Tracking liveweights of lambs using a Radio-frequency identification linked Walk Over Weighing system to analyse animals' response to supplementary feeding

Augustus Jacobs

AFNR4102 Research Project B / Research Paper

2017

Number of words: 6137 (exclusive of abstract, tables, figures and references)

Number of references: 29

Number of tables: 7

Number of figures: 11

Table of contents

Abstract

Lamb liveweight represents an objective measure which is known to have directly significant effects on economic outcomes, animal productivity, health and subsequent performance of ewe progeny. Radio frequency identification (RFID) linked remote walk over weighing (WOW) systems aim to provide accurate and timely feedback of animal performance and response to environmental and management based change. Research into the tracking of such important indicators is therefore warranted. RFID linked WOW is a concept of remote, field based weighing systems for sheep whereby animals pass over a strategically placed weigh platform and individual weights are recorded and linked to individual identification numbers. The weights are then collected on site (or remotely if available) and processed for analysis. Location, nutritional and production decisions are then made based on liveweight and growth curves constructed from data. The study analysed the effective tracking of liveweight response to supplementary grain feeding. Trial groupings of breed; Merino and Crossbred (XB), ewe and wether were assessed. Raw data was processed to remove illogical values. Treatment v Control of all lamb groups showed significant difference in growth rate ($P < 0.0006$). Seven of eight replicate groups showed significant difference in growth rates ($P < 0.05$). Application of price data to liveweight tracking allowed for further estimation of economic implications to supplementary feeding. Treatment lambs were found to have a net profit $/head/day increase of $0.03 on control group lambs based of price received at final sale of trial animals. The results suggest that tracking of liveweight and growth curve using

RFID linked WOW successfully showed animal response to supplementary feeding. Issues highlighted include technological efficiency and maintenance barriers along with time periods of significant data collection and associated neophobic tendencies of some animals. Whilst this technology requires further development, reliable tracking of liveweight and growth curves was efficient in the analysis of animal response and subsequent economic implications of supplementary feeding.

Introduction

The management and tracking of production animals can deliver vital clues to the productive efficiency of decisions and the financial outcomes associated. The collection of data has become increasingly valuable with advanced and reliable sensors able to monitor animal development over extended time periods and increased spatial zones (Handcock et al. 2009). Frequent data flow from technology such as walk over weighing (WOW) is improving our understanding of management decisions in ways that were once thought impossible. The ability to enhance productivity, profitability and subsequent sustainability is presented directly to commercial livestock producers through the efficiency of data collection. Whilst many are yet to appreciate the scope of precision provided by constant, non-invasive weight analysis technology in a standard pastoral business, equivalent monitoring is already used in many sectors of high input animal production (Brown et al. 2012). Applying this information to areas of increased spatial production remains in its relative infancy.

Electronic weighing of free range animals was first undertaken in 1960's America (Martin et al. 1970) with another two decades passing before this technology was broadened to allow for electronic tagging of animals (Anderson and Weeks 1989). As is customary with many pioneers of emerging technology, the researchers found several preliminary issues pertaining to the reliability of the tracking systems. There was found to be no link between any plant/animal factors and the recorded live weight profiles of cattle in the study. Further research has since been undertaken to improve both the data gathering systems along with analysis and understanding of values provided. The poultry industry (Turner et al. 1984), the pork industry (Schofield 1990) and more recently the dairy industry (Cveticanin 2003) have all invested confidently in technology providing precise and timely information regarding animal liveweights.

Recent work has been undertaken to examine the value of information for research or commercial purposes taken from live, remote weighing systems in sheep flocks. Brown et al. (2014) focused on the remote WOW weighing system produced by Tru-Test and its application on a whole-flock basis. Analysing merino ewe flocks of 200 – 450 head over a 10-month period the study concluded that, whilst WOW was comparable to static weighing data, there are limitations regarding the reliability and accuracy of data particularly when raw data is poorly filtered.

As a cornerstone of Australia's agricultural industry, sheep production should remain a strong focus for technological improvement. Much scope exists to improve production with wool production potential (Ferguson et al. 2011), progeny growth potential (Dove et al. 1994) and lamb survival (Oldham et al. 2011) all being associated with maternal liveweight changes. Such crucial indicators demand research and development in the monitoring of sheep liveweight.

Monitoring of liveweights using a WOW system developed by *Tru-Test Group, NZ* employs the use of radio frequency identification (RFID) tags individually attached to each animal in the study. This allows for each animal to be individually scanned every time it crosses the weigh scales. This is known as Walk Over Weighing WOW (Richards et al. 2010). This is different to the mob based walk over weighing (MBWOW) systems used by Brown et al. (2012) which monitors mob liveweights collectively with analysis undertaken on a whole group basis without any single animal data being accessible. Whilst both systems have seen minimal published research Lee et al. (2008) compared WOW data to that of weekly static (manual, yard based) weighing. The static data was compared to both filtered and unfiltered WOW figures with repeatability of static data proving the highest (0.99). Filtered WOW figures were found to be acceptable from a repeatability viewpoint (~0.9) whilst the unfiltered data showed substandard results (0.35).

The objective of this paper is to assess and report the results from WOW in a pastoral based lamb production system. Validation of a supplementary feeding program and growth tracking will provide more comprehensive understanding of the value provided to the sheep industry through WOW technology. The hypothesis of the study was that remote WOW can effectively track growth patterns of animals and provide information of the animals' response to management and environmental change. This data will be sufficiently frequent to then allow for calculation of financial implications based on real time price estimates of animal value accessible to producers.

Materials and methods

All experimental procedures reported in this paper were approved by the Research Integrity and Ethics Administration of The University of Sydney. All procedures were undertaken in accordance with the procedures and guidelines of the national code of practice for the care and use of animals for scientific purposes.

The research took place on a commercial property near the town of Wallendbeen, New South Wales Australia.

Wallendbeen Station; 113 km north east of Canberra (longitude 148.163194 and latitude -34.540298)

The property of Wallendbeen Station is a family farm which included all relevant infrastructure suited to the production of lambs. The property receives an average annual rainfall of 612mm predominantly through winter and spring. Below average rainfall was received in the months prior to trial commencement with late summer to early autumn feed levels acting as a limiting factor to animal performance in the prelude and early stages of the trial period. This was combated by the inclusion of wheaten hay made available to all animals during the opening 20 days of the data collection period. Above average rainfall was then received for the duration of the trial period excluding the final 15 days where well below the mean was recorded (Fig. 1).

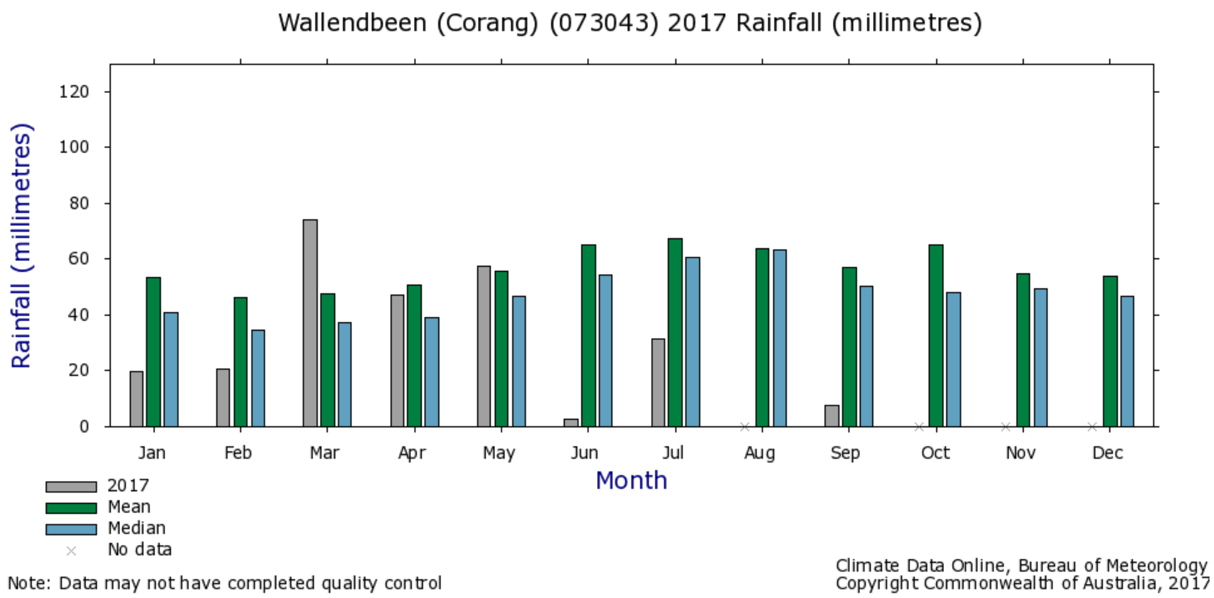

Figure 1. Rainfall data, Wallendbeen

The experiment ran from mid-March to mid-June with a total data collection period of 94 days. A total flock of 144 lambs grazed freely on approximately 22 acres of annual grass/sub clover. This pasture is typical of the south west slopes region. Consisting mainly of *Lolium rigidum*, *Hordeum glaucum* and *Trifolium subterraneum* at levels of almost 20%, good soil fertility accommodated by bi-decade fertiliser application provides a healthy forage diet for grazing sheep.

The flock consisted of merino and crossbred (XB) lambs of both sex with the structure being dictated by animal availability at owner discretion. The mob consisted of;

- 61 merino ewes
- 50 merino wethers
- 15 crossbred ewes
- 18 crossbred wethers

Merino lamb bloodlines were based upon SRS breeding principles characterised through ‘Severn Park’ bloodlines and on-property breeding programs. Their larger frames and plain bodies are seen to be perfect for a dual-purpose operation to suit a mixed farming enterprise. XB sheep were White Suffolk x merino cross lambs. These Lambs are targeted for their quick growth and production of a large, lean carcase.

Taken from the middle to tail of a 2016 August/September drop mob the lambs were marked in November and weaned in December. All animals received 2ml (low volume) ‘5 in 1’ clostridial vaccine for protection against blackleg, malignant oedema, puply kidney and black disease. Castration and tail docking was done via the rubber ring method. All animals received an external application of ‘Vetrazin’ a water-soluble suspension containing the active ingredient cyromazine, an insect growth regulator that breaks the lifecycle of the blowfly before any damage occurs. Each visit to yarding facilities included a walk-through foot bath treatment in 1:10 zinc sulphate to water solution aimed at preventing any cases of ovine foot rot. The entire mob was also drenched with 'Trigaurd Triple Combination' sheep drench once prior to the trial commencement and twice during the data collection period. This treatment is a high potency triple-combination protection for the control and treatment of internal parasites of sheep.

Each animal was manually tagged with an electronic RFID ear tag and one remote weighing station was installed at the single water source to record the liveweight of animals each time water was accessed. Using existing fencing infrastructure, a permanent gateway was further narrowed with portable yarding equipment to funnel sheep into a 30m x 30m yard containing a fixed water trough. Weigh bars were attached to a reinforced steel platform of dimensions 72 x 130cm to act as the weighing platform. A single RFID panel reader was attached to the yarding panel at the top right (as animal enters watering area) of the scales. Tags were placed on the right ear of each animal meaning that RFID readings and tag recording only took place upon entry to the watering facility. The single-entry point also acted as the exit point for all animals. One 12V AGM Deep Cycle battery was used to supply power to the unit with a portable 12V solar panel connected to increase battery longevity. A second battery was kept on site and interchanged when necessary.

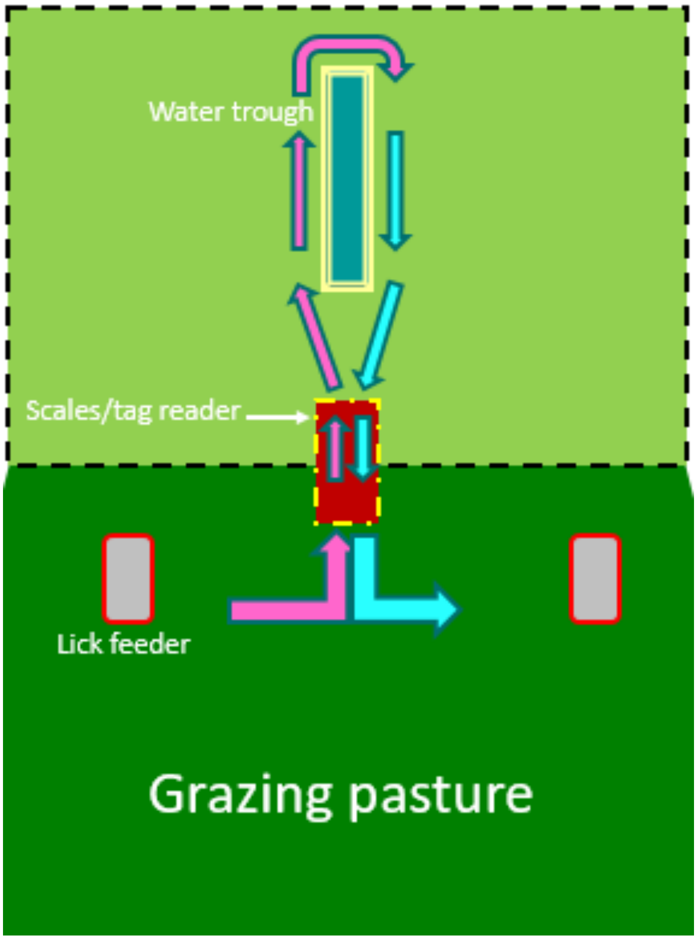

Figure 2. Trial set-up and animal flow.

Figure 3. Trial WOW platform

Figure 4. Lambs prior to tagging

The system recorded animal individual electronic identification (EID), date, time and liveweight. The mob was placed in the paddock with no WOW infrastructure for three weeks prior to the trial commencement. This familiarised animals with the existing permanent gateway leading to the watering location. One week prior to commencement the portable yarding panels were installed to narrow the gateway gap without the presence of a weigh platform. Two 3yr old merino ewes were run with the flock for the initial stages of infrastructure adaption. This was done on recommendation of the owner to provide 'flock leaders' that would teach the younger, less experienced lambs. On the day of trial commencement, following installation of weigh platform and RFID panel reader, the mob were mustered from the external grazing area and pushed/encouraged across the platform. Animals were then left to return freely before the process was repeated later in the day. This mustering was conducted again the following day. On day three of the trial animals were observed from a distance to be freely crossing the platform to access watering facilities and no further mustering was deemed necessary. Three large (8x4x3 approx. 500kg) wheaten hay bales were provided as forage at trial commencement due to the significant lack of carry over summer pasture available because of below average rainfall to the month of February.

The entire mob was run as a single group for 43 days of a control period. On 26 April 45 lambs were removed to act as a control group while the remaining stock commenced a supplementary feeding program. Following the removal of control lambs the mob consisted of:

Control group

- 6 crossbred ewes
- 9 crossbred wethers
- 17 merino ewes
- 12 merino wethers

Treatment group (supplementary grain feeding program)

- 7 crossbred ewes
- 11 crossbred wethers

- 40 merino ewes
- 34 merino wethers

Control group was removed from the trial paddock and placed on similar pasture. These animals were statically weighed on three occasions (13 May, 3 June, 15 June) following removal. Treatment group was returned to the original pasture with two ‘Bromar’ sheep lick feeders situated in the free grazing area providing feed barley grain taken from farm storage facilities. Feeder openings were set to provide minimum grain access as lambs were slowly introduced to a grain concentrate ration to avoid acidosis (Agric.wa.gov.au, 2017). After 10 days lick feeders were opened to the managers discretion allowing further grain access to the end of trial period. The supplementary feeding period was run for a period of 51 days. Following the trial period animals were sold at the owner’s discretion.

Price data was entered as estimates based on available data provided by MLA (Mla.com.au, 2017). Where several market opportunities were available owners’ discretion was accounted for in selecting relevant sale market. Example: Merino ewe lamb value was estimated as breeding stock whilst wether lambs value was calculated by over the hook prices.

Data analysis

Only animals crossing the platform contribute to the liveweight data report. WOW data in its raw form contains a significant number of outliers and ‘false’ readings including many zero weights, half animal weights and double weights. The accuracy of readings and proportion of false readings can have a significant effect of the individual weight profiles of lambs. Data from the WOW station was filtered to remove as many outliers as possible. This was achieved by fitting the data to B-splines penalised on the coefficients (Eilers and Marx 1996) for each EID tag selecting the smoothing parameter with the lowest Schwarz Bayesian criterion. Data outside 1.5 times below or above the residuals for each lamb were removed and the penalised B-spline fitted once more to acquire the predicted liveweight. Daily growth rate was calculated as the first derivative of the predicted liveweight curve. The days between successive weight recordings for each lamb were also calculated. Data from the liveweight and liveweight curve were then combined to provide and average for each animal and previous day statistical analysis with a mixed effects linear regression model using date as repeated factor for each animal and group as a fixed effect (Gonzalez et al., 2014)

Complex statistical analysis was performed using r-studio. Statistical significance of relationships was determined using the $P < 0.05$ criterion.

Major statistical analysis and visual data analysis was produced using Microsoft excel with animal performance analysis and growth relative to dates and price ranges being processed using excel software.

Results

Table 1. Descriptive statistics of liveweight data remotely collected in free grazing and supplementary fed sheep

	n	Minimum	Mean	Maximum	s.d.
All	20556	0	24.75	78	16.53
Filtered values	12490	15	31.66	68	8.486
Predicted	12489	15.01	33.23	67.91	8.782
Growth rate kg/day	12489	-0.2459	0.2463	0.9872	0.1094
Days between observations	7594	0	1.627	45	1.914
no. observations per animal	7730	26	56.84	156	14.75
no observations per day	12489	0	0.965	8	0.949

20 561 liveweights were recorded at the weighing station over a period of 94 days with an average of more than 200 observations per day over the entire study. Data filtering removed 39.3% of observations classified as outliers. The final data set contained 12 490 liveweight values meaning 60.7% of all recorded observations were considered to be accurately reflective of animal true liveweight. Raw data omitted contained frequent extreme values impossible for the range of animal weights partaking in the trial. Of animals present over the entire 94-day time period (suppl. fed treatment group) there was a successful observation entered into the data set every 0.65 days when a nine-day blackout (loss of battery power) is accounted for. Gaps in data were also observed with a maximum number of three days between successive true data observations for six of the treatment animals. The highest number of successful observations per day for a single animal was six whilst each supplementary fed animal entered an average of 144.6 successful data points over 94 days.

Fig. 5 & 6 show the information received from two lambs indicative of wider supplementation trends. A XB wether part of the treatment group and a merino ewe part of the control group. Growth rate curves are indicative of3 the response to supplementary feeding. Raw data can be seen along with liveweight values, predicted liveweight curve and growth rate curve obtained through the aforementioned process. When compared directly to a control group animal it can be seen that the point of supplementary feeding maintains the growth rate far more effectively than control.

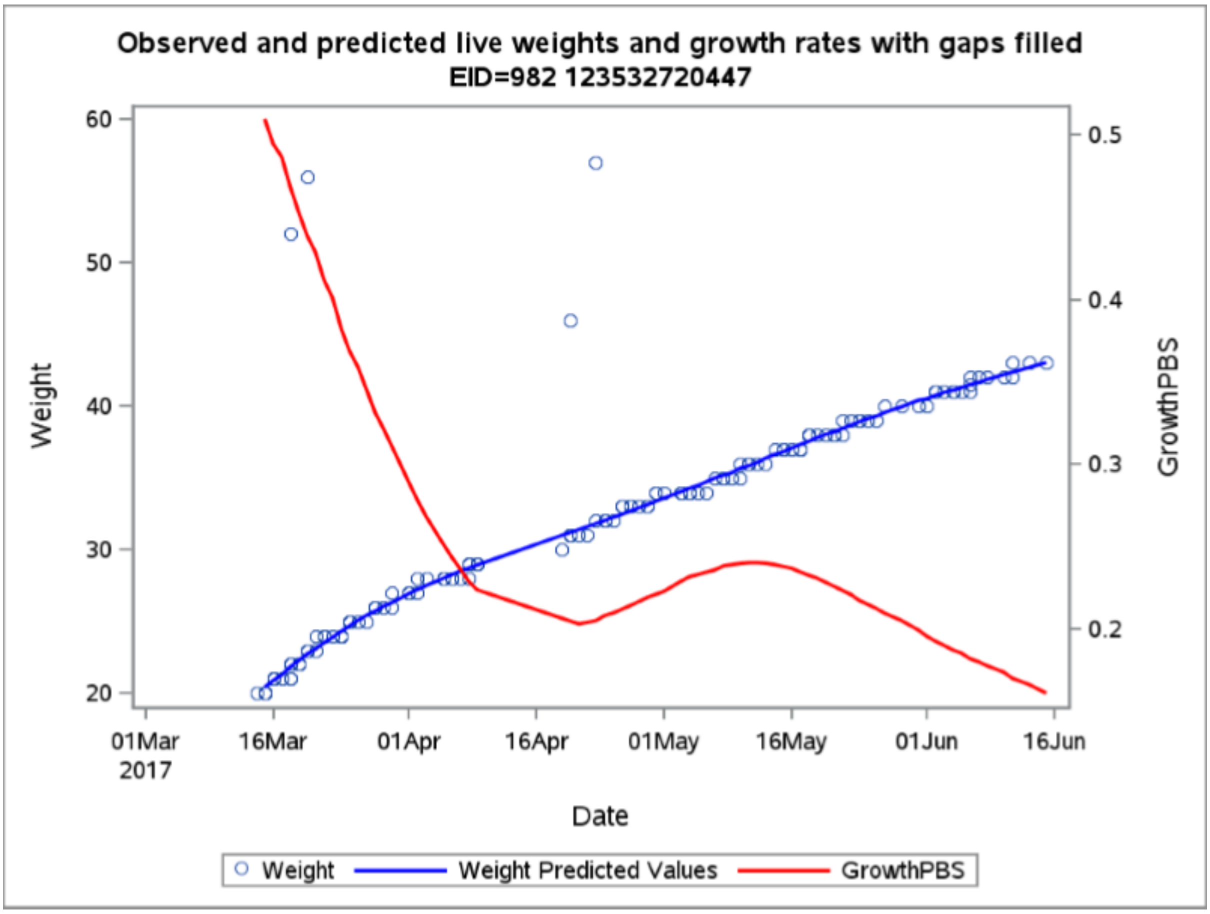

Figure 5. Processed WOW data figures of field number 148, a crossbred wether lamb from the treatment (supplementary fed) group

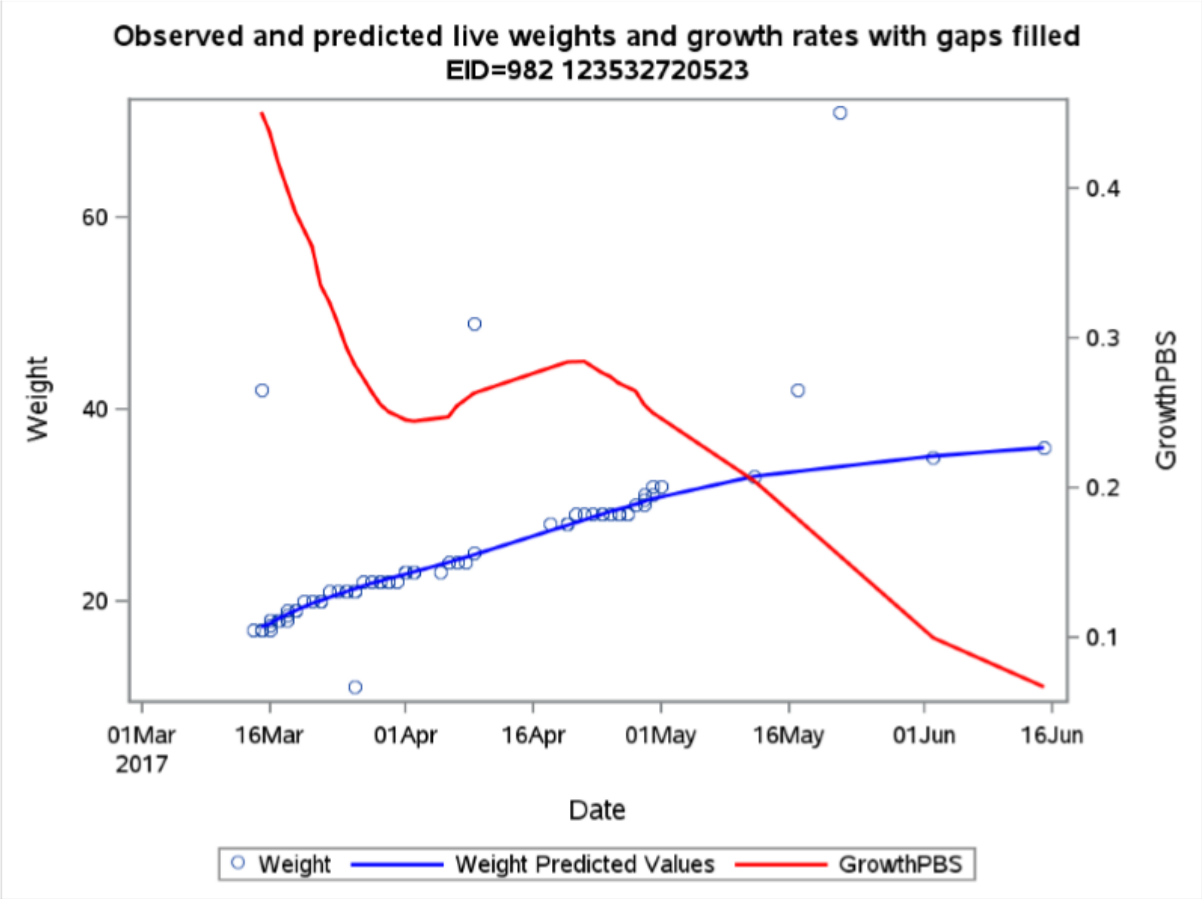

Figure 6. Processed WOW data figures of filed number 72, a merino ewe lamb part of the control group

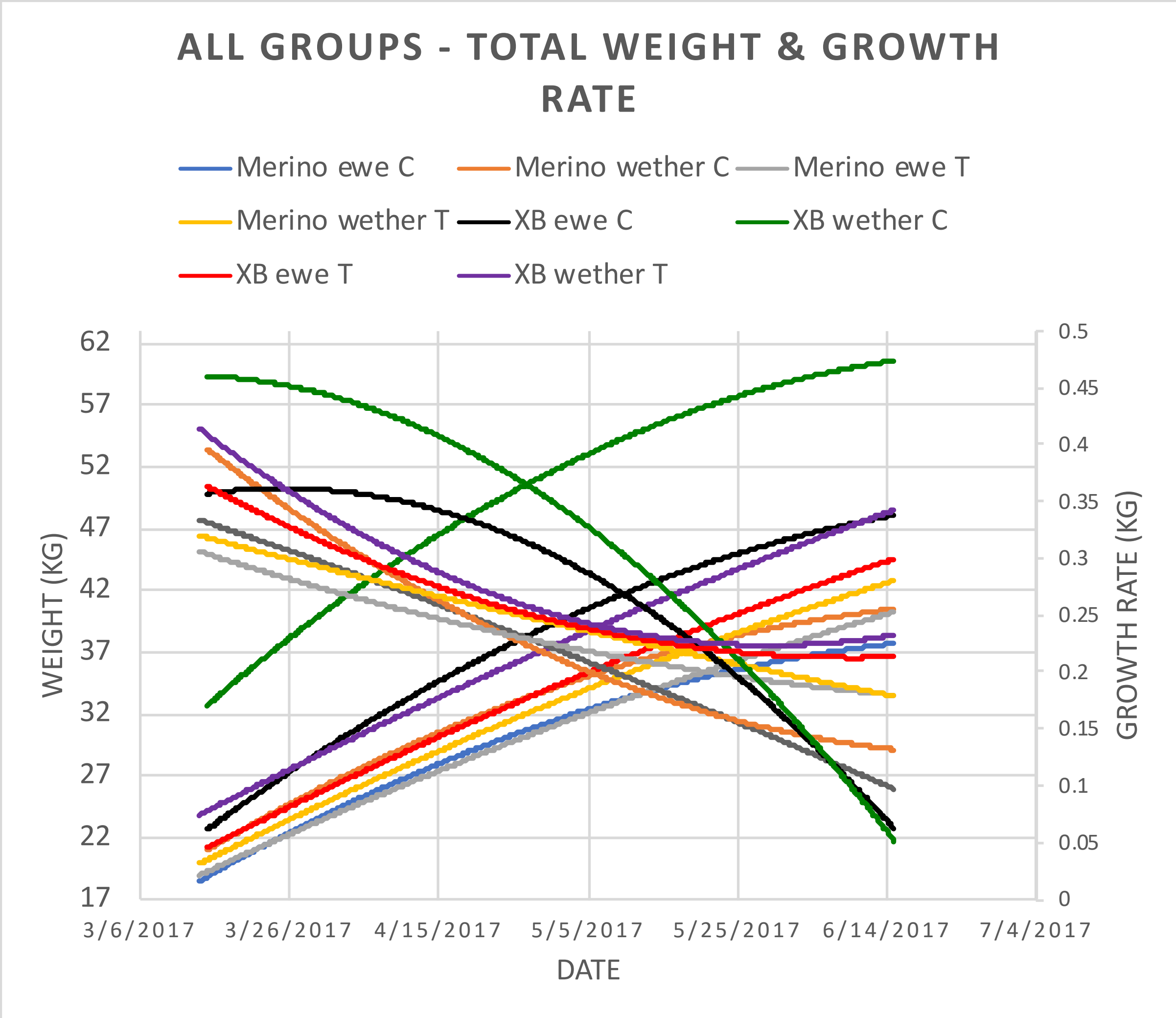

Figure 7. Live weight total & growth rate for each of the 8 replicate groups spaning the entire study period. note; C - Control, T – Treatment

There was significant difference between treatment and control growth rates encompassing all breed and sex ($P < 0.0006$). Overall growth trends showed that growth rate per day moved on a negative trajectory with entire mob rate dropping form approximately 0.35kg per day at trial commencement to 0.15kg per day at trial period finalisation. It was seen that treatment groups with higher entry weights experienced the highest rate of growth decline in control whilst treatment lambs were able to maintain higher growth weights. Fig. 7 shows XB control ewes and wethers both began with high average body weight figures and experienced the most significant decline with XB control wethers dropping from an entry growth rate of approx. 0.46kg/day to 0.05kg/day over the trial period. Conversely XB treatment wethers dropped from approx. 0.42kg/day to 0.23kg/day.

	Group	Average of start weight (kg)	Average weight gain (kg)	% growth	Average
Not Suppl.	Ewe	21.14	21.62	102.27%	
	Wether	27.01	23.27	86.15%	
					94.21%
Suppl.	Ewe	19.90	22.42	112.67%	
	Wether	21.68	23.76	109.57%	
					111.12%

Table 2. Growth percentage relative to starting weight. Animal sex response to treatment.

Accounting for animal sex response to supplementary feeding, results showed both ewes and wethers to have a positive response to barley grain consumption. In both control and treatment groups growth percentages found to be significantly different between ewes an wethers ($P < 0.0001$). With an increased growth percentage of 111.12% of initial body weight the treatment group outperformed control growth percentage of 94.21%. Whilst ewe lambs showed the greatest increase of body weight (112.67%), wether lambs showed the greatest improvement between treatment and control displaying a 23.42% difference in body percentage growth.

	Group	Average of start weight (kg)	Average weight gain (kg)	% growth	Average
Not Suppl.	XB	28.26	25.395	89.86%	
	Merino	19.88	19.485	98.01%	
					93.94%
Suppl.	XB	21.985	24.405	111.01%	
	Merino	19.59	21.765	111.10%	
					111.06%

Table 3. Growth percentage relative to starting weight. Animal breed response to treatment

Analysis of breed performance shows merino lambs to have higher weight gain relative to carcass size in control group and treatment with growth percentage gains found to be significantly different ($P < 0.0001$). The control group experienced 98.01% increase of start weight compared to 89.86% in XB. The treatment group outperformed control however there was little difference between breeds with 111.1% and 111.01% increase of start weight for merino and XB respectively.

	Group	Average of start weight (kg)	Average weight gain (kg)	% growth	Average
Not Suppl.	XB ewe	23.35	24.45	104.71%	
	XB wether	33.17	26.34	79.41%	
					92.06%
	Merino ewe	18.92	18.78	99.26%	
	Merino wether	20.84	20.19	96.88%	
					98.07%
Suppl.	XB ewe	20.7	23.79	114.93%	
	XB wether	23.27	25.02	107.52%	
					111.22%
	Merino ewe	19.09	21.04	110.21%	
	Merino wether	20.09	22.49	111.95%	
					111.08%

Table 4. Growth percentage relative to starting weight. All replicate groups

Viewing results of all replicate groups allows for an understanding of more detailed performance indicators. Merino control v treatment was found to be significantly different comparing ewes and wethers ($P < 0.0059$, $P < 0.0016$). XB control v treatment was found to be significantly different in wether lambs ($P < 0.0001$) but ewe lambs were not found to be significantly different ($P < 0.0556$). All treatment animals more than doubled initial liveweight with XB treatment ewes achieving almost 115% increase on average start weight by the conclusion of the trial. Treatment merinos followed closely whilst XB wethers exhibited the lowest gain in treatment group. XB wethers performed poorly in control group, increasing initial body weight by 79%.

Assessing results from direct weight gain values, XB lambs gained significantly higher levels of weight than merino lambs whilst wether lambs in both breeds and treatments scenarios gained more weight than ewes with average wether weight gains recorded as 1.65kg and 1.34kg higher for control and treatment respectively.

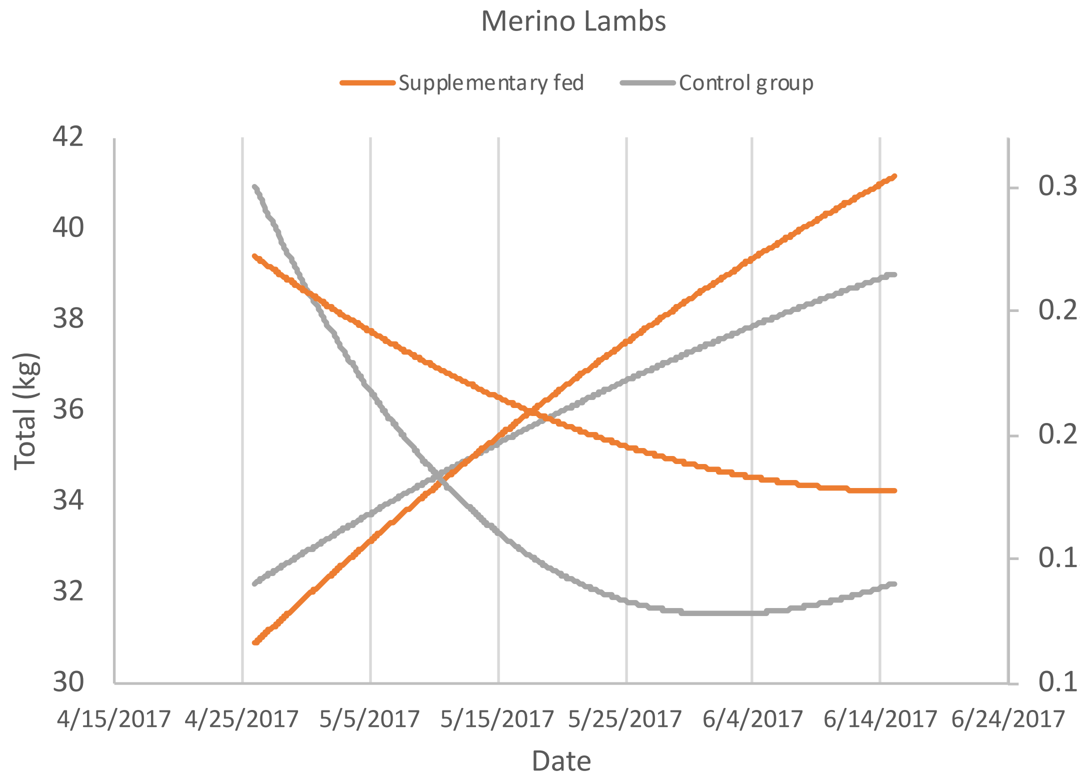

Figure 8. Merino lambs total weight and growth rate per day over treatment period. Control v Supplementary fed

Merino lambs represented the highest number of replicates present in the research and therefore provided increased accuracy for liveweight growth curve and total weight assessments. Analysis of significance found Merino control v treatment lambs to be significantly different in growth rates ($P < 0.0001$). Fig. 8 provides a clear illustration of animal growth response to supplementary feeding in merino lambs. Entering the treatment period with a higher average weight, the control group experienced significant decline in growth rate when compared to treatment group, eventually finishing 1.99kg lighter in total weight.

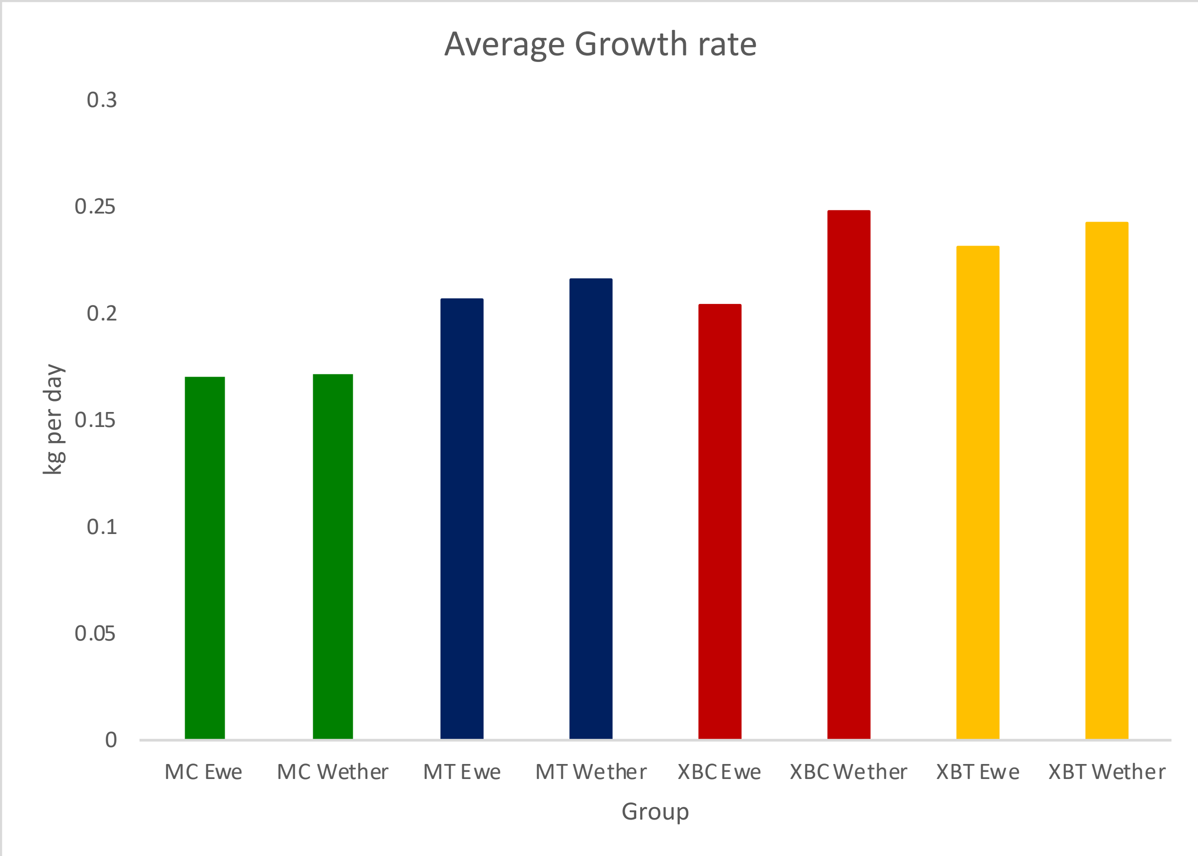

Figure 9. Average growth final growth rate per day by replicate groups over treatment period. Note; M – merino, XB – crossbred, C – control, T – treatment.

Growth rates of the treatment phase are indicative of animal response and performance when entered in a supplementary grain feeding program. Merino treatment lambs showed clear average growth kg/day increase over control merinos. XB treatment also showed higher average growth rate kg/day than control. XB control wether lambs did show unexpected growth rate gains however when percentage of total weight is accounted for this can be attributed to increased trial entry weight. Wether lambs showed higher growth rates kg/day when compared to ewes of the same treatment group across 3 of the 4 breed/sex groupings, control merinos showed even growth rates between ewe and wether lambs

		average growth kg/day	Average Final weight kg	% growth/day	average
Not Suppl.	Merino ewe	0.17	37.7	0.45%	
	Merino wether	0.17	41.02	0.41%	
					0.43%
	XB ewe	0.2	47.81	0.42%	
	XB wether	0.25	59.51	0.42%	
					0.42%
Suppl.	Merino ewe	0.21	40.13	0.52%	
	Merino wether	0.22	42.58	0.52%	
					0.52%
	XB ewe	0.23	44.49	0.52%	
	XB wether	0.24	48.29	0.50%	
					0.51%

Table 5. Growth rate per day as percentage of final body weight. Treatment period, all groups

Daily growth rate averages highlight the efficiency of feed and nutrient conversion into products of financial value, in this case meat or healthy reproductive animal frames. In evaluation of significance between relevant groupings (Control v treatment, ewe v wether, Merino v XB) there was significant difference between growth rates ($P < 0.05$) in all grouping except XB ewe control v treatment ($P < 0.0556$). The treatment group exhibited higher growth kg/day relative to final weight than control. There was little difference in sex or breed with ewes demonstrating to be marginally increased growth over wether lambs

Financial indicators

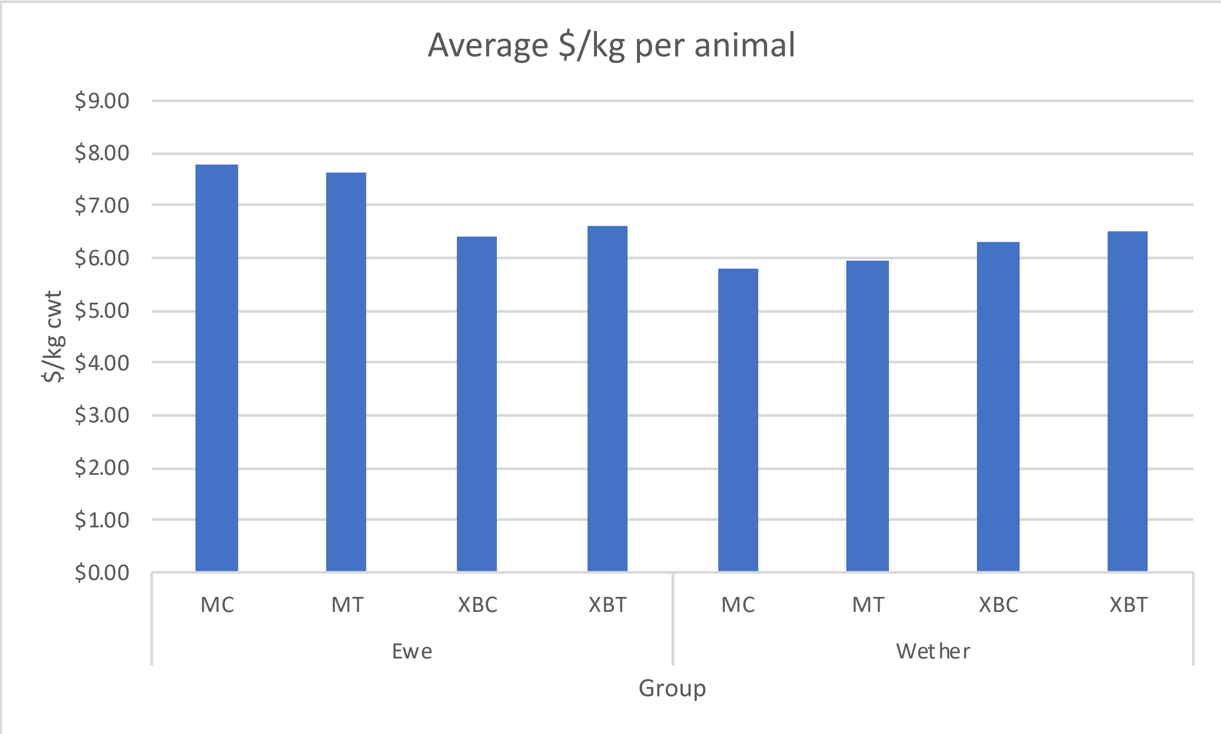

Figure 10. Value $/kg per replicate groups. Note; M – merino, XB – crossbred, C – control, T – treatment.

Fig 10. Represents the relative value/kg of animal carcase weight across the replicate groups. Whilst different replicate groups are grown for diverse purposes (i.e. merino ewes for breeding stock) this is provided as a normalised indication of animal value to a mixed production enterprise. Merino ewes were shown to be significantly more valuable than XB ewes or either sex wethers. Merino wethers are shown to be the least valuable on a $/kg basis.

	Control		Feed supplemented
Growth rate over feeding period (kg/day)	0.19		0.22
Average $/kg received @final sale	$6.56		$6.42
Cost per day feed/head	$0.00		$0.13
Gross profit per day gain	$1.25		$1.41
Net profit per day gain	$1.25		$1.28

Table 6. Calculation of net profit based on final price received. Control v Supplementary fed

Net profit calculations were made to evaluate the financial implications of the supplementary grain feeding program. Allowing for grain costs, supplementary fed animals produced approx. 3 cents per day, per animal more carcase weight profit than control group animals.

		Cost per	Return per
Cost of feed (Barley purchased @$177/t)	$619.78		
Days	51	$12.15	$15.60
Animals	94	$0.13	$0.17
Total	$619.78		$795.80
Return on investment	28.40%		

Table 7. ROI of barley feed. Calculation based on final sale of animals. Supplementary fed group

Return on investment calculations were made to evaluate the efficiency of supplementary feeding grain. After final sale ROI was found to be 28.4% on the initial $620 grain costs.

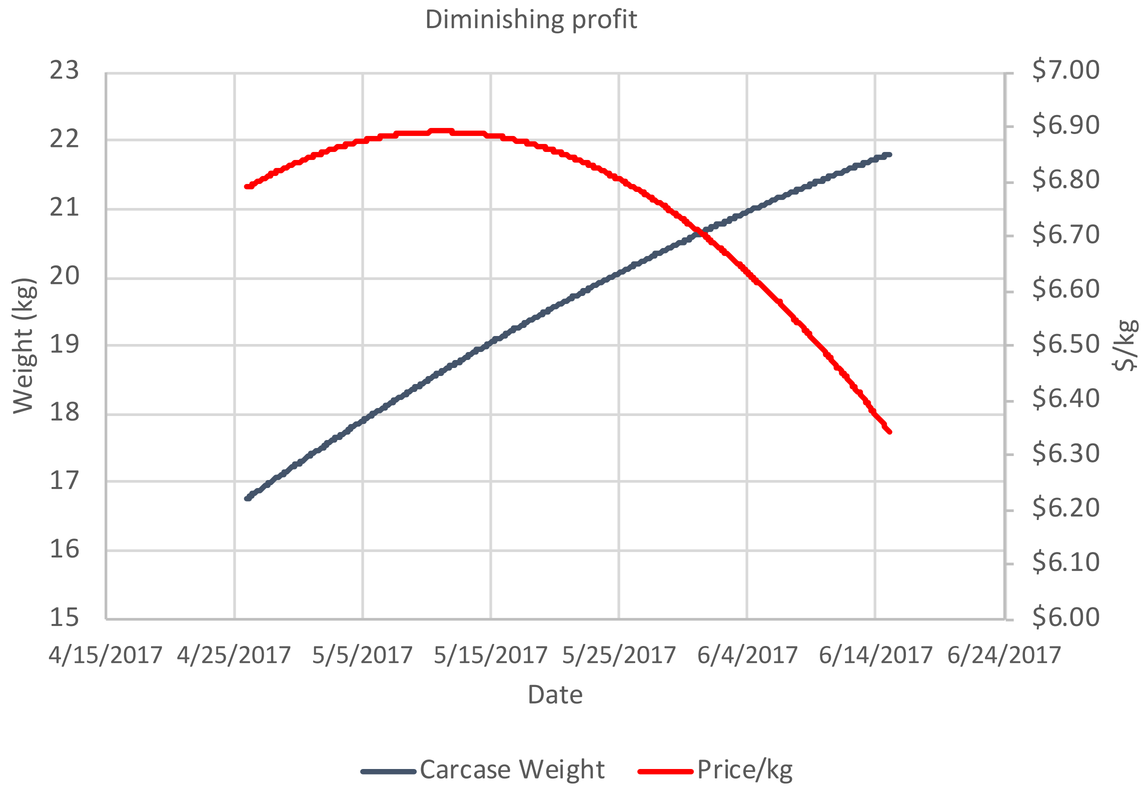

Figure 11. Real time animal carcase weight of treatment group against the average price received per kilogram of carcase (using true price data)

As carcase weight increases there is shown to be a decrease in $/kg received. This can be attributed to both market fluctuations and changes in animal market value do to weight category variation. From peak average price range to final sale the $/kg value diminished by approx. 1.8 – 2 cents per day. Peak ROI of grain input was estimated at 67.5% on 13/5. A 1.18% per day decline of ROI was calculated to the final sale on 16/6 where a 28% ROI was achieved.

Discussion

Whilst remote weighing systems have been developed and commercially available for many years (Charmley et al. 2006) there has been limited uptake on a commercial scale. There has also been a limited amount of research directly relating to sheep and the benefits of RFID based WOW in a mixed mob situation. Liveweight and growth curve figures supplied on a daily basis show the growth profile of individual animals and in this study, have allowed for the grouping of breed and sex replicates to be analysed in a single study and treatment scenario. Processing the data presents analysis in simple, visual figures allowing for the assessment of response to management practices. There was clear response to grain supplementation ($P < 0.0006$) with treatment animals displaying a 16.9% improvement of weight gain over the control group animals when calculated using liveweight trial entry figures. Assessment of rainfall data also provides and understanding of growth rate change in all treatment groups immediately prior to supplementation commencement. With a noted lack of available grazing pasture in the opening weeks attributed to below average rainfall in the 3 months prior to trial commencement, well above average rainfall was received at the trial site in the month of March. This corresponds with an increase in available pasture and a change in growth rates experienced by all groups at the beginning of April.

Visual assessment of sheep both in paddock and a more hands on, in yards approach, is the most common and simple manner of tracking livestock performance for managers. Jones et al. (2011) found that approx. 50% of producers indicated these methods as key to tracking sheep performance. Besier and Hopkins (1989) surveyed 237 farmers, asking them to estimate sheep weight based on visual assessment. It was found that the farmers, on average, estimated the weights 18% below that of the true value. Simple visual appraisal is inherantly unreliable and can be affected by factors such as pregnancy, wool length and gut-fill (Suiter 1994). Such methods are useful for general livestock wellbeing evaluations, are cheap, and relatively simple. However, the margin for error is far too great for this method to be relied upon for efficient and sustainable lamb production (Behrendt et al. 2011). Currently static weighing is considered the most reliable method of obtaining liveweight data from sheep for nutritional management purposes. This must be done on a regular basis and is a labour-intensive task for producers. Static weighing has been confirmed as more repeatable than WOW (Lee et al. 2008) however the quantity of data provided is substantially lower and requires greater levels of manual processing to achieve similar growth rate and liveweight curve establishments within animal groups.

WOW requires the sheep to walk over the weigh platform in a calm manner, one animal at a time to gain reliable liveweight data. Of the data received in this study 39.3% was filtered to remove illogical records. This equates to approximately 3 of every 5 measurements recorded supplying relevant liveweight data. Gonzalez et al. (2014) recorded a 64% success rate of data recording in a WOW study containing free grazing cattle. A previous study of sheep using mob based WOW (non-RFID) found a filtering level of 25% and grouping of data into 5 day groups was necessary to strengthen the statistical relationship between WOW data and static weighing data (Brown et al. 2012). No camera monitoring system was used to evaluate the significance of these illogical data points; however, it is believed to be a result of sheep running, playing, fighting or funnelling through the weigh point at a rate too high for the scales to manage individual recordings. In a review of WOW technology, it was estimated that between 25-30% of data is considered illogical with criteria being set at the discretion of the manager involved (Brown et al. 2014). Once filtered, the study data provided clear growth trends and data clustering to suggest relative accuracy was achieved**.**

Merino ewe lambs responded positively to grain supplementation when average growth rate per day was compared to control group merino ewe lambs ($P < 0.0059$). A 0.07% growth rate per day advantage is considered significant in ewe lamb production when the effects of ewe liveweight on the performance of the ewe and her future progeny have been confirmed. Several studies including; Behrendt et al (2011) Thompson et al. (2011) and Schreurs et al. (2012) have focused on this topic. Wool characteristics such as fleece weight, fibre diameter, staple length and staple strength have all been found to differ significantly ($P<0.05$) between nutritional treatments (Behrendt et al. 2011). When products of economic value such as merino wool are considered to be significantly affected by nutritional based increase of live weight it is crucial that animal growth performance is measured efficiently to maintain and maximise performance in a commercial enterprise. Whilst this paper did not focus on such areas, economic based research into wool performance and pasture/supplementary feeding would serve as a useful guide to dual purpose producers.

A majority of merino ewes involved in the trial were sold as breeders. Behrendt et al. (2011) also looked at reproductive performance and progeny survival of ewes finding that lamb survival to marking was influenced ($P<0.01$) by ewe nutritional treatment. Ewes on high nutrition support achieved 116% lambs marked in comparison to those on low nutrition marking at 100%. The progeny of ewes receiving high nutritional support also performed better than the progeny of low nutritional support ewes. This highlights the significance of healthy growth performance in breeder ewes. This study found a significant improvement in total weight for merino ewe lambs ($P < 0.0059$) when supplemented barley grain as an inclusion to pasture grazing. Conversely XB ewe lambs were not found to be statistically significant ($P < 0.0556$). Treatment ewe lambs showed a 112.67% increase in total body weight over the trial period whilst control group ewes only showed 102.2% body weight increase. It should be noted that this encompasses entire trial weight averages over the 94 days. Considering the fact that grain feeding only occurred in the final 51 days, it is assumed that a majority of the 10.4% improvement between groups was gained over the feeding period.

Wether lambs are most commonly sold over the hooks and differ from ewes in production targets. Wether lambs are grown for meat and in merino cases wool production. This study found wether lambs of both breeds to provide increased meat production. Whilst ewe lambs were able to increase proportionate body size, wether lambs remained the largest producers of liveweight per head. A large, lean carcase is preferred for over the hook animals with excess weight receiving a price penalty. Wether lambs responded to grain supplementation ($P < 0.0016$) with merinos showing a 2.3kg liveweight gain providing significant income increase over control animals.

Due to the availability of animals available for the trial, fewer XB lambs were included which does not provide the corresponding level of confidence achieved through the increased replicates. Whilst this was considered at trial outset it was accepted as an unavoidable limitation with XB replicates deemed acceptable to provide relevant data. This did create certain anomalies such as the maximum growth being achieved by XB control group wether lambs. However, a closer analysis shows the entry weight to be significantly higher for this replicate group. When percentage of start weight gain is calculated this grouping as the second lowest growth rate of all 8 replicates.

Trial issues revolved around power supply over extended time periods. In mid-April, a nine-days period occurred where no data was collected. This is observed in growth curves (fig. 5 & 6) and occurred due to a loss of battery power. Whilst a portable solar panel was installed to trickle charge the 12V battery, no charge life indications were available. This created a situation where regular inspection was required. This was further complicated by the very confined space equipment was installed within to avoid adverse weather effects. Whilst this trial situation required regular inspection, a commercial enterprise may not be as willing to undertake such systematic checking and battery maintenance protocols without a more structured understanding of battery life and performance. It important that battery life is extended and design is minimalistic. This will help to avoid data loss whilst refining the portability of WOW systems.

One of the important factors assessed in the trial was the ability to apply real time price estimates to liveweight data. This allowed for tracking of price gain/loss relative to real time growth and market weight brackets. Price estimation also allowed for analysis of the financial success of supplementary feeding. Lambs were given a price estimate per day over the supplementary feeding period based on carcass weight and the expected price received if sale was made at next market opportunity. Whilst all ewe lambs were estimated to be sold as breeders over 'Auctions plus' a majority of prices were based on weekly over the hook sales reports. An illustration of $/kg loss over growth period can be seen in fig. 11 with 1.8 -2 cents per day average price drop from peak $/kg in early May. Whilst market fluctuations and change are unpredictable this was undertaken to provide true management parameters to the study. Supplementary feeding was found to have a significant return on investment (ROI). Animals fed with supplementary grain provided a $0.03/head per day average gain on control group animals after grain costs were accounted for. A 28% ROI at final sale was calculated dropping from a peak of 68% at price maximum. Whilst this does not equate to a large financial gain within this study, when extrapolated over larger flock number it provides a large financial return on effective feed supplementation. The WOW can be an effective tool in managing such growth targets. It was seen that supplementation was able to slow growth rate decline and provide more even weight gain over the trial period. WOW highlight these trends with growth rate analysis. If connected for remote data download this provides near real time information on individual and flock based performance. In a supplementary feeding program where substantial economic costs are applied WOW can give direct feedback on performance relative to flock diet, thus saving time and money for producers (Rowe and Masters 2005; Geenty et al. 2007).

WOW technology may provide an alternative weighing method for intensive free grazing and sheep production systems. Data collection requires voluntary actions by animals with the incentive of supplements or water. Key to lamb growth is the availability of clean drinking water (Australian government department of energy and environment, 2000) When WOW systems use water source as incentive this may cause shy animals to avoid crossing the platform threshold. These animals are known to exhibit neophobia (a fear of new things). This may induce poor animal performance and result in subsequent financial loss (Arnold and Bush 1968). 4 animals in this trial provided ineffectual figures that were not sufficiently significant to provide liveweight or growth curves. This may be attributed to either faulty RFID tags or neophobic tendencies. Issues may also arise when little stimulation exists to tempt animals across the scales, such as an abundance of green pasture feed through which animals can satisfy water needs. It has been shown that a minimum of 12 RFID-linked records are required to estimate the liveweight of an individual sheep to within 2kg with a 95% level of confidence (Brown et al. 2014). This may present a important hurdle to the appropriate generation of accurate liveweight estimates. Several animals in the trial took up to 23 days to enter 12 RFID-linked weight values of significance. This has been seen in other studies where animals have taken 21 days to generate the required level of data values for the entire mob (Brown et al. 2014). When this is extrapolated over larger mob sizes it may equate to large groups of animals remaining unaccounted for.

Conclusion

The aim to effectively track liveweight and animal response to management factors using RFID based WOW was achieved. WOW data collected showed a significant difference in growth between animals receiving supplementary grain in a free grazing pasture system and control group animals not receiving supplementary feed on a free grazing pasture based system ($P < 0.0006$). Lamb growth trends were also consistent with previous research and expected outcomes in all but one group (XB ewe control v treatment) which showed no significant difference. RFID linked WOW provides relevant data to for the assessment of lamb liveweights and construction of liveweight curves and growth date values. Incorporation of price data allowed for specific, economic estimation of treatment performance per day and per animal. This will be very useful for high input producers who must carefully manage feed quality and productivity to achieve maximum economic gain. The system is fully automated which is extremely important for commercial application in sheep grazing production systems. Raw data must be filtered correctly which may present challenges to operation feasibility. Issues exist with the monitoring of individual animals primarily due to factors of neophobia and lack of necessity to enter data collection points. As multiple data points are required to construct effective growth curves and treat management influenced response (Brown et al. 2014) RFID linked WOW technology must be developed further to minimise loss of data or adverse effects on animal production. This includes improvement in design and longevity of the power supply unit and portability of equipment. Given that such areas of improvement can be mechanically addressed, much scope exists for research to improve confidence of WOW data for targeted application in sheep production systems.

Acknowledgments

I would like to thank my supervisor Professor Luciano Gonzalez for his assistance throughout the year. I would also like to thank Mr David Jacobs who provided the property, sheep and extra equipment necessary to conduct the trial. Final thanks must also be extended to the Australian Wool Education Trust (AWET) without whom this research project would not have been possible. Funding was provided through the AWET undergraduate project scholarship program which delivers invaluable research opportunities to aspiring members of the nation’s agricultural industry.

References

Anderson DM, Weeks DL (1989) Cattle live weight sampled on a continuous versus intermittent basis. *Livestock Production Science* 23, 117–135.

Agric.wa.gov.au. (2017). Grain overload, acidosis, or grain poisoning in stock | Agriculture and Food. [online] Available at: https://www.agric.wa.gov.au/feeding-nutrition/grain-overload-acidosis-or-grain-poisoning-stock [Accessed 6 Oct. 2017].

Arnold GW, Bush IG (1968) Observations on non-feeding in groups of hand fed sheep. CSIRO Division of Plant Industry Field Station Records 7, 47–58.

Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian government department of energy and environment. Volume 1 The Guidelines (Chapters 1–7) October 2000

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

Bom.gov.au. (2017). Daily Rainfall graph - 073043 - Bureau of Meteorology. [online] Available at: http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av [Accessed 15 Oct. 2017].

Besier B, Hopkins D (1989) Farmers estimations of sheep weights to calculate drench dose. *West Australian Journal of Agriculture* 30, 120–121.

Brown DJ, Savage DB, Hinch GN, Semple SJ (2012) Mob-based walk-over weights: similar to the average of individual static weights? *Animal Production Science* 52, 613–618.

Brown DJ, Savage DB, Hinch GN (2014) Repeatability and frequency of in-paddock sheep walk-over weights: implications for flock-based management. *Animal Production Science*

Charmley E, Gowan TL, Duynisveld JL (2006) Development of a remote method for the recording of cattle weights under field conditions. *Australian Journal of Experimental Agriculture* 46, 831–835.

Cveticanin D (2003) New approach to the dynamic weighing of livestock. *Biosystems Engineering* **86,** 247-252.

Dove H, Freer M, Donnelly JR (1994) Effects of early to mid pregnancy nutrition of ewes on ewe and lamb liveweight and body composition, and on milk intake by lambs. *Proceedings from the Australian Society of Animal Production* 20, 285–288.

Eilers PHC, Marx BD (1996) Flexible smoothing with B-splines and penalties. Statistical Science 11, 89-121

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

Geenty KG, Smith AJ, Dyall TR, Lee GJ, Smith D, Brewer H, Uphill GC (2007) Remote drafting technology for management of pregnant Merino ewes. In 'Proceedings from the Recent Advances in Animal Nutrition in Australia'. (Eds P Cronje, N Richards) pp. 223–228. (University of New England Publishing Unit: Armidale, NSW)

González L. A., Bishop-Hurley G., Henry D., Charmley E. (2014) Wireless sensor networks to study, monitor and manage cattle in grazing systems. *Animal Production Science* **54**, 1687-1693

Handcock RN, Swain DL, Bishop-Hurley GJ, Patison KP, Wark T, Valencia P, Corke P, O'Neill CJ (2009) Monitoring animal behaviour and environmental interactions using wireless sensor networks, GPS collars and satellite remote sensing. Sensors 9, 3586–3603.

Jones A, van Burgel AJ, Behrendt R, Curnow M, Gordon DJ, Oldham CM, Rose IJ, Thompson AN (2011) Evaluation of the impact of Life time wool on sheep producers. *Animal Production Science* 51, 857–865.

Lee GL, Sladek MA, Atkins KD, Semple SJ (2008) Variance components of liveweights of pregnant ewes measured by manual or remote methods, with and without process by data screening. In 'Proceedings of the first joint conference of the Australian and New Zealand Societies of Animal Production (ANZSAP) the Australian Society of Animal Production (ASAP) and the New Zealand Society of Animal Production (NZSAP), Vol. 27'. (Eds DG

Barber, RT Cowan, AR Anstis) p. 22. (Australian Society of Animal Production, University of Queensland: St Lucia, Qld).

Martin, A. H., Fredeen, H. T., Weiss, G. M. and Newman' J. A. 1970. Prediction of lean yield of beef carcasses. Can. I. Anim. Sci. 50: 31-41.

Mla.com.au. (2017). Market reports & prices | Meat & Livestock Australia. [online] Available at: https://www.mla.com.au/prices-markets/market-reports-prices/ [Accessed 14 Mar. 2017].

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

Richards JS, Atkins KD, Thompson T, Murray WK (2010) Practical application of precision sheep management. In 'Proceedings of the 25th annual conference of The Grassland Society of NSW'. (Eds C Waters, D Garden) pp. 53-56.

Rowe JB, Masters DG (2005) Precision nutrition for Merino ewes. Recent Advances in Animal Nutrition in Australia 15, 221–228.

Schofield CP (1990) Evaluation of image as means of estimating the weight of pigs. *Journal of agricultural Engineering Research* **47** (Sep-Dec), 287-296.

Schreurs NM, Kenyon PR, Morel PCH, Morris ST (2012) Meta-analysis to establish the response of having heavier mature ewes during gestation on the birth weight of the lamb and the weaning weight of the ewe and lamb. *Animal Production Science* 52, 540–545.

Suiter J (1994) Body condition scoring of sheep and goats. Farm note 69/94. Department of Agriculture and Food, Perth. Available at: http://www.sevenhillstallarook.com.au/media/user/file/condition%20scoring.pdf

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

Turner MJB, Gurney P, Crowther JSW, Sharp JR (1984) An automated weighing system for poultry. *Journal of Agricultural Engineering Research* **29**, 17-24