during restricted feeding so that ewes in the low CS treatment group had a smaller decrease in condition score at the same low levels of feeding and gained significantly more condition at the higher feeding levels. Ewes with low CS and in the lowest feeding group (40%) lost approximately a quarter of a CS (0.24 ±0.07CS) while ewes from the high CS group at the same feeding level lost over a third of a score (0.39 ±0.05CS). In the highest feeding group (180%), ewes from the low CS group gained almost half a condition score (0.49 ±0.08CS) while ewes from the high CS group gained just over a quarter of a score (0.28 ±0.08CS; $P<0.05$; Table 15). Thus there was a small but significant reduction in the difference between the high and low condition score groups at the end of the fasting period. At the end of the *ad libitum* period, the CS groups were still significantly different but the difference between the groups had reduced further (CS3.39 ±0.04 for the high CS group and CS2.95 ±0.04 for the low CS group; $P<0.001$; Table 15).

Fasting liveweight was significantly different between the condition score treatment groups at allocation ($P<0.001$) so that ewes in the high condition score group weighed 70.8kg (±0.70kg) and ewes in the LOW condition score treatment group weighed 62.4kg (±0.66kg). Liveweight was not significantly different between the feeding treatment groups at allocation or following acclimation. Following restricted feeding fasting liveweight had declined for ewes on 40%, 60%, 80% and 100% of maintenance, and increased for ewes on 140% and 180% of maintenance. The groups were significantly different so that the fasting liveweight for ewes in the lowest feeding group was 49.8kg (±1.43kg) and for ewes in the highest feeding treatment was 62.6kg (±1.75kg; $P<0.001$; Table 15). At the same time point, there was still a significant difference in liveweight between the CS treatment groups so that ewes from the high CS group were 60.1kg (±0.98kg) and ewes from the low CS group were 53.2kg (±0.94kg; $P<0.001$; Table 15). Following the period of *ad libitum* feeding there were still significant differences for fasting liveweight between the feeding treatment groups, although the range had reduced from 12.8kg to 7.7kg between the highest and the lowest feeding treatments (70.0 ±1.30kg versus 62.3 ±1.11kg respectively; $P<0.001$; Table 15). The range between the high and low CS treatment groups had also reduced by the end of *ad libitum* feeding (68.7 ±0.74kg versus 62.6 ±0.71kg respectively; $P<0.001$; Table 15).

Daily liveweight change during the restricted feeding period was significantly associated with feeding treatment ($P <0.001$), but not with condition score treatment. Ewes in the lowest feeding treatment (40%) lost 153g per head per day (±9g) while ewes in the highest treatment (180%) gained 116g per head per day (±10g). Ewes in the group at 100% of expected maintenance lost 16g per head per day (±10g; $P<0.001$; Table 15).

Daily liveweight change during the *ad libitum* feeding period was inversely related to their feeding level during the restricted feeding period so that ewes in the lowest feeding treatments had the highest rates of liveweight gain during *ad libitum* feeding. Ewes in the lowest feeding group (40%)

gained 469g/day (±29g) and ewes in the highest feeding group (180%) gained 349g/day (±32g; P<0.01; Table 15). There was also a significant association between the condition score treatment group and fasting liveweight change so that ewes in the low CS treatment group had higher liveweight gain than those ewes in the high CS treatment group (437g/day ± 23g versus 385g/day ±24g respectively; P<0.05).

Insert table 15 here.

9.2.4.5 Ultrasound muscle and Fat depth

Ultrasound fat and muscle depth was significantly different between the CS treatment groups at the start so that ewes in the high CS group had more sub cutaneous fat and muscle than ewes in low CS group (28.4 ±0.35mm versus 25.4 ±0.34mm respectively for muscling and 3.9 ±0.13mm versus 2.7 ±0.12mm for fatness; P<0.001; Table 16). At the end of the restricted feeding period, fat and eye muscle depth were still significantly higher for ewes in the high CS group than the low CS group, by 2.7mm for muscle depth (27.3 ±0.36mm versus 24.6 ±0.35mm respectively; P<0.001), and by 1.0mm for fat depth (3.4 ±0.10mm versus 2.4 ±0.10mm respectively; P<0.001; Table 16). Feeding treatment was significantly and positively related to fat and eye muscle depth. Muscle depth for ewes in the lowest feeding group (40%) was 24.9mm (±0.55mm) and fat depth was 2.4mm (±0.15mm), while muscle depth for ewes in the highest feeding group (180%) was 27.8mm (±0.64; P<0.05) and fat depth was 3.5mm (±0.18mm; P<0.01; Table 16).

At the end of the *ad libitum* feeding period, feeding treatment was positively associated with muscle and fat depth, and ewes in the high CS treatment group still had more muscle and fat depth than ewes from the low CS group. Ewes in the high CS treatment group had 2.9mm more muscle depth than ewes in the low CS group (27.8 ±0.29mm versus 24.9 ±0.28mm respectively; P<0.001), and ewes that were previously in the lowest feeding group (40%) had 25.0mm (±0.44mm) in comparison to ewes that had been at the highest level (180%; 28.1 ±0.52mm; P<0.001; Table 16). Ewes in the high CS treatment group had 1.1mm more fat depth than ewes in the low CS group (4.1 ±0.11mm versus 3.0 ±0.11mm respectively; P<0.001), and ewes that were previously in the lowest feeding group (40%) had 3.0mm (±0.17mm) in comparison to ewes that had been at the highest level (180%; 4.6 ±0.20mm; P<0.001; Table 16).

The change in sub cutaneous muscle depth was significantly associated with feeding treatment but only during the restricted feeding period, so that ewes in the lowest feeding group (40%) lost 2.0mm (±0.51mm) of muscle depth and ewes in the highest feeding group gained 1.18mm (±0.59mm; P<0.01; Table 16). Change during *ad libitum* feeding was not significantly different between either the CS or feeding treatment groups. The change in sub cutaneous fat depth during restriction was significantly different for both CS and feeding treatments. Ewes in the HIGH CS group lost 0.5mm (±0.09mm) of fat depth while ewes in the low CS group lost 0.2mm (±0.09mm; P<0.05; Table 16). Change in fat depth ranged from -0.7mm (±0.13mm) for ewes in the lowest feeding group (40%), to 0.3mm (±0.16mm) for ewes in the highest feeding group (P<0.001; Table 16). There was also a significant change in fat depth during the *ad libitum* feeding period associated with feeding treatment, so that ewes previously in the lower feeding treatment groups gained approximately 0.5mm and were not significantly different from each other while ewes in the highest feeding treatment gained 1.1mm (±0.14mm; P<0.01; Table 16).

Insert table 16 here.

9.2.4.6 Dual x-ray absorptiometry (DXA) body composition

Condition score treatment was significantly associated with reductions in all tissues at the start of the feeding treatments. Total tissue mass (excluding the head) was 56.7kg (±0.65kg) for high CS ewes and 49.7kg (±0.62kg; P<0.001; Table 17) for low CS ewes. High CS ewes had 45.0kg (±0.44kg) of lean tissue and 11.6kg (±0.29kg) of fat tissue, and low CS ewes had 41.4kg (±0.42kg) of lean tissue with 8.3kg (±0.28kg; P<0.001) of fat tissue leading to a significant difference in the tissue proportions (percentage fat - 20.3 ±0.37% versus 16.6 ±0.35% for high and low CS ewes respectively; P<0.001; Table 17). Bone mineral content was also significantly different (1.3 ±0.02kg versus 1.2 ±0.01kg for high and low CS treatment ewes respectively; P<0.001; Table 17).

During the restricted feeding period, there was a significant difference between feeding treatments for changes in total tissue mass and the lean and fat tissue masses. For ewes in the 40% feeding treatment, lean mass reduced by 4.9kg (±0.23kg), fat mass reduced by 1.0kg (±0.09kg) so that 5.9kg (±0.25kg) in total body mass was lost. Ewes in the 180% feeding treatment gained 4.3kg (±0.29kg) of total tissue mass, made up of 3.2kg (±0.27kg) of lean tissue and 1.1kg of fat tissue (±0.10kg; P<0.001; Table 17). For ewes in the 100% feeding treatment (expected maintenance), lean tissue was still being lost (-0.9 ±0.27kg) while fat tissue was maintained (0.0 ±0.10kg; Table 17). During the restricted feeding period there were no significant differences between the condition score treatment groups for changes in the tissue types. There were no significant changes in bone mineral content or percentage of body fat.

At the second scan the ewes had significant differences in tissue mass between the condition score treatment groups. Total tissue mass (excluding the head) was 55.6kg (±0.70kg) for high CS ewes and 48.5kg (±0.67kg; P<0.001; Table 17) for low CS ewes. High CS ewes had 44.0kg (±0.47kg) of lean tissue and 11.5kg (±0.30kg) of fat tissue, and low CS ewes had 40.3kg (±0.45kg) of lean tissue with 8.2kg (±0.29kg; P<0.001) of fat tissue. Tissue proportions (percentage fat) were 20.5 ±0.36% versus 16.9 ±0.34% for high and low CS ewes respectively (P<0.001; Table 17). Bone mineral content remained significantly different (1.3 ±0.02kg versus 1.2 ±0.02kg for high and low CS treatment ewes respectively; P<0.001; Table 17). Total and lean tissue mass were significantly different between the feeding treatment groups at the second scan so that total tissue mass was 47.7kg (±1.04kg) for ewes in the 40% feeding treatment group and 57.5kg (±1.24kg) for ewes in the 180% feeding treatment group (P<0.001; Table 17). Lean tissue mass was 38.7kg (±0.70kg) for ewes in the 180% feeding treatment and 46.5kg (±0.84kg) for ewes in the lowest feeding treatment (P<0.001; Table 17). There was a trend for differences in fat tissue mass with a range of 2kg between the lowest and highest feeding treatments (9.0 ±0.44kg and 11.0 ±0.53kg respectively; P=0.08). Bone mineral content and body fat percentage were not significantly different between the feeding treatments.

During the *ad libitum* feeding period changes in the total tissue mass and lean tissue mass were significantly different between the condition score treatment groups. Ewes in the high condition score group gained 7.4kg (±0.42kg; P<0.05) of total mass and 6.2kg (±0.36kg; P<0.05) of this was lean tissue, while ewes in the low condition score group gained 8.4kg (±0.41kg) of total mass with 7.1kg (±0.35kg; Table 17) of this being lean tissue. The change in percentage body fat was also significantly different with a change of -0.45% (±0.12%) for ewes in the high condition score group versus a change of -0.16% (±0.11%; P<0.05; Table 17) for ewes in the low condition score group. There were also significant differences in tissue changes between the feeding treatment groups. Gain in total tissue mass was highest for ewes in the 40% feeding treatment at 9.2kg (±0.54kg) and lowest for ewes in the highest feeding treatment (180%; 6.6 ±0.61kg; P<0.01; Table 17). This difference was driven by changes in lean tissue mass which was 8.1kg (±0.47kg) for ewes in the 40% feeding treatment and 5.0kg (±0.53kg; P<0.001; Table 17) for ewes in the 180% feeding treatment. Fat tissue gain was highest for ewes in the 180% feeding treatment (1.6 ±0.14kg) and lowest for ewes in the 40% feeding treatment (1.1 ±0.12kg; P<0.05; Table 17). The changes in fat tissue as a proportion were also different so that for ewes in the 40% feeding treatment the proportion of fat tissue declined (-0.92 ±0.17%) and for ewes in the 180% feeding treatment the proportion of fat tissue increased (0.54 ±0.19%; P<0.001; Table 17). Bone mineral content did not significantly change during *ad libitum* feeding.

At the final scan the ewes had significant differences in tissue mass between the condition score treatment groups. Total tissue mass was 63.0kg (±0.70kg) for high CS ewes and 56.9kg (±0.67kg; P<0.001; Table 17) for low CS ewes. High CS ewes had 50.2kg (±0.51kg) of lean tissue and 12.8kg (±0.30kg) of fat tissue, and low CS ewes had 47.3kg (±0.49kg) of lean tissue with 9.6kg (±0.28kg; P<0.001) of fat tissue. Tissue proportions (percentage fat) were 20.1 ±0.33% versus 16.6 ±0.32% for high and low CS ewes respectively (P<0.001; Table 17). Bone mineral content remained significantly different (1.3 ±0.02kg versus 1.2 ±0.02kg for high and low CS treatment ewes respectively; P<0.001; Table 17). Total, lean and fat tissue mass were significantly different between the feeding treatment groups at the final scan so that total tissue mass was 56.7kg (±1.05kg) for ewes in the 40% feeding treatment group and 64.2kg (±1.24kg) for ewes in the 180% feeding treatment group (P<0.001; Table 17). Lean tissue mass was 46.6kg (±0.75kg) for ewes in the 40% feeding treatment and 51.6kg (±0.87kg) for ewes in the highest feeding treatment (P<0.001; Table 17). Fat tissue mass was 10.1kg (±0.45kg) for ewes in the 40% feeding treatment and 12.6kg (±0.52kg) for ewes in the highest feeding treatment (P<0.01; Table 17). Bone mineral content and body fat percentage were not significantly different between the feeding treatments.

Insert table 17 here

9.2.4.7 Relationships between intake and measures of energy change

All changes in liveweight and tissue mass were significantly related to feed intake during restricted feeding when measured using animal level models. The models tested included linear change in liveweight (model 1), change in fasting liveweight (model 2; Figure 10), change in total tissue as measured by DXA (model 3), change in lean tissue mass (model 4) and change in fat tissue mass (model 5; Figure 11). The coefficients, as well as the variance accounted for, are shown in Table 18. For all change variables aside from fat tissue these relationships were curvilinear. The variance accounted for by these models was high, ranging from 67% (liveweight change derived from weekly liveweight measurements) to 87% (DXA measured total tissue change).

Insert table 18 here

Insert table 19 here

The models described less of the variance associated with energy change during the *ad libitum* feeding period (Table 19). Variance explained was only 12% for liveweight change, and up to 30% for changes in lean tissue as measured by DXA. Animals that were lighter at the start of the *ad libitum* period gained more liveweight than animals that were heavier (P<0.001), and more of this liveweight was lean tissue (P<0.001). Heavier animals gained more fat tissue than animals that were lighter at the start of the *ad libitum* period (P<0.01). This was similar for the relationships between tissue change and [previous] feed intake, so that ewes that had been the most restricted gained more liveweight, and the weight they gained was significantly directed towards lean tissue, while ewes that had been fed above maintenance in the previous period gained less lean tissue and more fat tissue.

Insert figure 10 here

Insert figure 11 here

9.2.4.8 Maintenance requirements

Maintenance requirements for the energy change models were not significantly different between the condition score treatment groups (

Table 20). Maintenance of fasting liveweight was estimated at 712.6g/head per day for an adult ewe with a metabolic liveweight of 20.97kg (equivalent to 57.8kg liveweight), or 0.33MJ of ME/kg of metabolic liveweight. Maintenance of lean tissue was higher than the maintenance of fat tissue (764.5g/head versus 685.4g/head respectively). When maintenance was expressed as zero change in whole body energy, the requirement was 698g/day or 0.323MJ/day.

Insert table 20 here

9.2.5 Discussion

Significant differences in intake and liveweight change were achieved during restricted feeding and these changes were still significant during *ad libitum* feeding. During restricted feeding the mean feed intake per day and the resulting liveweight change were significantly affected by feeding treatment (P <0.001). Ewes in the lowest feeding treatment (40% of maintenance) lost 153 g/day. Ewes in the highest feeding treatment (180% of maintenance) gained 116 g/day. Ewes at 100% of maintenance achieved close to liveweight maintenance (-16 g/day). However this entailed maintenance of fat tissue (1.1 g/day) at the cost of lean tissue (-24.7 g/day). This means that the maintenance of whole body energy stores would be associated with a small degree of liveweight loss.

Differences in condition score had little effect on whole body energy changes during *ad libitum* feeding. Ewes that were in the LOWCS treatment group did gain significantly more weight (1kg) during *ad libitum* feeding however, the gain had similar proportions of fat and lean to ewes from the HIGHCS treatment group. However, previous feeding treatment had a significant effect on both the total mass gained, and the proportions of fat and lean, so that for ewes from the lowest feed treatment group (40%) gain in mass was both higher (2.6kg) and comprised of almost 90% lean tissue, while this was 75% for ewes from the highest feed treatment group (180%). This corresponds with work by Oddy (pers. Com.) who suggested that prior feeding level would impact metabolic efficiency so that ewes previously consuming at a restricted level would have lower maintenance requirements due to the reduction in demand of the metabolically active organs (spleen, liver, kidneys, GIT). Work by Kabbali *et al.* (1992) demonstrated that refeeding lambs following liveweight loss (25-31%) led to the rapid increase of organ weights and fat was a smaller component of liveweight gain. The serial slaughter technique used in Kabbali *et al.* (1992) showed that at the same liveweight, the re-fed lambs were leaner. Therefore in addition to being able to store more feed energy as surplus to maintenance requirements, the proportional difference in tissue gain in our experiment could be explained by the reactivation of these organs which are largely lean tissue.

Liveweight, fasted liveweight change and changes in estimates of total, fat and lean tissue mass derived by dual-x-ray absorptiometry had essentially linear relationships with feed intake with some curvilinearity evident at the highest feeding levels. Estimates of maintenance requirements per kilogram of metabolic liveweight ($LW^{0.75}$) was 0.330MJ of ME/KG per day. Maintenance of fat tissue was achieved at 0.317 MJ of ME/KG per day and maintenance of lean tissue at 0.354 MJ of ME/KG per day. Maintenance requirements were slightly lower than current industry recommendations however this may be due to the definition of “confinement” varying from group pens to individual pens. Grazing activity constitutes the major expenditure of energy in extensive systems as well as the heat increment associated with processing feed energy (Blaxter 1962). In confinement systems the diets tend to be processed or semi processed so heat increment is also reduced (Lachica and Aguilera 2005).

In group housing, social interactions and investigative behaviours will still be an additional component to energy expenditure in contrast to individually penned animals where social interactions and play are limited. Current recommendations are to feed 83.75% of maintenance for ewes in confinement (Corbett *et al.* 1990), however the ewes in this experiment required 76% of this recommendation to maintain liveweight. Results derived from animal house experiments must account for these differences when extrapolating to recommendations for extensive management systems.

Maximum intake was considerably higher than current industry understanding with maximum intakes (measured as a 5 day average) at 4.2 - 4.4% of final liveweight, Current understanding is that intake (of pasture at 75% digestibility) is around 3% of liveweight (ie 1.5kg for a sheep with a standard reference weight of 50kg;(Corbett *et al.* 1990)), and will be increased in line with digestibility and with shorter fibre lengths (ref), however not to the extent observed in our results. Previous work demonstrated that maternal type ewes gained more liveweight than could be predicted using the Australian Ruminant Feeding Standards (Behrendt *et al.* 2019), Thompson *et al.* unpublished), and the results of the current experiment suggest that potential intake could make a significant contribution to the observed differences. It may be that the potential intake for other sheep (such as the Merino) may need to be re-visited. The ability of maternal type ewes to consume at much higher than predicted levels will affect the management of these ewes both at pasture and during confinement, and should mean they can be run at higher stocking rates than current understanding suggests.

The relationship between intake and liveweight change was essentially linear with some plateau towards the upper limits. This is in contrast to the Australian Feeding Standards (Corbett *et al.* 1990) where ruminants are definitively more efficient at maintenance than during liveweight gain. This has implications for extension messages as currently producers are advised that if supplementary feeding is required it is more efficient to maintain sheep than it is to allow them to lose weight and then regain it (Young *et al.* 2011). The results of our experiment suggest this is not the case, and periods of liveweight loss could be part of an optimum profile for maternal type ewes managed in pasture based Mediterranean systems without affecting whole farm efficiency.

9.2.6 Conclusions

Previous work as part of the Lifetime Maternals project demonstrated that the current feeding standards were unable to predict the intake and liveweight change of maternal type ewes when managed in commercial situations. Whole farm analysis demonstrated a number of variables that might account for the discrepancies, including potential intake, the efficiency of energy use for maintenance and the energy content of the weight gain and loss. The results of this experiment show that potential intake is greater than is currently accounted for and this will be an important factor to account for in extension messages directed specifically to the management of maternal type ewes. While liveweight gain is higher, the energy value of gain is lower for ewes that have previously been on restricted diets so that these ewes gained more lean tissue negatively affecting the overall proportion of fat tissue. This factor could also contribute to high liveweight gains observed in maternal type ewes under some conditions. Condition score did not affect liveweight or energy value of gain, however the range tested may not have been large enough for the detection of these differences. Maintenance requirements were lower than expected however this is likely due to the level of confinement rather than due to significant alteration in actual basal metabolic rates. In combination with the other experiments in this project, the coefficients developed here will assist in the development of extension messages suited to the management of maternal type ewes in Australian farming systems.

9.2.7 References

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9.2.8 Figures and Tables

Table 13. Allocation of maternal type adult ewes to feeding treatment for the testing of feed intake and energy requirements.

	Condition score treatment	
Feeding treatment	LOW	HIGH
40%	n = 20	n = 16
60%	n = 16	n = 12
80%	n = 12	n = 12
100%	n = 12	n = 12
140%	n = 12	n = 12
180%	n = 12	n = 12
Per treatment	n = 84	n = 76

Total ewes	n = 160

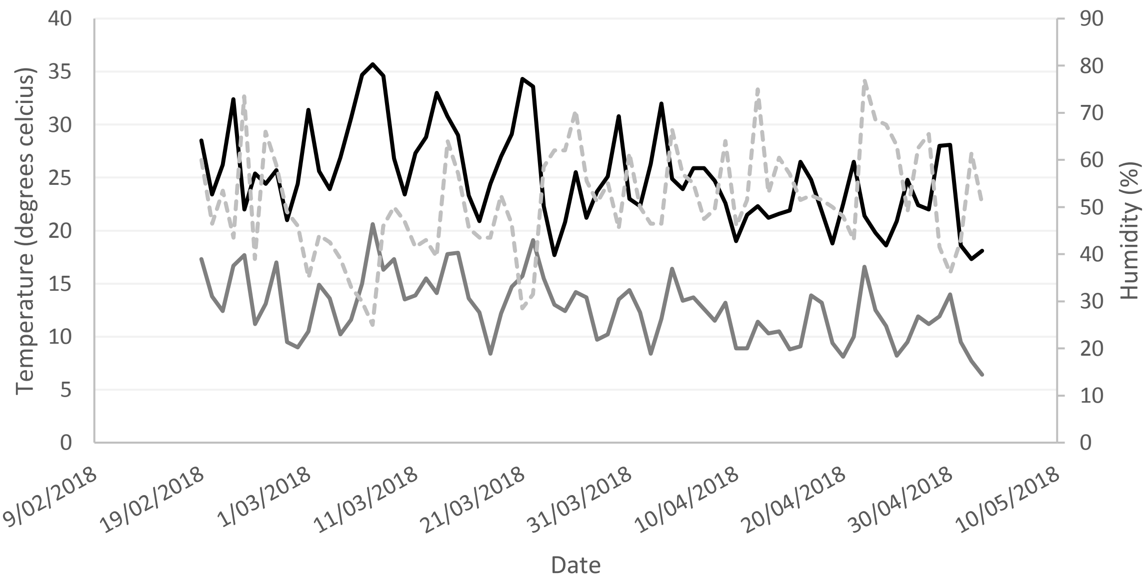

Figure 8. The maximum (black line) and minimum (grey line) temperature and relative humidity (grey broken line) during the Lifetime Maternals animal house experiment conducted at Katanning, Western Australia.

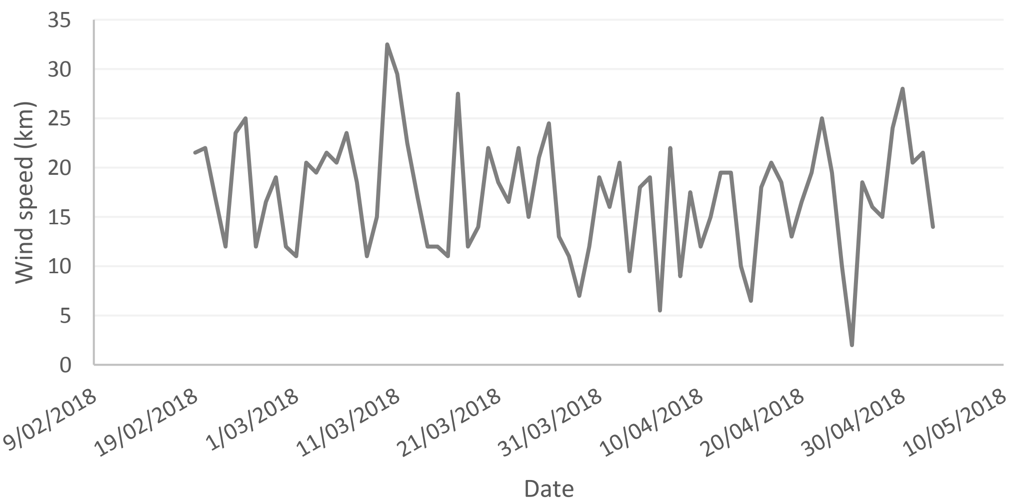

Figure 9. The mean daily wind speed (km/hr) during the Lifetime Maternals animal house experiment conducted at Katanning, Western Australia.

Table 14. The measured feed intake (g/day) during pen acclimation (maintenance requirement for confinement derived from individual liveweights where a 50kg dry ewe requires 6.7MJ of ME per day), restricted feeding, ad libitum adaptation, ad libitum feeding total, ad libitum 14, ad libitum intake in final 5 days of measurement, maximum intake, and ad libitum 14, ad libitum 5, and maximum intake as percentages of fasting liveweights collected during the ad libitum feeding period (±standard error). Intake for the restricted feeding period was based on individual ewe fasting liveweights collected post acclimation.

	Feeding treatment							Condition score treatment		
Feeding treatment	40	60	80	100	140	180	*P*-value	HIGH	LOW	*P*-value
Parameter										
pen acclimation intake (maintenance)	485 *(7)*	475 *(8)*	483 *(9)*	492 *(9)*	479 *(9)*	483 *(9)*	P=0.82	*507* (5)	459 *(5)*	P<0.001
restricted intake 42 days (g/day; back transformed)	262	390	523	665	912	1176		608	554	
log 10 transformed	*-581 (7)*	*-409 (7)*	*-282 (8)*	*-177 (8)*	*-40 (8)*	*70 (8)*	*P<0.001*	*-216 (5)*	*-257 (4)*	*P<0.001*
post restriction adaptation intake	685 *(18)*	691 *(19)*	726 *(20)*	822 *(20)*	966 *(20)*	1181 *(20)*	P<0.001	886 *(13)*	805 *(13)*	P<0.001
post restriction *ad libitum* intake 21 days (inc adaptation)	1575 *(41)*	1539 *(45)*	1670 *(48)*	1666 *(48)*	1810 *(48)*	2004 *(48)*	P<0.001	1783 *(27)*	1639 *(26)*	P<0.001
post restriction *ad libitum* intake (post adaptation)	1868 *(53)*	1822 *(57)*	1979 *(62)*	1947 *(62)*	2086 *(62)*	2277 *(62)*	P<0.001	2079 *(35)*	1914 *(34)*	P<0.001
post restriction *ad libitum* intake 14 days (post adaptation)	1826 *(52)*	1794 *(57)*	1935 *(61)*	1910 *(61)*	2050 *(61)*	2240 *(61)*	P<0.001	2039 *(35)*	1880 *(33)*	P<0.01
Ad libitum intake 5 days (immediately prior to final fasting liveweight)	2316 *(80)*	2238 *(87)*	2391 *(93)*	2406 *(93)*	2518 *(93)*	2696 *(93)*	P<0.01	2508 *(54)*	2348 *(52)*	P<0.05
Maximum *ad libitum* intake	2836 *(98)*	2852 *(103)*	3005 *(108)*	2904 *(108)*	3179 *(108)*	3220 *(108)*	P<0.01	3092 *(78)*	2906 *(77)*	P<0.01
Ad libitum intake 14 as a percentage of fasting liveweight at the start of *ad libitum* feeding								3.4 *(0.06)*	3.5 *(0.05)*	P=0.09
Ad libitum intake 5 as a percentage of fasting liveweight at the start of *ad libitum* feeding							NS			NS
Ad libitum intake 5 as a percentage of fasting liveweight at the completion of *ad libitum* feeding								4.2 *-0.11*	4.4 *-0.11*	P<0.05
Maximum *ad libitum* intake as a percentage of fasting liveweight at the start of *ad libitum* feeding								5.1 *(0.14)*	5.5 *(0.13)*	P<0.01

Table 15. Liveweight and condition score including metabolic iveweight of maternal type ewes at allocation, during restricted feeding, and during ad libitum feeding*, and liveweight and condition score change during these periods.*

	Feeding treatment							Condition score treatment		
Feeding treatment	40	60	80	100	140	180	*P*-value	HIGH	LOW	*P*-value
Parameter										
allocation liveweight (kg)	-	-	-	-	-	-	NS	70.8 *(0.7)*	62.4 *(0.66)*	P<0.001
allocation condition score (subjective score 1-5)	-	-	-	-	-	-	NS	3.32 *(0.02)*	2.55 *(0.02)*	P<0.001
restricted feeding										
fasting liveweight at start of restricted feeding (kg)	-	-	-	-	-	-	NS	61.6 *(0.68)*	54.5 *(0.65)*	P<0.001
metabolic liveweight at start of restricted feeding (fasting liveweight ^0.75; kg)	-	-	-	-	-	-	NS	21.96 *(0.18)*	20.04 *(0.18)*	P<0.001
condition score at start of restricted feeding (1-5)	-	-	-	-	-	-	NS	3.14 *(0.04)*	2.62 *(0.04)*	P<0.001
liveweight change during restricted feeding (from fasting liveweights; g/day)	-153 *(9)*	-99 *(9)*	-64 *(10)*	-16 *(10)*	67 *(10)*	116 *(10)*	P<0.001	-	-	NS
daily liveweight change during restricted feeding (from linear relationship; g/day)	-182 *(10)*	-135 *(11)*	-86 *(11)*	-71 *(11)*	-13 *(11)*	60 *(11)*	P<0.001	-	-	NS
Condition score change during restricted feeding period (1-5)	-0.32 *(0.05)*	-0.21 *(0.05)*	-0.08 *(0.06)*	0.12 *(0.06)*	0.17 *(0.06)*	0.39 *(0.06)*	P<0.001	-	-	NS
Feeding treatment x Condition score treatment HIGH	-0.39 *(0.07)*	-0.24 *(0.08)*	-0.11 *(0.08)*	0.22 *(0.08)*	0.27 *(0.08)*	0.28 *(0.08)*	P<0.05			
Feeding treatment x Condition score treatment LOW	-0.24 *(0.07)*	-0.17 *(0.07)*	-0.05 *(0.08)*	0.02 *(0.08)*	0.07 *(0.08)*	0.49 *(0.08)*				
ad libitum feeding										
fasting liveweight at start of ad libitum feeding	49.84 *(1.43)*	53.5 *(1.62)*	55.7 *(1.75)*	57.87 *(1.75)*	60.4 *(1.75)*	62.6 *(1.75)*	P<0.001	60.09 *(0.98)*	53.21 *(0.94)*	P<0.001
condition score at start of ad libitum feeding	2.43 *(0.07)*	2.77 *(0.08)*	2.84 *(0.08)*	2.94 *(0.08)*	3.08 *(0.08)*	3.31 *(0.08)*	P<0.001	3.15 *(0.05)*	2.65 *(0.05)*	P<0.001
liveweight change during ad libitum feeding (from fasting liveweights)	469 *(29)*	442 *(31)*	400 *(32)*	440 *(32)*	368 *(33)*	349 *(32)*	P<0.01	385 *(24)*	437 *(23)*	P<0.05
daily liveweight change during ad libitum feeding (from linear relationship)	680 *(43)*	587 *(46)*	546 *(50)*	650 *(50)*	508 *(50)*	455 *(50)*	P<0.01	512 *(29)*	631 *(27)*	P<0.01
Condition score change during ad libitum feeding	0.42 *(0.05)*	0.21 *(0.06)*	0.24 *(0.06)*	0.25 *(0.06)*	0.25 *(0.06)*	0.26 *(0.06)*	P=0.07	-	-	NS
fasting liveweight at end of ad libitum feeding	62.33 *(1.11)*	62.73 *(1.21)*	64.05 *(1.3)*	66.94 *(1.3)*	67.9 *(1.3)*	70 *(1.3)*	P<0.001	68.72 *(0.74)*	62.59 *(0.71)*	P<0.001
condition score at end of ad libitum feeding	2.84 *(0.06)*	2.98 *(0.07)*	3.1 *(0.07)*	3.19 *(0.07)*	3.34 *(0.07)*	3.57 *(0.07)*	P<0.001	3.39 *(0.04)*	2.95 *(0.04)*	P<0.001

Table 16. Liveweight and C site fat and muscle depth for maternal type ewes collected before restricted feeding, at the completion of restricted feeding and at the completion of ad libitum feeding, as well as the changes in liveweight and tissue depth at scanning during the restricted and ad libitum periods.

	Feeding treatment (%)							Condition score treatment		
Feeding treatment	40	60	80	100	140	180	*P*-value	HIGH	LOW	*P*-value
Parameter										
Post pen acclimation										
Starting liveweight at scanning (non fasting)	-	-	-	-	-	-	NS	63.3 *(0.7)*	56.2 *(0.66)*	P<0.001
Starting metabolic liveweight (from scan wt)	-	-	-	-	-	-	NS	22.4 *(0.19)*	20.5 *(0.18)*	P<0.001
Starting C site muscle depth	-	-	-	-	-	-	NS	28.4 *(0.35)*	25.4 *(0.34)*	P<0.001
Starting C site fat depth	-	-	-	-	-	-	NS	3.9 *(0.13)*	2.7 *(0.12)*	P<0.001
Post restricted feeding										
Mid liveweight at scanning (non fasting)	52.4 *(1.07)*	53.6 *(1.16)*	56.1 *(1.25)*	57.9 *(1.25)*	60 *(1.25)*	63.1 *(1.25)*	P<0.001	60.8 *(0.71)*	53.6 *(0.68)*	P<0.001
Mid metabolic liveweight (from scan wt)	19.4 *(0.29)*	19.8 *(0.32)*	20.5 *(0.34)*	21 *(0.34)*	21.5 *(0.34)*	22.4 *(0.34)*	P<0.001	*21.7* *(0.19)*	19.8 *(0.19)*	P<0.001
Mid C site muscle depth	24.9 *(0.55)*	25.7 *(0.59)*	25.4 *(0.64)*	26 *(0.64)*	26 *(0.64)*	27.8 (0.64)	P<0.05	27.3 *(0.36)*	24.6 *(0.35)*	P<0.001
Mid C site fat depth	2.4 *(0.15)*	2.8 *(0.17)*	2.7 *(0.18)*	3 *(0.18)*	*3.1* *(0.18)*	3.5 *(0.18)*	P<0.01	3.4 *(0.1)*	2.4 *(0.1)*	P<0.001
Scanning liveweight change during restricted feeding	-7.38 *(0.44)*	-5.21 *(0.47)*	-3.75 *(0.51)*	*-2.25* *(0.51)*	-0.67 *(0.51)*	3.42 *(0.51)*	P<0.001	-	-	NS
C site muscle change during restricted feeding	-2.04 *(0.51)*	-0.66 *(0.55)*	*-1.55* *(0.59)*	-1.37 *(0.59)*	-0.92 *(0.59)*	1.18 *(0.59)*	P<0.01	-	-	NS
C site fat change during restricted feeding	-0.7 *(0.13)*	-0.73 *(0.14)*	-0.58 *(0.16)*	-0.52 *(0.16)*	0.13 *(0.16)*	0.3 *(0.16)*	P<0.001	-0.48 *(0.09)*	-0.22 *(0.09)*	P<0.05
Post ad libitum feeding										
End liveweight at scanning (non fasting)	63.1 *(1.17)*	62.7 *(1.27)*	64.4 *(1.36)*	67.5 *(1.36)*	68.7 *(1.36)*	71.3 *(1.36)*	P<0.001	69.2 *(0.83)*	63.3 *(0.8)*	P<0.001
End metabolic liveweight (from scan wt)	22.4 *(0.31)*	22.2 *(0.33)*	22.7 *(0.36)*	23.5 *(0.36)*	23.8 *(0.36)*	24.5 *(0.36)*	P<0.001	24 *(0.22)*	22.4 *(0.21)*	P<0.001
End C site muscle depth	25 *(0.44)*	25.1 *(0.48)*	26 *(0.52)*	27.1 *(0.52)*	27.1 *(0.52)*	28.1 *(0.52)*	P<0.001	27.8 *(0.29)*	24.9 *(0.28)*	P<0.001
End C site fat depth	3 *(0.17)*	3.3 *(0.19)*	3.3 *(0.2)*	3.4 *(0.2)*	3.6 *(0.2)*	4.6 *(0.2)*	P<0.001	4.1 *(0.11)*	3 *(0.11)*	P<0.001
Scanning liveweight change during ad libitum feeding	10.7 *(0.58)*	9.1 *(0.62)*	8.3 *(0.66)*	9.6 *(0.66)*	8.6 *(0.66)*	8.2 *(0.66)*	P<0.01	8.4 *(0.44)*	9.7 *(0.43)*	P<0.01
C site muscle change during ad libitum feeding	-	-	-	-	-	-	NS	-	-	NS
C site fat change during ad libitum feeding	0.6 *(0.12)*	0.5 *(0.13)*	0.6 *(0.14)*	0.5 *(0.14)*	0.5 *(0.14)*	1.1 *(0.14)*	P<0.01			NS

Table 17. Body composition (total mass, lean mass, fat mass, bone mineral content and body fat percentage) measured using DXA imaging for maternal type ewes collected before restricted feeding, at the completion of restricted feeding and at the completion of ad libitum feeding, as well as the changes over the restricted and ad libitum periods.

	Feeding treatment							Condition score treatment		
Feeding treatment	40	60	80	100	140	180	*P*-value	HIGH	LOW	*P*-value
Parameter										
DXA scan at start (post pen acclimation)										
fasting liveweight (kg)	-	-	-	-	-	-	NS	61.6 *(0.68)*	54.5 *(0.65)*	P<0.001
fasting metabolic liveweight (kg)	-	-	-	-	-	-	NS	22.0 *(0.18)*	20.0 *(0.18)*	P<0.001
total tissue mass (kg)	-	-	-	-	-	-	NS	56.7 *(0.65)*	49.7 *(0.62)*	P<0.001
lean tissue mass (kg)	-	-	-	-	-	-	NS	43.8 *(0.43)*	40.2 *(0.41)*	P<0.001
fat tissue mass (kg)	-	-	-	-	-	-	NS	11.6 *(0.29)*	8.3 *(0.28)*	P<0.001
bone mineral content (kg)	-	-	-	-	-	-	NS	1.3 *(0.02)*	1.2 *(0.01)*	P<0.001
percentage fat	-	-	-	-	-	-	NS	20.3 *(0.37)*	16.6 *(0.35)*	P<0.001
DXA scan mid (post restricted feeding)										
fasting liveweight mid (kg)	49.8 *(1.43)*	53.5 *(1.62)*	55.7 *(1.75)*	57.9 *(1.75)*	60.4 *(1.75)*	62.6 *(1.75)*	P<0.001	60.1 *(0.98)*	53.2 *(0.94)*	P<0.001
fasting metabolic liveweight mid (kg)	19.5 *(0.30)*	19.8 *(0.32)*	20.4 *(0.35)*	21.0 *(0.35)*	21.6 *(0.35)*	22.2 *(0.35)*	P<0.001	21.7 *(0.20)*	19.8 *(0.19)*	P<0.001
total tissue mass mid (kg)	47.7 *(1.04)*	48.6 *(1.15)*	50.8 *(1.24)*	52.9 *(1.24)*	54.9 *(1.24)*	57.5 *(1.24)*	P<0.001	55.6 *(0.70)*	48.5 *(0.67)*	P<0.001
lean tissue mass mid (kg)	37.4 *(0.69)*	37.7 *(0.76)*	40.1 *(0.82)*	41.2 *(0.82)*	43.7 *(0.82)*	45.3 *(0.82)*	P<0.001	42.7 *(0.46)*	39.1 *(0.44)*	P<0.001
fat tissue mass mid (kg)	-	-	-	-	-	-	NS	11.5 *(0.30)*	8.2 *(0.29)*	P<0.001
bone mineral content mid (kg)	-	-	-	-	-	-	NS	1.3 *(0.02)*	1.2 *(0.02)*	P<0.001
percentage fat mid	-	-	-	-	-	-	NS	20.5 *(0.36)*	16.9 *(0.34)*	P<0.001
change in fasting liveweight during restricted feeding (kg)	-5.8 *(0.34)*	-3.8 *(0.36)*	-2.5 *(0.39)*	-0.6 *(0.39)*	2.6 *(0.39)*	4.5 *(0.39)*	P<0.001	-	-	NS
change in fasting liveweight during restricted feeding (g/day)	-152.7 (8.81)	-99.2 (9.38)	-64.4 (9.97)	-16.5 (9.97)	66.5 (9.99)	116.1 (9.97)	P<0.001	-	-	NS
change in total tissue mass during restricted feeding (kg)	-5.9 *(0.25)*	-4.2 *(0.27)*	-2.5 *(0.29)*	-0.9 *(0.29)*	2.0 *(0.29)*	4.3 *(0.29)*	P<0.001	-	-	NS
change in total tissue mass (g/day)	-155.8 *(6.39)*	-108.9 *(6.94)*	-65.4 *(7.49)*	-22.2 *(7.49)*	50.7 *(7.49)*	111.9 *(7.49)*	P<0.001	-	-	NS
change in lean mass during restricted feeding (kg)	-6.7 *(0.65)*	-3.4 *(0.74)*	-2.2 *(0.8)*	-1.0 *(0.8)*	1.4 *(0.8)*	3.2 *(0.8)*	P<0.001	-	-	NS
change in lean mass during restricted feeding (g/day)	-129.6 *(5.97)*	-88.6 *(6.48)*	-57.6 *(7.00)*	-24.7 *(7.00)*	35.4 *(7.00)*	82.4 *(7.00)*	P<0.001	-	-	NS
change in fat mass during restricted feeding (kg)	-1.0 *(0.09)*	-0.8 *(0.10)*	-0.3 *(0.10)*	0.0 *(0.10)*	0.5 *(0.10)*	1.1 *(0.10)*	P<0.001	-	-	NS
change in fat mass during restricted feeding (g/day)	-27.0 *(2.33)*	-21.1 *(2.52)*	-8.1 *(2.72)*	1.1 *(2.72)*	14.0 *(2.72)*	28.7 *(2.72)*	P<0.001	-	-	NS
change in BMC during restricted feeding (kg)	-	-	-	-	-	-	NS	-	-	NS
change in percentage fat during restricted feeding	-	-	-	-	-	-	NS	-	-	NS
DXA scan end (post ad libitum feeding)										
fasting liveweight end (kg)	62.3 *(1.11)*	62.73 *(1.21)*	64.1 *(1.30)*	66.9 *(1.30)*	67.9 *(1.30)*	70 *(1.30)*	P<0.001	68.7 *(0.74)*	62.6 *(0.71)*	P<0.001
fasting metabolic liveweight end (kg)	22.2 *(0.29)*	22.3 *(0.32)*	22.6 *(0.34)*	23.4 *(0.34)*	23.6 *(0.34)*	24.2 *(0.34)*	P<0.001	23.8 *(0.19)*	22.2 *(0.19)*	P<0.001
total tissue mass end (kg)	56.7 *(1.05)*	57.1 *(1.15)*	58.5 *(1.24)*	61.3 *(1.24)*	62 *(1.24)*	64.2 *(1.24)*	P<0.001	63.0 *(0.7)*	56.9 *(0.67)*	P<0.001
lean tissue mass end (kg)	45.4 *(0.73)*	45.1 *(0.79)*	46.6 *(0.85)*	48.4 *(0.85)*	49.4 *(0.85)*	50.3 *(0.85)*	P<0.001	48.9 *(0.5)*	46.1 *(0.48)*	P<0.001
fat tissue mass end (kg)	10.1 *(0.45)*	10.8 *(0.48)*	10.6 *(0.52)*	11.7 *(0.52)*	11.4 *(0.52)*	12.6 *(0.52)*	P<0.01	12.8 *(0.3)*	9.6 *(0.28)*	P<0.001
bone mineral content end (kg)	-	-	-	-	-	-	NS	1.3 *(0.02)*	1.2 *(0.02)*	P<0.001
percentage fat end	-	-	-	-	-	-	NS	20.1 *(0.33)*	16.6 *(0.32)*	P<0.001
change in fasting liveweight during *ad libitum* feeding (kg)	9.8 *(0.6)*	9.3 *(0.63)*	8.3 *(0.67)*	9.1 *(0.67)*	7.6 *(0.67)*	7.3 *(0.67)*	P<0.01	8.1 *(0.47)*	9.1 *(0.46)*	P<0.05
change in fasting liveweight during *ad libitum* feeding (g/day)	469.1 *(29.28)*	441.6 *(30.87)*	400.2 *(32.48)*	440.1 *(32.48)*	367.7 *(32.52)*	349.1 *(32.48)*	P<0.01	385.2 *(23.64)*	437.4 *(23.27)*	P<0.01
change in total tissue mass during *ad libitum* feeding (kg)	9.2 *(0.54)*	8.6 *(0.57)*	7.6 *(0.61)*	8.5 *(0.61)*	7.1 *(0.61)*	6.6 *(0.61)*	P<0.01	7.4 *(0.42)*	8.4 *(0.41)*	P<0.05
change in total tissue mass during ad libitum feeding (g/day)	441.0 *(26.61)*	411.6 *(28.11)*	364.6 *(29.62)*	410.3 *(29.62)*	345.5 *(29.65)*	316.1 *(29.62)*	P<0.01	355.6 *(21.26)*	407.4 *(20.9)*	P<0.01
change in lean mass during *ad libitum* feeding (kg)	8.1 *(0.46)*	7.5 *(0.49)*	6.4 *(0.52)*	7.2 *(0.52)*	5.8 *(0.52)*	5.0 *(0.52)*	P<0.001	6.2 *(0.35)*	7.1 *(0.34)*	P<0.05
change in lean mass during *ad libitum* feeding (g/day)	386.1 *(22.62)*	357 *(23.98)*	309.2 *(25.34)*	347.5 *(25.34)*	278 *(25.37)*	238.4 *(25.34)*	P<0.001	295.9 *(17.73)*	342.8 *(17.4)*	P<0.01
change in fat mass during *ad libitum* feeding (kg)	1.1 *(0.12)*	1.1 *(0.13)*	1.2 *(0.14)*	1.3 *(0.14)*	1.4 *(0.14)*	1.6 *(0.14)*	P<0.05	-	-	NS
change in fat mass during ad libitum feeding (g/day)	54.66 *(6)*	54.79 *(6.3)*	55.89 *(6.7)*	61.65 *(6.7)*	67.33 *(6.7)*	76.12 *(6.7)*	P<0.05	-	-	NS
change in BMC during *ad libitum* feeding (kg)	-	-	-	-	-	-	NS	-	-	NS
change in percentage fat during *ad libitum* feeding	-0.92 *(0.17)*	-0.82 *(0.18)*	-0.34 *(0.19)*	-0.56 *(0.19)*	0.28 *(0.19)*	0.54 *(0.19)*	P<0.001	-0.45 *(0.12)*	-0.16 *(0.11)*	P<0.05

Table 18. The coefficients (±SE) and R2 for the relationships between changes in body energy and intake during restricted feeding. Energy change measures in grams per day include: 1) liveweight change derived from three times weekly weights, 2) liveweight change between fasting liveweights collected at DXA scanning, and changes in 3) total tissue, 4) lean tissue and 5) fat tissue as measured by DXA.

Model	Energy change parameter	Constant	Intake (g/day)	Intake squared (g/day)	Liveweight ^0.75 (kg)*	R2 (%)
1	Liveweight change (g/day)	-93.56 ±56.66	0.381 ±0.069 ***	-0.00009 ±0.00005 *	-8.55 ±2.47 ***	66.8%
2	Fasting liveweight change (g/day)	-77.15 ±43.43	0.437 ±0.053 ***	-0.0001 ±0.00004 **	-8.75 ±1.89 ***	83.6%
3	DXA total tissue change (g/day)	-118.23 ±35.86	0.420 ±0.044 ***	-0.00009 ±0.00003 **	-6.76 ±1.57 ***	87.4%
4	DXA lean tissue change (g/day)	-123.00 ±33.52	0.340 ±0.041 ***	-0.00008 ±0.00003 **	-4.30 ±1.46 **	83.4%
5	DXA fat tissue change (g/day)	11.82 ±11.95	0.062 ±0.003 ***		-2.59 ±0.58 *	68.5%

* Liveweight for model 1 was derived from the intercept of a model that described the linear relationship between time and liveweights collected throughout the restricted period and metabolic liveweight was derived from the intercept for this relationship. Liveweight for models 2, 3, 4 and 5 was derived from the fasting liveweight collected immediately prior to DXA scanning and metabolic liveweight was derived from fasting liveweight.

* P<0.05

**P<0.01

***P<0.001

Table 19. The coefficients (±SE) and R2 for the relationships between changes in body energy and intake during ad libitum feeding. Energy change measures in grams per day include: 1) liveweight change derived from three times weekly weights, 2) liveweight change between fasting liveweights collected at DXA scanning, and changes in 3) total tissue, and 4) lean tissue as measured by DXA.

Model	Energy change parameter	Constant	Intake (g/day)	Intake squared (g/day)	Fasting liveweight ^0.75 (kg)	Previous intake (g/day)	R2 (%)
1	Liveweight change (g/day)	1113.34 ±211.61	0.131 ±0.069 *		-33.65 ±12.16 ***	-0.158 ±0.078 *	12.1%
2	Fasting liveweight change (g/day)	256.40 ±237.00	0.622 ±0.219 **	-0.00011 ±0.00005 *	-26.53 ±6.04 ***	-0.112 ±0.039 **	26.2%
3	DXA total tissue change (g/day)	710.70 ±100.67	0.130 ±0.032 ***		-25.08 ±5.73 ***	-0.104 ±0.037 ***	24.2%
4	DXA lean tissue change (g/day)	633.34 ±88.19	0.111 ±0.028 ***		-21.58 ±5.03 ***	-0.132 ±0.032 ***	30.5%
5	DXA fat tissue change (g/day)	-49.43 ±50.59	0.148 ±0.047 **	-0.00003 ±0.00001 **	-3.44 ±1.29 **	0.027 ±0.008 **	14.6%

* Liveweight for model 1 was derived from the intercept of a model that described the linear relationship between time and liveweights collected throughout the *ad libitum* period. Liveweight for models 2, 3, 4 and 5 was derived from the fasting liveweight collected immediately prior to DXA scanning at the start of the *ad libitum* period and metabolic liveweight for all models was derived from this fasting liveweight.

* P<0.05

**P<0.01

***P<0.001

Table 20. Estimates of feed energy (± lower and upper confidence limits at 95%) required for maintenance of liveweight, fasting liveweight (including within condition score treatment groups), and total tissue, lean tissue and fat tissue as measured by DXA – also expressed as whole body energy - for maternal composite ewes. Estimates are expressed in grams/day (as fed) and as megajoules of metabolisable energy per kilogram of metabolic liveweight (liveweight$^{0.75}$) and are derived from the models for predicting liveweight and tissue change measures during the restricted feeding period.

Model	Metabolic LW	predicted maintenance actual feed intake (g/day, as fed)	lower 95% CL	upper 95% CL	predicted maintenance ME requirement (MJ/day/kg BW^0.75)	lower 95% CL	upper 95% CL
Daily LWC (g/day)	20.97	913.1	851.5	989.2	0.422	0.394	0.458
Fasting LWC (g/day)	20.97	712.6	665.9	747.6	0.330	0.308	0.346
high CS treatment	*21.97*	*774.2*	*720.4*	*830.6*	*0.342*	*0.318*	*0.367*
low CS treatment	*20.07*	*711.4*	*687.0*	*736.2*	*0.344*	*0.332*	*0.356*
Total tissue (g/day)	20.97	734.7	705.6	760.8	0.340	0.326	0.352
Lean tissue (g/day)	20.97	764.5	730.4	798.9	0.354	0.338	0.370
Fat tissue (g/day)	20.97	685.4	652.9	733.0	0.317	0.302	0.339
Whole body energy (kJ/day)	20.97	698.0	673.3	739.1	0.323	0.311	0.342

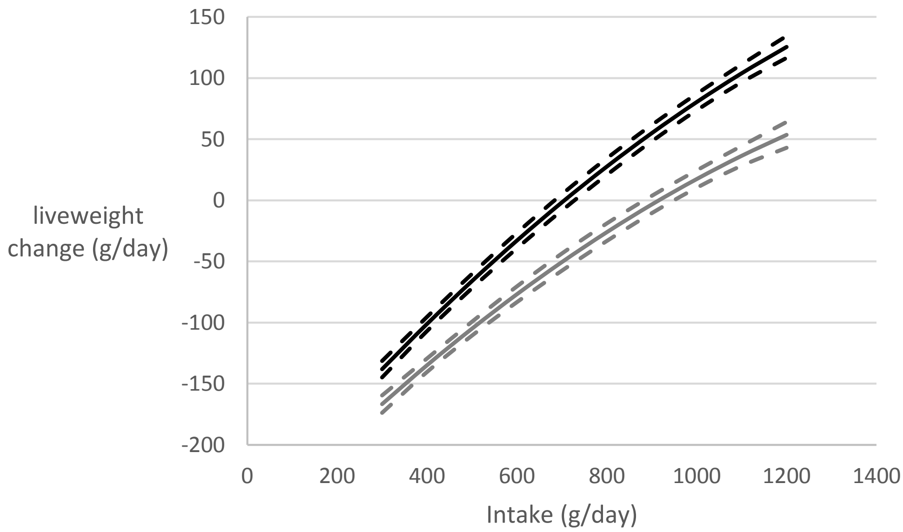

Figure 10. Relationship between daily feed intake (g/head/day) and daily liveweight change measured using weekly weights (grey line), and daily liveweight change measured using fasting liveweights (black line) at the start and finish of a restricted feeding period for adult maternal composite ewes managed in individual pens. The dashed lines represent the standard error.

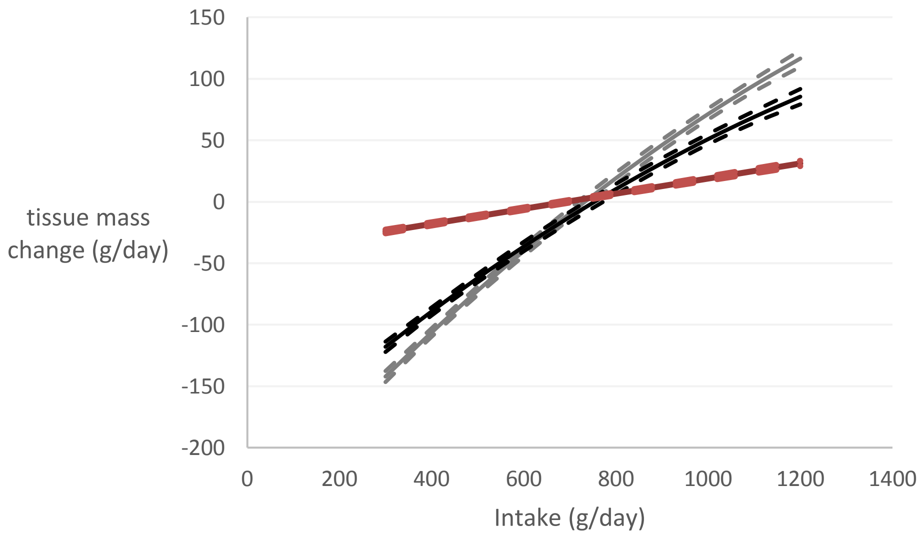

Figure 11. Relationship between daily feed intake (g/head/day) and daily tissue change measured using DXA, for total tissue change (grey line), lean tissue change (black line) and fat tissue (red line) during a restricted feeding period for adult maternal composite ewes managed in individual pens. The dashed lines represent the standard error.

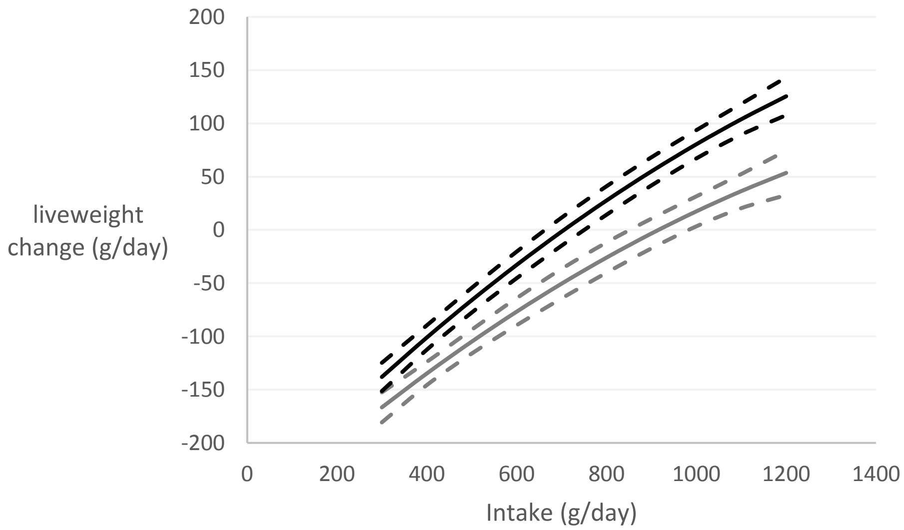

Figure 12. Relationship between daily feed intake (g/head/day) and daily liveweight change measured using weekly weights (grey line), and daily liveweight change measured using fasting liveweights (black line) at the start and finish of a restricted feeding period for adult maternal composite ewes managed in individual pens. The dashed lines represent the confidence limits.

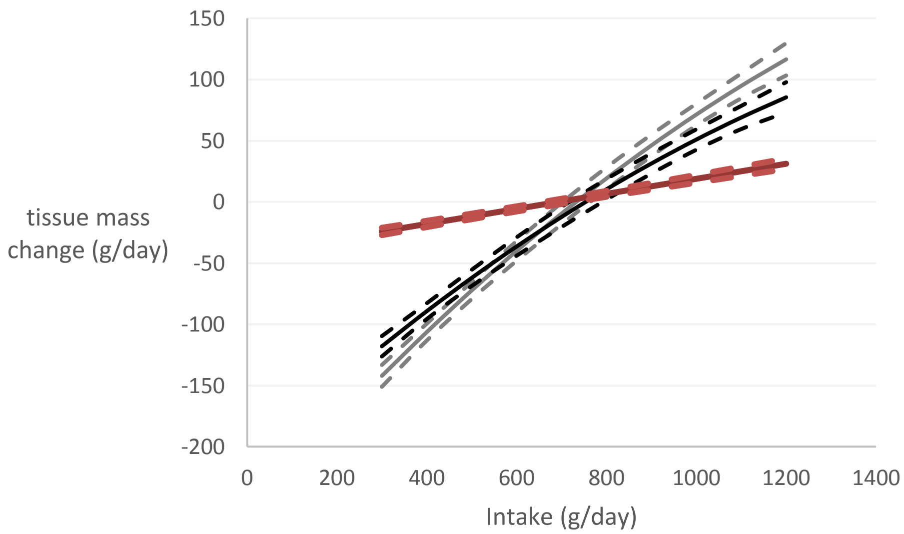

Figure 13. Relationship between daily feed intake (g/head/day) and daily tissue change measured using DXA, for total tissue change (grey line), lean tissue change (black line) and fat tissue (red line) during a restricted feeding period for adult maternal composite ewes managed in individual pens. The dashed lines represent the confidence limits.

9.2.9 Katanning data

Katanning LTM2 data.xlsx

9.3 Struan experiment (draft paper)

9.3.1 Pasture intake of crossbred ewes in late pregnancy.

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9.3.2 Introduction

A significant proportion of total Australian lamb supply are produced from non-Merino or Merino-cross ewes, such as Border Leicester x Merino (BLM). Management guidelines for Australian sheep production systems have been based on 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). However, Merino and non-Merino ewes generally perform differently when managed together (Holst *et al.* 2002; Blumer *et al.* 2016; Hocking Edwards *et al.* 2018) and the economic value of improving the number of lambs weaned is much greater for crossbred than Merino ewes (Young *et al.* 2014). This suggests that management guidelines developed for Merinos may not be directly transferrable to other breeds of sheep.

Recently, the production responses relating changes in liveweight and condition score of maternal ewes during pregnancy and feed-on-offer during lambing and lactation to lamb birth weights, weaning weights and survival, and carry-over ewe reproduction where calculated using a range of ewe genotypes in multiple environments (Behrendt et al; Thompson et al). Condition score targets at lambing of 2.7 for single ewes and 3.3 for multiple-bearing maternal ewes are likely to achieve near-maximum lamb survival and weaning rates. However, poor nutrition during early and or late pregnancy reduces lamb weaning weight, and these adverse impacts cannot necessarily be overcome by improving feed-on-offer from the point of lambing until weaning. In addition, ewes maintained or lost less weight on much lower feed-on-offer levels than those estimated using current Feeding Standards, contradicting the current recommendations for FOO levels during pregnancy to achieve target condition score at lambing. Defining more accurate feed on offer targets to meet these condition score targets especially during late pregnancy and at lambing are also prerequisites for precise management of ewe nutrition to optimise stocking rates and feed utilisation

Pasture intake of grazing animals is predicted by models utilising estimates of potential intake and relative intake (Freer *et al.* 2007). Potential intake is determined by body size and physiological state whereas, relative intake is influenced by the quality and structure (height and density) of the pasture, and the ability of the animal to harvest the pasture (time spent grazing, bite size and bite rate (Allden and Whittaker 1970)). If the coefficients for these parameters do not reflect the modern Australian ewe and her production system, then current industry recommendations may not be correct.

This paper tested the hypothesis that intake of pasture by crossbred ewes in late pregnancy is greater than that predicted by models used for feeding guidelines by Australian lamb producers. A grazing experiment was undertaken to quantify feed intake associated with the quantity of feed on offer in order to develop revised feed-on-offer targets for maternal ewes in late pregnancy to achieve condition score targets at lambing. Pasture intake is acknowledged to be inherently difficult to measure and new techniques are consistently being developed (Dove 2010; Cottle 2013; Robinson *et al.* 2016; Greenwood *et al.* 2017). Intake was estimated using pasture disappearance and gas accumulation and sensor technology was used to estimate time spent grazing.

9.3.3 Methodology

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 # 03/17).

9.3.3.1 Experimental design

The trial was conducted at the Struan Research Centre, near Naracoorte in the south east of South Australia (37.1S/140.48E). Rainfall, wind speed and temperature were obtained from recorded observations taken at the NRM Robertson weather station located approximately 15 km from the trial site (http://aws.naturalresources.sa.gov.au/southeast/?aws_id=ROB001&view=download).

An incomplete block design consisting of six replicates of four nutritional treatments (400, 700, 1000 kg DM/ha, and *ad libitum*) was undertaken at Struan Research Centre over a 5-week period. Prior to experimental grazing, target FOO treatments were achieved through controlled grazing of non-experimental livestock. Within each of the FOO treatments, two adjacent sub-plots (acclimatisation and trial plots) were measured to achieve a grazing area of 0.15ha each, and enclosed using three portable electrical wires. Each plot was used once only throughout the study. Pasture comprised of mixed annual grasses (17%), subterranean clovers (4%), and *Phalaris aquatica* (79%).

9.3.3.2 Experimental sheep and management

Border Leicester x Merino (BLM; n =627) ewes aged 5-7 years were allocated to one of five groups (group 1 = 107 ewes, groups 2-5=130 ewes/group), stratified for live weight, condition score and age at the commencement of the trial. In order to ensure ewes began experimental measures at the same stage of pregnancy at each intake over the five-week experimental period, ewes underwent oestrus synchronisation at weekly intervals to allow for a staggered natural mating. Ewes allocated to group one were synchronized on day 1, ewes allocated to group two were synchronized on day 8, ewes allocated to group three were synchronized on day 15, and so on. Ewes within a group were synchronized using a controlled internal drug release device containing progesterone (0.3g, EAZI-Breed CIDR Sheep, Zoetis Inc), inserted intravaginally for 12 days. After CIDR removal, an intramuscular injection serum gonadotrophin (500IU/ewe; Pregnacol, Bioniche) to stimulate ovulation. Following oestrus synchronisation, ewes were introduced to Poll Dorset rams for a period of no less than five weeks for mating to occur. Ewes in groups 1, 2 and 3 were managed together in a single mating group, and ewes in groups 4 and 5 were managed together in a second mating group.

Ewes were pregnancy scanned between 42 and 58 days of pregnancy by a commercial operator using real-time abdominal ultrasound to determine the presence and number of fetuses conceived in the first cycle after synchronization, and those carrying twins were selected for trial measurements (n=236). Ewes not selected for the trial were returned to the commercial flock. After pregnancy scanning, ewes were managed as a single mob and were weighed and condition scored regularly throughout gestation.

At 129 days after rams were introduced, ewes were weighed, condition scored and allocated to one of four feeding treatments, stratified for liveweight, condition score and age. Ewes were placed onto a 0.15ha plot (acclimatisation sub-plot) of their allocated feeding treatment in groups of 9 to allow ewes to become accustomed to their treatment feeding level. Ewes then grazed the trial sub-plot during the treatment period when estimates of intake were recorded.

On entry to their treatment plots, ewes were fitted with a halter on which was mounted an ActiGraph motion detecting sensor, on the left side of the halter on the cheek strap, and a purpose built sheep motion detector (groups 1, 3 and 5 only), on the right side of the halter, on the jaw strap. Both sensors were wrapped in self-fusing silicone tape prior to attachment to the halter to aid in water resistance and protection of the sensors.

After three days grazing, ewes were removed from the acclimatisation plot, weighed, condition scored and allocated to one of three gas measurement replicates, balanced for treatment. Ewes were confined to a portable accumulation chamber (PAC) for 60 minutes for measurement of CH4 and CO2 excretion and O2 disappearance at 20, 40 and 60minutes (Robinson *et al.* 2016). Following their PAC measures, ewes were returned to the trial sub-plot with the same FOO treatment as the acclimatization sub-plot. Following three days grazing the trial sub-plot, ewes were removed from their plots, weighed, condition scored and had another PAC measure taken. On completion of the final experimental measure, ewes were returned to an extensive paddock and monitored throughout lambing. Lambing rounds were undertaken once daily to record date of birth and number of lambs born, as well as date of death where appropriate. Where a lamb was not recorded for a ewe (N=23), two lambs and average date of birth of the plot were assigned to that ewe. This process was repeated at weekly intervals for each group, with group one starting experimental measures on day 143, group two on day 150, group three on day 157 and so on, such that each cohort began experimental measures on day 129 from ram introduction.

9.3.3.3 Pasture management

Immediately prior to, and after, grazing FOO was assessed in the acclimatisation and trial sub-plots utilising a combination of previously published methods. For each sampling time, a visual estimate of FOO was undertaken by the same observer at 20 sites within a sub-plot (Lodge and Garden 2000; Ferguson *et al.*, 2011). Values for the visual estimates were regressed against 20 calibration quadrats that covered the range in feed on offer (Ferguson *et al.*, 2011). Calibration quadrats were harvested at ground level using an electric handpiece, rinsed to remove non-vegetative organic matter and oven dried at 60 C for 48 hours before weighing. Regression curve procedures to determine the relationship between actual and estimated values used a linear model (Cayley and Bird, 1996) as this was best fit for the data giving the highest R2 values (Lodge and Garden 2000). Additional visual FOO and rising plate measures were taken daily in each trial sub-plot.

To determine pasture growth rate over the study, three pasture cages were placed equidistant at representative sites along the length of each paddock at the commencement of the experimental period. Measures of pasture growth were made using harvesting of paired quadrats (Lodge and Garden 2000). Quadrats were harvested to ground level and oven-dried at 60oC for 48 hours. The cumulative difference was used to estimate pasture growth over time (kg DM/ha. day-1). Pasture height, pasture composition, percentage green and ground cover were also assessed within each sub-plot at each sampling time.

Pasture nutritive value was assessed for each trial sub-plot immediately prior to, and after, grazing. Thirty samples were collected within the trial sub-plot using the toe-cut method (Cayley and Bird, 1996). Samples taken immediately prior to grazing were sent to Livestock Logic, Hamilton, Victoria for analysis of dry matter (DM), moisture content, digestibility (DDM & DOMD), metabolisable energy (ME), crude protein (CP), fibres (NDF & ADF), water soluble carbohydrates (WSC) and ash by NIR spectroscopy. Samples collected from trial sub-plots after grazing were dried at 60 C for 48-hours and stored for later analysis by Livestock Logic.

Pasture DM intake (kg DM/head.day-1) for each sub-plot was subsequently calculated as the sum of pasture disappearance and pasture growth for the trial sub-plot divided by the number of animals grazing the trial sub-plot and the number of days in the grazing period (Hebart *et al.*, 2016). ME intake (MJ /kg DM.d-1) was calculated from the product of ME of pasture prior to grazing and pasture DM intake.

9.3.3.4 Statistical Analysis

At each time point (into plot a, into plot b, out plot b) ewe data were analysed using plot level means using mixed models (SAS version 9.3, SAS Institute, Cary, NS, USA) to test the effect of target FOO treatment on liveweight, CS, FOO in, FOO out, pasture height, pasture growth, pasture nutritive values, intake, grazing time, time spent idle, rumination time and time spent walking. Target FOO (400, 700, 1000, ad lib) was included in the model as a fixed effect and week (1- 5) and plot (1-12) nested within week (24 classes) were included as random effects. For the analysis of nutritive value, time (In, Out) were also included as a fixed effect. Sensor data was only analysed from weeks 1-4. Treatment means were compared using Welchs t-test (P=0.05).

PAC analysis

The relationship between intake and FOO was analysed using mixed models (SAS version 9.3, SAS Institute, Cary, NS, USA) with FOO included in the model and week and plot included as random effects. Feed intake was calculated in 4 ways: (i) pasture DM intake from pasture disappearance; (ii) intake predicted by Grazfeed (GrazfeedTM 2002) using actual pasture measurements and actual ewe liveweight; (iii) intake predicted by Grazfeed using actual pasture measurement and constant 66kg ewe liveweight; and (iv) pasture and ME intake predicted from lifetime wool feed budget tables for green pastures in south eastern Australia for a 60kg pregnant ewe grazing a high quality pasture (12MJ/kg DM; http://www.lifetimewool.com.au/tools/fbtgreeen.aspx accessed 29 May 2018). The relationship between each method of calculation and FOO were initially analysed in separate models to derive solutions for each method. The methods of intake prediction were then compared by including method and FOO in as fixed effects and week (1- 5) and plot (1-12) nested within week (24 classes) were included as random effects. Least square means at different FOO levels were then compared.

9.3.4 Results

9.3.4.1 Weather

Average air temperature over the entire experiment was 9.8°C, with an average minimum temperature of 5.6°C and an average maximum temperature of 14.3°C (Figure 14).

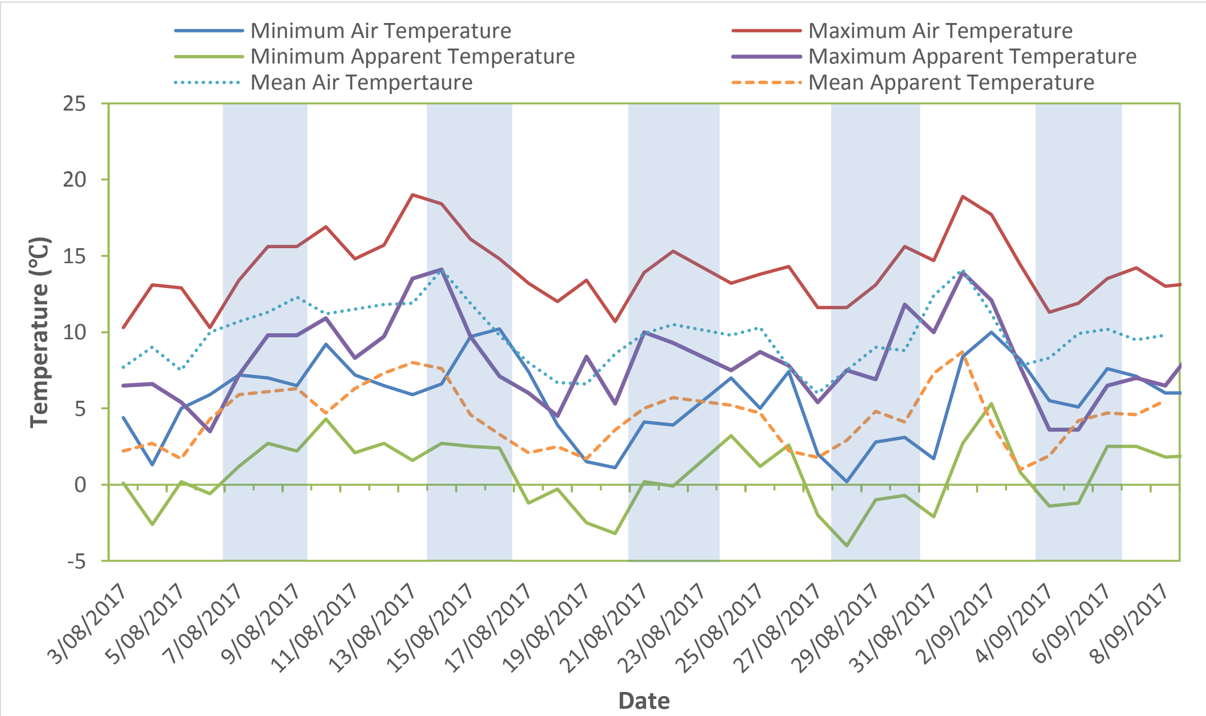

Figure 14. The mean, maximum, minimum air and apparent temperature during the study period. The five 3-day trial grazing periods are shaded.

Of the 34 days over the measurement period 157mm of rain was recorded with 22 days having daily rainfall greater than 0.5mm. A total of 70mm rain fell through the trial period (Figure 15).

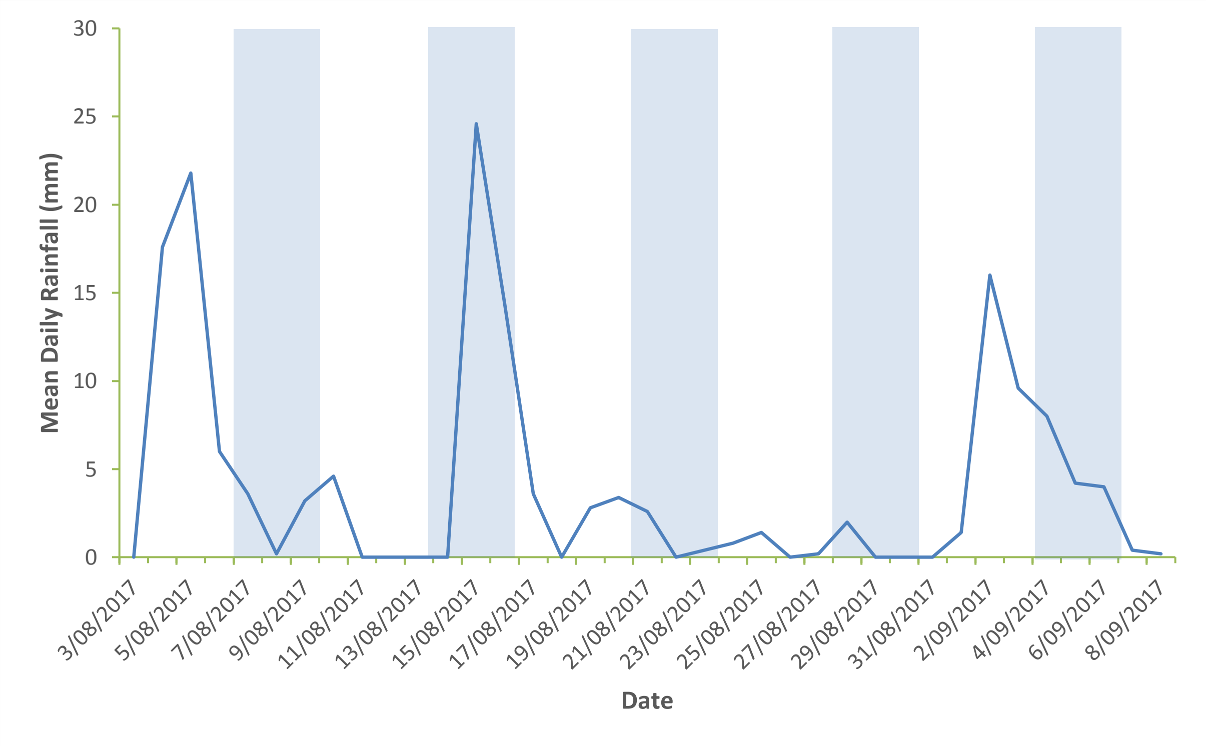

Figure 15. The mean daily rainfall during the study period. The five 3-day trial grazing periods are shaded.

Average wind speed of the period was 9.6km/h with average daily wind speed of 37.8km/h (Figure 16). Average chill index over the period was 1173.

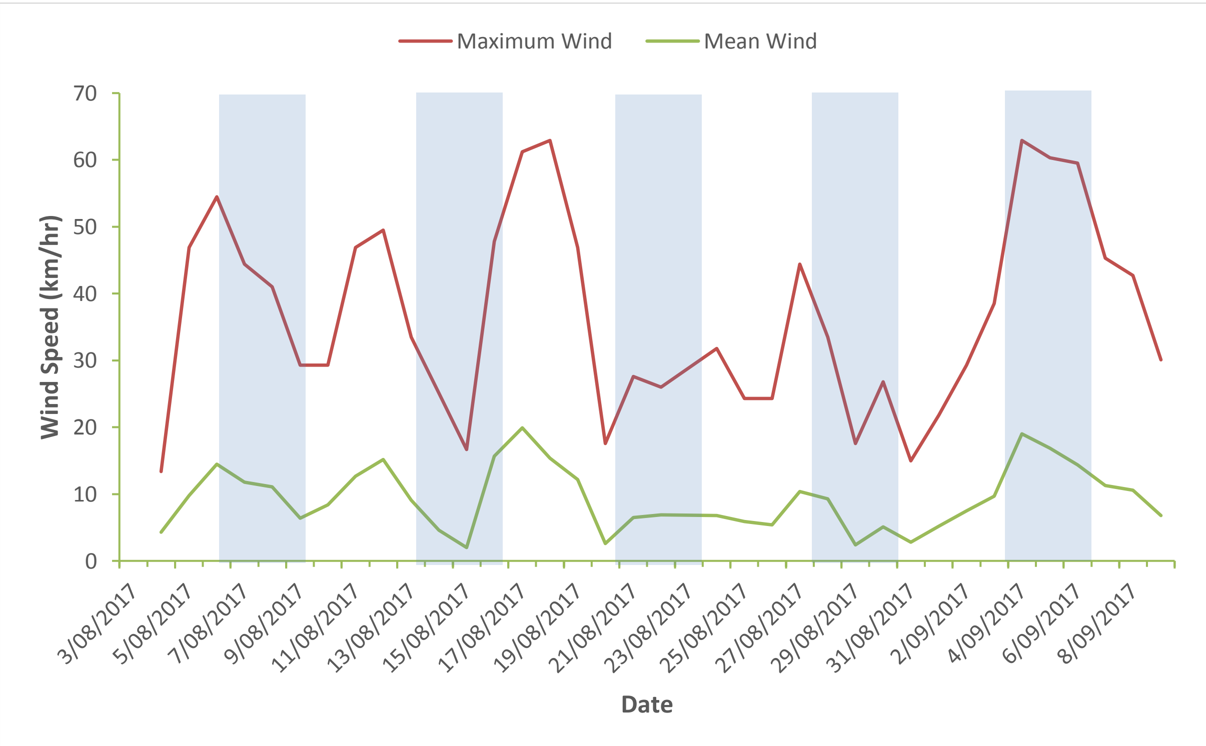

Figure 16. The maximum and mean daily wind speed (km/hr) during the study period. The five 3-day trial grazing periods are shaded.

9.3.4.2 Feed on offer

There was a significant difference between all treatment in the actual FOO on entry into and exit from both the acclimatisation and trial plots (Table 21). Actual FOO into the trial period ranged from 519 kg DM/ha in the 400 FOO target to 1325 kg DM/ha in the *ad lib* target treatment. A similar range occurred in the acclimatisation plots. Likewise, there was a significant effect of target FOO on pasture height at the start and end of the trial period. There was no difference in pasture height between the 400 and 700 FOO treatments, however these pastures were shorter than the pastures in the 1000 FOO treatment which was shorter than the pastures in the ad lib treatment (Table 21). There was a significant correlation between FOO and pasture height at the start of the trial (Figure 17; R=0.835; P<0.0001).

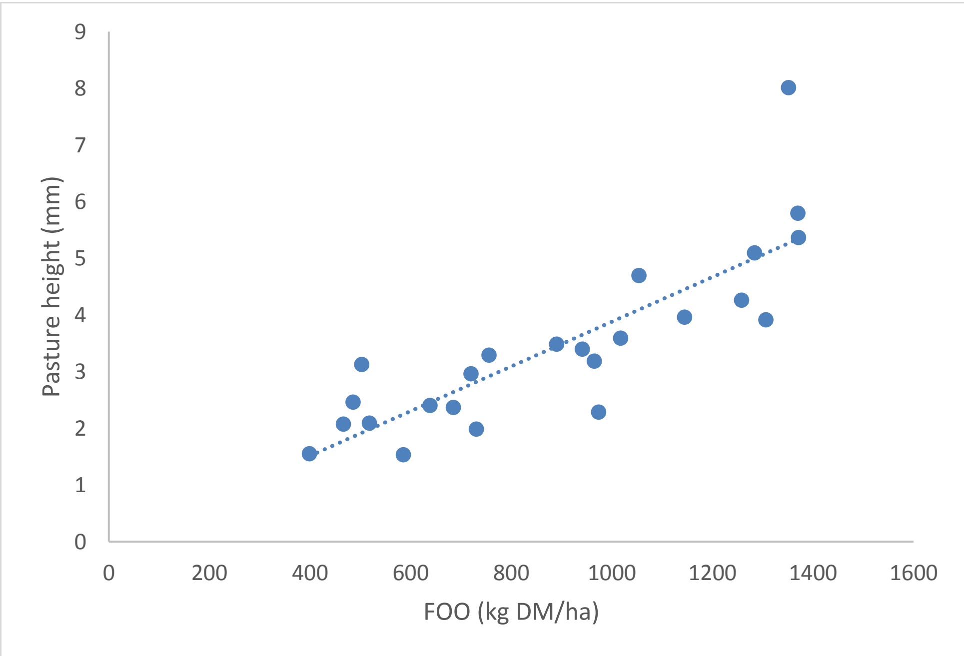

Figure 17. Relationship between feed on offer and pasture height at entry into the trial plots.

There was no difference in pasture growth rate between treatments which ranged from 8 to 11 kg DM/ha.d^{-1} across the 4 treatments. However, growth rate in week 5 (28 kg DM/ha.d^{-1}) was significantly greater than pasture growth in the first 4 weeks of the trial which ranged from 4 to 7 DM/ha.d^{-1} (P<0.0001).

Table 21. Target feed on offer (FOO; kg/DM.ha) and actual FOO at entry and exit into the acclimatisation and trial plots and pasture height (mm) of the trial plots. Least square means and the standard error of the mean (SE) and probability (Prob) are presented.

Target		400	700	1000	Ad lib	SE	Prob
Acclimatisation	In	525a	738b	1021c	1358d	61.3	<0.001
	Out	302a	451b	764c	1000d	51.5	<0.001
Trial	In	519a	722b	998c	1325d	38.5	<0.001
	Out	306a	446b	705c	983d	39.5	<0.001
Pasture height	Into trial	2.3a	2.6a	3.4b	5.5c	0.41	<0.001
	Out of trial	1.7a	1.5a	2.2b	3.0c	0.12	<0.001

9.3.4.3 Pasture composition and nutritive value

Phalaris was the dominant species, ranging from 73% of the pasture in the 1000 FOO treatment, 75% in the 400 treatment, 80% in the 700 treatment and 88% of the pasture in the 1500 FOO treatment (SEM = 3.9; P=0.06). Other grasses ranged from 24% in the 1000 FOO treatment, 20% in the 400 treatment, 15% in the 700 treatment and 10% in the 1500 FOO treatment (SEM = 3.5; P<0.05). There was only a small proportion of clover in the plots, ranging from 3% in the 1500 treatment to 5% in the 400 and 700 treatments (SEM = 1.20).

There was no difference in DDM, ME or NDF between treatments (Table 22). Crude protein was higher in the 400 and 700 FOO treatment than in the ad lib treatment (Table 22; P<0.05). There was 3.7% more green pasture (P<0.001) and 7.5% more bare ground in 400 FOO treatment (P<0.01) compared to the ad lib FOO treatment. There was also 6.6% more bare ground in the 400 FOO treatment compared to the 1000 FOO treatment (P<0.05). There was a significant decrease in DDM, ME and CP between entry onto the plots and removal of the sheep from the plots. There was a significant increase in NDF and the amount of bare ground in the plots at the end of the trial period (Table 22).

Table 22. Dry matter digestibility (DDM; %), metabolisible energy (ME; MJ/kg DM) crude protein (CP; %), neutral detergent fibre (NDF; %) and the proportion of green pasture (%) and bare ground (%) at 4 target feed on offer (FOO) treatments at entry and exit to the trial plots. Least square means and the standard error of the mean (SEM) and probability (Prob) are presented.

	DDM	ME	CP	NDF	Green	Bare (%)
400	73.4	11.0	23.4a	53.9	98.6a	10.5a
700	73.6	11.0	22.3a	54.0	97.2ab	5.5ab
1000	75.3	11.3	20.8ab	53.4	97.1ab	3.9b
Ad lib	71.2	10.7	18.8b	55.4	94.9b	3.0b
SEM	2.30	0.40	1.07	1.58	0.65	1.85
Prob	n.s.	n.s.	0.0137	n.s.	0.0011	0.0429
In	75.7a	11.4a	24.1a	51.8a	97.0	4.3a
Out	71.4b	10.7b	18.5b	56.5b	97.0	7.2b
SEM	2.10	0.37	0.75	1.36	0.50	1.14
Prob	<0.0001	<0.0001	<0.0001	<0.0001	0.8606	0.0349

Different letters within columns indicate significant differences (P<0.05) between treatments

9.3.4.4 Liveweight and condition score

Prior to mating, average ewe liveweight was 66kg with an average CS of 3.3. Target FOO did not have a significant effect on ewe liveweight or condition score at any time point (Table 23). There was a significant effect of week on both liveweight and condition score. Ewes were 4.3 to 5.4kg heavier and had a greater condition score in week 5 compared to average liveweight (P<0.05) and ewes in week 2 were 5.4 to 3.7kg lighter (P<0.05) than average liveweight at each of the time points (84kg). In addition ewes in week 5 were 0.5CS greater (P<0.05) than the average CS (3.8CS).

Table 23. Least square mean ewe liveweight and CS for four FOO target treatments at entry to acclimatisation (Acclim), entry into trial and exit from trial plots.

	Liveweight (kg)			Condition Score		
	Acclim	Entry	Exit	Acclim	Entry	Exit
400	84.8	83.7	83.0	3.8	3.8	3.8
700	85.0	83.6	83.4	3.8	3.8	3.7
1000	84.8	83.9	84.3	3.9	3.9	3.8
Ad lib	85.4	84.3	84.3	3.8	3.8	3.8

SEM	1.38	1.83	1.55	0.17	0.16	0.13
Prob	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

9.3.4.5 Gas accumulation

There was no effect of treatment on rate of CO_2 accumulation (Predicted mean = 513ml/min; SE = 21.9ml/min), nor was there any relationship between average FOO and CO_2 accumulation. When CP is included in the analysis, CP and CO_2 accumulation describe average FOO.

9.3.4.6 Predicted intake

There were significant linear relationships between FOO at entry onto the plots and feed intake estimated using pasture disappearance ($P<0.0001$; Table 24; Figure 18). The increase in feed intake as FOO increases was greater when intake was calculated from pasture disappearance than that predicted using Grazfed, particularly when actual ewe liveweight of the ewes were used to predict feed intake. The coefficients between FOO and intake during the acclimatisation period and the trial period are very similar.

Table 24. The coefficients (± S.E.) and significance levels (Prob) for the fitted linear relationships between feed on offer (FOO) and feed intake estimated from pasture disappearance during the trial period and during the acclimatisation period (Acclim), feed intake predicted from Grazfeed with actual liveweight and condition score of ewes on each plot (Grazfeed actual LWT), feed intake predicted from Grazfeed using 66kg ewe and metabolisable energy intake (ME). The coefficients for the relationship between pasture height and pasture disappearance are also presented.

Intake estimate	Constant	FOO coefficient	Prob
Pasture disappearance (Trial)	0.9116 ± 0.1488	0.0008 ± 0.00015	<0.0001
Pasture disappearance (Acclim)	0.7190 ± 0.3356	0.0009 ± 0.00031	0.0074
Grazfeed actual LWT	1.0865 ± 0.08924	0.0002 ± 0.00006	0.0019
Grazfeed 66kg ewe	1.1908 ± 0.07344	0.0004 ± 0.00006	<0.0001
ME Intake	10.2325 ± 1.8401	0.0090 ± 0.00180	<0.0001
Pasture height	1.1938 ± 0.1512	0.1188 ± 0.04014	0.0072

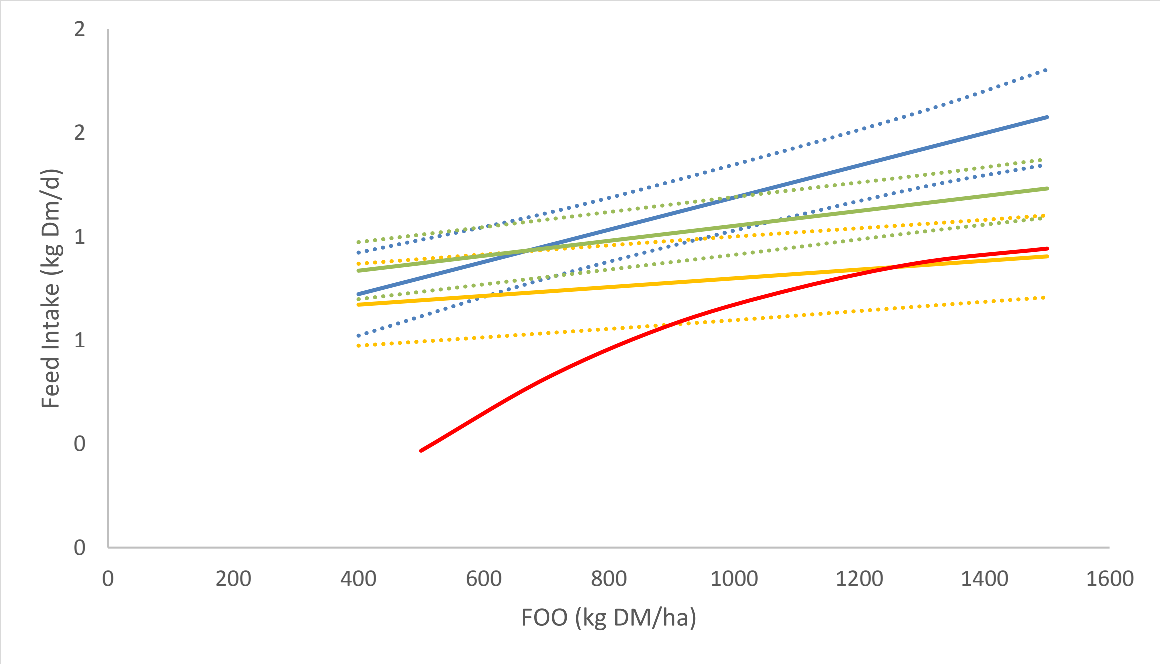

Figure 18. Fitted linear relationships (solid lines) between feed on offer (FOO) and feed intake (FI) estimated from pasture disappearance (blue line), FI predicted from Grazfeed with actual liveweight and condition score of ewes on each plot (yellow line), FI predicted from Grazfeed using 66kg ewe (green line) and FI predicted from lifetime wool feed budget for green pastures in eastern Australia (red line). The dotted lines indicate lower and upper 95% confidence limits.

When pasture intake estimated using pasture disappearance and the two Grazfeed predictions were compared, there was no difference in intake between the three methods of prediction at 400 kg DM/ha FOO (Table 25). At 700 kg DM/ha FOO, there was no difference in intake predicted using pasture disappearance or Grazfeed with a standard ewe weight, but predicted intake was significantly lower using actual ewe liveweight (P<0.01). From 1000 to 1500 kg DM/ha FOO, measured pasture intake was significantly greater than predicted intake estimated with constant ewe liveweight (P<0.01) which was greater than intake estimated using the actual 84kg ewe liveweight (Table 25; P<0.001).

Table 25. Predicted feed intake at five feed on offer (FOO) levels using four methods of prediction.

FOO	400	700	1000	1300	1500
Pasture disappearance	1.21	1.45a	1.68a	1.92a	2.08a
Grazfeed actual ewe	1.19	1.24b	1.30b	1.35b	1.39b
Grazfeed 66kg ewe	1.30	1.43a	1.56c	1.69c	1.78c
SEM	0.08	0.06	0.05	0.07	0.09
Lifetimewool 60kg ewe		0.82		1.38	1.44

Different letters within columns indicate significant differences (P<0.05) between treatments

Pasture intake (Table 25) and ME intake (Figure 19) calculated from lifetime ewe green feed budgets were lower than observed intake from 400 to 1500 kg DM/ha FOO.

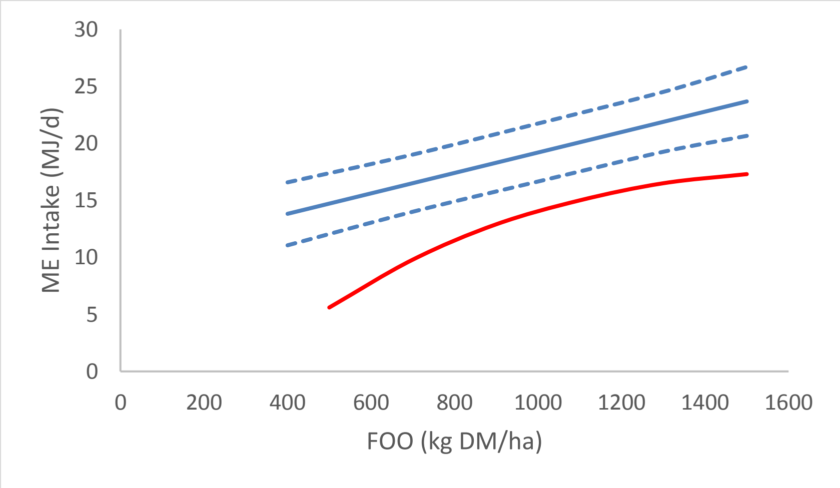

Figure 19. Fitted linear relationships (solid lines) between feed on offer and metabolisable energy (ME) intake estimated from pasture disappearance (blue line), and ME intake predicted from lifetime wool feed budget for green pastures in eastern Australia (red line). The dotted lines indicate the lower and upper 95% confidence limits.

9.3.4.7 Time spent grazing

In the plot means analysis, there was no effect of treatment on time spent grazing, idleness, time spent running or walking (Table 26). There was a significant difference between treatments in rumination time ($P<0.01$), with ewes in the lowest FOO spending less time ruminating than ewes in the higher FOO treatments.

Table 26. Time (minutes) crossbred ewes spent grazing, idle, ruminating, running and walking at 4 target feed on offer (FOO) treatments. Least square means and the standard error of the mean (SEM) and probability (Prob) are presented.

TMT	Grazing	Idle	Rumination	Running	Walking
400	430	625	291a	10	78
700	410	603	331ab	9	90
1000	399	600	352bc	10	79
1500	358	562	402c	10	107
SEM	26.5	44.1	26.8	0.7	9.5
Prob	0.124	0.382	0.003	0.707	0.104

Different letters within columns indicate significant differences ($P<0.05$) between treatments

There was a significant negative relationship between FOO and time spent grazing (R^2=0.49; $P<0.05$; Table 27) and a positive relationship between time spent ruminating and FOO (R^2=0.71; $P<0.0001$; Table 27; Figure 20). Although not significant, there was a positive trend between actual FOO and time spent walking ($P=0.07$) and a negative relationship with idleness ($P=0.08$). Similar relationships occurred with intake and the sensor measurements (Table 28). The prediction of pasture intake was further improved by including grazing time (r^2 = 0.42; $P<0.05$; Figure 21) and the maximum variance in intake explained by measurements of sheep behaviour using sensors was 49%.

Table 27. The coefficients (± S.E.) and significance levels (Prob) for the fitted linear relationships between feed on offer (FOO) and time spent either grazing, idle, ruminating or walking.

FOO	grazing	idle	rumination	walking

Constant	470	657	237	67
Coeffic	-0.08	-0.07	0.12	0.03
Prob	0.0118	0.0773	0.0001	0.0653

Table 28. The coefficients (± S.E.) and significance levels (Prob) for the fitted linear relationships between feed intake and time spent either grazing, idle, ruminating or walking.

Intake	grazing	idle	rumination	walking
Constant	505	689	191	49
Coeffic	-65.79	-56.59	94.75	24.84
Prob	0.028	0.1099	0.0028	0.0507

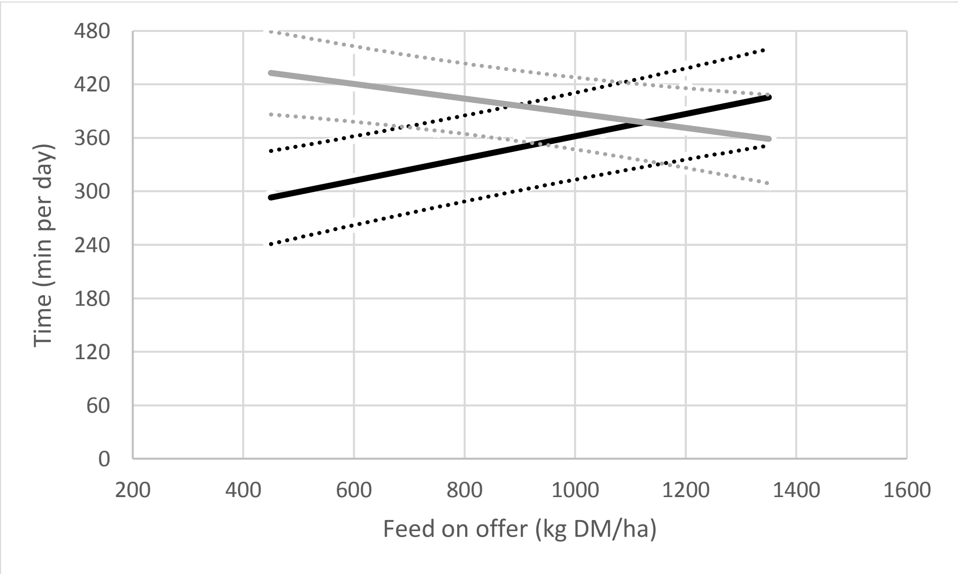

Figure 20. Fitted relationship between feed on offer and rumination (black) and grazing (grey) time for cross-bred ewes in late pregnancy estimated from pasture disappearance. The dotted lines indicate lower and upper 95% confidence limits.

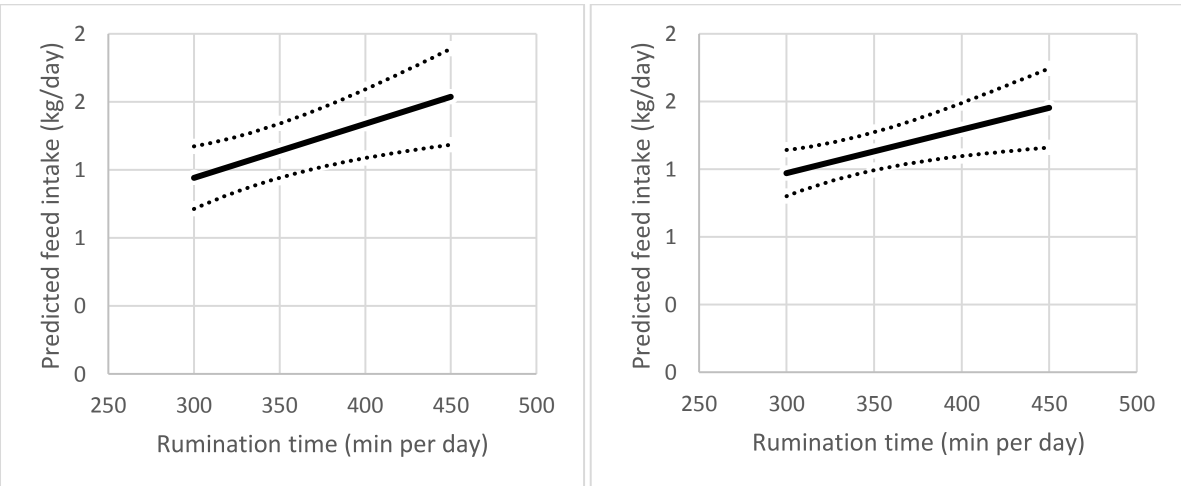

Figure 21. Fitted relationship between rumination time without (left) or with grazing time (right) in the model and feed intake for cross-bred ewes in late pregnancy estimated from pasture disappearance. The dotted lines indicate lower and upper 95% confidence limits.

9.3.5 Discussion

At 1000 kg DM/ha FOO and above, observed pasture intake was greater than that predicted using Grazfeed, with ewes consuming between 0.3 – 0.7kg DM more than predicted at 1500kg DM/ha FOO. However, at low levels of FOO (400-700kg DM/ha) feed intake as measured by pasture disappearance was similar to that predicted using Grazfeed, particularly if SRW was used rather than actual ewe liveweight, with predictions and actual intakes varying by only 20 – 90g DM. The main hypothesis, that intake of pasture by crossbred ewes in late pregnancy at low levels of FOO is greater than that predicted by Grazfeed was therefore not supported. Indeed, given the level of precision estimating FOO using pasture disappearance, pasture intake at low levels are remarkably consistent when using Grazfeed predictions.

Conversely, there was a large discrepancy between observed pasture intake and that predicted using the Lifetime ewe green feed budgets throughout the range of FOO levels measured in this trial. Indeed, at 700kg DM/ha FOO, the observed intake of ewes was 77% greater than that predicted using lifetime ewe feed budget. This supports the hypothesis that intake of pasture by crossbred ewes in late pregnancy is greater than that predicted by models used for feeding guidelines by Australian lamb producers. The greatest discrepancy occurred at low levels of FOO, and thus lifetime ewe predictions of intake at low FOO are significantly underestimating potential intake for crossbred ewes. If intake is higher than expected at low levels of FOO, this may explain the observation that maternal ewes are able to maintain weight at lower levels of FOO than predicted (Thompson 2016), and has implications for stocking rate management, economy of production and whole-farm profit.

The ewes in this experiment were approaching CS4, but there does not appear to be any depression in feed intake. Intakes of pasture were inversely related to fat depth in all seasons, but tended to be of smaller magnitude in winter (late pregnancy). When the upper range of body fat exceeded 20% a negative relationship between intake and body fat occurs in lactating ewes (Foot and Russel, 1979; Cowan *et al.*, 1980) and in dry sheep (Foot, 1972; Foot and Russel, 1978; Djajaneegara and Doyle, 1989 Fogarty *et al.*, 2006).

It is possible that the depression in intake that Grazfeed uses for fatness is overestimating the effect in pregnant ewes – particularly as (Lee *et al.* 1995) reported that the relationship in late pregnancy in Merinos was a smaller magnitude.

A small depression in intake during late pregnancy of twin-bearing ewes relative to dry or single bearing ewes, probably reflects the inclusion of conceptus in the maternal liveweight (Lee *et al.* 1995). Although we found little or no effect of pregnancy on DOMI, the nutrient requirements of the pregnant ewe increase markedly in the last trimester. The effects of pregnancy on intake, as previously reported, remain unclear. For example, intakes in late pregnancy have been reported to increase (Arnold, 1975), decrease (Hadjipieris and Holmes, 1996; Owen *et al.* 1980; Weston, 1988) or not be affected (Arnold and Dudzinski, 1967). Intakes over the last few weeks of pregnancy by twin-bearing ewes relative to ewes bearing single lambs are similar (Foot and Russel 1979); Newton and Orr, 1981).

Feed intake allows the animal to meet its requirements for basal metabolism, growth, reproduction and fat deposition. Appetite is controlled by neuronal pathways in the arcuate nucleus of the hypothalamus; these pathways are regulated by feedback from signals of the animal's nutritional status through peripheral levels of circulating metabolites and metabolic hormones, including leptin and ghrelin (Cone *et al.* 2001; Williams *et al.* 2001). The potential mechanisms that underlie the higher pasture intake observed in the BLM ewes compared to the prediction models remains to be defined. Previous studies have, however, suggested that variation in hypothalamic gene expression of appetite-regulating neuropeptides may contribute to differences in appetite (and thus DM intake) in a range of species including sheep (Wagner *et al.* 2004).

Several novel methods of estimating pasture intake were assessed in this work. The results from the Actigraph data indicate that this technology in assisting in estimating and understanding pasture intake. However, although the use of gas accumulation has potential on pellet or grain based diets in sheep and cattle (Paganoni *et al.,* 2017; Arthur *et al.*, 2018) its use in pasture trials is unlikely to be successful.

9.3.6 Conclusions

Lifetime ewe guidelines underestimate ME intake at low FOO for crossbred ewes. New predicted feed intake and ME intake guidelines need to be developed. Whether the guidelines are also under predicting feed intake for Merino ewes also needs to be addressed.

9.3.7 Acknowledgements

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The authors declare no conflicts of interest.

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9.3.9 Struan data

Struan LTM2 data.xlsx

9.4 Whole farm modelling (detail)

9.4.1 Calibration of whole farm inputs

9.4.1.1 Background

There has been a demand from industry for nutrition guidelines for Maternal breeds following on from the success of the Lifetimewool (LTW) research programme and the Lifetime Ewe Management (LTEM) extension programme that developed guidelines for the nutrition of Merino ewes at joining, during pregnancy and lactation. It has been hypothesised by people working with Maternal sheep that the optimum management for maternal ewes will be different than that required for a Merino ewe. This was supported by a survey of producers and consultants that showed that many producers didn't believe that the Merino guidelines are relevant for their flocks.

There are several reasons that the Merino guidelines may not be correct for maternal breeds. Firstly, the wool produced by Merino progeny is more valuable than the wool produced by progeny of maternal breeds. Young *et al.* (2011) showed that about one third of the value of improved management of the nutrition profile of Merino ewes occurs through improvements in the value of wool produced by the progeny. Secondly, Maternals are bigger, have higher reproductive rates and lamb survival and the prime lamb is ideally turned off in the shortest time possible (around 5-6 months of age). Thirdly, the progeny of maternal breeds are more resilient and have lower death rates. The argument therefore is that the optimum profile for maternal ewes may include greater weight loss than the profile for merino ewes.

Project B.LSM.0064 "Lifetime Maternals - development of management guidelines for non-Merino ewes" quantified the production response of maternal ewes and their progeny to varying nutrition during pregnancy and lactation. That project developed a range of coefficients that related lamb birth weight, weaning weight and number of lambs conceived to ewe LW profile and lamb survival to lamb birth weight. However, the project was unable to draw conclusions about nutritional guidelines from the modelling carried out because the feed budgeting for maternal genotypes using the equations and parameters from the Australian Feeding Standards did not replicate the measured performance of the ewes in the research trials. Specifically, the high rates of liveweight gain measured in the experiments could not be feasibly achieved in the feed budgets using current methods of prediction. This indicated that either predicted intake is too low or the predicted energy requirements for maintenance or weight gain are too high. As a consequence, the patterns that lost condition during pregnancy were penalised in the post-weaning period because a very high quality diet was required to gain the lost weight.

Sensitivity analysis showed that possible parameter changes in the feed budget equations had different ramifications on the optimal ewe nutrition profile. Therefore, it was necessary to clarify why the equations did not accurately predict the liveweight changes measured in the paddock trials. The current project has carried out experiments to measure intake and energy requirements of composite ewes and crossbred ewes so that the prediction equations could be improved.

The animal research in the current project involved 3 sites in total. The first site (Struan, SA) measured intake on pasture of pregnant Border Leicester Merino (BLM) ewes with varying levels of feed on offer (FOO). The other 2 sites (Hamilton, Victoria & Katanning, WA) measured maternal composite ewes under intensive feeding conditions with close control and measurement of feed intake and measurement of liveweight and body composition (using DXA scanning). Data from these 3 sites was used to evaluate the parameters in the feed budgeting equations used in the modelling.

The analysis described in this report followed a process as described by Young *et al.* (2011):

1. A number of LW profiles were generated for ewes during the pregnancy and lactation period
2. Ewe and progeny production was adjusted using the relationships developed in project B.LSM.0064
3. Farm profitability was estimated using the MIDAS model when ewes followed each of the LW profiles.
4. Guidelines for ewe nutrition management were derived from a comparison of the profitability of different nutrition profiles.

9.4.2 Method

9.4.2.1 Production adjustment coefficients (B.LSM.0064)

In project B.LSM.0064 research experiments were conducted at four sites across southern Australia (Hamilton and Pigeon Ponds Victoria, Struan SA and Mount Barker WA) to collect the information necessary to develop coefficients relating ewe liveweight and condition score profile during pregnancy on lamb birth weight, peri-partum lamb survival, and weaning weight. The carryover effect of the ewe liveweight and condition score prior to joining on reproductive rate the following year was also assessed.

The coefficients from the combined sites and combined year analysis were used in this economic analysis, except for reproduction and carryover effects on reproduction which are from 2014 combined sites analysis. A summary of the coefficients is provided in Table 29, Table 30, Table 31, Table 32 and Table 33. The coefficients were derived from the maternal liveweight and changes in maternal live weight during pregnancy (the correction to conceptus free liveweight was based on the Wheeler (1971) equation). These coefficients are unpublished (Kearney *pers. comm.*) although the 2014 results combined across sites is published in Behrendt *et al.* (2019)

Table 29: Coefficients fitted in the statistical model that explains progeny birth weight from ewe liveweight (LW) at joining (kg) and LW change (LWC - kg) during pregnancy.

Constant		4.0310
LW	Joining	0.02253
LWC	Join-90	0.03838
	90-Lamb	0.02534
Sex	Male	0.3485
	Female	0.0
Birth type	1	0.0

	2	-1.079
	3	-2.012

Table 30: 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.

Constant		-8.033
Birth wt	kg	3.055
	kg^2	-0.2419
Sex	Male	-0.3043
	Female	0.0
Birth type	1	0.0
	2	-0.1594
	3	-0.6154
Ewe CS at lambing	CS	1.217
	CS^2	-0.1992

Table 31: Model to explain weaning weight from birth weight and post weaning lamb growth rate (if weaned when oldest animal is 15 weeks).

Constant		19.69
LW	Joining	0.1453
LWC	Join-90	0.1666
	90-Lamb	0.1061
Sex	Male	1.5272
	Female	0.0
BTRT	11	0.0
	21	-3.649
	22	-6.850
	31	-7.35
	32	-9.942
	33	-11.144

Table 32: Coefficients fitted in the statistical model that explains ewe reproduction in the current year from ewe liveweight (LW) at joining (kg) and birth type (BT) of the ewe.
Estimating reproductive performance from the coefficients is a multi-step calculation

1. *Boundary0/1 = Cut off0/1 – (Site effects + 0.03755 LW_J + relevant BT coefficient). Similarly calculate Boundary 1/2*
2. *BT Boundary i = EXP(Boundary i-1/i)/(1+EXP(Boundary i-1/i)) for i =1 and i=2*
3. *% Dry = BT Boundary 1, % Singles = BT Boundary 2 – BT Boundary 1, % Twins = 1 – BT Boundary 2*
4. *Scanning % = % Singles + 2 x % Twins*

Cut off (with site)	0/1	0.727
	1/2	3.122
LW	Joining	0.03755
BT	1	-0.4804
	2	0.0
Combined site effects		0.773

Table 33: Coefficients fitted in the statistical model that explains carry over ewe reproduction from ewe BT and ewe liveweight (LW) at previous joining (kg) and LW change (kg) during previous pregnancy and lactation.(Coefficients are also provided if calculating based on LW for the current joining and LWC during the previous reproductive cycle).
Estimating reproductive performance from the coefficients is a multi-step calculation

1. *Boundary0/1 = Cut off0/1 – (Site effects + 0.03182 LW_J + 0.058 LWC_{J-L} + 0.04781 LWC_{L-W} + 0.0318 LWC_{W-J} + relevant BT coefficient). Similarly calculate Boundary1/2*
2. *BT Boundary i = EXP(Boundary i-1/i)/(1+EXP(Boundary i-1/i)) for i =1 and i=2*
3. *% Dry = BT Boundary 1, % Singles = BT Boundary 2 – BT Boundary 1, % Twins = 1 – BT Boundary 2*
4. *Scanning % = % Singles + 2 x % Twins*

		LW previous joining	LW this joining
Cut off	0/1	0.113	0.113
	1/2	2.507	2.507
LW	previous Joining	0.03182	
LWC	Join-Lamb	0.058	0.02618
	Lamb-Wean	0.04781	0.01599
	Wean-Join	0.0318	-0.00002
LW	current Joining		0.03182
BT	1	-0.5229	-0.5229
	2	0	
Combined site effects		0.524	0.524

9.4.2.2 Feeding standards equations

Data from the 3 trial sites in this project were used to alter the feeding standards equations to improve the representation of maternal ewes. The basis of the equations is that liveweight change can be quantified by determining the difference between energy intake and energy required for maintenance, and dividing the surplus or deficit by the energy content of a kilogram of liveweight change. Presented mathematically:

Equation 1: $Empty\ Body\ weight\ Gain\ (EBG) = \frac{ER}{EVG}$

Equation 2: $Liveweight\ Change = \frac{EBC}{0.92}$

Equation 3: $Energy\ Retained\ in\ non\ reproducing\ animals\ (ER) = k_g\ (MEI - ME_m)$

Equation 4: $MEI = Feed\ Intake * {}^{M}/_{D}$

The components of the above equations provide multiple options for parameters that could be altered so that predicted liveweight change (LWC) is similar to actual LWC.

Equation 5: $Maintenance\ requirement\ (ME_m) = \frac{\mathbf{0.26}\ LW^{0.75}\ e^{-0.03Age}}{\boldsymbol{k_m}} + 0.09MEI + ECold + \frac{EGraze}{k_m}$

Equation 6: $k_m = \mathbf{0.02}\ {}^{M}/_{D} + 0.5$

Equation 7: $k_g = \mathbf{0.035}\ (1 + 0.33L)\left(1 + 0.12\ \frac{-Latitude}{40} sin\left(6.28\ \frac{day\ of\ year}{365}\right)\right){}^{M}/_{D}$

Equation 8: $Energy\ Value\ of\ \ Gain/Loss\ (EVG) = (6.7 + R) + \frac{(\mathbf{20.3}-R)}{1 + e^{-6(P-0.4)}}$

Equation 9: $Maximum\ Potential\ intake\ (PI_{max}) = \mathbf{0.04}\ SRW\ Z\ (1.7 - Z)$ *– with Z≤1*

Equation 10: $Effect\ of\ relative\ condition\ on\ PI = PI_{max}\ RC\ \frac{(\mathbf{1.5}-RC)}{(\mathbf{1.5}-1)}$ *– with RC≥1*

Equation 11: $Relative\ Availability\ (RA) = (1.0 - e^{-\mathbf{1.51}*HF*FOO}) * (1 + \mathbf{0.6}\ e^{-((1.3\ HF*FOO)^2)})$

Equation 12: $Relative\ Ingestibility\ (RI) = 1 - 1.7\left((0.8 - (1 - L) * SF) - DMD\right) + RA^2 * 0.17\ L$

Equation 13: $Relative\ Intake = RA * RI$

Equation 14: $Voluntary\ Feed\ Intake\ (I) = Potential\ Intake * Relative\ Intake$

Where:

Age is age in years
DMD is dry matter digestibility (as a proportion, 0-1)
ECold is additional energy expenditure for animals in a cold stress situation
EGraze is additional energy for animals not in a housed situation
FOO is feed on offer (t dry matter/ha)
HF is the height factor scalar for the pasture compared to the standard (std value = 3 cm/tonne)
k_g is net efficiency of ME for growth
k_m is net efficiency of ME for maintenance
L is legume content of the pasture (as a proportion, 0-1)
LW is current LW of the animal
M/D is metabolizable energy (MJ) per kg of DM
MEI is metabolizable energy intake
MEp is dietary ME being used for production
P is LW / SRW
R is adjustment for rate of gain or loss of LW ($= \frac{EBC}{4\ SRW^{0.75}}$)
RC is relative condition with a minimum value of 1.0. RC = current weight / normal weight
SF is a species factor (0 for C3 grasses & 0.16 for C4 grasses)
SRW is standard reference weight
Z is relative size with a maximum of 1.0. Z = normal weight / SRW

The equations that were assessed in this exercise were Equation 5, Equation 6, Equation 8, Equation 9, Equation 10 & Equation 11. Comparisons were carried out in Sheep Explorer[1] (version Dec 2012) which includes the equations from the feeding standards as described above. The comparisons were carried out for the period between DXA scans for the Hamilton Vic and Katanning WA experiments.

9.4.2.3 Standard Reference Weight and change in LW with change in CS

The average liveweight and CS difference between the lowest and highest CS treatments in the 2014 and 2015 experiments was calculated across measurements taken from day 90 to lambing and at marking and weaning. The average difference in liveweight, fasted liveweight or DXA total tissue mass and CS between the highest and lowest treatment was also calculated for measurement dates in the Hamilton and Katanning restricted feeding experiments where animals had been significantly segregated based on liveweight and CS. The mean data was then used to calculate the ratio of liveweight change (kg) to CS (Table 6.) The mean change in liveweight per change in CS across all experiments was 15.1kg within a range of 12.6 to 23.0 for estimates in different experiments. The ratio between kg LW: 1 CS was assumed to be 15kg for the modelling in this report.

Table 34: The average difference in weight measurements and CS between the highest and lowest nutritional treatments in various experiments with maternal composite ewes and the ratio of weight change to CS change

Year	Site / Experiment	Period of measurement	Average Weight	Average CS Difference	kg LW:1 CS

[1] Sheep Explorer website: www.grazplan.csiro.au/

			Difference (kg)		
2014	Hamilton	Day 90 to weaning	10.7*	0.75	14.3
2014	Pigeon Ponds	Day 90 to weaning	9.9*	0.68	14.6
2014	Mount Barker	Day 90 to weaning	10.7*	0.77	14.0
2014	Struan	Day 90 to weaning	7.1*	0.56	12.6
2015	Hamilton	Day 90 to weaning	7.8*	0.34	23.0
2015	Pigeon Ponds	Day 90 to weaning	8.7*	0.67	13.0
2015	Mount Barker	Day 90 to weaning	10.8*	0.67	16.1
2015	Struan	Day 90 to weaning	6.2*	0.41	15.3
2018	Katanning	Allocation LWT and CS	8.4*	0.77	10.9
2017	Hamilton	End restricted feeding	10.5*	0.50	21.0
2017	Hamilton	End restricted feeding	6.8^	0.50	13.6
2018	Katanning	Start of restricted feeding for CS group	7.1^	0.52	13.7
2018	Katanning	End restricted feeding	12.8^	0.71	18.0
2017	Hamilton	End restricted feeding	7.5#	0.50	15.0
2018	Katanning	Start of restricted feeding for CS group	7.0#	0.52	13.5
2018	Katanning	End restricted feeding	9.8#	0.71	13.8
		Average across all experiments	8.9	0.60	15.1

* Difference between the highest and lowest treatment based on measures of raw liveweight.
^ Difference between the highest and lowest treatment based on measures of fasted liveweight.
# Difference between the highest and lowest treatment based on measures of the DXA total tissue mass.

9.4.2.4 Intake at Pasture

At the Struan site, dry matter intake of pregnant BLM ewes grazing pasture with different levels of FOO was estimated using pasture disappearance over a short period of high intensity grazing. The data on voluntary feed intake was used to generate a relationship for the impact of FOO on pasture intake (Figure 22 - to replace Equation 11) and a relationship between animal SRW and PI to adjust the parameter value in Equation 9.

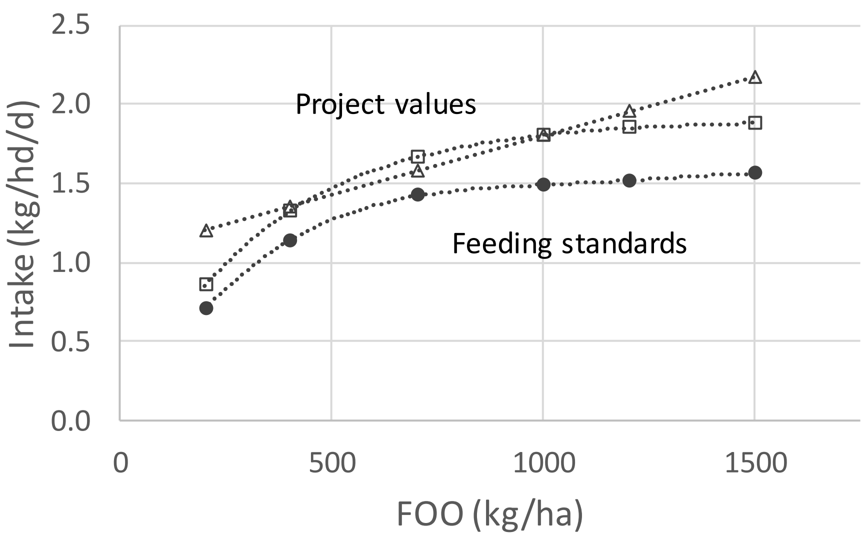

Figure 22: Fitted predictions of intake measured by pasture disappearance for BLM ewes (kg/hd/d) when grazing plots with different FOO (kg/hd) compared with values from the Feeding Standards.

The animals were weighed and condition scored prior to joining at 66kg and CS 3.3. Using the estimate that LW varies by 15 kg for each condition score results in an estimate of SRW of 61.5kg.

The relationship developed for the impact of FOO on intake was:

New Equation 11: $Relative\ Availability\ (RA) = (1.0 - \ 0.997042^{FOO})$

A linear function was determined to be a better fit over the range of FOO in the experiment but the exponential form was used because it extrapolates to predict more sensible intake at lower FOO levels between 100 and 400kg/ha.

The predicted maximum intake for the pasture in the SA trial (with a digestibility of 73.5%) was 1.902kg/ha/d (99% of maximum intake was predicted with a FOO of 1555 kg/ha.).

Using Equation 12 with DMD = 0.735 relative ingestibility (RI) is calculated to be 0.889. The above fitted relationship and this estimated value for RI was used to estimate the parameter value in Equation 9 that matched predicted intake (Equation 14) with measure intake. The term RA^2 x 0.17L in Equation 12 was ignored because in the trial the proportion of legume was only 4% and deleting the term made solving for the parameter achievable.

The parameter in Equation 9 therefore needs to be 0.05 which is a 25% higher than the standard value. When FOO is low (200kg/ha) the increase in intake is increased to approximately 35%. This level of increase in potential intake is consistent with, but lower than the ad lib intake measured in the feed sheds on pellets which measured intakes 50%-60% higher than predicted using the feeding standards equations.

9.4.2.5 Impact of Relative Condition on Potential Intake

The intake measured in the feed sheds was used to examine the impact of higher condition score on *ad libitum* feed intake. During the restricted period of feeding at the beginning of the experiments the treatments had different levels of feeding and by the end of the restricted period (start of the ad lib period) each treatment group varied in LW and relative condition. The intake scalar for relative condition for each treatment group was calculated by dividing measured intake of each treatment group by the measured intake of the treatment group with the lowest liveweight at the start of the ad-lib feeding period. The analyses of the maximum post-restriction *ad libitum* feed intake at Hamilton showed no difference in feed intake between the treatment levels for Maternal ewes ($P>0.05$) with individual with RC up to 1.33. At Katanning, animals that had been on higher levels of feeding during the restricted feeding period had higher feed intake ($P<0.01$). In addition, ewes that had been managed to low condition score at the start of the experiment had lower feed intake than ewes that had been managed to be at a higher starting CS ($P<0.05$). The latter results are opposite to the relationship proposed by current predictions.

However, in the paddock trial in B.LSM.0064 the ewes that had been fed to achieve different CS, when returned to feeding in common, converged in LW & CS at a faster rate than can be explained by only varying maintenance requirement. This suggest that intake is different for the thinner and fatter ewes, however, the intake was not measured in the paddock scale trials.

The conclusion derived for the modelling was that RC had an effect on intake but it was less than predicted by the feeding standard equations. Equation 10 was adjusted so that PI was reduced at a slower rate when RC is greater than 1 (see Figure 23).

New Equation 10: $Effect\ of\ relative\ condition\ on\ PI = PI_{max}\ RC\ \frac{(1.7-RC)}{(1.7-1)}$ – *with RC≥1.0*

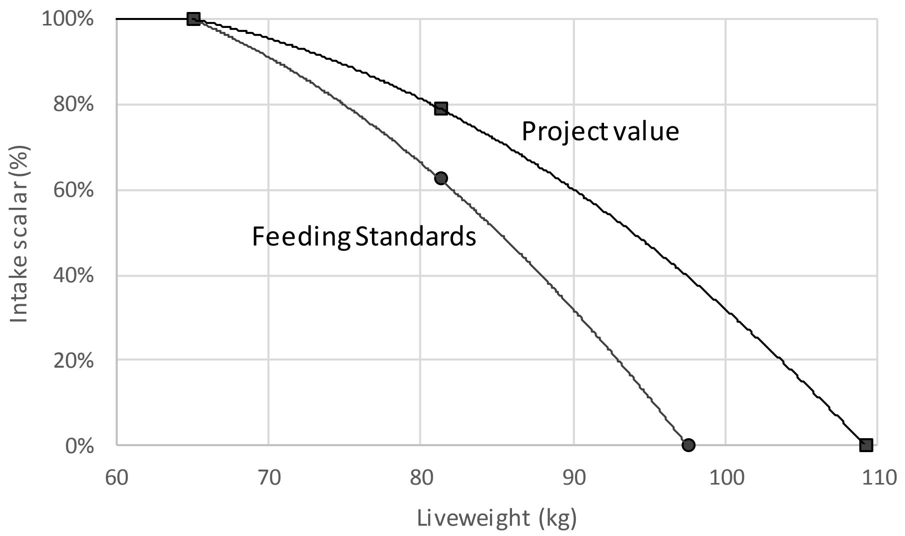

Figure 23: Impact of liveweight or relative condition on intake for mature animals with a SRW of 65kg.

9.4.2.6 Maintenance Requirement and efficiency of energy use

Maintenance requirement and efficiency of energy use were tested by comparing the actual energy retained against the predicted energy retained. The change in actual energy retained in the body was calculated from the corrected levels of fat and lean using the assumptions in Table 35. The raw data from the Vic and WA DXA scans were corrected using the relationships developed by Hunter *et al.* (2011) (Table 36). These corrections were to remove bias in the DXA scan results because no direct measurement of muscle and fat in the body was undertaken in this experiment. Hunter *et al.* (2011) was selected because they evaluated composite genotypes and it also was the most comprehensive study having measured all body tissues. Pearce *et al.* (2009) did not include internal fat and both Pearce *et al.* (2009) and Ferguson (PhD) did not include skin and viscera, both of which would be expected to change with nutrition. Furthermore, there were issues with the Pearce *et al.* (2009) results as discussed by Hunter *et al.* (2011).

Table 35: Energy content of Fat & lean tissue

Tissue	DM content	Energy content MJ/kg DM	MJ/kg tissue
Fat	91.4%[1]	39.3[2]	35.92
Muscle	22.5[3]	23.6[2]	5.31

[1] Anon 1996 (DXA manual) and DeGirolamo & Owens (1976).

[2] SCA (1990).

[3] Based on SCA (1990) “The deposition of 1 g of protein in body tissue is associated with an accretion of 3-4g of water”. That is, muscle is 20 – 25% dry matter.

Table 36: Summary of the experiments that calculated corrections for DXA measurements.

	Hunter *et al.* 2011	Pearce *et al.* 2009	Ferguson (PhD)
Number of animals	28	50	44
Correction	Log(weight) =	Weight =	Weight =
Fasted LW = *f*(TTM)[1]	-0.04 + 1.03Log(DXA)	0.29+0.001DXA	
Lean tissue = *f*(LTM)[2]	0.056+0.955Log(DXA)	1.99+0.29DXA	0.48+0.29DXA
Fat tissue = *f*(FTM)[3]	-0.085+1.16Log(DXA)	-2.52+0.37DXA	2.22+0.71DXA
Genotype	Composite	Merino	Merino
Tissues measured	Carcase, head, skin, viscera, blood, feet	Carcase	Carcase, kidney fat,
Tissue not measured		Legs, skin, head, viscera, internal fat	Legs, skin, head, viscera

[1] TTM Total tissue mass assessed by DXA
[2] LTM Lean tissue mass assessed by DXA
[3] FTM Fat tissue mass assessed by DXA

For both the Vic & WA data sets the predicted energy retained was approximately 1.4 MJ/hd/d less than the actual energy retained (Figure 24). This discrepancy could be due to predicted maintenance requirement being greater than actual, predicted efficiency of energy use for maintenance (k_m) being less than actual or due to errors in the correction of the DXA scan measurements to actual lean and fat mass.

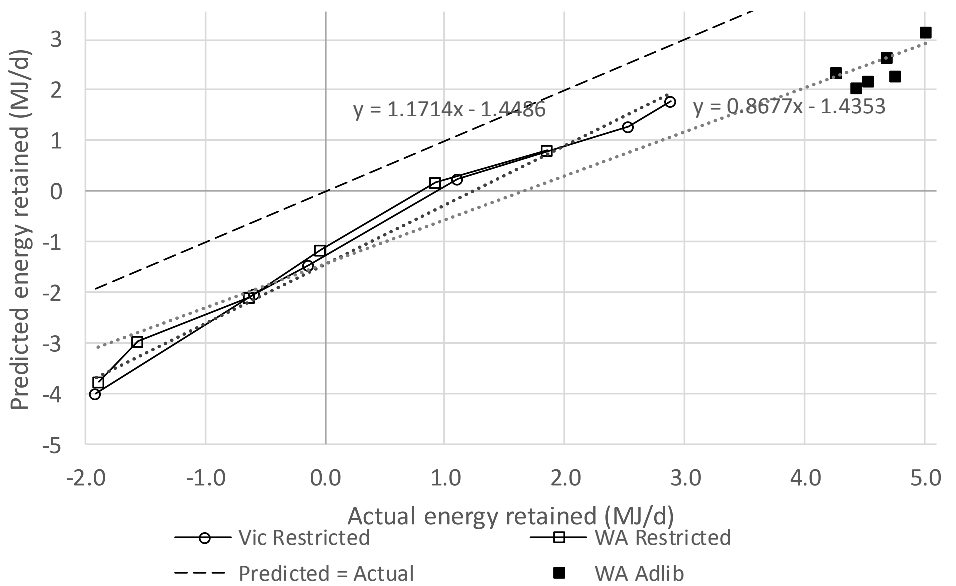

Figure 24: Comparison of measured change in energy retained (MJ/d) with the change in energy retained predicted by Sheep Explorer using measured MEI.

A further issue was uncovered in discussion of our experimental results with Hutton Oddy who identified an issue that is not included in the current feeding standard equations that will impact on the results of the experiment. It is expected that increasing prior feeding level will increase the energy required for maintenance because organs will be more metabolically active, and there is a lag before metabolic activity adjusts to the new level of intake. The current feeding standards equations do not include this lag phase and assume that the animal is acclimatised to the level of feeding being tested.

At the Victorian site the period of feeding prior to the measurements in the restricted period were at ad-lib whereas in WA, feeding was at maintenance or below maintenance. Quantitative adjustment for this effect in Sheep Explorer has not been attempted. However, in the feeding standards the allowance made for the level of feeding on the requirement for maintenance is 0.09 MEI (see Equation 5).

The Victorian sheep were fed ad-lib during the pre-feeding period and could have been consuming greater than 25 MJ/hd/d. Therefore, the predicted maintenance requirement for the animals on maintenance during the restricted period (consuming 14 MJ/d) could be underestimated by up to 1 MJ/d depending on the length of the lag phase. This would increase the discrepancy between actual and predicted at maintenance and increase the slope of the relationship to a value further from 1.0.

In WA the animals were fed for maintenance or weight loss during the pre-feeding phase and therefore the maintenance requirement of the animals during the ad-lib phase could be overestimated (by up to 0.9 MJ/d). This would reduce the discrepancy between predicted and actual during the ad lib period but has little effect during the restricted period for WA. It would also increase the slope of the relationship taking it closer to 1.0.

The conclusion following the meeting with Hutton Oddy was that for the parameters associated with estimating maintenance requirement, efficiency and energy retained there was insufficient experimental evidence to indicate a requirement for change. However, further research is recommended to better quantify the relationship between live DXA scans and the proportions of chemical fat and protein and their energy content in maternal sheep because there is limited experimental evidence for correcting the DXA information to remove bias.

9.4.2.7 Energy Value of Gain

EVG was directly estimated from the change in energy retained from the DXA scans and change in fasted liveweight (Figure 25). EVG was estimated as the slope of the relationship (Table 37). The discrepancy between the measured EVG and predicted EVG for the Vic ewes is less than 5%, however, for the WA ewes the discrepancy is more than 45%.

The estimation of EVG is sensitive to the correction used for the DXA scan results. Most of the values are low but the results using Pearce *et al.* (2009) and Ferguson (PhD) are particularly low. This discrepancy between the 3 correction options indicate that further work to clarify the correction required for DXA to live animal composition is warranted.

There is a large variation between sites in the estimation of EVG. Using the Hunter corrections with the Hamilton results, generates a value that is similar to the existing feeding standards predictions, however, the Katanning values are much lower. EVG is further examined in the next section in which the new equations and parameters are compared with the LW changes measured in project B.LSM.0064.

Table 37: Slope of line: change in WBE/change in FLW. This is a measure of the marginal EVG and it compares with a predicted value from the feeding standards of 26.4 MJ/kg.

	Marginal EVG		
	Hunter *et al.*	Pearce *et al.*	Ferguson
Hamilton restricted	25.3	6.4	11.5
Katanning restricted	14.1	4.0	6.5
Katanning combined	11.1	3.2	4.9

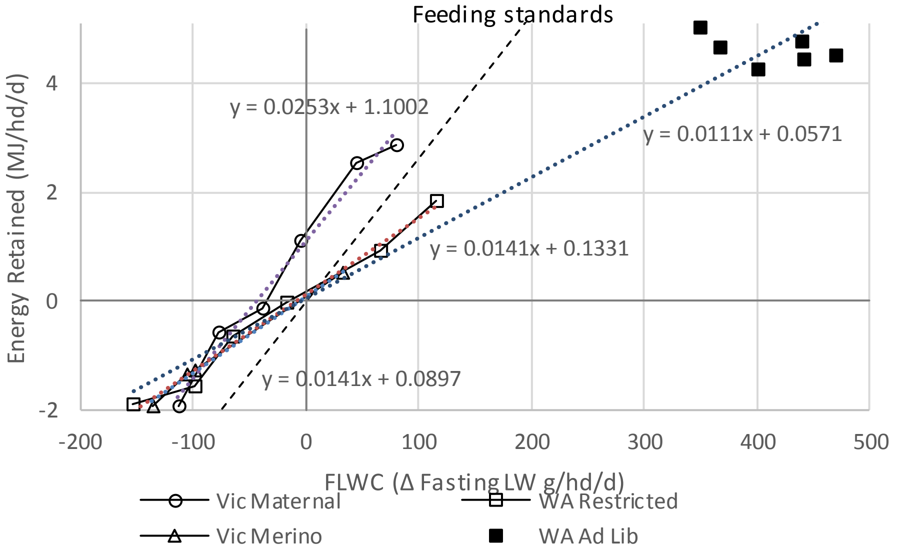

Figure 25: Actual energy retained versus actual fasted LW change. Note: The slope of this relationship is the marginal EVG.

9.4.2.8 Comparison with B.LSM.0064 animal measurements

The Pigeon Ponds and WA sites in project B.LSM.0064 had recorded FOO and supplement fed during late pregnancy, and a linear model was fitted to describe LWC from FOO and supplement offered. The predictions of this linear model have been compared with the recalibrated MIDAS simulation model.

The genotype used at the WA site in project B.LSM.0064 is the same genotype used at the Katanning site in this trial.

The MIDAS simulation was set up with animals that reflected the SRW of animals at each of the sites (Pigeon Ponds 53.3kg, WA 64kg). The simulation was started at the SRW at either day 66 or day 94 of pregnancy depending on the time period assessed at the trial site. The FOO levels investigated were 100, 200, 300, 400, 500 and 600 kg/ha and supplement fed was 0, 250, 500, 750 and 1000 g/hd/d. The MIDAS pasture was 11.7 MJ of ME/kg. The results of these 30 runs were compared with the WA linear model (day 65-110 and day 97-139) and the Pigeon Ponds linear model (day 90-140).

The predicted values were graphed against the actual data for the equations

1. Prior to making adjustments to the prediction equations (Figure 26).
2. After altering potential and relative intake as described in the previous section (Figure 27)
3. After altering the energy value of gain. Reduced from 26.4 MJ/kg EBG down to 17.4 MJ/kg (Figure 28)

Increasing potential intake by 25% and altering the relative intake equation reduces the gap between the actual and predicted LWC, however, the slope of the fitted relationship is further from unity (Figure 26 compared with Figure 27).

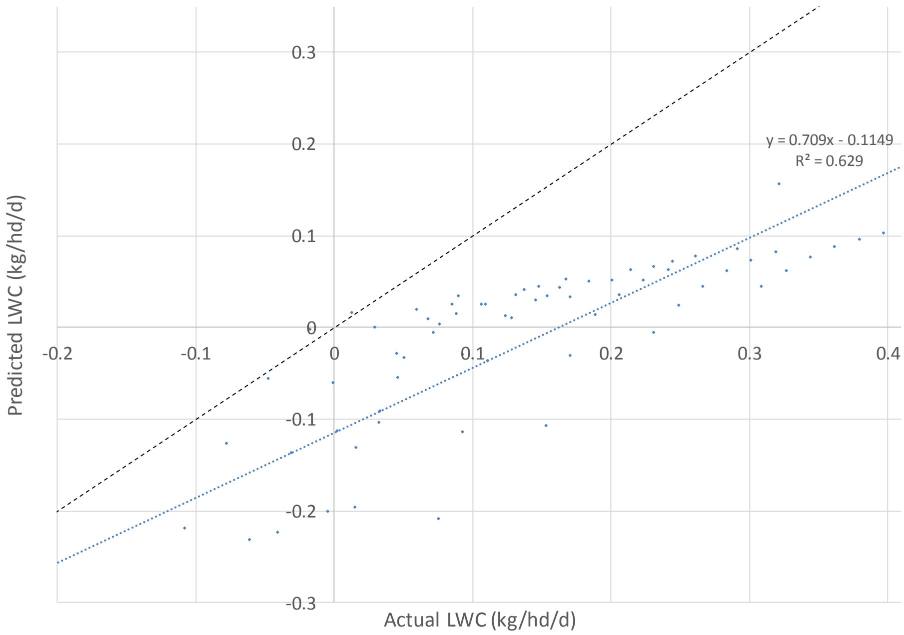

Figure 26: Relationship between actual LWC measured in project B.LSM.0064 and predictions made prior to altering the equations using information from this project.

The slope of the relationship in Figure 27 is 0.6 which indicates that with the altered PI and RI that the equations are under-predicting the increase in LWC as pasture supply increases and the potential to gain weight increases. This is consistent with the findings for predicted and measured LWG under intensive feeding conditions (data not presented). Reducing the energy value of gain will increase the predicted LWC as the potential for LWG increases.

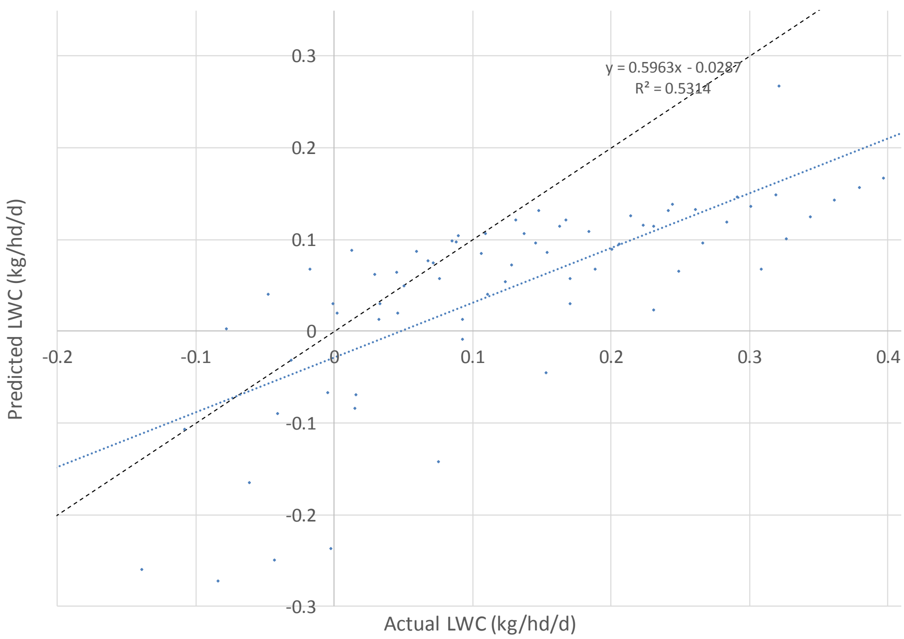

Figure 27: Relationship between actual LWC measured in project B.LSM.0064 and predictions using updated PI (=5% of SRW) and updated RA (=1-0.997042^{FOO}) but unchanged EVG (= 26.4 MJ/kg).

If EVG is reduced to 17.4 MJ/kg EBG (by reducing the coefficient in Equation 8 from 20.3 down to 11.0) then the slope of the relationship between actual and predicted LWC approaches unity (Figure 28). This value is lower than the measured EVG using DXA data from Hamilton and the Hunter *et al.* (2011) correction, but is greater than the value measured in Katanning using the same corrections (Table 37).

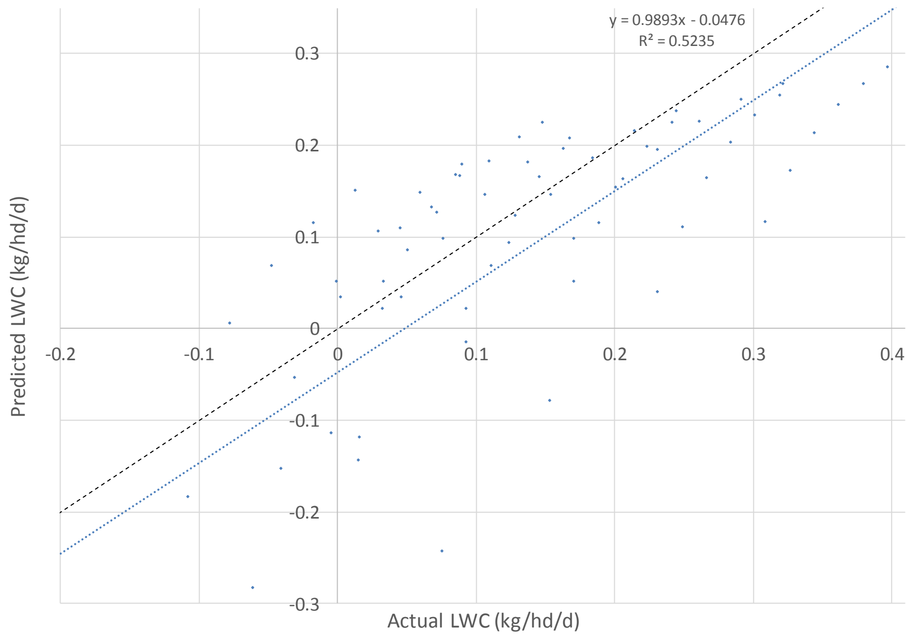

Figure 28: Relationship between actual LWC measured in project B.LSM.0064 and predictions using EVG = 15.5 MJ/kg

The r^2 of the updated predictions (0.52) is low but it was expected that the predictions would not be a close fit with the measured data because data was lacking to calibrate many of the parameters in the model and many of the measurements of FOO had a large confidence interval due to the measurement error. The calculations were carried out using the standard MIDAS long term average values for pasture quality and weather conditions. Therefore, the potential errors are large, although it is expected that the errors would be consistent between feed treatments at each site. The systematic bias of those errors would lead to a vertical displacement of the predicted values but only a small impact on the slope. Therefore, using this data to adjust the EVG - which alters the slope of the relationship - is valid.

The suggested reduction in the coefficient is double the magnitude of the reduction that is involved in the feeding standards equations to represent the high muscling cattle breeds such as Charolais, Limousin, Maine Anjou and Simmental (SCA 1990). For these cattle breeds the recommendation is to use a value of 16.5. This indicates that this suggested reduction in EVG for maternal type sheep is extreme compared with the variation measured in cattle breeds. A potential source of variation is the DXA correction. However, if the correction was altered to align the measured EVG (Table 37) with predicted by increasing the corrected value for energy retained, this would increase the discrepancy between predicted and actual energy retained (see Figure 24) for animals with high levels of energy retained.

It is difficult to draw a firm conclusion from the data about the value of EVG, however, one explanation for the variation observed is that there is variation associated with genotype. Some "maternal" breeds have been infused with "terminal" traits and the Greeline genotype that was the source of the animals in WA for both trials has 25% East Friesian and 37.5% Texel. Terminal breeds have been heavily selected for increased lamb growth rate, high muscling and reduced fat, and improvements in each of these traits could reduce EVG. Therefore, a contribution to the differences between the Katanning and Hamilton EVG result could be the "terminal" component of the WA sheep.

The approach taken for the modeling was to use the EVG from the feeding standards and then do a sensitivity analysis if the EVG was 17.4 MJ/kg.

9.4.2.9 Mortality and rate of liveweight loss

A relationship between rate of LW loss and mortality was included (Figure 29) to represent the increase in death rate of animals that are rapidly losing weight. There is little data on which to base this relationship, and the values used are a combination of anecdotal evidence and observed rate of LW loss in experiments. The allowable rate of LW loss of dry sheep and reproducing sheep in early pregnancy was considered to be 250 g/hd/d. For reproducing ewes the allowable rate of loss in late pregnancy reduces to 175 g/hd/d for singles and 100 g/hd/d for multiples prior to day 120 of gestation and maintenance after day 120. Allowance was made for variation between individuals in the mob for rate of LW loss and a further 20% safety margin was included to allow for the precision of on-farm management in achieving the guidelines, making the guideline rates of LW loss 160 g/hd/d for dry sheep and early pregnancy, 120 g/hd/d for singles in mid and late pregnancy, 55g/hd/d for multiples in mid pregnancy and maintenance for multiples in late pregnancy.

A sensitivity analysis was carried out to examine the implications of not requiring the safety margin on the optimum profile and farm profitability.

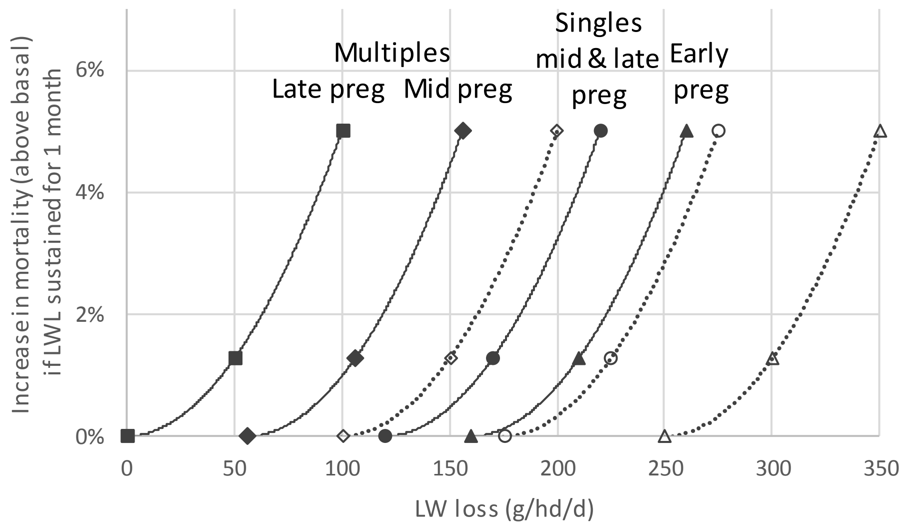

Figure 29: Relationship used in the modelling between rate of LW loss during pregnancy and mortality. Solid line is with safety margin and dashed line is without. All ewes in early pregnancy (joining to day 90) – Δ, Singles mid and late pregnancy (day 90 to lambing) - ○, multiples mid pregnancy (day 90 to day 120) - ◊, multiples late pregnancy (day 120 to lambing) - □.

9.4.2.10 Mortality associated with high CS at lambing

A relationship was included between ewe CS at lambing and ewe and lamb mortality due to dystocia and getting cast (Figure 30). There is also very little data on which to base this relationship and the evidence used was based on increases in observed lamb mortality in project B.LSM.0064. This data indicated that the threshold condition for single bearing ewes is lower than for multiple bearing ewes.

For single ewes increased mortality was observed if individual ewes were above CS 3.5 and for multiple ewes it is considered this may occur at CS 3.8. It is estimated that the proportion of ewes above these thresholds will begin to increase if the mob average CS increased above CS 3.3 for singles or CS 3.6 for multiples. Furthermore, to include a safety margin to account for the precision of on-farm management the threshold for the guidelines was reduced to CS 3.0 for single ewes and CS 3.5 for multiples. The safety margin for multiple bearing ewes is smaller because it is considered less likely that farmers will have their multiple bearing ewes in too high a condition, the risk is more likely that they will lose LW too quickly during pregnancy.

The sensitivity analysis mentioned in the previous section also included this safety margin for CS at lambing.

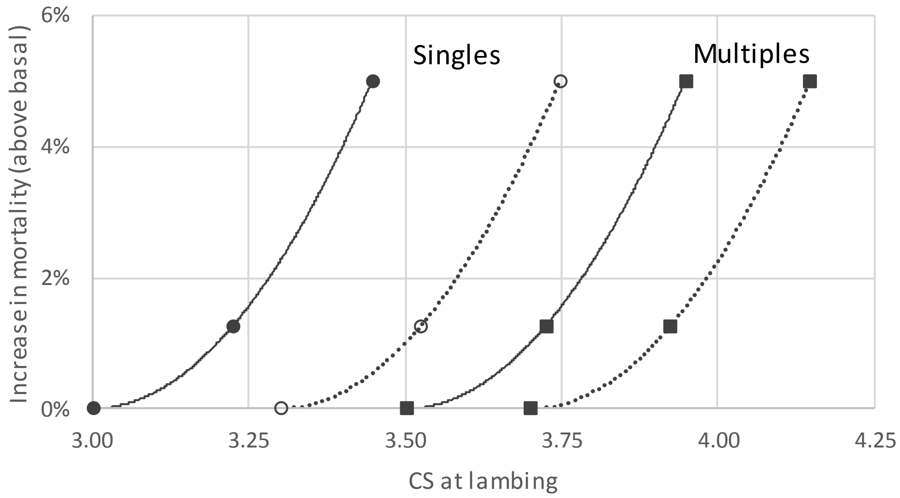

Figure 30: Relationship used in the modelling between ewe CS at lambing and mortality. Solid line is with the safety margin and dashed line is without. Singles - ○, Multiples - □.

9.4.3 MIDAS (regions & TOL)

This economic analysis was carried out using 2 regional versions of the MIDAS models (Kingwell & Pannell (1987), the Hamilton version of the MIDAS model (Young *et al.* 2010, 2011 & 2014) and the Great Southern version (Young *et al.* 2011). Both regions were evaluated with lambing occurring in autumn and winter and the Hamilton version was also evaluated with lambing in spring.

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, Freer *et al.* 2007), these are also the basis of the GrazFeed model. The equations and parameters have been adjusted as outlined in the previous section. 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. To examine the impact of seasonal variation on the optimal patterns, sensitivity analysis was carried out on the farm stocking rate. Constraining the stocking rate above the optimum level is similar to a farmer in a poor year in which pasture growth is less than expected for the number of stock they are carrying, and constraining the stocking below the optimum is similar to a farmer in a good year.

9.4.3.1 The model farms

The following section outlines the main assumptions for each regional version of the model.

9.4.3.1.1 Hamilton, Victoria

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 38).

Table 38: Description and area of each LMU on the Hamilton 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.

Pasture production - The pasture production in the Hamilton model 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.*).

9.4.3.1.2 Great Southern, WA

Land management units - The model represents the average farm in the Icon Agriculture farm benchmarking database (Andrew Ritchie *pers. comm*). The total area of the farm is 2130ha and is comprised of 3 LMUs (Table 39).

Table 39: Description and area of each land management unit on the Great Southern model farm.

Land Management Unit	Area (ha)	Description
Deep sands	150	Deep sand not often waterlogged
Gravelly sands	1500	Duplex soil with gravelly sand over clay at 30 – 40cm. Ironstone ridges prevalent in the landscape
Loamy sands	500	Duplex soil with loamy sand over clay at 30 – 40cm. Granite outcropping is prevalent in the landscape

Pasture production - The pasture production in the Great Southern model is based on a mixed sward of sub-clover and volunteer annual grasses with capeweed. The profile of growth rates during the season has been based on measured pasture growth (DPIRD unpub. trials). The total pasture production has been calibrated from the Icon Agriculture farm benchmarking database so that farm stocking rate and level of supplementary feeding are consistent.

9.4.3.2 Animal production system

The analysis is based on a composite ewe genotype that is purchased as an 18 month old animal and all ewes are mated to a terminal sire. Three lambing times were evaluated in the Hamilton model and two times in the Great Southern model (Table 40). All offspring are weaned at an average age of 14.5 weeks and they are sold as finished lamb at 45-50kg LW. Single lambs are sold at approximately 4.5 mo and multiples at approximately 5.5 mo. The average production for the genotype is outlined in **Error! Reference source not found.**. If the ewes are scanned they are separated into groups based on heir litter size. Each group can then be offered differential nutrition.

Table 40: Summary of the management regime implemented in each regional model for each time of lambing.

	Hamilton			Great Southern	
	Autumn	Winter	Spring	Autumn	Winter
Rams in date	29-Oct	15-Dec	18-Feb	28-Nov	26-Dec
Lambing date	15-Apr	1-Jun	5-Aug	15-May	12-Jun
Shearing time	7-Oct	18-Nov	25-Jan	30-Oct	12-Jan
Weaning date	25-Jul	10-Sep	14-Nov	28-Aug	21-Sep

Table 41: Summary of production assumptions for the genotype evaluated. The values represent the ewe flock averages (2, 3, 4 and 5 year old) for ewes that are joined at CS 3.5 and maintained through to lambing.

Standard reference weight (kg)	65
Fleece weight (clean kg/hd)	2.5
Mean fibre diameter (μm)	30
Scanning rate (%)	160
Weaning rate (%)	140

9.4.3.3 Standard Prices, Production and Sensitivity Analysis

The prices used in this analysis are summarised in Table 42.

Table 42: Standard prices assumed in this analysis.

		Sensitivity
Wool price (cents/kg clean sweep the board; 30 um)	600	
Meat price		± 33%
Lamb ($/kg DW)	6.50	4.30 – 8.60
Ewe hoggets ($/hd purchase price)	170	115 – 225
CFA ewes ($/hd net sale price)	140	95 - 185
Grain price		± 33%
Barley ($/t fed out)	275	185-365
Lupins ($/t fed out)	350	235 - 465

The optimum profile for an unscanned flock in each regional model was calculated with meat prices increased and decreased by 33% on the standard values (this corresponds to lamb prices of $4.30/kg,

\$6.50/kg and \$8.60/kg) and with grain prices increased and decreased by 33% (this corresponds to lupin price ranging from \$235/t up to \$465/t).

9.4.3.4 Predicting proportion of dry, single and twin bearing ewes from scanning.

Scanning data from project L.LSM.0013 (Managing fecund flocks to improve the survival of triplet dams and their lambs) was used to relate the proportion of dry, single, twin and triplet bearing ewes to the scanning percentage. The database includes 80 flocks that were scanned as part of that project. A multiple regression analysis related the proportion of ewes of each birth type to scanning percentage, (scanning percentage)^2, (scanning percentage)^3 and (scanning percentage)^4. The coefficients are in Table 43. The range of scanning percentage in the data was from 100% up to 225% so this is the range over which the equations are valid (Figure 31).

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%.

Table 43: Multiple regression coefficients relating proportion of dry, single, twin and triplet bearing ewes to the scanning percentage.

	Dry	Single	Twin	Triplet
Constant	0.7816	0.3306	-0.4771	-2.3618
Scan %	-0.8413	1.1754	0.1926	6.9585
(Scan %)^2	0.2828	-1.1528	0.7376	-7.4275
(Scan %)^3	-0.0237	0.2606	-0.2844	3.3827
(Scan %)^4				-0.5433

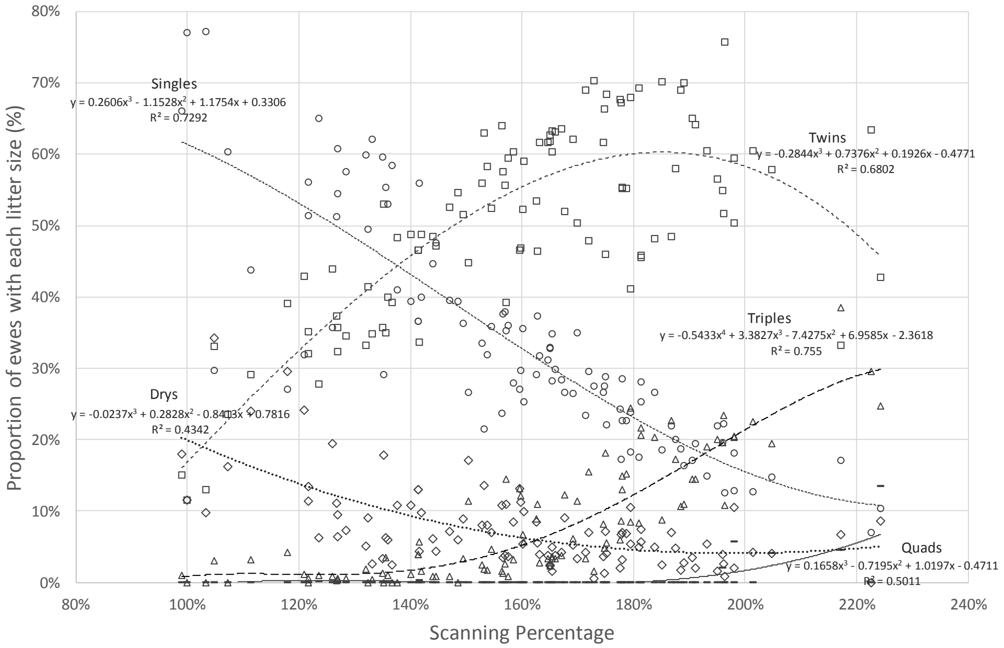

Figure 31: Data points used for the multiple regression (◊ dry, ○ single, □ twin, Δ triplet and - quads) and the fitted relationship (dashed lines) between the proportion of dry, single, twin and triplet bearing ewes and scanning percentage.

9.4.4 The analysis

The analysis was carried out in 3 sections:

1. Determination of the optimum LW profile for ewes and the effect of altering prices and grazing intensity, genotype assumptions and inclusion of the safety margin.
2. Evaluation of the cost of missing targets at different stages of the reproductive cycle.
3. Evaluation of the sensitivity of profit to the joining CS and the impact on the optimum management during pregnancy.

9.4.4.1 Optimum LW pattern

The optimum LW pattern was generated starting with a standard feed supply which would result in the ewes following a typical pattern of weight gain and loss throughout the year. From this standard feed profile, variations in feed supply were generated that would alter the LW profile of the ewes by about 50 g/hd/d (equivalent to 1.5 kg/hd/month or 0.1 CS/month). The variations were then divided into 4 periods that aligned with:

1. Joining to scanning
2. Scanning to lambing
3. Lambing to weaning
4. Weaning to joining

The nutrition level was adjusted in each period as described below and for each nutrition profile the energy demands and the resulting production of the ewes was simulated using the MIDAS simulation spreadsheet. The production levels of the progeny were adjusted as described in the previous section. In the appendix (Table 60, Table 61, Table 62, Table 63 and Table 64), the reproductive performance and energy demands of the ewe, and the estimated progeny birth weight, weaning weight and survival are outlined for the standard feed supply and if the feed supply is varied in each reproduction feed period.

Ewe CS profile was calculated from the ewe LW profile assuming ewes are CS 3 at their SRW and CS changes by 1 unit for each 15 kg of LW change.

9.4.4.1.1 Unscanned mob

For each of the above 4 (reproductive) periods the following process was followed

1. The profitability using the standard feed supply was calculated
2. The standard feed supply was varied up and down by one, two, three or four unit of the variation for each of the reproduction feed periods sequentially.
3. The highest profit combination of feed supply was selected and a factorial analysis was carried out varying each of the reproduction feed periods up and down by one unit. This was to identify if there is an interaction between periods for the most profitable level of feeding.
4. The highest profit combination was selected and steps 2 & 3 were repeated with a smaller increment in feed supply. This was repeated a further 3 times to increase the resolution of the optimum that was identified.

The outcome of this process is an optimum feed profile for an unscanned mob of ewes. The profile should be accurate to less than 0.1 CS units at each of the periods of reproduction.

9.4.4.1.2 Scanned mobs

Mobs were evaluated that had been scanned for multiples i.e. separate the mob into dry, single and multiple bearing ewes. The multiple ewes are a mix of twin & triplet.

A similar process was followed as for the unscanned flock varying each of the separated flocks in each step. The order that the separated flocks were evaluated was based on the number of ewes in each group. For a flock scanned for multiples the order was: Multiples, Singles & Drys.

The options evaluated for the feed supply in the period from joining to day90 and from weaning to next joining were constrained to represent that all ewes are being run together and therefore must be fed the same during each period.

9.4.4.1.3 Optimum profile sensitivity

The same process was followed to determine the optimum profile for the unscanned flock with:

a. higher and lower meat price,
b. higher and lower grain price and
c. higher and lower grazing pressure.

The prices used are outlined in Table 42. Stocking rate was not re-optimised in response to increasing or reducing meat and grain prices. Therefore, the results are for a tactical decision responding to a short-term change in meat and grain prices with current stocking rates, rather than a strategic decision made in response to a long-term change in meat or grain prices. It is more likely that the optimum profile will change for a tactical response than a strategic response because in a tactical setting there are fewer variables (e.g. stocking rate) available to adjust, so a change in ewe LW profile is a more likely response.

The variation in grazing pressure was achieved by constraining the number of DSE/ha on the farm to -33% and +33% compared with the optimum stocking rate. The calculation of DSE/hd was based on the animals SRW and therefore the DSE/hd doesn't change with the nutrition profile.

Sensitivity analysis was also carried out for a flock scanned for multiples to determine the change in profile and the change in profit if:

a. the safety margin built into the ewe & lamb mortality assumptions was removed
b. the changes made to the intake equations as derived in this project were removed
c. the optimum profile as extended in LTEM was evaluated
d. a lower EVG corresponding to a "terminal" type ewe.

9.4.4.2 Cost of missing targets

To evaluate the cost of offering different levels of feed and following a different nutrition profile, a flock scanned for multiples (i.e. triplets not separated from the twins) was examined. The feed supply of the optimum profile was altered so that LW gain or LW loss was between 50 & 100 g/hd/d different to the optimum pattern in each reproduction feed period individually for each class of stock (dry, single & multiple). The reduction in farm profit was divided by the number of ewes and the change in the LW profile of the ewe at the next reproduction point (joining, scanning, lambing or weaning). The value is a calculation of the importance of the optimum level of feeding during the prior period and is simply measured by the change in CS at the end of the period.

9.4.4.3 Joining CS

There were 2 parts to this analysis

1. The impact of altering joining CS for an unscanned flock was evaluated by changing the level of feed offered during the period from weaning to joining. 11 levels of feed were tested, and the ewes were offered the same feed during the pregnancy & lactation period as the ewes following the optimum nutrition profile.
   The flock was based on buying in ewes prior to the 2yo joining so the joining LW for that age group was not altered.
2. A 5x5 factorial experiment was carried out with 5 levels of nutrition in the period from weaning to joining and 5 levels of nutrition during the period joining to lambing. This analysis can demonstrate if the optimum nutrition during pregnancy changes if CS at joining changes, however, the resolution of the test is coarse because only 5 levels are tested.

9.4.5 Results & Discussion

9.4.5.1 Optimum Farm management

The Hamilton farm is in a higher rainfall, longer growing season environment and this is reflected in the higher optimum stocking rate, which then flows into higher income and higher profit per hectare. The Hamilton model doesn't include the opportunity to crop, whereas in the Great Southern region cropping is an option and between 25% and 35% is optimum depending on the time of lambing (Table 44).

In Hamilton, lambing later increases profitability and spring lambing has higher stocking rates and higher income per hectare. However, in the Great Southern later lambing is a lower profit, lower production system because the cost of finishing the late born lambs is high and increases the requirement for supplementary feeding. This result may be different if turning off store lambs was examined.

Table 44: Production and management parameters for the optimum ewe nutrition profile if ewes are scanned for multiples.

	Hamilton, Victoria			Great Southern, WA	
	Autumn	Winter	Spring	Autumn	Winter
Area of pasture (ha)	1000	1000	1000	1553	1328
Area of crop (ha)	-	-	-	577	802
Profit ($/ha)	312	530	733	207	145
Sheep sales income ($/ha)	1220	1296	1563	439	304
Wool sales income ($/ha)	157	148	167	58	38
Number of ewes (hd)	7513	7379	8275	4389	2448
Stocking rate (DSE/WGHa)[1]	14.2	14.0	15.7	5.3	3.5
Supplementary feeding (kg DSE)	46.9	22.0	21.9	5.4	18.8
Supplementary feeding (t)	666	307	345	44	86
Scanning (%)[2]	144	144	147	147	146
Weaning (%)	128%	128%	131%	123%	124%
Pasture growth (t/ha)	8.7	9.0	9.2	4.6	4.0
Pasture utilization (%)	55%	53%	55%	43%	30%

[1] WGHa – winter grazed hectare
Stocking rate calculated using DSE ratings as outlined in the Farm Monitor Project, Dec 2001
[2] Reproductive rate achieved at a constant joining LW is expected to vary depending on the date of joining, however, this is not included in this version of MIDAS. Scanning % is simply a function of joining weight as described in Table 33.

9.4.5.2 Optimum profiles

The precision of on-farm assessment and management of CS is in the range +/- 0.25CS. The modelling has been done to a greater level of precision but for extension messages, variation of less than the on-farm precision is unnecessary.

9.4.5.3 Standard prices

The general guidelines for nutrition targets during pregnancy for maternal ewes are consistent between the regions for each time of lambing with the variation between regions being minor, with the targets for CS at joining and the CS at lambing only varying ±0.2CS (Table 45).

Table 45: Optimum CS at joining and lambing for each scenario if scanned for multiples.

			CS at Lambing		
Location	TOL	CS Join	Dry	Singles	Multiples
Hamilton	Autumn	3.8		3.1	3.7
	Winter	4.1	3.0	3.1	3.5
	Spring	3.9	3.1	3.0	3.4
Great	Autumn	4.2	3.1	3.1	3.3
Southern	Winter	3.9	2.9	3.0	3.4

The optimum profile is to join in CS 4 (± 0.2) which is achieved through access to green feed during the spring flush. For the autumn and winter lambing flocks the peak LW needs to be managed to ensure that subsequent LW loss required is not excessive while still attaining the target CS at lambing that minimises losses due to dystocia. For the later lambing flock in both environments it is profitable to feed supplement to limit LW loss from the peak to joining such that joining CS is maximised while ensuring that the rate of LW loss during pregnancy when feed is limiting is not excessive.

The CS targets at lambing for singles is close to 3.0, which is the maximum CS for single bearing ewes without increased risk of mortality due to dystocia. The lambing CS target for multiple bearing ewes is to be about 0.4 CS higher than the single bearing ewes and to achieve this during late pregnancy by maintaining LW or only allowing slow LW loss if this is the most feed limiting period of the year.

9.4.5.4 Sensitivity to meat price

Varying meat price has a more than proportional effect on farm profit for the Hamilton flocks (Table 46). The effect is less for the Great Southern because of the inclusion of crop in the system. Varying the meat price in the range +/- 33% has only a very minor effect on the condition score targets (Table 47). This indicates that the calculated profiles are robust over a wide range of meat price and the guidelines do not need to be adjusted based on market fluctuations.

Table 46: Higher meat prices increase profitability (profit as a % of profit with the standard meat price).

Meat Price	Hamilton, Victoria			Great Southern, WA	
	Autumn	Winter	Spring	Autumn	Winter
+33%	119%	64%	54%	15%	9%
Standard	0%	0%	0%	0%	0%
-33%	-118%	-64%	-54%	-14%	-17%

Table 47: Optimum CS profile for twin bearing ewes in an unscanned mob for each scenario and varying meat prices.

Meat price	Hamilton, Vic						Great Southern, WA			
	Autumn		Winter		Spring		Autumn		Winter	
Scenario	CSJ	CSL	CSJ	CSL	CSJ	CSL	CSJ	CSL	CSJ	CSL

+33%	3.9	3.3	4.3	3.3	3.9	3.1	4.1	3.1	3.9	3.2
Standard	3.8	3.3	4.2	3.1	3.9	3.1	4.1	3.0	3.9	3.1
-33%	3.7	3.1	4.2	3.2	3.8	2.9	4.1	3.0	3.9	3.1

9.4.5.5 Sensitivity to Grain price

In the Great Southern scenarios, increasing grain price increases farm profit whereas for Hamilton an increase in grain price reduces profitability (Table 48). This difference reflects the role of crop in the Great Southern farm system. For the GS farm the change in profit due to varying grain price is a trade-off between the increase in income from the crop enterprise and the increase in cost for supplementary feeding in the livestock enterprise.

Similar to meat price, varying the grain price only has a minor impact on the optimum CS profile (Table 49). Again indicating that the optimum profile is robust and the guidelines do not need to include adjustment for grain prices.

Table 48: Impact of varying grain prices on profitability (profit as a % of profit with the standard grain price).

Grain Price	Hamilton, Victoria			Great Southern, WA	
	Autumn	Winter	Spring	Autumn	Winter
+33%	-35%	-7%	-4%	47%	40%
Standard	0%	0%	0%	0%	0%
-33%	37%	8%	5%	-18%	-18%

Table 49: Optimum CS profile for twin bearing ewes in an unscanned mob for each scenario and varying grain prices.

Grain price Scenario	Hamilton, Vic						Great Southern, WA			
	Autumn		Winter		Spring		Autumn		Winter	
	CSJ	CSL	CSJ	CSL	CSJ	CSL	CSJ	CSL	CSJ	CSL
+33%	3.8	3.3	4.2	3.2	3.9	3.0	3.9	2.9	3.9	3.2
Standard	3.8	3.3	4.2	3.1	3.9	3.1	4.1	3.0	3.9	3.1
-33%	4.1	3.4	4.3	3.3	3.9	3.1	4.1	2.9	3.9	3.1

9.4.5.6 Sensitivity to grazing pressure

Varying grazing pressure is a primary driver of profitability in the livestock enterprise (Figure 32). At low levels of grazing pressure there are insufficient animals to convert a high proportion of pasture into product. At high grazing pressures there is insufficient pasture available per animals and either production per head is reduced or the amount of supplementary feeding must be increased. Profitability is slightly less sensitive in the Great Southern because the farm includes a component of crop and this buffers changes in farm profit with changes in stocking rate.

This analysis has examined the degree to which the optimum management at low and high grazing pressure is to allow the profile to change or to actively manage the profile to maintain production per head.

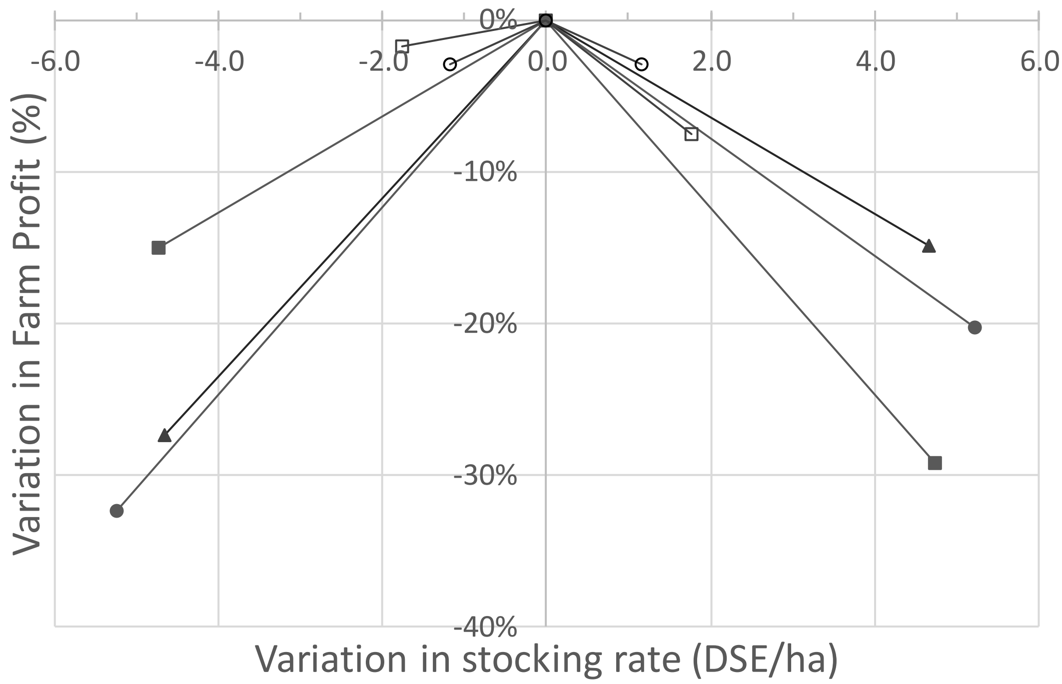

Figure 32: Altering grazing pressure has a major impact on farm profitability. Hamilton Vic - solid symbols, Great Southern WA - open symbols. Autumn lambing - □, Winter lambing – Δ, Spring lambing - ○.

There are moderate changes to the optimum profile when grazing pressure is altered (Table 50). The optimum joining condition for Hamilton reduces by up to 1.4 CS when the stocking rate is doubled from the low to the high level evaluated. This is consistent with the extra liveweight that would be volunteered with a lower stocking rate. The increase in CS at joining with a lower stocking rate is associated with greater weight loss during pregnancy and only a small change in CS at lambing.

In the Great Southern there is less variation in optimum CS at joining, with only a 0.2 CS reduction when SR is doubled. This indicates that feed is being more actively managed in this shorter growing season environment and is likely due to the requirements to finish the lambs competing more strongly with feed for the ewes.

Table 50: Optimum CS profile for twin bearing ewes in an unscanned mob for each scenario and varying stocking rate.

Stocking rate Scenario	Hamilton, Vic						Great Southern, WA			
	Autumn		Winter		Spring		Autumn		Winter	
	CSJ	CSL	CSJ	CSL	CSJ	CSL	CSJ	CSL	CSJ	CSL
+33%	3.5	3.1	3.9	3.2	3.2	3.1	3.9	2.9	3.7	3.0
Standard	3.8	3.3	4.2	3.1	3.9	3.1	4.1	3.0	3.9	3.1
-33%	4.4	3.4	4.5	3.4	4.6	3.1	4.1	3.0	3.9	3.1

9.4.5.7 Sensitivity to the safety margin

A safety margin was built into the modelling because of uncertainty surrounding the level of ewe and lamb mortality when the rate of LW loss during pregnancy is high. To test the importance of these assumptions and the implications for the profitability of the profiles extended in the guidelines the optimum profile was calculated if the safety margin was not required (Table 51 compared with Table 52). Then the profitability of the guidelines pattern was compared with the optimum if the safety margin was not necessary and the profitability of following the 'no safety margin' pattern if the safety margin was required (Table 53).

Table 51: Optimum CS profile for each scenario scanned for multiples if the safety margin is not required.

			Dry			Singles			Multiples		
Location	TOL	CSJ	J-90	90-L	L-W	J-90	90-L	L-W	J-90	90-L	L-W
Hamilton	Autumn	3.8	0.1	-0.5	-1.7	0.0	-0.6	-0.5	0.1	0.0	0.3
	Winter	4.3	-0.1	-1.0	-1.5	-0.1	-0.7	-0.6	-0.1	-0.4	0.2
	Spring	4.2	-0.8	-0.4	-0.2	-0.8	-0.2	1.0	-0.8	0.0	1.2
Great	Autumn	4.1	-0.5	-0.7	0.8	-0.5	-0.6	0.7	-0.5	-0.3	0.8
Southern	Winter	3.9	-0.2	-0.8	0.9	-0.2	-0.6	0.9	-0.2	0.0	0.8

Table 52: Optimum CS profile for each scenario scanned for multiples for the standard production & management (with the sfety margin included).

			Dry			Singles			Multiples		
Location	TOL	CSJ	J-90	90-L	L-W	J-90	90-L	L-W	J-90	90-L	L-W
Hamilton	Autumn	3.8	-0.2	0.8	-0.8	-0.2	-0.5	-0.3	-0.1	0.0	0.3
	Winter	4.1	-0.4	-0.7	-0.8	-0.4	-0.6	-0.3	-0.4	-0.2	0.2
	Spring	3.9	-0.6	-0.2	0.0	-0.6	-0.3	1.1	-0.6	0.1	0.8
Great	Autumn	4.2	-0.6	-0.5	0.7	-0.6	-0.5	0.9	-0.6	-0.3	0.7
Southern	Winter	3.9	-0.5	-0.5	1.1	-0.5	-0.4	1.1	-0.5	0.0	0.8

Table 53: Reduction in profit from managing with a safety margin when it is not required or managing without a safety margin when it is required.

Location	TOL	Reduction in Profit ($/ewe) if:	
		Manage to a safety margin when not required	Don't have a safety margin when it is required
Hamilton	Autumn	-1.79	Excessive deaths
	Winter	-1.41	Excessive deaths
	Spring	-0.11	-1.87
Great	Autumn	-0.46	-2.40
Southern	Winter	-0.13	-3.52

A comparison of the optimum profile with the safety margin (Table 51) and without the safety margin (Table 52) shows that the profiles vary. There is relatively small difference in CS at joining but the rate and timing of LW loss varies. The change depends on the timing of the availability of feed. The rate of LW loss tends to increase during the period when feed is most limiting, this adjustment is most obvious in the dry sheep where there is no production overlay affecting selection of the optimum profile. Where the increase in the rate of LW loss occurs in mid to late pregnancy the rate of LW loss in early pregnancy is usually reduced, this indicates that the target is a given quantity of LW loss over pregnancy to reach a target CS at lambing to reduce deaths due to dystocia.

The reduction in profit due to following the more conservative pattern if it is not necessary (i.e. mortality doesn't increase with higher LW loss or higher CS at lambing) is between $0.11 and $1.80 per ewe depending on the region and time of lambing. This is much less than the cost associated with following the 'no safety margin' pattern when it is required and increased mortality is incurred. In 2 of the 5 scenarios it was not possible to calculate the impact on profitability because ewe mortality was greater than 10% and in the other 3 scenarios the cost varied from $1.87 up to $3.50 per ewe. This indicates that it is justified to include the safety margin in the guidelines because the reduction in profit from including the safety margin is much less than the risk associated with not including the safety margin.

9.4.5.8 Sensitivity to EVG

The EVG calculated from the DXA results varied for the ewes measured in Hamilton and the ewes measured in Katanning. There could be many contributing factors, but one is that there is variation between genotypes and that there are some maternal bloodlines that have more terminal influence in their breeding and that these bloodlines have a lower EVG. A sensitivity analysis was carried out to determine if the optimum profile differs for this type of sheep. Then the reduction in profit for a "terminal" type following the profile that is optimum for a "maternal" type and a "maternal" type following the optimum profile for a "terminal" type was calculated to determine whether the discrepancy is important to resolve.

The "terminal" type ewe has a lower EVG and therefore for a given energy deficit will lose more LW, or for a given energy surplus will gain more weight. Therefore, when offered the same feed over a period of a year the "terminal" type will display a larger fluctuation in LW from peak to trough. Understanding this is important for producers to be able to feed budget for their bloodline. Furthermore, if death rate is related to rate of LW loss (as assumed in this analysis) the terminal type ewe will have higher mortality when offered the same feed over a cycle of LW gain and LW loss. This extra mortality reduces the profitability of a "terminal" type ewe being offered the optimum feed profile for a "maternal" type ewe (range -$1.40 to -$5.34/ewe), however, there is much lower cost associated with a "maternal" ewe following the feed profile that is optimum for a "terminal" type (range -$0.39 to -$1.59).

Table 54: Optimum CS profile for each scenario for a "terminal" type sheep.

			Dry			Singles			Twins		
Location	TOL	CSJ	J-90	90-L	L-W	J-90	90-L	L-W	J-90	90-L	L-W
Hamilton	Autumn	4.0	-0.4	-0.5	-0.9	-0.4	-0.5	-0.1	-0.3	0.0	0.4
	Winter	4.3	-0.7	-0.7	-0.7	-0.8	-0.5	-0.2	-0.7	-0.1	0.4
	Spring	4.1	-0.8	-0.4	-0.3	-0.8	-0.3	1.5	-0.8	0.2	1.0
Great	Autumn	4.2	-0.8	-0.5	0.8	-0.8	-0.6	1.3	-0.8	-0.3	1.1
Southern	Winter	3.8	-0.3	-0.4	1.0	-0.4	-0.4	1.4	-0.4	0.1	0.8

Table 55: Reduction in profit for a "terminal" type ewe being offered the feed profile that is optimum for a "maternal" type ewe and for a "maternal" type ewe being offered the feed profile that is optimum for a "terminal" type ewe.

Location	TOL	Reduction in profit	
		"Terminal" on "Maternal" feed	"Maternal" on "Terminal" feed
Hamilton	Autumn	Excessive deaths	0.39
	Winter	5.34	1.59
	Spring	1.72	0.71
Great	Autumn	1.42	0.61
Southern	Winter	2.05	0.57

It is considered important to improve our understanding of the variation observed in EVG. The variation could be associated with the technique used with the DXA or due to variation in genotype. If it is associated with technique this is important to resolve so that DXA can be accurately used in future. If it is associated with genotype, this is important for researchers to understand and target their research and also important for producers so they can accurately feed budget.

9.4.5.9 The improvement in the guidelines from this project

This project has developed our understanding of the productivity of maternal sheep with the aim of developing guidelines for optimal nutrition of maternal ewes. To quantify the impact of project L.LSM.0008 the profitability of the optimum profile generated in this project has been compared with the profile being extended as part of LTEM and the best bet profile that could have been generated prior to this project.

The profitability of the optimum maternal profile is between $7 and $11/ewe more profitable for maternal enterprises than the LTEM profile (Table 56). This is a substantial improvement and is due to accounting for the difference in:

a. The production responses for maternal ewes and Merino ewes to nutrition during pregnancy
b. The energy requirements for the lambs being finished for slaughter compared with Merino lambs being retained to hogget age or as breeding ewes.
c. The intake capacity of the maternal ewes compared to Merino

On an industry wide basis with 11million maternal ewes this could increase industry profitability by $11m per year if 10% of the industry is incorrectly using the LTEM recommendations.

The current guidelines compared with the best bet guidelines that could have been developed prior to this project, increases profitability between $2 and $8 per ewe. This is also a substantial improvement and this project has also increased the confidence associated with the guidelines that have been developed.

Table 56: Increase in profit for the guidelines profile compared to the profile being extended in LTEM and the best bet profile prior to this project being carried out.

Location	TOL	Increase in profit compared with:	
		LTEM	B.LSM.0064
Hamilton	Autumn	8.28	Excessive deaths
	Winter	10.09	Excessive deaths
	Spring	11.13	8.01
Great	Autumn	7.00	1.96
Southern	Winter	7.42	2.91

Table 57: Comparison of the guidelines profile with the profile being extended in LTEM and the best bet profile excluding the information from this project.

		Guidelines		LTEM		w/o L.LSM.0008	
Location	TOL	CS Join	CS Lamb	CS Join	CS Lamb	CS Join	CS Lamb
Hamilton	Autumn	3.8	3.4	3.3	3.4	5.0	3.9
	Winter	4.1	3.3	3.3	3.3	4.5	3.8
	Spring	3.9	3.2	3.4	3.3	4.3	3.6
Great	Autumn	4.2	3.2	3.3	3.1	4.2	3.4
Southern	Winter	3.9	3.2	3.3	3.2	3.9	3.4

Optimising the ewe nutrition profile is complementary with improving productivity per hectare. The optimum nutrition profile increases profit at all stocking rates (Figure 33, Figure 34, Figure 35, Figure 36 & Figure 37). In some of the scenarios the optimum stocking rate increases and in other the optimum stocking rate reduces, however, the changes are small and for the guidelines the message can be to remain at the current stocking rate.

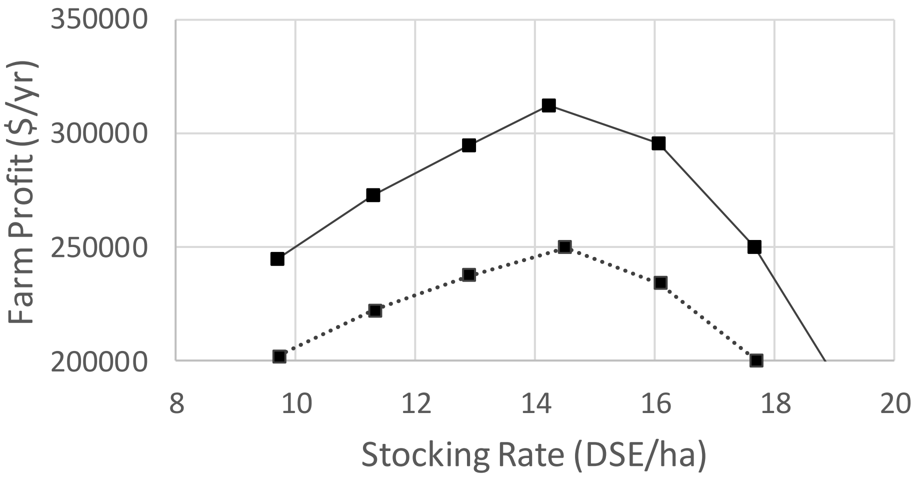

Figure 33: Hamilton Autumn lambing. Comparison of the profitability of different profiles when stocking rate is altered. Solid line is the optimum profile with full information and the dotted line is the profile recommended by LTEM.

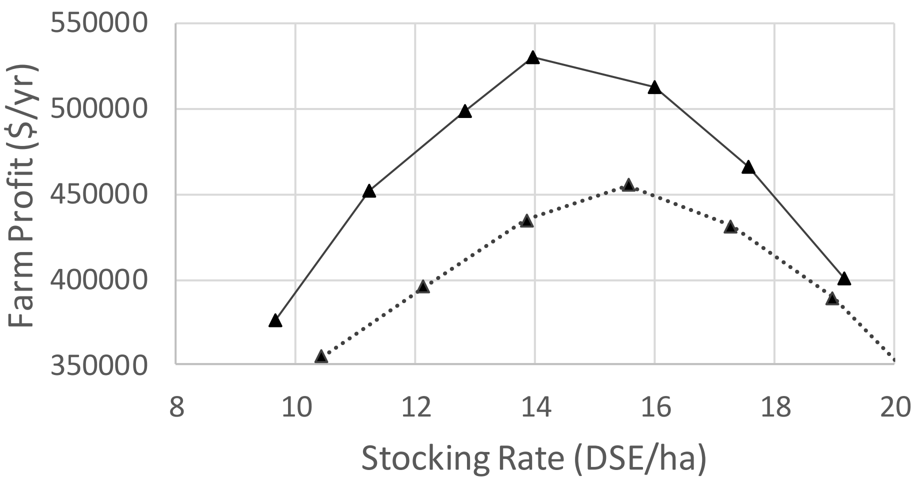

Figure 34: Hamilton Winter. Comparison of the profitability of different profiles when stocking rate is altered. Solid line is the optimum profile with full information and the dotted line is the profile recommended by LTEM.

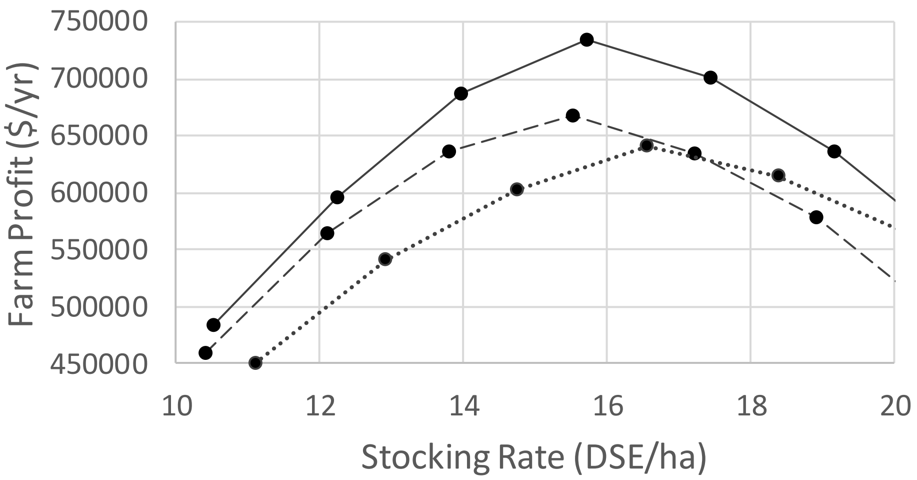

Figure 35: Hamilton Spring. Comparison of the profitability of different profiles when stocking rate is altered. Solid line is the optimum profile with full information, dashed line is optimum without this project and the dotted line is the profile recommended by LTEM.

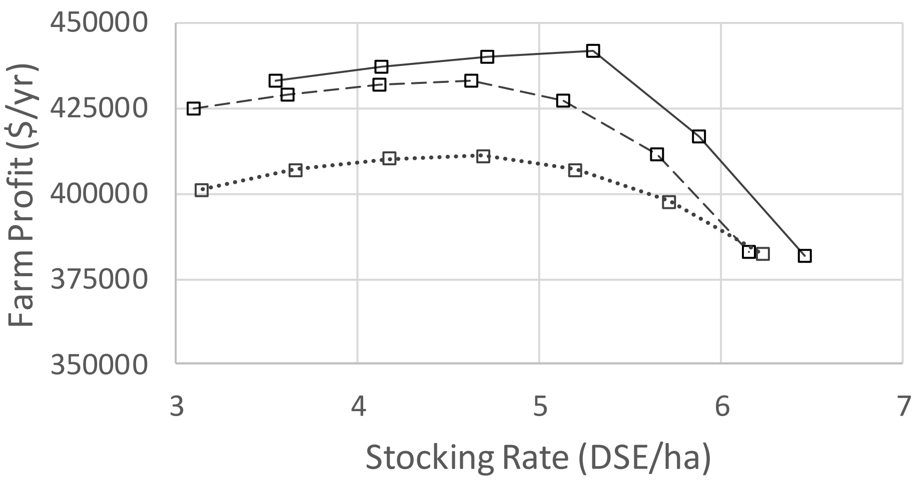

Figure 36: GS Autumn. Comparison of the profitability of different profiles when stocking rate is altered. Solid line is the optimum profile with full information, dashed line is optimum without this project and the dotted line is the profile recommended by LTEM.

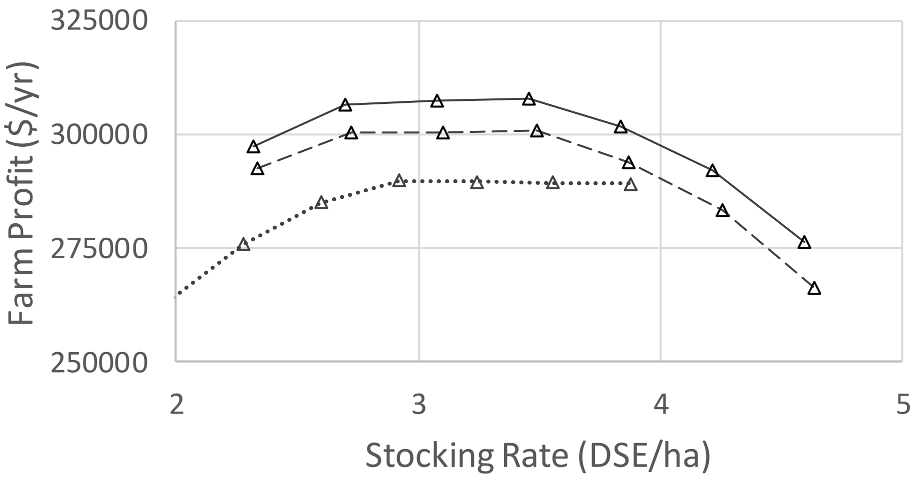

Figure 37: GS Winter. Comparison of the profitability of different profiles when stocking rate is altered. Solid line is the optimum profile with full information, dashed line is optimum without this project and the dotted line is the profile recommended by LTEM.

9.4.5.10 Cost of non-optimal feeding

To evaluate the cost of offering different levels of feed, the feed supply of the optimum profile was altered so that LW gain or LW loss was between 50 and 100 g/hd/day different to the optimum pattern in each reproduction feed period individually for each class of stock (dry, single & multiple). The reduction in farm profit was divided by the number of ewes and the change in the LW profile of the ewe at the next reproduction point (joining, scanning, lambing or weaning).

The cost of non-optimal feeding is a trade-off between the value of the feed and the change in production. At the optimum feeding level, the cost of providing the feed is equal to the production advantage achieved from feeding. The cost of the feed is either the cost of supplementary feed or the opportunity cost of pasture that can be utilised to adjust the number of stock carried. The change in production is associated with the production coefficients previously outlined and the mortality of ewes.

A low cost of missing a target indicates that the change in production is similar to the value of the change in feed. Where there is a big difference between the cost of over and under feeding this is likely due to the increase in mortality, either due to increased LW loss if associated with under feeding, or due to dystocia if associated with overfeeding.

Under-achieving LW at joining is a low priority target with values generally being low except for the later lambing flocks in each environment for which it is profitable to supplementary feed to limit LW loss prior to joining. Over-achieving the joining target has a very high cost in the Great Southern and moderate cost in Hamilton. For the earlier lambing flocks the ewes can be allowed to volunteer their CS at joining provided that it is not too high in which case feed should be restricted. For the laterlambing flocks it is profitable to reduce LW loss from the peak through to joining.

CS at day 90 is also a low priority target, either under- or over-achieving, unless the targets for CS at lambing cannot be achieved without excessive LW loss in late pregnancy.

The target LW change in late pregnancy and the target CS at lambing is the most important target for all scenarios, both under- and over-achieving. This is due to managing the trade-off between excessive weight loss causing mortality through pregnancy toxaemia and insufficient weight loss leading to heavy ewes at lambing with increased risk of dystocia. Therefore, as for Merinos the most important target is LW/CS at lambing.

The cost of over-achieving the target for the LW at weaning is very high for the winter lambing flock in the Great Southern. This occurs because the target is being achieved by feeding high quality spring flush to the ewes and there is little scope to offer more FOO or better quality pasture at this time of year on annual pasture.

Table 58: Change in profit ($/ewe/kg) if there is deviation from the LW targets for ewes with different litter size – Hamilton Victoria.

		Autumn			Winter			Spring	
	Dry	Single	Mult.	Dry	Single	Mult.	Dry	Single	Mult.
LW at joining									
Low		-0.36			-0.45			-1.42	
High		-0.82			-2.99			-1.60	
LW at day 90									
Low		-0.67			-0.49			-0.55	
High		-1.14			-0.71			-0.01	
LW at lambing									
Low	-0.40	-3.08	-1.66	-2.46	-1.92	-1.91	-0.33	-0.50	-0.36
High		-2.61	-1.78	-0.91	-3.58	-3.04	-0.48	-2.36	-1.03
LW at weaning									
Low	-0.63	-1.86	-2.55	-1.05	-2.33	-2.19	-0.18	-0.36	-0.95
High	-0.47	-0.86	-0.89	-0.38	-0.43	-0.65	-0.17	0.09	-0.07

Table 59: Change in profit ($/ewe/kg) if there is deviation from the LW targets for ewes with different litter size – Great Southern in WA.

	Autumn			Winter		
	Dry	Single	Mult.	Dry	Single	Mult.
LW at joining						
Low		-0.79			-1.27	
High		-13.93			-8.02	
LW at day 90						
Low		-0.26			-0.48	
High		-1.66			-0.07	
LW at lambing						
Low	-1.95	-2.33	-1.57	-4.09	-1.60	-2.17
High	-0.79	-1.33	-0.52	-0.31	-0.64	-0.60
LW at weaning						
Low	-0.07	-0.14	-2.04	-0.09	-0.25	-0.21
High	-0.59	-3.10	-3.29	-8.93	-14.88	-28.50

9.4.5.11 Optimum CS at joining

The optimum condition for joining is between 3.8 and 4.2. In the Great Southern for both times of lambing and for winter lambing in Hamilton, the reduction in profit from gaining condition above the optimum is much steeper than if nutrition is below the optimum (Figure 38). For autumn and spring lambing in Hamilton the reduction in profit from being lighter than optimum is similar to, or slightly greater than, the reduction in profit from being heavier than optimum until CS at joining is greater than 4.5.

In the longer growing season environment gaining extra weight is less costly. For the late lambing flock the extra CS at joining can be achieved through extra grain feeding to reduce LW loss from the peak, however, the early lambing flock are being mated close to peak liveweight on green feed and extra LW is gained by reducing stocking rate to increase selectivity when grazing the spring pasture. In the shorter growing season environment, there is less scope for increasing selectivity so the reduction in stocking rate is greater and extra supplementary feeding is also required.

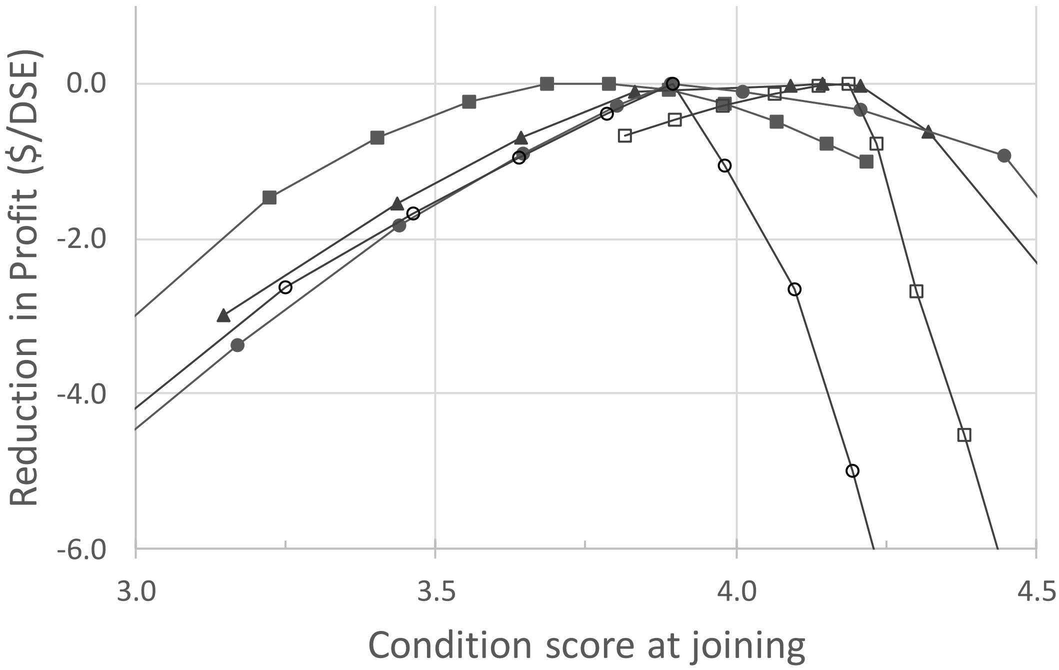

Figure 38: Impact of altering the target CS at joining on farm profitability. Hamilton Vic - solid symbols, Great Southern WA - open symbols. Autumn lambing - □, Winter lambing – Δ, Spring lambing - ○.

If ewes volunteer a higher CS at joining then the optimum management is to allow a greater level of LWL during pregnancy (Figure 39) to lamb in a similar condition (Figure 40). The amount of the extra condition that is lost during pregnancy varies with the scenario but is in the range 60% to 90% of the extra condition that has been gained.

Losing extra condition during pregnancy is in contrast with the finding for Merino ewes for which the optimum was to follow the same pattern of LWC during pregnancy regardless the LW at joining.

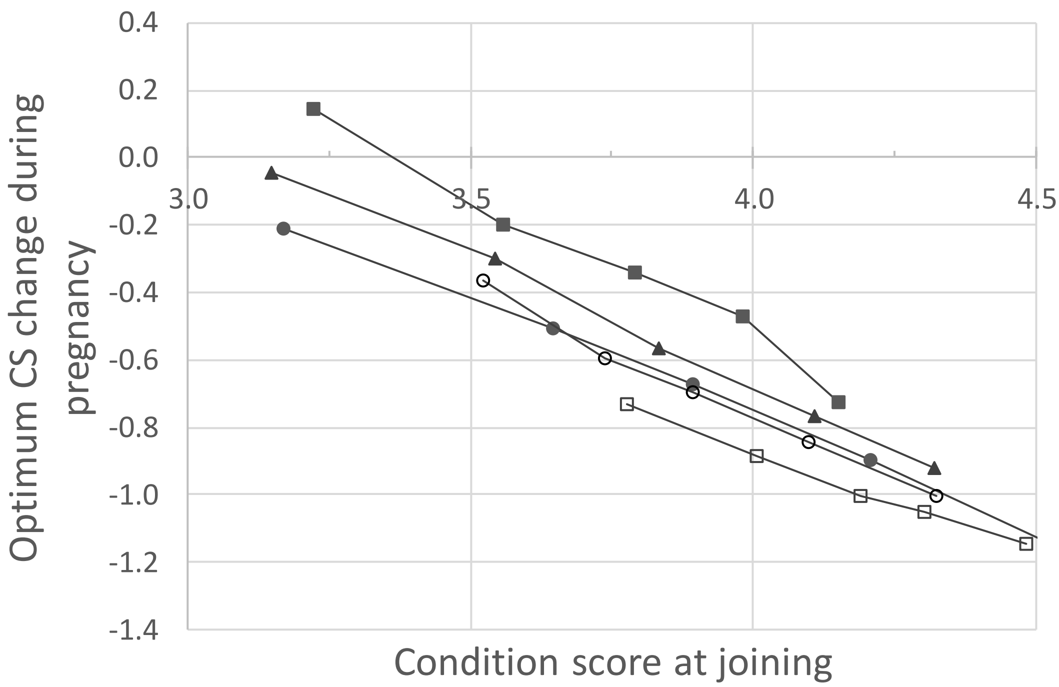

Figure 39: Higher CS at joining is associated with an increase in the optimum CS loss during pregnancy. Hamilton Vic - solid symbols, Great Southern WA - open symbols. Autumn lambing - □, Winter lambing – Δ, Spring lambing - ○.

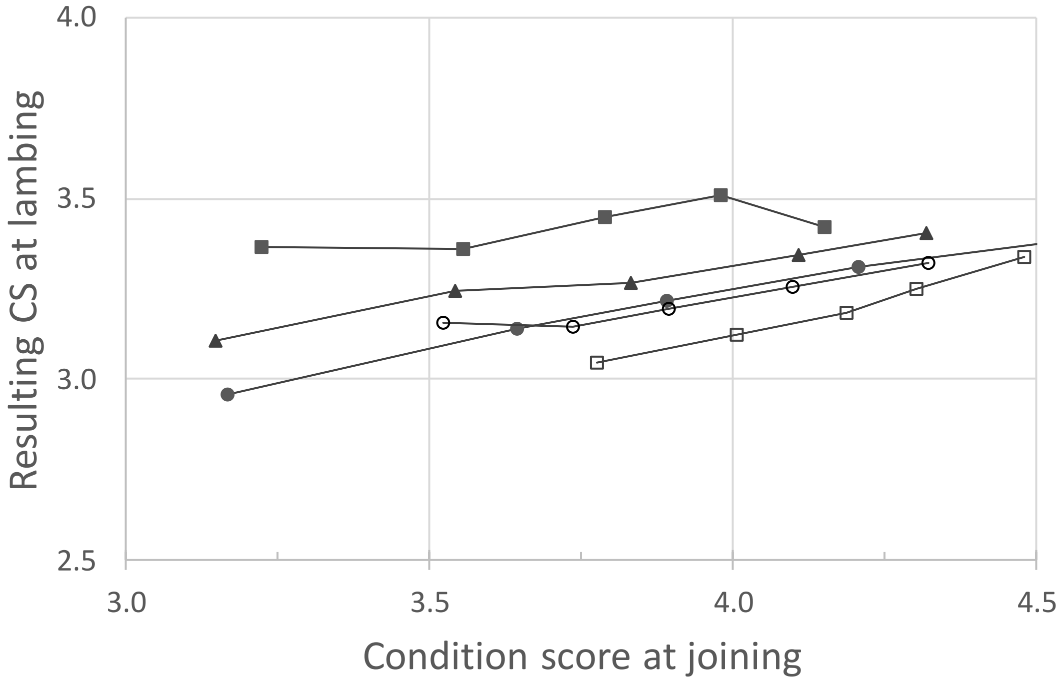

Figure 40: Relationship between optimum CS at lambing (weighted average of lambing ewes) and how it changes if different CS is volunteered at joining. Hamilton Vic - solid symbols, Great Southern WA - open symbols. Autumn lambing - □, Winter lambing – Δ, Spring lambing - ○.

Profitability is much more sensitive to condition score at lambing than condition score at joining (Figure 41 compared with Figure 38). This is consistent with the above results that demonstrate that the optimum level of weight loss during pregnancy varies with the joining condition score. This is showing that the target at lambing is the high priority target which is also shown by the high value of missing the lambing target. So, management prior to joining and during pregnancy is aimed at achieving the lambing CS targets.

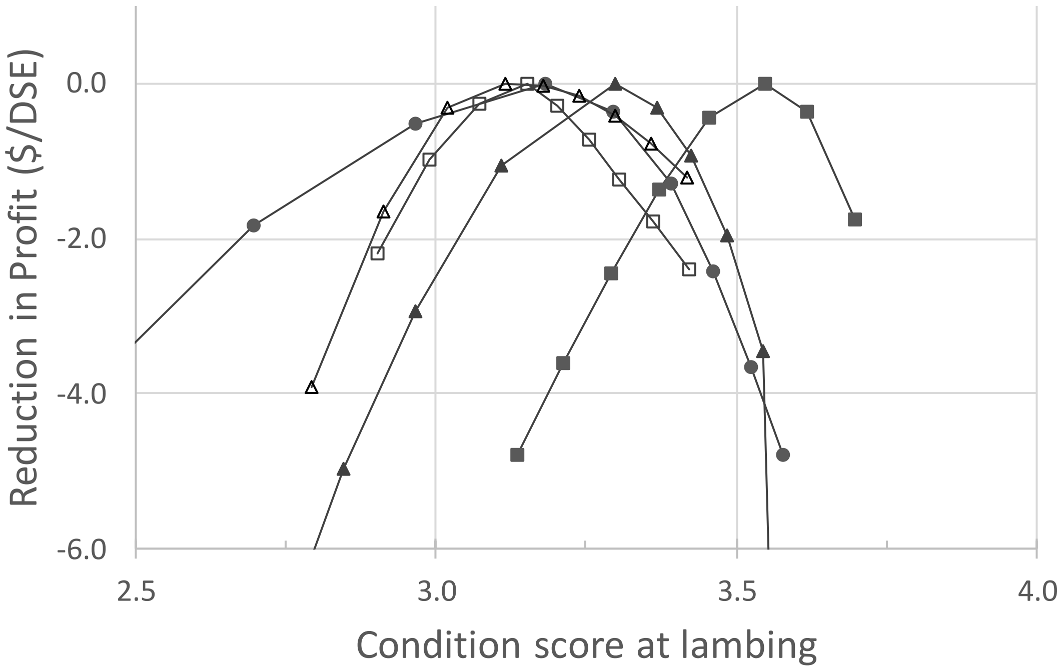

Figure 41: Sensitivity of profit to altering the target CS at lambing. Hamilton Vic - solid symbols, Great Southern WA - open symbols. Autumn lambing - □, Winter lambing – Δ, Spring lambing - ○.

9.4.5.12 Managing seasonal variation

Based on the findings from the CS at joining and stocking rate sensitivity testing it is concluded that producers who receive a favourable spring can allow the ewes to increase in CS provided that they are able to manage nutrition during pregnancy (and for the later lambing flocks, prior to joining) to achieve the targets at lambing. It may be difficult to manage weight in flocks that are not scanned or only scanned wet/dry because weight loss in late pregnancy may be required to achieve the targets for the ewes bearing singles, however, this could have an adverse outcome for the ewes bearing multiples.

9.4.6 Conclusions

Value of the project: Project L.LSM.0008 has developed guidelines for maternal ewes that are significantly better than the profiles being extended through the LTEM program and better than the best profile that could have been developed in the absence of this project. The increase in profit compared with the LTEM profile is between $7 and $11/ewe and the improvement compared with the previous best bet is between $2 and $8/ewe.

Condition score targets: The targets for maternal type ewes are different to the targets developed for Merino ewes. The optimum is to join in condition score of 3.8 to 4.2 and lose condition (up to 1 CS) during pregnancy to lamb at CS 3.0 to 3.1 for singles and CS 3.3 to 3.7 for multiple bearing ewes. For the earlier lambing flocks the optimum is to lose condition in both early and late pregnancy whereas for later lambing the optimum is to lose condition in early pregnancy and maintain condition in late pregnancy. The maximum rate of loss of condition during pregnancy is limited to the level that can be lost without increasing ewe mortality.

For earlier lambing the optimum CS at joining is the level that the ewes volunteer, without supplementary feeding, however, peak CS needs to be managed so that the target lambing CS can be achieved without excessive LW loss during early and late pregnancy. For later lambing the LW loss from the peak is managed with supplementary feeding to achieve the joining CS that allows the lambing target to be achieved without excessive LW loss.

If ewes volunteer a higher or lower CS at joining then the optimum loss of CS during joining is altered. Heavier ewes at joining lose more condition during pregnancy and the CS target at lambing is not altered markedly. In all cases the optimum CS at lambing for singles is about CS 3 and between CS 3.3 and 3.7 for multiples.

The price of supplementary lupin grain was tested in the range $235/t up to $465/t and the price of meat was tested in the range $4.30 to $8.60/kg for lamb, over these ranges there was no change of practical significance to the optimum CS profile.

Safety margin: The impact of the rate of LW loss during pregnancy and CS at lambing on maternal ewe mortality is important for these guidelines. It is an area with little data and a safety margin was included in the guidelines developed. Analysis shows that the cost of including the safety margin is much less than the risk of not including. However, further research is recommended on defining the relationship between rate of weight loss during pregnancy and the risk of pregnancy toxaemia and hypocalcaemia, and ewe CS at lambing and the risk of dystocia.

Feeding standard equations: The two components of the recalibration of the experiments that were least robust were:

1. The value of EVG. There are limited datasets available with which to correct the DXA measurements and to accurately estimate the change in whole body energy reserves. Reducing the EVG increases the predicted fluctuation in LW and CS if offered the same feed which increases the mortality predicted for the ewes. There is an effect of between $0.11 and $3.50 per ewe associated with the variation in EVG, which suggests this is important for the guidelines, however the main driver for understanding the EVG of maternal ewes is so farmers can accurately feed budget and be able to implement the guidelines on farm. Therefore, it is recommended that further studies be done to develop a more robust database to improve the estimation of EVG and help improve the estimation of maintenance requirements and energy use efficiency.
2. the impact of relative condition on potential intake. There was conflicting evidence from our experiments with the standards on the effects of RC on potential intake. Data from the intensive feeding of a pelleted diet showed no effect of RC on intake whereas measurements of LW change in the paddock implied an impact of RC on intake. Varying RC has little effect on the optimum CS profile but does alter the on-farm management practices associated with managing peak CS to ensure high rates of LW loss are not required during pregnancy to achieve the lambing targets.

9.4.7 References

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9.4.8 Production impact of varying the feed supply

Table 60: Scanning percentage, weaning percentage and energy requirements for ewes that follow the optimum profile and the changes from adjusting the feed supply by 5 units in each reproduction feed period – autumn lambing Hamilton, Vic.

	Standard pattern	Adjustment from 1 unit of variation in period			
		Join – D90	D90 – Lamb	Lamb - Wean	Wean - Join
Scanning %	144	-3.0	-3.7	-16.3	-7.0
Weaning %	131	-2.5	-4.1	-14.3	-5.8
BWt & lamb survival					
Singles	5.6 / 95%	-0.1 / 0%	-0.1 / 0%	-0.1 / 0%	0.0 / 0%
Twins	4.8 / 91%	-0.1 / 0%	-0.2 / -1%	-0.1 / 0%	-0.1 / 0%
Triplets	3.8 / 74%	0.1 / 2%	-0.1 / -2%	0.1 / 2%	0.1 / 2%
WWt & proportion of lambs					
Singles	34.7 / 36%	-0.6 / 2%	-0.5 / 3%	-1.5 / 9%	-0.5 / 4%
Twins	29.9 / 62%	-0.8 / -1%	-0.9 / -2%	-1.8 / -9%	-0.7 / -3%
Triplets	25.4 / 2%	0.7 / 0%	0.2 / 0%	-0.3 / 0%	0.7 / 0%
ME required					
Join – D90					
Dry	15.5	-0.7	0.5	2.5	2.4
Singles	13.5	-0.8	0.9	2.5	2.3
Twins	13.9	-0.8	0.7	2.5	2.3
Triplets	13.9	-0.4	0.8	2.9	2.8
D90 – Lamb					
Dry	21.6	1.9	0.8	4.3	3.3
Singles	11.6	0.2	-1.9	0.7	0.6
Twins	16.0	0.2	-2.7	1.0	0.7
Triplets	16.1	4.4	-1.4	5.4	5.1
Lamb – Wean					
Dry	9.2	0.5	0.2	-3.2	0.9
Singles	17.9	0.2	0.2	-9.0	0.2
Twins	26.1	1.2	1.9	-5.0	1.8
Triplets	28.2	2.8	5.3	0.8	4.0
Wean – Join					
Dry	14.1	-0.6	-0.5	-0.1	-3.7
Singles	16.8	-0.8	-0.7	-2.6	-4.6
Twins	16.8	-0.2	0.1	0.2	-3.2
Triplets	17.4	-1.2	-0.6	0.0	-3.8
LW change					
Join – D90					
Dry	2.4	-1.6	1.3	6.4	5.5
Singles	-2.5	-1.6	2.5	7.6	6.4
Twins	-1.3	-1.7	1.6	6.8	5.9
Triplets	-1.4	-0.6	2.0	7.4	6.5
D90 – Lamb					
Dry	11.7	2.6	1.0	6.1	4.5
Singles	-7.3	1.4	-2.6	3.5	2.6
Twins	0.0	0.4	-5.1	1.9	1.4
Triplets	-0.4	5.7	-2.6	7.2	6.5
Lamb – Wean					
Dry	-11.3	1.8	0.8	-8.2	3.2
Singles	-4.6	1.6	1.6	-20.6	1.9
Twins	4.1	2.4	3.8	-9.2	3.6
Triplets	3.2	4.1	8.3	2.6	6.0
Wean – Join					
Dry	-1.7	-2.6	-3.0	-4.3	-12.8
Singles	15.4	-1.1	-1.2	9.5	-10.6
Twins	-1.8	-1.0	-0.1	0.5	-10.5
Triplets	-0.3	-8.9	-7.5	-17.2	-18.7

Table 61: Scanning percentage, weaning percentage and energy requirements for ewes that follow the optimum profile and the changes from adjusting the feed supply by 5 units in each reproduction feed period – winter lambing Hamilton, Vic.

	Standard pattern	Adjustment from 1 unit of variation in period			
		Join – D90	D90 – Lamb	Lamb - Wean	Wean - Join
Scanning %	144	-3.7	-7.4	-18.1	-3.9
Weaning %	131	-3.0	-9.3	-15.4	-2.8
BWt & lamb survival					
Singles	5.5 / 94%	0.0 / 0%	-0.3 / -1%	0.0 / 0%	0.0 / 0%
Twins	4.7 / 91%	-0.1 / 0%	-0.4 / -3%	0.0 / 0%	0.0 / 0%
Triplets	3.7 / 71%	0.1 / 2%	0.0 / 0%	0.1 / 2%	0.1 / 3%
WWt & proportion of lambs					
Singles	34.7 / 36%	-0.6 / 2%	-1.0 / 6%	-1.5 / 10%	0.0 / 2%
Twins	29.4 / 62%	-0.6 / -2%	-1.2 / -6%	-1.7 / -9%	-0.1 / -2%
Triplets	24.9 / 2%	2.2 / 0%	2.3 / 0%	1.4 / 0%	2.7 / 0%
ME required					
Join – D90					
Dry	11.5	-0.7	1.6	2.8	1.8
Singles	11.7	-0.6	1.6	2.8	1.9
Twins	11.8	-0.7	1.5	2.8	1.8
Triplets	11.8	-0.4	1.7	3.1	2.1
D90 – Lamb					
Dry	6.9	0.3	-3.9	0.8	0.4
Singles	10.9	0.7	-3.4	1.4	0.7
Twins	13.9	0.8	-4.2	1.8	0.8
Triplets	13.9	3.6	0.4	4.8	3.4
Lamb – Wean					
Dry	6.0	0.0	0.0	-6.0	0.0
Singles	18.2	0.3	0.3	-9.2	0.2
Twins	25.9	0.9	2.0	-8.2	0.4
Triplets	28.0	11.2	11.8	9.5	10.1
Wean – Join					
Dry	19.4	-1.3	-1.2	-2.7	-3.4
Singles	20.8	-1.0	-0.7	-2.0	-2.8
Twins	19.0	-0.5	0.8	1.3	-1.9
Triplets	19.7	-4.9	-4.6	-2.5	-5.6
LW change					
Join – D90					
Dry	-6.1	-0.6	5.1	9.0	5.9
Singles	-6.4	-0.6	5.1	9.3	6.0
Twins	-5.9	-0.6	4.8	9.1	5.9
Triplets	-6.0	-0.1	5.5	9.5	6.2
D90 – Lamb					
Dry	-9.8	2.0	-5.9	4.3	1.7
Singles	-8.4	2.8	-5.7	5.4	2.2
Twins	-3.4	3.0	-7.9	4.8	2.2
Triplets	-4.0	6.0	1.4	7.9	5.7
Lamb – Wean					
Dry	-12.0	1.8	3.5	-16.7	1.0
Singles	-5.0	2.0	3.9	-20.9	1.1
Twins	3.6	2.0	5.6	-18.7	1.0
Triplets	2.3	14.3	15.4	12.5	12.6
Wean – Join					
Dry	28.9	-2.4	-1.6	3.7	-7.8
Singles	20.8	-3.4	-2.2	6.6	-8.6
Twins	6.7	-3.6	-1.4	5.2	-8.3
Triplets	8.7	-19.3	-21.2	-29.5	-23.7

Table 62: Scanning percentage, weaning percentage and energy requirements for ewes that follow the optimum profile and the changes from adjusting the feed supply by 5 units in each reproduction feed period – spring lambing Hamilton, Vic.

	Standard pattern	Adjustment from 1 unit of variation in period			
		Join – D90	D90 – Lamb	Lamb - Wean	Wean - Join
Scanning %	147	-4.9	-9.3	-9.9	-5.0
Weaning %	134	-6.0	-16.5	-8.3	-4.1
BWt & lamb survival					
Singles	5.6 / 95%	-0.2 / -1%	-0.6 / -3%	0.0 / 0%	0.0 / 0%
Twins	4.7 / 91%	-0.3 / -2%	-0.7 / -9%	-0.1 / 0%	-0.1 / 0%
Triplets	3.7 / 72%	0.1 / 3%	0.2 / 4%	0.3 / 5%	0.3 / 5%
WWt & proportion of lambs					
Singles	39.4 / 35%	-1.6 / 4%	-2.1 / 11%	-0.2 / 5%	-0.3 / 2%
Twins	33.5 / 63%	-1.8 / -3%	-2.1 / -10%	-0.5 / -4%	-0.5 / -2%
Triplets	29.0 / 2%	-0.9 / 0%	0.3 / -1%	0.5 / -1%	0.4 / 0%
ME required					
Join – D90					
Dry	9.1	-2.9	0.2	0.9	0.7
Singles	9.2	-2.9	0.2	0.9	0.7
Twins	9.4	-2.9	0.1	0.9	0.7
Triplets	9.4	-2.5	0.8	1.3	1.1
D90 – Lamb					
Dry	10.9	0.1	-5.8	0.5	0.5
Singles	12.9	0.1	-6.4	0.6	0.6
Twins	16.4	-0.5	-8.0	0.0	0.0
Triplets	16.4	6.9	5.0	7.3	7.3
Lamb – Wean					
Dry	12.5	-1.5	-1.5	-8.0	-1.5
Singles	30.8	0.8	1.0	-6.3	0.5
Twins	31.9	2.7	2.9	-8.2	2.0
Triplets	34.5	4.3	2.4	1.2	2.1
Wean – Join					
Dry	15.5	0.0	0.2	-1.3	-3.6
Singles	15.6	1.1	2.3	1.5	-2.1
Twins	15.5	1.2	2.6	1.9	-1.9
Triplets	15.8	-1.4	-1.6	-1.3	-3.4
LW change					
Join – D90					
Dry	-8.8	-8.0	2.0	5.6	5.3
Singles	-9.4	-8.0	1.9	5.6	5.4
Twins	-9.0	-8.2	1.7	5.5	5.2
Triplets	-9.1	-7.4	3.5	6.2	5.9
D90 – Lamb					
Dry	-2.7	2.9	-11.3	2.3	2.5
Singles	-4.0	3.3	-12.8	2.5	2.7
Twins	1.5	0.8	-15.6	0.5	0.6
Triplets	1.2	9.6	5.7	9.1	9.3
Lamb – Wean					
Dry	-0.2	-0.6	1.2	-19.9	-2.1
Singles	16.9	3.6	6.8	-11.5	1.6
Twins	11.5	6.8	10.3	-17.5	4.2
Triplets	11.2	11.6	7.8	6.1	7.3
Wean – Join					
Dry	12.6	6.2	8.4	12.4	-5.4
Singles	-2.5	1.4	4.4	3.7	-9.3
Twins	-2.9	0.9	4.0	11.9	-9.7
Triplets	-2.3	-13.5	-16.6	-21.1	-22.2

Table 63: Scanning percentage, weaning percentage and energy requirements for ewes that follow the optimum profile and the changes from adjusting the feed supply by 5 units in each reproduction feed period – autumn lambing Great Southern, WA.

	Standard pattern	Adjustment from 1 unit of variation in period			
		Join – D90	D90 – Lamb	Lamb - Wean	Wean - Join
Scanning %	147	-1.4	-2.7	-6.7	-1.1
Weaning %	126	-1.5	-5.4	-4.6	-0.4
BWt & lamb survival					
Singles	5.5 / 92%	-0.1 / 0%	-0.2 / -1%	0.0 / 0%	0.0 / 0%
Twins	4.6 / 86%	-0.1 / -1%	-0.2 / -3%	0.0 / 0%	0.0 / 0%
Triplets	3.6 / 65%	0.2 / 5%	0.0 / 1%	0.3 / 7%	0.3 / 7%
WWt & proportion of lambs					
Singles	34.1 / 39%	-0.5 / 1%	-0.6 / 3%	0.2 / 3%	0.0 / 0%
Twins	29.4 / 59%	-0.4 / -1%	-0.5 / -3%	0.0 / -3%	0.0 / -1%
Triplets	26.5 / 2%	0.2 / 0%	0.1 / 0%	0.6 / 0%	0.6 / 0%
ME required					
Join – D90					
Dry	11.3	-0.8	0.2	1.3	0.3
Singles	11.4	-0.8	0.2	1.3	0.3
Twins	11.4	-0.8	0.2	1.3	0.3
Triplets	11.4	-0.6	0.2	1.5	0.5
D90 – Lamb					
Dry	8.5	0.1	-2.3	0.2	0.1
Singles	11.4	0.2	-3.2	0.2	0.1
Twins	14.1	0.3	-2.7	0.2	0.1
Triplets	14.1	5.2	0.4	5.0	4.9
Lamb – Wean					
Dry	17.7	0.0	0.1	-5.6	-0.2
Singles	27.4	0.4	0.4	-6.7	0.2
Twins	29.7	0.7	1.3	-6.5	0.3
Triplets	32.1	2.3	3.8	-1.3	1.5
Wean – Join					
Dry	16.5	0.4	0.6	0.2	-0.3
Singles	17.4	0.3	0.9	1.1	-0.4
Twins	17.4	0.2	0.7	1.5	-0.4
Triplets	17.8	-1.5	-1.0	-0.2	-2.0
LW change					
Join – D90					
Dry	-8.4	-2.7	0.7	4.4	1.2
Singles	-9.0	-2.7	0.7	4.5	1.2
Twins	-9.0	-2.7	0.7	4.5	1.2
Triplets	-9.1	-2.3	0.8	4.9	1.7
D90 – Lamb					
Dry	-7.2	1.0	-3.1	0.7	0.5
Singles	-8.2	1.2	-5.2	0.8	0.5
Twins	-4.3	1.4	-5.1	1.0	0.6
Triplets	-4.8	8.1	0.9	7.8	7.6
Lamb – Wean					
Dry	10.7	0.7	0.9	-8.7	-0.1
Singles	12.8	1.4	2.3	-11.1	0.6
Twins	10.4	1.6	3.2	-11.9	0.6
Triplets	10.3	1.6	4.5	-4.0	0.0
Wean – Join					
Dry	5.8	1.1	1.6	3.8	-1.5
Singles	5.2	0.2	2.3	6.1	-2.2
Twins	3.8	-0.2	1.3	6.8	-2.4
Triplets	4.5	-7.3	-6.2	-8.4	-9.2

Table 64: Scanning percentage, weaning percentage and energy requirements for ewes that follow the optimum profile and the changes from adjusting the feed supply by 5 units in each reproduction feed period – winter lambing Great Southern, WA.

	Standard pattern	Adjustment from 1 unit of variation in period			
		Join – D90	D90 – Lamb	Lamb - Wean	Wean - Join
Scanning %	146	-0.5	-2.8	-0.7	-1.7
Weaning %	127	-0.6	-5.8	0.2	-0.5
BWt & lamb survival					
Singles	5.5 / 92%	0.0 / 0%	-0.3 / -3%	0.0 / 0%	0.0 / 0%
Twins	4.7 / 86%	0.0 / 0%	-0.2 / -3%	0.1 / 0%	0.0 / 0%
Triplets	3.7 / 67%	0.1 / 3%	0.0 / 1%	0.2 / 4%	0.2 / 5%
WWt & proportion of lambs					
Singles	34.1 / 39%	-0.3 / 0%	-0.7 / 3%	0.3 / 0%	0.3 / 0%
Twins	29.5 / 59%	-0.3 / 0%	-0.4 / -3%	0.3 / 0%	0.2 / 0%
Triplets	26.6 / 2%	0.1 / 0%	0.2 / 0%	0.7 / 0%	0.6 / 0%
ME required					
Join – D90					
Dry	11.8	-0.9	0.6	0.7	0.9
Singles	11.9	-0.9	0.6	0.6	0.9
Twins	12.1	-0.8	0.5	0.7	0.9
Triplets	12.1	-0.2	0.7	1.3	1.6
D90 – Lamb					
Dry	8.1	0.4	-4.9	0.2	0.3
Singles	11.6	0.2	-4.9	0.0	0.2
Twins	15.7	0.6	-3.3	0.1	0.4
Triplets	15.7	4.0	-0.1	3.3	3.7
Lamb – Wean					
Dry	22.0	0.1	0.4	-2.0	0.0
Singles	31.5	0.1	0.5	-2.6	0.0
Twins	32.9	0.5	1.8	-3.1	0.0
Triplets	35.4	-0.7	0.0	-4.3	-1.2
Wean – Join					
Dry	14.8	0.1	1.1	0.1	-1.3
Singles	15.5	0.2	1.2	0.3	-1.2
Twins	15.1	0.1	0.5	0.4	-1.2
Triplets	15.5	-0.3	-0.2	0.1	-1.5
LW change					
Join – D90					
Dry	-7.1	-2.1	2.2	2.1	4.8
Singles	-7.7	-2.1	2.2	2.1	4.8
Twins	-7.7	-2.1	2.1	2.2	4.8
Triplets	-7.7	-1.7	2.3	2.6	5.2
D90 – Lamb					
Dry	-7.2	1.2	-9.1	0.0	0.7
Singles	-6.5	1.0	-9.4	-0.4	0.4
Twins	0.2	0.9	-6.6	-0.2	0.5
Triplets	-0.2	4.5	-0.4	3.4	4.1
Lamb – Wean					
Dry	16.5	0.4	3.2	-3.2	-0.1
Singles	16.7	0.6	3.7	-3.8	0.1
Twins	11.8	1.0	3.8	-4.2	0.1
Triplets	11.7	-1.6	-0.3	-6.7	-2.5
Wean – Join					
Dry	-1.3	0.4	3.8	1.1	-5.4
Singles	-1.6	0.5	3.7	2.1	-5.2
Twins	-3.4	0.2	0.8	2.2	-5.3
Triplets	-2.8	-1.3	-1.5	0.7	-6.7

9.4.9 Detailed profiles

Table 65: Optimum CS profile for autumn lambing ewes in Hamilton Victoria with standard prices and optimum grazing pressure.

		Dry			Singles			Twins			Triplets		
Scan	CSJ	J-90	90-L	L-W	J-90	90-L	L-W	J-90	90-L	L-W	J-90	90-L	L-W
Unscanned	3.8	-0.3	0.1	0.3	-0.3	-0.2	0.3	-0.3	-0.2	0.2	-0.3	-0.3	0.1
Wet/Dry	3.8	0.0	0.8	-0.8	-0.3	-0.1	0.3	-0.3	-0.2	0.3	-0.3	-0.2	0.2
Multiples	3.8	0.2	0.8	-0.8	-0.2	-0.5	-0.3	-0.1	0.0	0.3	-0.1	0.0	0.2
Triples	3.6	0.3	0.8	-0.8	0.0	-0.5	-0.3	0.0	0.0	0.3	0.1	0.3	0.3

Table 66: Optimum CS profile for winter lambing ewes in Hamilton Victoria with standard prices and optimum grazing pressure.

		Dry			Singles			Twins			Triplets		
Scan	CSJ	J-90	90-L	L-W	J-90	90-L	L-W	J-90	90-L	L-W	J-90	90-L	L-W
Unscanned	4.2	-0.6	0.0	0.4	-0.7	-0.3	0.3	-0.7	-0.4	0.2	-0.7	-0.4	0.1
Wet/Dry	4.0	-0.5	-0.6	-0.5	-0.5	-0.3	0.3	-0.5	-0.3	0.2	-0.6	-0.4	0.1
Multiples	4.1	-0.4	-0.7	-0.8	-0.4	-0.6	-0.3	-0.4	-0.2	0.2	-0.4	-0.3	0.2
Triples	3.9	-0.2	-0.6	-0.8	-0.2	-0.5	-0.3	-0.1	-0.2	0.2	-0.1	0.0	0.8

Table 67: Optimum CS profile for spring lambing ewes in Hamilton Victoria with standard prices and optimum grazing pressure.

		Dry			Singles			Twins			Triplets		
Scan	CSJ	J-90	90-L	L-W	J-90	90-L	L-W	J-90	90-L	L-W	J-90	90-L	L-W
Unscanned	3.9	-0.8	0.2	0.9	-0.8	0.0	1.0	-0.8	0.0	1.0	-0.8	0.0	1.0
Wet/Dry	3.9	-0.8	0.0	0.4	-0.8	0.0	1.0	-0.8	0.0	1.0	-0.8	0.0	1.0
Multiples	3.9	-0.6	-0.2	0.0	-0.6	-0.3	1.1	-0.6	0.1	0.8	-0.6	0.1	0.7
Triples	3.9	-0.6	-0.2	-0.2	-0.6	-0.3	1.1	-0.6	0.0	0.9	-0.6	0.6	1.0

Table 68: Optimum CS profile for autumn lambing ewes in the Great Southern of WA with standard prices and optimum grazing pressure.

		Dry			Singles			Twins			Triplets		
Scan	CSJ	J-90	90-L	L-W	J-90	90-L	L-W	J-90	90-L	L-W	J-90	90-L	L-W
Unscanned	4.1	-0.6	0.0	0.6	-0.7	-0.3	0.8	-0.7	-0.4	0.8	-0.7	-0.4	0.8
Wet/Dry	4.1	-0.7	-0.4	0.8	-0.7	-0.3	0.8	-0.7	-0.4	0.8	-0.7	-0.4	0.8
Multiples	4.2	-0.6	-0.5	0.7	-0.6	-0.5	0.9	-0.6	-0.3	0.7	-0.6	-0.3	0.7
Triples	4.2	-0.6	-0.5	0.7	-0.6	-0.6	0.9	-0.6	-0.3	0.7	-0.6	0.2	0.6

Table 69: Optimum CS profile for winter lambing ewes in the Great Southern of WA with standard prices and optimum grazing pressure.

		Dry			Singles			Twins			Triplets		
Scan	CSJ	J-90	90-L	L-W	J-90	90-L	L-W	J-90	90-L	L-W	J-90	90-L	L-W
Unscanned	3.9	-0.6	0.1	0.8	-0.6	-0.1	1.0	-0.6	-0.2	1.0	-0.7	-0.2	1.0
Wet/Dry	3.9	-0.6	-0.5	1.1	-0.6	-0.1	1.0	-0.6	-0.1	1.0	-0.6	-0.2	1.0
Multiples	3.9	-0.5	-0.5	1.1	-0.5	-0.4	1.1	-0.5	0.0	0.8	-0.5	0.0	0.8
Triples	3.9	-0.4	-0.5	1.0	-0.4	-0.5	1.1	-0.4	0.0	0.7	-0.4	0.2	0.5