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OPTIMISING A WEIGHING PROTOCOL FOR SHEEP

A dissertation submitted in partial fulfilment of the requirements for the Degree
of

Bachelor of Agricultural Science (Honours)

at

Lincoln University by

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Lincoln University

2014

Abstract of a dissertation submitted in partial fulfilment of the requirement
for the Degree of Bachelor of Agricultural Science (Honours)

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By

R.F. Wilson

A series of experiments designed to investigate live weight error and analyse the effect fasting and multiple weighing has on live weight measurements were carried out. In the first experiment 24 mixed aged ewes were fasted during a 24 hour period with live weight measurements taken at 0, 2, 4, 6, 8, 10, 12 and 24 hours fasted, with three measurements taken at each time point. At the conclusion of weighing all animals were slaughtered and their gutfill was weighed to enable calculation of their true (digesta-free) weight. In the second experiment 100 Coopworth ewes were weighed as described above on two separate occasions in May and July. On all occasions animals were individually identifiable with either visual ear tags or electronic identification tags (EID).

In experiment one live weight of ewes at the start of fasting ranged from 34.4 – 79.6 kg with a mean live weight of 61.3 kg. The mean live weight loss displayed a curvilinear response peaking at 4.1 ± 0.23 kg or $6.7\% \pm 0.348$ at 24h fasting, with a significant effect of time. The regression equations $y = -0.0073x^2 + 0.3445x$ for absolute live weight loss and $y = -0.012x^2 + 0.5636x$ for proportional live weight loss both explained 98% of the variation. The proportion of true live weight relative to measured live weight over 24 hours fasted increased from 0.85 ± 0.006 to 0.91 ± 0.004 . Despite being fasted for 24h the animals were only able to reach 91% of their true live weight as final digesta ranged from 2.5-7.3 kg with an average of 5.06 ± 0.27 kg. Therefore it was determined that attaining a reliable estimation of an animal's true body weight is unachievable when fasting them for 24 hours.

In experiment two, the live weight of 100 ewes was measured during a 24 hours fasting period with measurements taken at 0, 2, 4, 6, 8, 10, 12 and 24 hours in May which was repeated again in July. The live weight loss peaked at 7.87% in May which was considerably greater than the maximum live weight loss of 3.09% seen in the July experiment. The difference was likely due to a difference in weather conditions, with snowy conditions in July influencing the amount of feed ingested by the

animals. The relationship between live weight loss (kg) and (%) ranking at 24 hours fasted and the live weight loss (kg) and (%) at fasting times 2, 4, 6, 8, 10, 12 for experiment 2 (May and July) was analysed. The strongest relationships were seen at 12 hours fasted: $y=0.9878x$ ($R^2=0.8976$); for May, $y=0.9567x$ ($R^2=0.6623$) for July when expressed in kg. As a proportion of weight loss the greatest relationship was seen at 10 hours $y=0.716x$ ($R^2=0.8578$) and $y=0.8895x$ ($R^2=0.8895$) for May and July respectively. Probit analysis to fit 95% of their 24hr weight showed no significant difference was seen between the liveweight range from 0, 2 and 4 hours fasted; 4, 6, 8 hours fasted and 6, 8, 10, 12 hours fasted. In order to analyse the effect of multiple weighing a probit analysis to determine the range in weight which 95% of average the of three weights would fall indicated the only significant difference was at 10hrs fasted between one weight and the average of two weights.

In summary, live weight is a fundamental measurement which is used to monitor the production in the sheep industry. However live weight is only an estimate of an animal's true live weight which is unable to be reliably determined even following 24h fasting due to the variation in digesta weights. Relative to their 24h fasted live weights, fasting improved the accuracy and precision of the live weight estimate with little advantage observed when animals were fasting for periods greater than 8h. The method of multiple weighing had minimal effect on improving accuracy regardless of fasting time.

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1 General introduction

1.1 Introduction

Live weight measurements are fundamental for livestock production and breeding systems, as well as experimental research (Allden, 1970; Lawrence, Fowler, & Ebrary, 2002). The live weight of a living organism includes factors such as carcass composition of bone, muscle, fat, gut-fill content within the alimentary tract, internal organs, head content, pelt and wool. Recording and storing live weight data has become an easy, cost effective measurement with the use of technologies such as automated weighing setups, RFID and software systems. In practice and in experimental work it is often important to determine the growth rate of an animal. Monitoring live weight records are important for accurately meeting market specifications, reproduction performance, determining grazing management and for animal health and welfare issues (Sheep CRC, 2012). However, estimating growth rates of animals through weighing live weight is dependent upon the validity of live weight data (Hughes, 1976). Weighing an animal is an estimation of the animal's live weight measurement and therefore will always include some degree of error. According to Hughes (1976) and Lawrence et al. (2002), there are three factors contributing to the validity of weighing animals; the precision of the weighing machine, human error and the accuracy in apparent changes of live weight representing true changes in the animal's actual weight. It appears the third factor has the greatest influence on accuracy of measurements, as human error can be eliminated by the use of automated weighing platforms and data storage, and the error associated with weighing machines is constant and often minimal.

The change in live weight can be the result of increases and decreases in adipose and muscular tissue although variation is also expected between animals and particularly between different feed types and periods of weighing due to diurnal variation in gut fill. As expected, live weight fluctuates during the season depending on given nutritional stresses and environmental conditions. It appears such changes in the body throughout the season are not truly aligned with live weight change with subsequent changes in live weight over a season from pre-mating, lambing, mid-lactation and weaning not exactly reflecting the change in total live weight (Field, Suttle et al., 1968; Lambe et al., 2003). Further, energy changes can be assessed through either Body Condition Scoring (BSC) or Computed Tomography (CT) scanning and may not truly align with changes in live weight. It is suggested that some of this misalignment is due to weighing error and therefore defining an optimal weighing protocol is important. Sources of error may include the weight measurement itself, which could be determined by multiple weighing. Another source of error could be due to the weight of

the rumen contents, which may be expected to contribute up to 17% of the measured weight, and may be determined by fasting. This review will focus on the variation and error associated with live weight measurements, the impact of fasting and multiple weighing, the seasonal changes in live weight, the relationship between live weight and body composition and the uses of live weight measurements in practice.

2 Review of the Literature

2.1 Measuring Live weight

The process of measuring live weight has made considerable developments from a manual system to a highly efficient automated set-up, due to the use of Radio Frequency Identification (RFID) and automated equipment. Historically, measuring live weight involved reading identification tags and weights from the scale and recording on paper, while manually operating weight crates and gates. The excessive data handling involved in manually recording live weight has a greater risk of error and inaccuracy of information. Advances in technology have led to the use of electronic, automated systems, with minimal opportunity for translation errors.

The RFID system consists of 3 main components; an electronic tag, which is located on the animal for identification; the RFID tag reader, capable of reading and writing data to a transponder, which can be fixed or handheld; and the data processing subsystem, which uses the data in some useful manner (Engels, Scharfeld, & Sarma, 2007). As the animal approaches the weighing platform, the RFID reader sends a radio signal which excites the electronic transponder located in the animal. This then transmits a unique 16 digit number back to the reader. The electronic tag identifies the animal which is picked up by the fixed EID reader panels via cables or bluetooth. The load bars are located under the platform which send measurement signals to the weigh head unit from the electrical resistance placed on the bars by the animal (Nugent, 2005). This information is recorded and can be transferred to a computer and entered into farm management software (Development., 2014). Another variation on the weighing system explained above is manually operating the weight grate and entering each animal identification code into the head unit.

The resistance on the load bars located under the weight grate are used to determine an estimation of an animal's weight. There are two methods by which electronic weigh scales operate; a measurement will be taken when it is detected that animal movement is stabilised; or a measurement is given by using a statistical process from which several readings taken by the processor are averaged over a period of time (Smith & Turner, 1974). The first method relies on a stable period, which is often hard to achieve with animal movement fluctuations resulting in inaccuracies (Smith & Turner, 1974). The second method has proven to be more useful in practice, with accuracy of $\pm 1\%$ achievable (Smith & Turner, 1974).

2.2 Measurement Error

2.2.1 Human Error

Historically, weighing animals and recording live weight measurements was a manual and labour intensive task. In a manual setup individual tag numbers are read and recorded with the resulting live weight measurement. The data may then be further handled to make use of. This manual system relies heavily on the operator's ability to accurately record data while manually operating weighing equipment. The potential for human error has been reduced with the use of various technologies available to measure live weight. The automated electronic weighing system, with the use of RFID tags and computer software to clearly display data is probably the most effective system that reduces the chance of human error.

2.2.2 Scale Error

There are two methods by which weigh scales interpret an animal's live weight on the load bars (Nugent, 2005). Either a single weight is recorded during a stable period, when the animal has reduced movement, or a statistical process is used where the processor takes several readings over a short time period and averages them. It is difficult in practice to have long durations of stable periods and minimal movement, so the second method is often used (Smith & Turner, 1974).

The variation associated with weighing scales is expected to be very minimal, as technology has advanced. It is suggested that accuracies of $\pm 1\%$ of actual weight, or 0.91 kg for sheep is sufficient (Smith & Turner, 1974). Aiming for an accuracy of $\pm 1\%$ is desirable, given a 65 kg ewe variation can expect to fluctuate ± 0.65 kg. There is little research on specific weighing equipment accuracy for sheep, however, in most cases the same scale will be used for all animals in a weighing session, therefore the variation will be the same across all stock. A recent Australian study revealed that the variation of five commercial scales ranged from ± 1.9 kg to 2.8 kg for ewe body weight, see Table 2.1 (Nugent, 2005). The results from the Australian trial showed scale variation was greater than the ideal $\pm 1\%$ described above, with no explanation was given to the different variation.²

Table 2.2.1: Accuracy of scales tested by Kondinin Group

Scale type	Average Weight (kg)	Correlation (Accuracy)	Precision 95% Confidence Interval
Iconix FX41	45.9	0.986	± 1.9
Prattley draft crate	45.1	0.954	± 2.2
Ruddweigh 600	45.7	0.981	± 1.9
Thunderbird Ultrascale	44.9	0.957	± 2.8
Tru-Test XR3000	44.9	0.38	± 2.2

Source (Nugent, 2005)

Another study in relation to pig scales reported 99.8% confidence limit of ± 2 lb of the correct value using the averaging method, see Figure 2.1 (Smith & Turner, 1974). In addition a worst case scenario Figure 2.2 was simulated using a 152.5lb man to violently shake the weighing crate. Weight variation was calculated to be within ± 2 lb. Both live weight experiments had acceptable variations, around 1% proportional to body weight.

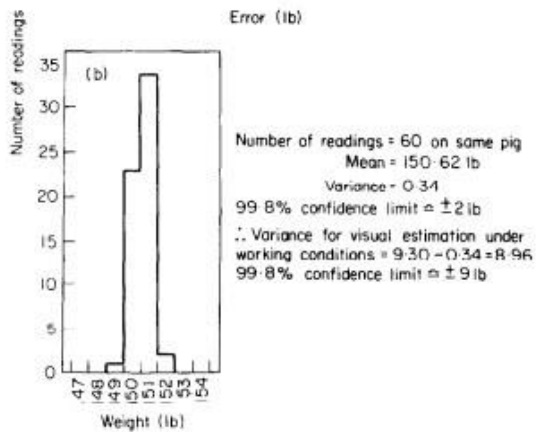


Figure 2.1: Histogram showing the results of repeated weighing of one pig using the averaging method

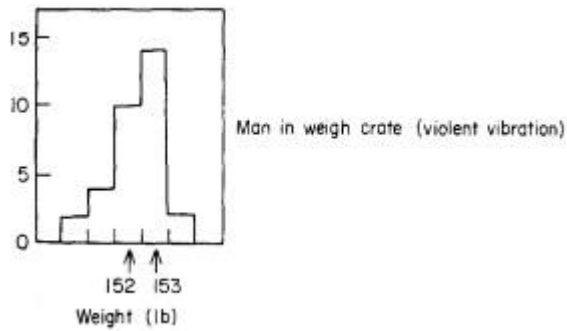


Figure 2.2: The results of repeated weighing averaging simulating worst case scenario

There is little research into scale error for commercial sheep scales including automatic weighing. The precision of a live weight is known as how close any weight is to the true live weight of an animal (Nugent, 2005). However, a live weight measurement is only an estimate as it is impossible to attain a true live weight reading on an animal at any given time. The accuracy of an estimated live weight can be shown by the variation in a repeatable estimate. It is acknowledged that there will always be a scales error which causes variation and it has been suggested that there is little advantage in obtaining fine precision; (Smith & Turner, 1974); (Hughes, 1976). Although attaining a greater accuracy may be useful in scientific experiments or when animals are weighed on an individual bases.

2.3 Live weight Error

2.3.1 Gutfill Variation

The digestive tract can make up a high proportion of an animal's mass, with up to 17% of total live weight accounted for in the contents of the rumen and reticulum (Lawrence et al., 2002). The amount of feed and water within the digestive tract is dependent on the time since the animal was fed and the rate of food passage (Hughes, 1976). It should be considered that weighing live animals will include an amount of gutfill, which will vary between animals, time of day measured, time off feed and previous feed type.

2.3.2 Diurnal Variation

The pattern of grazing events will dictate how much feed an animal has at any given point in time and therefore will influence the live weight and live weight changes throughout the day. Ruminants generally have three to five grazing events daily, with greatest intake periods to be in the early morning and late afternoon (Gregorini, Gunter, Beck, Soder, & Tamminga, 2008). Penning, Rook et al. (1991) reported ewe grazing patterns with 70-99% of grazing occurring during daylight hours and 25-48% during the 4 hours prior to sunset. In comparison, cattle have been reported to have around one third of their total grazing time occurring during dawn (Gregorini et al., 2008). Therefore, the

time at which the animals are weighed has a large effect on the amount of gut fill within an animal. Animals weighed at the start of the day will have a limited time grazing and therefore may have a reduced gut fill status compared with animals weighed mid-afternoon. Grazing patterns vary between animals depending on herbage quality, type of herbage and the environment. The timing of grazing events in relation to the timing of weighing animals can have a significant impact on the animal's estimated live weight. Herbage DM % increased during a 12 hour period from 15-24% grass and 12-18% clover. Starch content also increased 3-4.1% and 3.6-8.7%, for grass and clover respectively (Orr, Penning, Harvey, & Champion, 1997). In respect to grazing behaviour, animals are more inclined to gorge themselves on lower dry matter and lower starch pastures. According to Hamilton (1995), the greatest diurnal variation in estimated live weight was observed between 11am-1pm and the lowest variation reported at 9am and 4pm, with sunrise at 6am. In agreement, Hughes (1976) suggested weights taken at the middle of the day from a grazing period on a limited area were least variable. It is also recommended to muster animals before grazing to minimise gutfill error (Hughes, 1976). Diurnal variation should be considered when designing a weighing protocol, however a system should be adopted that is practical to the situation.

2.3.3 Feed Type Factors

The feed type along with diurnal factors have a major impact on gutfill. Sheep on lower quality, high fibrous feed have a low passage rate, which may lead to a reduced intake and gutfill. The greater the Neutral Detergent Fibre (NDF) content, the slower the passage rate. Conversely, sheep on high quality feed may have higher intakes, greater gutfill and passage rates. Therefore it can be assumed that true body weight is often overestimated for animals on high quality feed, in comparison with animals on lower quality feed. Table 2.3.1 shows differences between feeds with the average percentage of live weight lost greater in lupins and lucerne, in comparison with pasture in lambs. However, it should be noted that there was large variation within data and between different stock classes, so not all of this difference can be attributed to dietary effects.

Table 2.3.1: Mean percentage loss in live weight relative to time off feed off various feeds

	Time off Feed (hr)							
	2	3	4	5	6	8	10	12
Pasture -Lambs	1.18		2.75			4.83	4.71	
Lupins -Lambs			3.22		4.31			
Lucerene -Lambs	1.54			3.07				
Pasture -Hogget	1.41		4		6.21			6.36
Pasture - 70d pregnant	2.07	3.05			6.21			8.96
		2.52						

Source: (Greer, Logan, & Bywater, 2013)

Feed type factors are largely dependent on the environment and how the stock are managed. Sheep stocked at a higher stocking rate will have a greater grazing pressure and therefore are likely to have a lower average gutfill and digestibility. It is important to recognise feed quality and quantity factors between flocks prior to weighing, so that such factors are accounted for (Hughes, 1976).

2.4 Reducing Live weight Error

2.4.1 Multiple Weighing

In order to take a reliable live weight measurement of an experimental animal, Bean (1946) believes it is necessary to take more than one measurement. Taking multiple weight measurements of an animal over a period of time reduces the reliance on a single measurement and exposure to the associated error. Lush et al, (1928) recommended to weigh cattle over three consecutive days to remove inaccuracies associated with live weight measurements. This practice was recommended as a standard procedure for cattle in 1931 by a committee of the American Society of Animal Production (1932) as cited in (Patterson, 1947). In the original cattle study (Lush & Black, 1927) it was found the error of a three-day weight is only 57% that of a one-day weight. It is thought that the improved accuracy is particularly important when analysing the change of live weight on an individual animal bases (Hughes, 1976). However, the theory that three-day weights are more accurate than one-day weights has been challenged (Baker, Phillips, & Black, 1947); (H. W. Bean, 1946); (H. Bean, 1948). H. W. Bean (1946) found in swine, an increase in error with the use of a three-day average (31.7 ± 0.42), compared with first day weights (31.5 ± 0.40), although the

difference was not significant. In agreement, Baker et al. (1947) showed no significant difference between the 3-day average weight of 424.6 pounds and the one day weight of 425.9 pounds on 178 heifer and steer calves. In the 420-439 pound group, the error increased throughout the trial, first day weights (428.5 ± 1.19); second day (427.6 ± 1.75); third day (427.7 ± 2.35) with the threeday average (427.7 ± 1.66). Bean (1946) also concluded, using swine, that there was no increase in accuracy with using three-day weight averages versus one single measurement. Bean (1946) showed variation increased with multiple weighings with the 27-38 pound group weighing $31.47 \pm .40$ pounds on the first-day weights; second day $31.66 \pm .45$; third day $32.03 \pm .43$; three day averages $31.67 \pm .42$. Bean (1948) suggested that the weather conditions and physical conditions animals are under prior to weighing determine the difference between one day and three day weighing's averages. In the trial of Bean (1946), the lambs were not accustomed to being handled or the weighing process as they were brought in from the Western ranges just before the trial. It is expected animals will become familiar with the weighing environment with repeated weighing. However, it is accepted that weighing animals over consecutive days is impractical, especially in a pasture grazing system. A study by Galwey, Logan, and Greer (2013), quantified the variability of a live weight estimate over 24 hours fasting and with multiple weighing, shown in **Error! Reference source not found.** The study revealed that the average of two weights improved the accuracy of weight compared with the use of a single weight, however this is to be expected as the comparison of the best estimate was made to the average of three weights. At 0 hours fasted 99% of data from the first live weight measurement was within 0.69 ± 0.16 kg of the best estimate and the average of the first two weights was within 0.31 ± 0.09 kg of the best estimate, this was reduced to 0.43 ± 0.02 and 0.22 ± 0.06 kg after 24 hours fasted respectively. The minimal improvement in accuracy of weights made by weighing multiple times, if any, may not be worth the effort involved in labour and handling stock multiple times.

Table 2.4.1: Variation in live weight \pm s.e.m (kg) from the best estimate of the true live weight of an animal, derived as the mean of three weighings, required to include a given percentage of the population for when the of the population for when the first recorded weight alone or the mean of the first two weights for animals fasted 0, 24 hours.

Proportion of samples (%)	0 hours fasted		24 hours fasted	
	1st Weight	1st and 2nd Weight	1st Weight	1st and 2nd Weight
			1st Weight	1st and 2nd Weight
50	0.08 ± 0.07	0.01 ± 0.10	0.08 ± 0.01	0.04 ± 0.02
85	0.35 ± 0.10	0.14 ± 0.05	0.24 ± 0.01	0.12 ± 0.02
95	0.52 ± 0.12	0.22 ± 0.05	0.33 ± 0.01	0.16 ± 0.03
99	0.69 ± 0.16	0.31 ± 0.09	0.43 ± 0.02	0.22 ± 0.06

Source (Galwey et al., 2013)

2.4.2 Fasting

Fasting is a common practice in the sheep industry recommended before shearing, transport and pregnancy scanning. Fasting results in a curvilinear loss in live weight, with gutfill the main component of live-weight loss during the first 24 hours fasted, Figure 2.3. Thompson, O'Halloran, McNeill, Jackson-Hope, and May (1987) also demonstrated this curvature response in lambs with 0.82% lost in the first 0-3hours; 0.47% in 3-6 hours; 0.39% from hours 9-12 and 0.25% between 24-48 hours. There is little research conducted in the first 24 hours to compare percentage loss particularly in older stock. Live weight losses observed in fasting lambs equated to 5.25% of initial live weight during the first 24 hours, with only 2.48% during the following 24 hours (Warriss, Brown, Bevis, Kestin, & Young, 1987). However, it should be noted that water was not restricted during fasting, possibly explaining the low values of live weight loss. The result of fasting within the first 24 hours is largely due to losses in gutfill, and therefore the diurnal pattern becomes a major factor in the amount of live weight loss. Kirton, Quartermain, Uljee, Carter, and Pickering (1968) reported in lambs a 33% reduction in the weight of the stomach contents in the first 24 hours of fasting, confirming the loss is largely due to gutfill. Therefore by reducing gut fill, the animal is likely to be closer to their 'true' live weight, which in turn may be expected to reduce live weight measurement error.

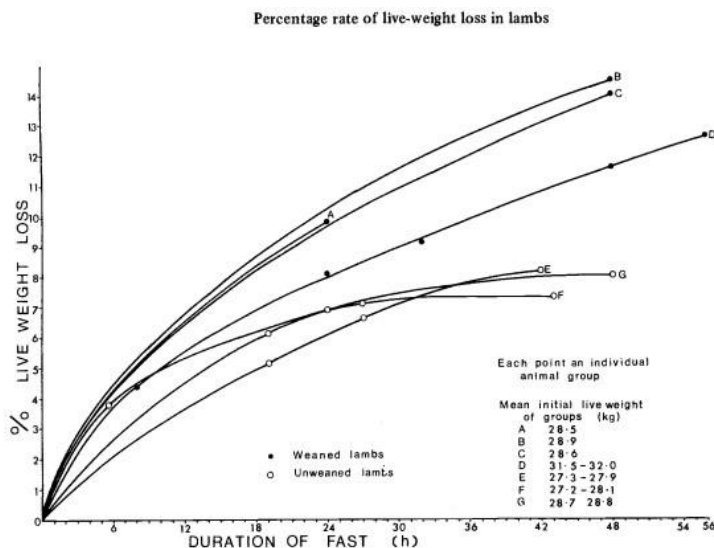


Figure 3 shows the rate of live-weight loss by lambs as a percentage of initial weight (Callaghan and Thompson, 1940; Kirton *et al.*, 1968; Kirton *et al.*, 1971). It indicates firstly that, when subjected to starvation, weaned lambs tend to lose live weight faster than unweaned lambs (Kirton *et al.*, 1971). Secondly, comparison of the regression curves ABC with curves DEFG supports an earlier finding (Emery *et al.*, 1958) that initial rate of live-weight loss is positively

Figure 2.3: Percentage of live weight loss from initial live weight of weaned and unweaned lambs during fasting. Source: (Hughes, 1976)

Fasting beyond 24 hours results in subsequent tissue loss and is much slower, which explains the tapering off to the curvature response. Previous research has showed live weight losses range from 3.5-15% of an animal's initial live weight prior to 24 hours fasted. In comparison, live weight losses in lambs were approximately 9% and 12% after 24 and 48 hours (Thompson et al., 1987). Similar results were found in >24hr fasting trials with Cole (1995) reporting a 9.9% loss of body weight, of which 80% was body water and 55.9% of the total weight loss was accounted for with stomach and gastrointestinal tract contents and tissue. The differences between experiments is likely due to the different gutfill at the start of fasting.

2.5 Seasonal Changes in Live weight

As expected, live weight fluctuates throughout the season. This can be influenced by the environment and the energy demands placed on the animal at any given time. Table 2.5.1 indicates the difference in Blackface ewes' live weight during a given season as reported by Field, Suttle & Gunn, (1968). Live weight declined from November through to May, during pregnancy and lactation. However, not all live weight loss was represented by the change in body tissue.

Table 2.5.1: Mean Live weight over each killing (kg)

	Oct	Nov	Jan	Apr	May (L)	May (B)	July
Liveweight	47.1	52.3	44.3	45.4	39.5	40.5	44

Source (Field, Suttle, & Gunn, 1968)

Another important factor to consider is the increase in conceptus weight as pregnancy increases. This indicated that there is possibly some error associated with weighing the animals or the change in tissue that is not fully represented by live weight changes. Similarly, NR Lambe et al. (2003) found live weight fluctuations during the season in Scottish Blackface ewes, shown in Table 2.5.2 with predicted tissue weight changes in barren ewes. An increase in live weight was reported from midlactation to weaning, weaning to pre-mating across all animals and pre-lambing to mid-lactation for barren 2 year old ewes (NR Lambe et al., 2003). The greatest loss was found in 2 year old ewes carrying twin lambs, -3.16 kg at pre-mating to pre-lambing. This may be caused by the low feed allowance over the winter time period. Table 2.5.2 shows that the amount of live weight loss or gain is varied across different ewe age and number of lambs.

Table 2.5.2: Live weight changes (kg) during different periods of the season of Carcass fat weight, internal fat weight and carcass weight.

Period in Season	2 Yr Old Ewes			3 Yr Old Ewes	
	0 Lambs	1 Lamb	2 Lambs	1 Lamb	2 Lamb
Pre-mating to pre-lambing	-2.24	-2.99	-3.16	-1.53	-1.91
Pre-lambing to mid lactation	3.47	-2.64	-1.62	-3.65	-0.93
Mid lactation to weaning	4.67	2.95	2.45	3.89	1.70
Weaning to pre-mating	0.79	2.76	2.18	2.92	2.45

Source (NR Lambe et al., 2003)

2.6 Methods of estimating body composition

Estimation of body reserves is an important management tool which can give an idea of the nutritional status of the sheep. Farmers can then feed their animals based on whether they need to improve their condition, which is particularly important in the lead up to tugging. Body condition scoring and Computed Tomography are two methods that give an indication of body reserve tissue.

2.6.1 Body Condition Scoring

Body condition scoring (BCS) is a low cost management tool to compare sheep using the tissue between the last rib and pelvis, 'loin chop' region. BCS is a measurement of an animal's health status relating to the production ability at one particular point in time. BCS is usually measured on a 1-5 score point scale, depending on the amount of fat tissue present on the last rib, see Figure 2.4: Body Condition Score Guide (Beef+LambNZ, 2014). An advantage of BCS is that the assessment is independent from frame size, breed, gestation and gutfill. However, in a commercial setting it may be impractical to individually score each animal as the method can be time consuming.

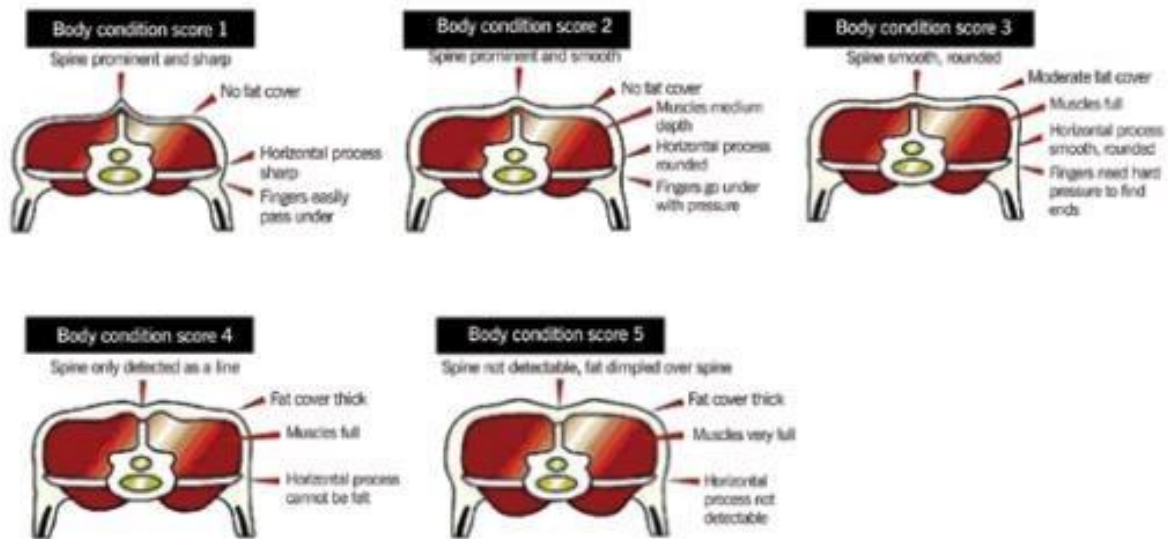


Figure 2.4: Body Condition Score Guide

Source (Beef+LambNZ, 2014)

In order to achieve high production, BCS targets can be set at different times of the year, particularly at tupping. An increase in one BCS at joining can result in an increase in ovulation rate by 0.13 to 0.19. Greater results have been reported of 0.56 of ovulation rate (Gunn and Doney) or 29% increase in number of lambs (Pollott and Kilkenny) per BCS (SCARM, 1994).

2.6.2 CT Scanner

One method of measuring body composition is with use of a CT (Computed Tomography) scanner, see Plate 2.1. CT scanning was initially developed for human medicine as a non-invasive way to collect images and information on body tissue. The scanner works by sending out a series of short duration, very narrow, fan-shaped beams of radiation (CREDO., 2000). Detectors rotate a full 360 degree angle around the animal and scan it. The detectors on the opposite side detect the absorbance of x-rays, which is dependent on the type and density of the tissue as it passes through the circular cavity (Lincoln University, 2011). One type of analysis is the Cavalieri, which takes cuts every 50mm with the density averaged out by the distance of each area. However, in most cases the seven reference slices are accurate enough to estimate muscle and adipose tissue. The body composition is estimated using CT 7 reference slices; TV1, TV2 (thoracic region); LV 1, LV5 (lumbar vertebrate region); Caudal; Ischium and Sacral region.



Plate 2.1: CT scanner

2.7 Change in Tissue

The proportion each adipose tissue site adds to the total carcass weight varies in different breeds of sheep, due to the final mature weight and the time taken to reach this weight, accounting for some of the variation described above. The order of tissue development is firstly through bone deposition, then muscular and finally adipose fat. Changes in bone composition as total body composition are very minimal, often the focus is towards protein and adipose distribution. It is thought that most hyperplasia in the perennial tissue is complete at the birth of a lamb (Lawrence et al., 2002). After this, hyperplasia is observed up to 100 days after birth, resulting in an increase of adipocytes in the subcutaneous and intramuscular deposits. It has been reported that these adipocytes may increase by 2 to 3 fold right up to maturity (Lawrence et al., 2002). The rate the adipose tissue matures at varies between breeds and between different regions i.e. limbs, brisket, thorax, shoulders, loin and rump. Generally the regions listed above are the last to deposit and the first to lose it in times of feed surplus and deficit (Frutos, Mantecon, & Giráldez, 1997).

2.8 Season Changes

A major factor in the change in body composition is the stage of season or the physiological state of the animal. During the season an animal faces different energy demands or different planes of nutrition which subsequently result in a change in body tissue. The major energy demands a ewe faces are

throughout the reproduction and lactation season. NR Lambe et al. (2003) found that both carcass and internal fat deposits were depleted during pregnancy and early lactation which were replenished mid lactation to mating the following period. This may be expected as energy demands one week prior to lambing for a 60 kg ewe are 16.5 and 20.0 MJME/kg DM for single and twin bearing ewes respectively (Kenyon & Webby, 2007). Subcutaneous fat was mobilised in preference to inter-muscular fat in Scottish Blackface ewes, with minimal reduction in muscular deposits (NR Lambe et al., 2003); (Cowan, Robinson, Greenhalgh, & McHattie, 1979). In contrast, Russel et al (1968) as cited in (NR Lambe et al., 2003) found a reduction in protein and ash content of 20% from pre-mating to the final week of pregnancy. It is assumed that fat deposits are first used as energy reserves followed by protein losses, which is dependent on a ewe's individual body composition. It is suggested that individual ewes hold different compositions of deposits and therefore in times of nutritional stress different energy stores will be depleted. This could explain the large variation between live weight and body condition score described above.

The seasonal change in body composition is largely explained by the carcass and internal fat weight, in barren 2yr old ewes 99% of live weight change was explained by carcass fat. Collectively, carcass and internal fat weight explained over 50% of live weight change (N. Lambe, Simm, Young, Conington, & Brotherstone, 2004). From pre-lambing to mid lactation, barren 2 year old ewes have a greater proportion of carcass muscle weight, which could be explained by the barren ewes having a lower energy demand so any excess net energy can be put towards fat and muscle deposition. The proportion of different fat and muscle compositions vary largely throughout the season and across different ages of ewes and number of lambs being carried. However, different body compositions result in different live weights. The weight of adipose tissue was significantly different, averaging 9.19, 2.28 and 1.19 kg on days 12, 41 and 111 for ewe live weight 60.2, 58.9 and 55.8 kg, respectively. It appears that the ewes lose more adipose tissue than live weight which suggests that the other tissue was mobilised over lactation and the relationship between adipose tissue and live weight is not entirely direct and may change throughout the season. In agreement, Table 2.8.1 illustrates the significant changes in carcass fat deposition between scanning events for barren ewes. In most cases, a significant result was shown between barren ewes and ewes carrying 1 to 2 lambs, with some differences between 2 and 3 year old ewes. This provides evidence of differences between ewes which can make predetermining adipose deposition through live weight measurement difficult.

Table 2.8.1: Proportional Changes between carcass fat weight, internal fat weight and carcass muscle weight between scanning events

Period in Season	2 Yr Old Ewes			3 Yr Old Ewes	
	0 Lambs	1 Lamb	2 Lambs	1 Lamb	2 Lamb
Pre-mating to pre-lambing					
Carcass Fat Weight	0.79	0.49	0.54	0.54	0.33
Internal Fat Weight	0.38	0.37	0.34	0.33	0.56
Carcass Muscle Weight	-0.17	0.14	0.12	0.13	-0.11
Pre-lambing to mid lactation					
Carcass Fat Weight	0.43	0.49	0.50	0.52	0.96
Internal Fat Weight	0.23	0.32	0.49	0.28	0.15
Carcass Muscle Weight	0.33	0.18	0.01	0.20	-0.11
Mid lactation to weaning					
Carcass Fat Weight	0.43	0.16	0.12	0.30	0.19
Internal Fat Weight	0.33	0.34	0.42	0.27	0.38
Carcass Muscle Weight	0.25	0.50	0.47	0.43	0.43
Weaning to pre-mating					
Carcass Fat Weight	0.99	0.64	0.71	0.65	0.67
Internal Fat Weight	0.56	0.34	0.31	0.41	0.43
Carcass Muscle Weight	-0.55	0.02	-0.02	-0.06	-0.10

Source: (NR Lambe et al., 2003)

2.9 Body Composition & Production

The energy demands at particular times of the season result in the mobilisation of tissue. Total energy reserves are difficult to measure, particularly glycogen and intra-abdominal fat reserves (Kenyon, Maloney, & Blache, 2014). It is expected that a ewe will face body condition changes over the season shown by fluctuations of BCS. The ability a ewe has to mobilise her energy reserves will in turn influence the production output or the amount of lamb per ewe. Borg, Notter, and Kott (2009) and Mathias-Davis, Shackell, Greer, and Everett-Hincks (2011) suggests that ewes which appear to be able to hold their condition in early gestation and utilise reserves in lactation outperform their peers who cannot. Evidence of this is outlined below in Table 2.9.1, the highest performing ewes were shown to have a condition score of <3 at weaning, presumably reflecting mobilisation of body reserves. Lamb growth rates are significantly affected by the change in ewe BCS from pre-lambing BSC to the BCS in lamb weaned (Mathias-Davis, Shackell, Greer, Bryant, & Everett-Hincks, 2013). These studies indicate high performing ewes have a greater ability or willingness to mobilise their own energy reserves. This suggests that perhaps farmers should be looking to identify such animals and making the most of this ability. Body condition is related to live weight measurement, as the increase in fat and muscle tissue

will undeniably lead to an increase in body mass. Therefore, there is potential to use live weight or change in live weight as an estimation of BSC, providing a more practical method for assessing changes in body reserves.

Table 2.9.1: The association between BC and Ewe Output (Total Lamb Weaned kg)

		Birth Rank				
		All	1	2	3	
BCSL	<3	48.4	35.4	52.5	60	
	3-3.5	48.8	35.1	53.3	61.4	
	>3.5	49.7	34.9	53.1	65.2	
BCSW	<3	50.9	48.9	36.6	55.2	64.4
	3-3.5	43.8	35.3	52.6	62	
	>3.5		33.8	46.8	52.6	

BCSL = Body Condition Score Lambing

BCSW = Body Condition Score Weaning

Source (Mathias-Davis et al., 2011)

2.10 Live weight Gain or Loss

Reports have shown after periods of animal feed restriction, there has been an increased rate of fat deposition (McMeekan 1941, Keys et al 1950, Osborn and Wilson 1960 as cited in (Allden, 1970)). This suggests that fat tissue more readily deposits than other tissues, when an increase in feed plane is exerted. However, another study showed weight gain did not really differ from the composition of live weight loss (Meyer and Clawson, 1964 as cited in (Allden, 1970)). There was a small significant result between control and restricted diet treatments, however no significance was found within the restricted groups with a range of treatments from 20-84% feed restriction from the control group. Often animals are restricted from feed during periods where their energy demands outweigh the feed available or the cost of feed is too high. However, animals are not often effected in the long term as compensatory growth follows periods of nutritional restriction (Ryan, Williams, & Moir, 1993).

The plane of nutrition is another factor that needs to be considered. Ewes which were fed to increase or decrease by one body condition equated to a 8.72 kg and 8.65 kg in comparison with a static plane which resulted in an additional 6.95 kg (Caldeira & Portugal, 1991). The difference is likely due to the difference in alimentary tract, the size of the tract increases with an increase in the plane of nutrition.

It is obvious that there is large variation between breeds and even within breeds with the amount of live weight change per BCS. This variation has not really yet been explained in research, but it is likely that changes in gutfill and body composition are major factors.

2.11 Body Condition Score and Live weight Relationship

There is an indisputable relationship between BCS and live weight, as changes in adipose and muscular tissue will involve an increase in the mass of an animal. The relationship between live weight and BCS for Merino ewes was 9.2 kg or 0.19 x standard reference weight increase in weight per unit of BCS. However, there was considerable variation in this relationship even within breed with a range within of 6.3 – 11.3 kg in merino sheep (Van Burgel et al., 2011). Similarly, Jefferies (1961) as cited in (SCARM, 1994) noted a change of 7 kg in Corriedales and Merinos per unit of BCS. The intercept, or kg of live weight per body condition score is variable across individual sheep, physiological state and breed. Table 2.11.1 shows the large variation between breeds, dry and lactating animals. The frame size of the animal is an important factor to consider, with a greater live weight for 1 unit of BSC in the larger frame animals. Dorset Down and Polwarth breeds have a greater mature weight resulting in a greater live weight between BCS compared to their smaller frame peers. With that said, considerable variation in frame size can be expected within breeds as well as between breeds highlighting the difficulty of providing breed-specific values.

Table 2.11.1: Change in liveweight to BCS (SCARM)

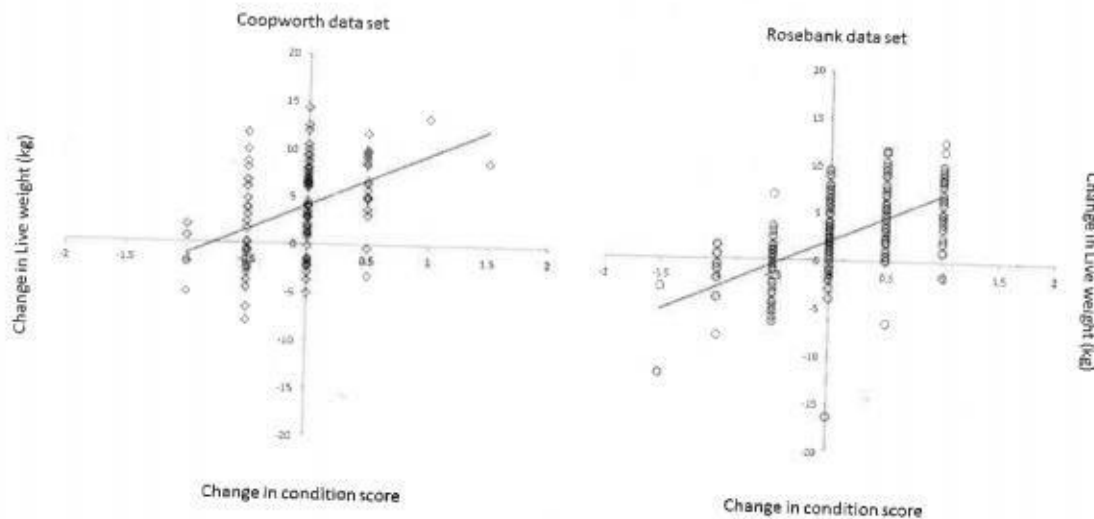
Ewes (dry)	Change in Lwt (kg) per BCS
Polwarth x SA Merino	6.5
Saxon Merino	5.6
Scottish Blackface	10.6
Ewes (lactating)	
Sth Aust Merino	5
Saxon Merino	5.5
Corriedale	11.9
Dorset	11.8

Source (SCARM, 1994)

There is also large variation within breeds between the change in live weight per condition score as reflected by annual Coopworth and Rosebank data set, shown in Figure 2.5 (Greer et al., 2013). The equation of best fit for the Coopworth data equated to $y = 5.2937x + 4.1776$ ($R^2 = 0.2$) and $y =$

$5.0075x + 2.1058$ ($R^2 = 0.38$). The overall change per condition score is 5 kg however, large variation is shown in Figure 2.5, with a range of 10 kg. In order to use live weight as an indicator of body tissue reserves this variation needs to be minimised.

Figure 2.5: Change in Live weight relative to condition score: Coopworth (2011-2012) & Rosebank



(2012-2013) Data set

2.12 Use of Live weight Measurements in Industry

Live weight measurements are an easily attainable measurement which are commonly used in the livestock industry, as outlined below. As outlined above, live weight measurements are exposed to error from a number of sources, all of which may affect both the precision and accuracy of the live weight estimate. As may be expected, the accuracy and precision of the live weight required is dependent on the purpose.

2.12.1 Marketing & Selection

Live weight information is collected and goes into the selection process on Sheep Improvement Ltd (SIL) for the calculation of an animal's genetic potential for growth targets. Live weight measurements are taken for the growth rates of lambs (g/day) and weaning weight at various ages. Live weight gains, in particular lamb growth rates, are important to assist in optimising finishing systems and improve the efficiency of the farming system. Alternatively, the selection of which animals are sent to market can be made based on live weight and taking into account the expected dressing out percentage. Under such uses, a lower precision of live weight estimates may be appropriate providing sufficient accuracy is achieved.

2.12.2 Determining dose rates

A live weight measurement is needed in order to accurately determine dose rates for drenches and pour on dips. It is recommended to separate mobs into similar weight ranges and drench to the heaviest weight. The accuracy of the animal's live weight is important to provide a sufficient dosage of drench. Ensuring effective drench rates is an important factor in preventing drench resistance. It can be effective to weigh stock into different lines and drench accordingly to ensure greater efficiency of drench use.

2.12.3 Monitoring Progress

Monitoring ewe live weight gives an indication of sheep performance on a whole flock or individual basis. Commonly, a sample of 10% of a flock is weighed to give an indication of flock progress (Edward, 2009). It is important that live weight during tupping period is monitored along with body condition. Higher weights, along with adequate body condition ewes, have greater ovulation and conception weights. Ovulation rate was significantly greater between ewes' conditions 1 ½ and 3 (Gunn, Doney, & Russel, 1969). As a result, it is expected that greater condition ewes have greater conception rates. Research conducted by Rutherford, Nicol, and Logan (2003) suggested that the mean ovulation rate was effected by smaller-framed ewes ($OR = 0.02616 \times jLW + 0.463$). However, no relationship was found between ovulation rate and joining live weight of the larger framed ewes, with maximum ovulation rate predicted to occur at 67.5 kg joining live weight. It is beneficial for farmers to have a set target of live weight throughout times of the year, depending on the season and breed of stock. It is important when setting target live weights that consideration is given to the mature weight of the breed and the availability of feed. It is recommended to aim for at least a 3 out of 5 BCS at tupping (Rick & Peter Cameron, Southland pg 27 (PGG Wrightsons, 2013), although the optimum live weight may be dependent on frame size. Measuring change in live weight may reflect change in nutrient status which is useful from a farm management perspective. Thus the precision of a live weight estimate becomes more important than accuracy to enable flux in live weight to be assessed. It is suggested that monitoring ewe live weight to identifying the elasticity of ewes could be beneficial for farmers. As identified in 2.9, body composition and production (Mathias-Davis, 2011) showed ewes that mobilised their own body reserves over lambing and lactation produced larger lambs, resulting in a lower BCS. There is potential for live weight measurements to be used to identify high performing stock, however, the error associated with live weight measurements and the differences between live weight and BCS need to be analysed.

2.13 Summary

The use of live weight measurements to monitor changes in body tissue reserves would be a useful management tool. However, there is considerable variation within live weight measurements and live weight changes between BCS. Body condition scoring does give a reliable assessment on energy reserves, however, it is quite a slow, manual process. Live weight measuring is a quick, automated process which can be assessed in quite a short space of time. However, live weight is only an estimate of the true live weight of an animal which can only be calculated on slaughter. In order to reduce the variation associated with live weight and the difference between BCS, it is important to uncover where the variation is coming from. Designing a suitable weighing protocol could reduce some error and help explain differences between BCS throughout the season.

3 General Methodology

3.1 Experiment 1

The live weights of twenty four mixed-age ewes with a mean initial (non-fasted) live weight of $61.3 \pm$ SEM kg were compared at different times of fasting with their digesta-free weights (true live weight). The ewes were identified individually with visual ear tags and had been grazing ryegrass white clover pastures prior to housing. From housing, access to feed or water was withheld for a period of 24h prior to slaughter. This occurred on three separate occasions with ten, six and eight ewes respectively. At the time of housing and during the 24 hour fasting period, the live weight of each ewe was repeatedly recorded, as per the weighing protocol described below. Immediately prior to slaughter, the live weight of each animal was recorded with the weight of digesta contained within the alimentary tract also recorded post-slaughter, to enable calculation of the true live weight of each individual, as described below.

3.1.1 Weighing protocol

On each occasion, all animals were removed from pasture two hours post-sunrise. Live weight of each individual was recorded with electronic scales with a sensitivity of 0.2 kg upon removal from pasture (0hrs fasted) and every two hours thereafter until 12hrs fasting, and again after 24hrs fasting. To obtain a best estimate of live weight at each fasting time, the live weight was recorded three times, with a maximum of 5 min between each weight recording (run). After 24 hours, fasting animals were slaughtered. No attempt was made to influence the order in which animals were weighed. For each fasting time the first recorded live weight was compared with the mean of the three weights to determine the benefit of multiple weight recordings. The live weight at each fasting time was compared to evaluate the benefit of fasting on reducing the variation in live weight estimates.

3.1.2 Slaughter procedure and true body weight estimates

As described above, after 24 hours fasting animals were slaughtered and the weight of digesta was measured to enable calculation of the true body weight of each individual. Due to the time taken to slaughter animals (up to two hours), each animal was again repeatedly weighed, as above, immediately prior to slaughter. For slaughter, animals were stunned with the use of a captive bolt followed by exsanguination caused by severance of the jugular vein and carotid artery. Immediately upon death the internal organs including the gastrointestinal tract were ligated and removed. The rumen, reticulum, omasum and abomasum were opened onto a table and the contents collected into a tarred bucket. The digesta contents of the small intestine, large intestine, colon and rectum were

removed by running the intestinal material between the thumb and forefinger of the operator and were collected into the same bucket. Care was taken to ensure as much of the digesta was collected as possible. The digesta contents were then weighed and subtracted from the live weight recorded immediately prior to slaughter to give the estimate of the true body weight for each individual animal.



Plate 3.1: Emptying gutfill

3.2 Experiment 2

The change in live weight during fasting for a period of 24 hours was recorded in 100 pregnant mixed-age ewes on two separate occasions (May and July). All ewes had been previously tagged with individual electronic identification (EID) tags and were shorn 48h prior to the start of measurement to remove fleece weight as a factor. In the May experiment the ewes were removed from feed, two hours post-sunrise and deprived of feed and water. Due to poor weather conditions in July the ewes were kept in the yards after shearing and fed baleage prior to the experiment. Live weights were recorded using an electronic tag reader and automated weighing and drafting unit at the time of removal from pasture (time 0hrs) and every two hours until 12 hours and again at 24 hours. Fasting occurred in an identical protocol to that described above, with the exception being a maximum of 10 minutes between each triplicate weight recording (run) due to the time taken to weigh all 100 animals. No attempt was made to influence the order in which animals were weighed.

3.3 Statistical Analysis

The statistical software used for analysis was GenStat (version 13, VSN International Limited) and Minitab 15 (Minitab Inc, version 15, 2006). For Experiment 1, no difference in the profile of live weight loss, either as absolute weight loss or as a percentage, between the three separate occasions was found ($P > 0.05$), consequently the data was pooled and analysed as one study. For analysis, each

fasting trial was considered as one rep, giving three replicates in total (one for Experiment 1 and two for Experiment 2). To determine the benefit of fasting on improving the accuracy of live weight estimates, regression equations of live weight loss at each fasting time were compared with digesta-free live weight (for Experiment 1) and 24 hour fasted live weight (for Experiments 1 and 2) using ANOVA. For each rep, the deviation of the first weight recorded from the 24 hour fasted weight for each fasting time was compared using probit analysis to give the range in weight required to encompass 95% of the population (LD95). The LD95 values for each fasting time were then compared using ANOVA with 95% least significant differences calculated. Further, the correlations between the rank of live weight loss between time 0 hours and 2-12 hours (where 1=greatest LW loss) and the rank of total live weight loss (0hrs less 24hrs) were compared to determine if the relative order of live weight loss was constant between individuals.

To determine the benefit of multiple weight recordings within time periods, for each rep and for each fasting time (0 hours to 24 hours) the variation between the first weight recorded or the mean of the first two weights recorded and the mean of all three recorded weights was calculated. This was compared using probit analysis to calculate the weight variation required to encompass 95% of the variation (LD95) which was then compared between multiple weighings for each fasting time using ANOVA with 95% LSD calculated. Further, the regression equations when the y intercept was set to 0 and the regression co-efficient (R^2) within each fasting time for either the first weight or the mean of the first two weights compared with the mean of all three weights were calculated and compared using ANOVA.

4 Results

4.1 Live weight loss relative to fasting time

4.1.1 Experiment 1

Mean live weight of the ewes \pm s.e.m. for the average of all three weights recorded at 0h, 2h, 4h, 6h, 8h, 10h, 12h and 24h of fasting is given in Figure 4.1. Live weight of the ewes at the start of fasting ranged from 34.4 kg to 79.6 kg, with a mean of 61.3 kg. Overall, there was no effect of run ($P>0.05$) but there was an effect of time ($P<0.001$), reflecting a decrease in mean live weight from 61.3 ± 2.53 kg at time 0 to 57.2 ± 2.42 kg at 24h fasting. This reduction was curvilinear, with an equation of best fit being $y = 0.0062x^2 - 0.3074 + 61.074$ ($R^2=98.8$).

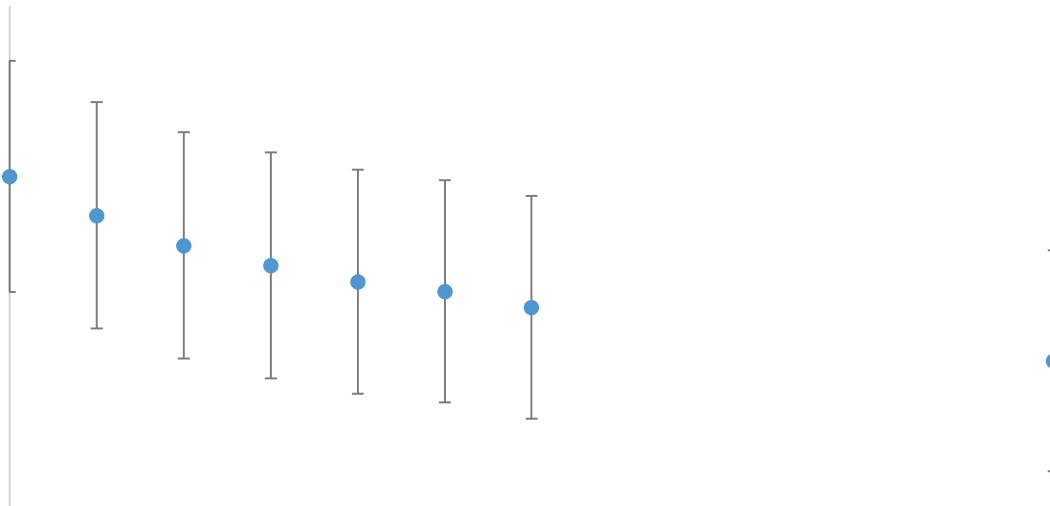


Figure 4.1: Mean of three repeated measurements of live weight (kg \pm s.e.m) relative to time fasting time from feed and water (h) for 24 ewes. The line of best fit represented the logarithmic equation $y=0.0062x^2-0.3074x+61.074$ ($R^2=0.988$).

4.1.1.1. Live weight Loss- Experiment 1

Mean live weight lost during fasting for 24 hours for the 24 sheep using the average of three multiple weights in absolute (kg) and as a proportion of initial live weight are shown in Figure 4.2 and Figure 4.3 respectively. Overall, for both absolute and proportional live weight loss there was no effect of run ($P>0.05$) but there was an effect of time ($P<0.001$), with live weight loss displaying a curvilinear response, peaking at 4.1 ± 0.23 kg and $6.7\% \pm 0.348$, respectively, after 24 hours fasting. The regression equations, $y = -0.0073x^2 + 0.3445x$ for absolute live weight loss and $y=-0.012x^2+0.5636x$ for proportional live weight loss, both explained 98% of the variation.

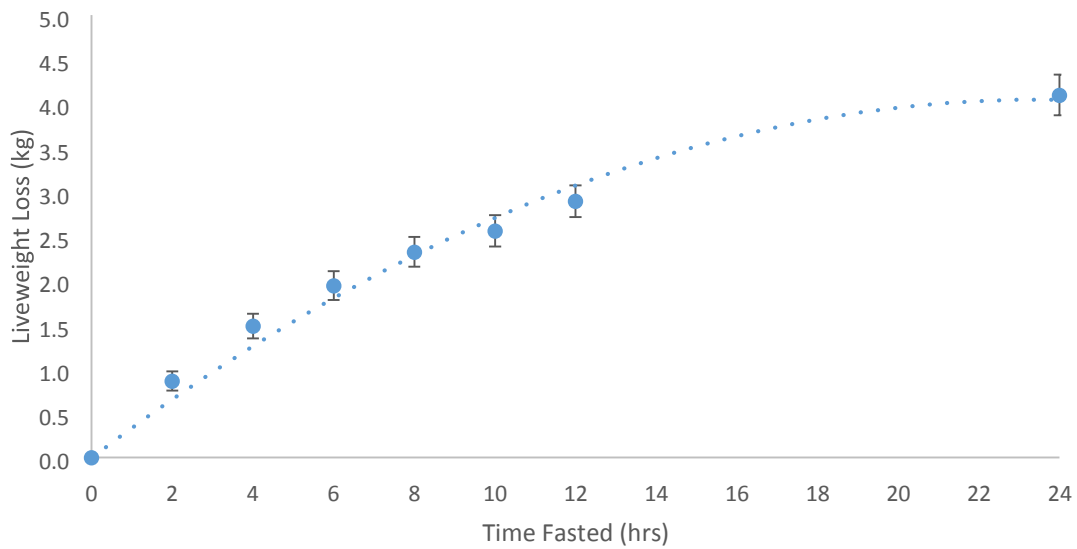


Figure 4.2: The Mean live weight loss of initial live weight in absolute terms ($\text{kg} \pm \text{s.e.m}$) relative to time fasting time from feed and water (h) for *experiment one* (24 ewes). The line of best fit represented the logarithmic equation $y = -0.0073x^2 + 0.3445x$ ($R^2 = 0.9845$).

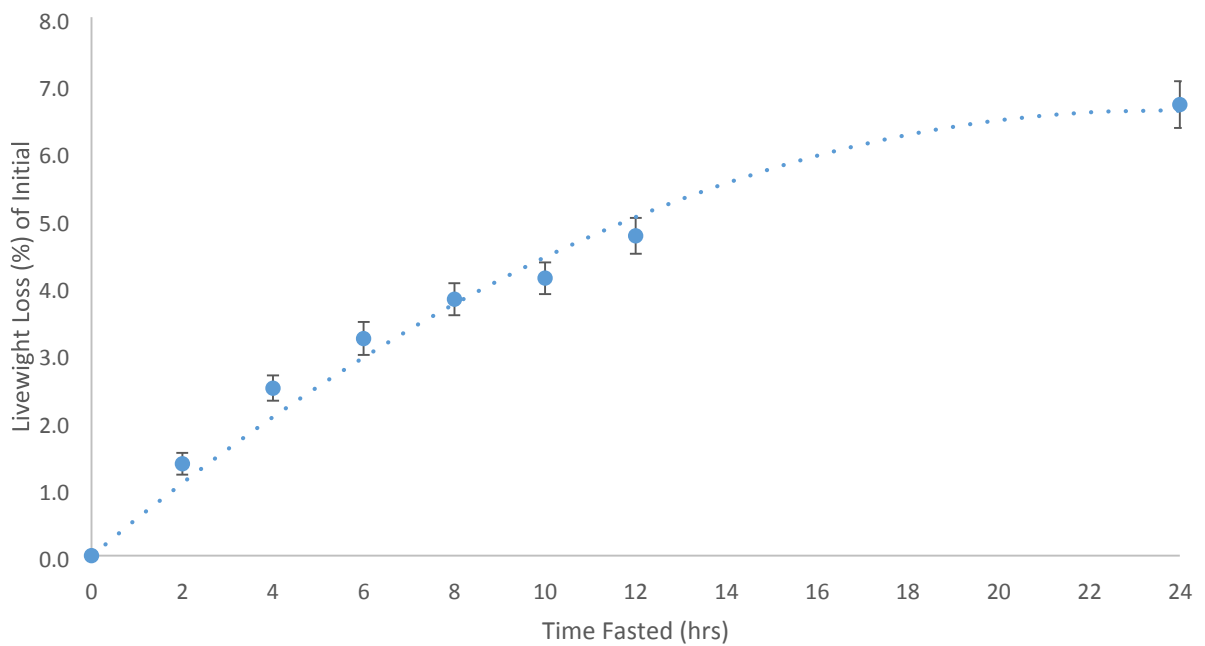


Figure 4.3: The Mean live weight loss as a percentage of initial live weight ($\% \pm \text{s.e.m}$) relative to time fasting time from feed and water (h) for *experiment one* (24 ewes). The line of best fit represented the logarithmic equation $y = -0.012x^2 + 0.5636x$ ($R^2 = 0.9823$).

4.1.1.2. True Body Weight as Proportion

The proportion of true live weight relative to measured live weight over 24 hours fasted is given in Figure 4.4. True live weight was calculated by taking the 24 hours fasted live weight and subtracting off the digesta weight measured at slaughter. Overall, there was a time x run interaction ($P=0.043$) reflecting a difference between the run 1 and run 2 at 10h fasting only. Across all three runs, the mean proportion of live weight recorded that was true live weight increased from 0.85 ± 0.0056 to 0.91 ± 0.0041 from 0 hours fasted to 24 hours, reflecting an increase in the accuracy of live weight estimate with increased fasting.

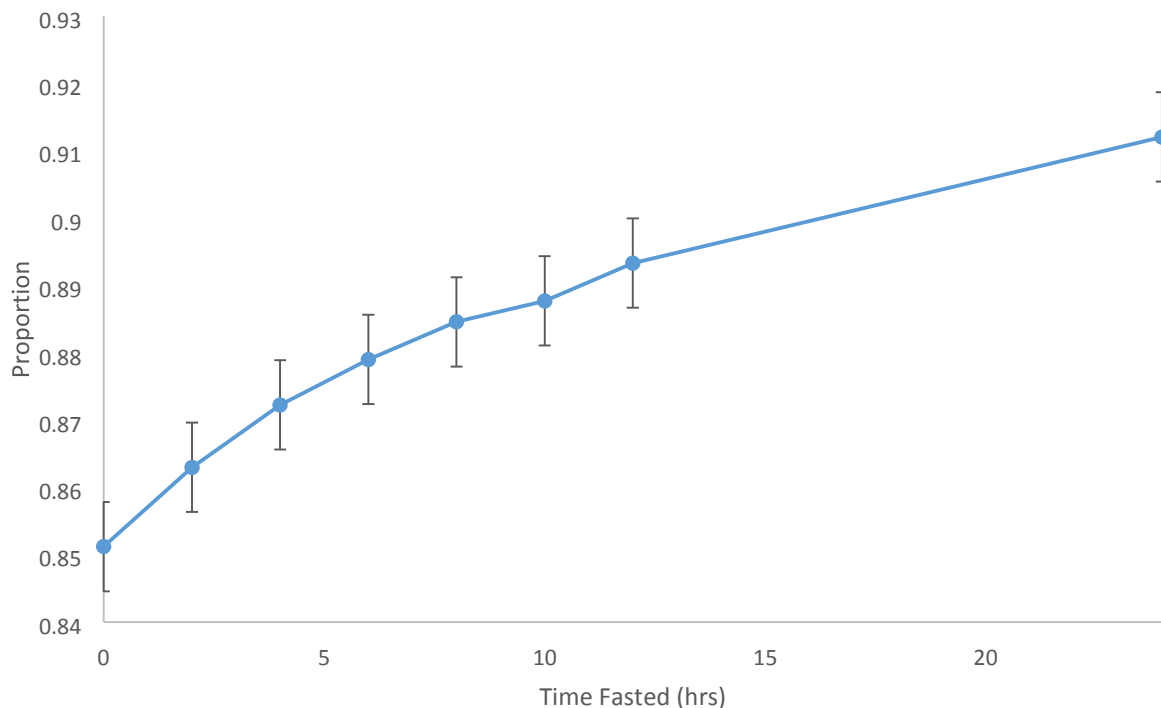


Figure 4.4: The Proportion of Measured Live weight is of True Live weight (proportion \pm s.e.m) relative to time fasting time from feed and water (h) for 24 ewes.

4.1.1.3. Digesta at 24hr Fasted and Proportion of True Body Weight

Mean digesta weight after 24h fasting ($\text{kg} \pm$ s.e.m) along with the digesta weight as a proportion of true live weight, is given in Figure 4.6. Mean final digesta weight was $5.06 \text{ kg} \pm 0.27 \text{ kg}$, ranging between 2.5 kg to 7.3 kg across the 24 ewes. The proportion the digesta was of the true live weight

(digesta-free) was $9.86 \pm 0.498\%$, ranging from 6.29 to 15.4%. Expressing the digesta as a proportion of true live weight slightly decreased the coefficient of variation from 0.266 for the digesta weight to 0.248 for the proportion of true live weight.

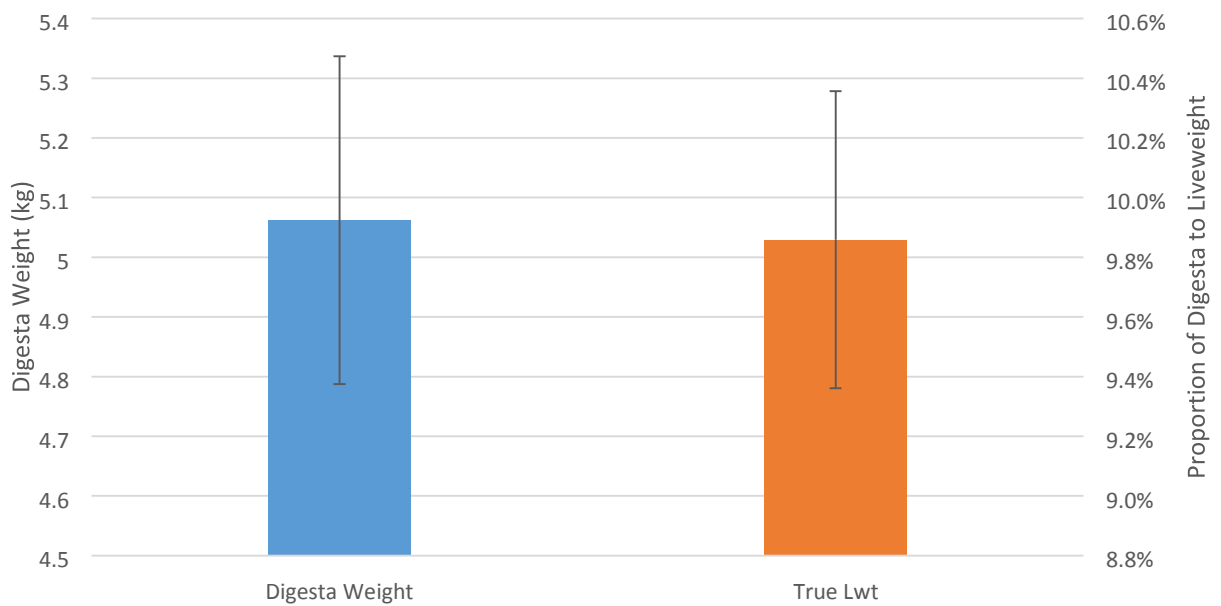


Figure 4.5: Mean final digesta weight at 24h fasted (kg \pm s.e.m) along with the proportion of digesta to true live weight (proportion \pm s.e.)

4.1.2 Experiment 2

The live weight loss as a proportion of initial live weight is shown in Figure 4.3 for experiment one (May and July). In the May experiment, live weight loss peaked at 7.87% of initial live weight which was greater than the maximum loss of 3.09% seen in the July experiment. The May experiment resulted in a regression equation of $y = -0.0002x^2 + 0.0077x$ representing 97.9% of the data and the regression equation for the July experiment was $y = -2E-05x^2 + 0.0018x$ ($R^2 = 0.9954$).

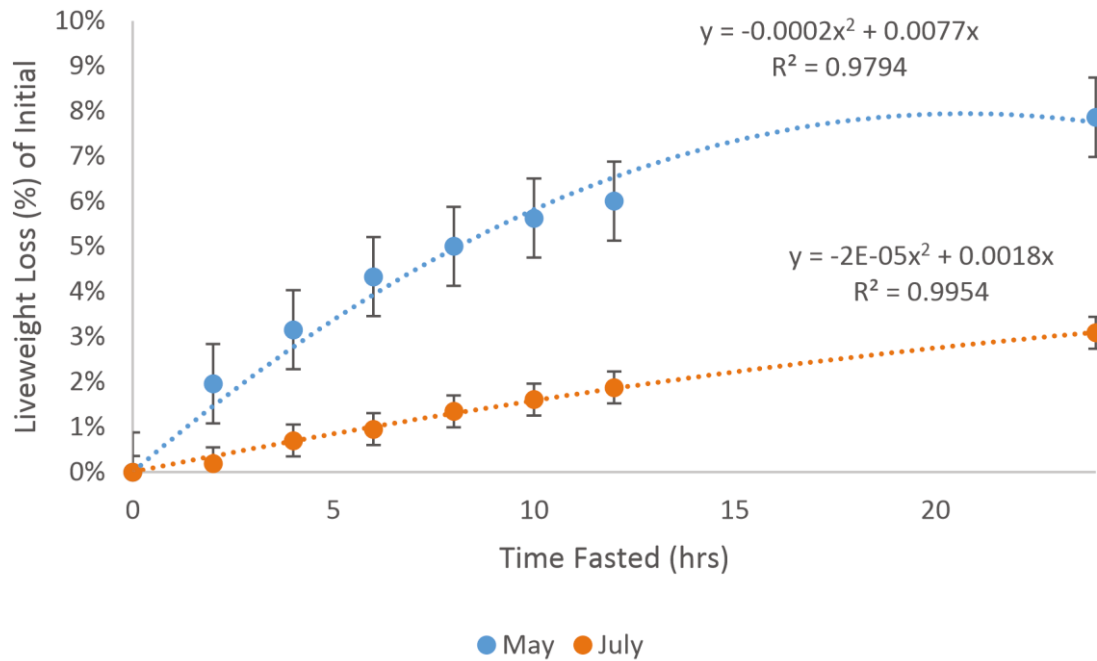


Figure 4.6: The Mean live weight loss as a percentage of initial live weight ($\% \pm \text{s.e.m}$) relative to time fasting time from feed and water (h) for 100 ewes in experiment two. The line of best fit for the May Experiment represented the logarithmic equation $y=0.0002x^2+0.0077x$ ($R^2=0.9794$) and the line of best fit for the July Experiment represented the logarithmic equation $y=-2E-05x^2+0.0018x$ ($R^2=0.9954$).

4.2 Coefficient of Variation

4.2.1 Experiment 1

The coefficient of variation declined over the 24 hour fasting period for the absolute and proportional live weight loss shown in **Error! Reference source not found.**. At time 0 hours fasted, the coefficient of variation is 62.9 and 58.5% for absolute and proportional live weight loss respectively, this drops to 27.9 and 25.4% over the 24 hours fasted. The greatest drop in variation was observed over the first 2 hours fasted with a drop of 18 and 21.6% for live weight loss expressed by absolute values and on a proportional bases.

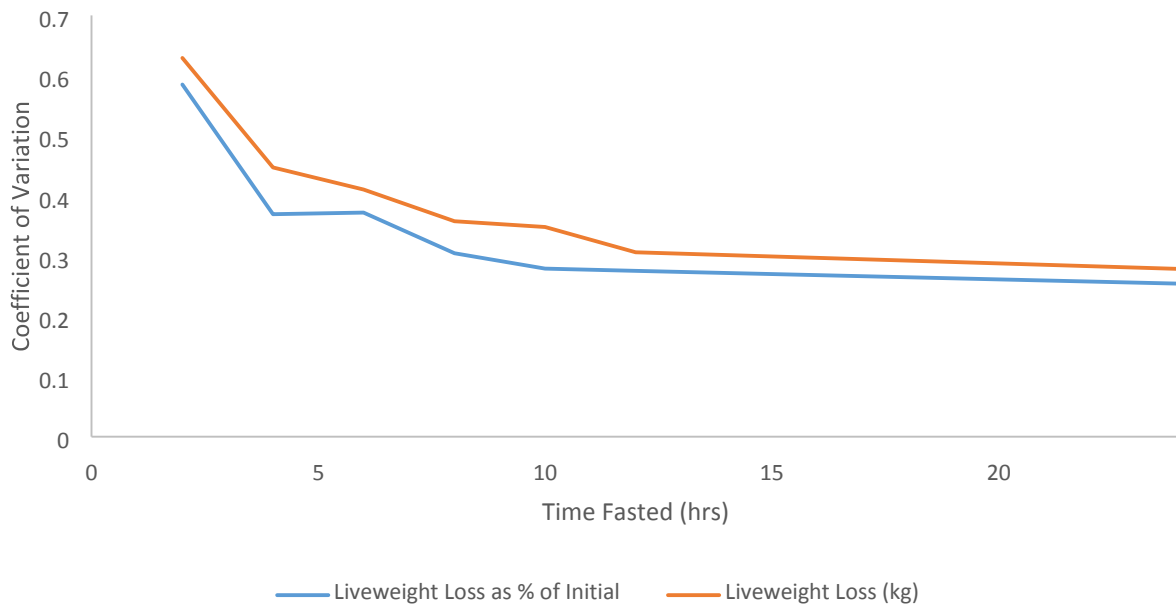


Figure 4.7: The Coefficient of variation for the live weight loss (kg) and the live weight loss as a percentage of initial live weight for experiment one

The precision of estimation was not improved as the co-efficient of variation (see Figure 4.8) only slightly reduced from 3.21 to 2.19 between 0 and 24 hours fasted, an effect that was not significant when compared with run as replicates ($P>0.05$).

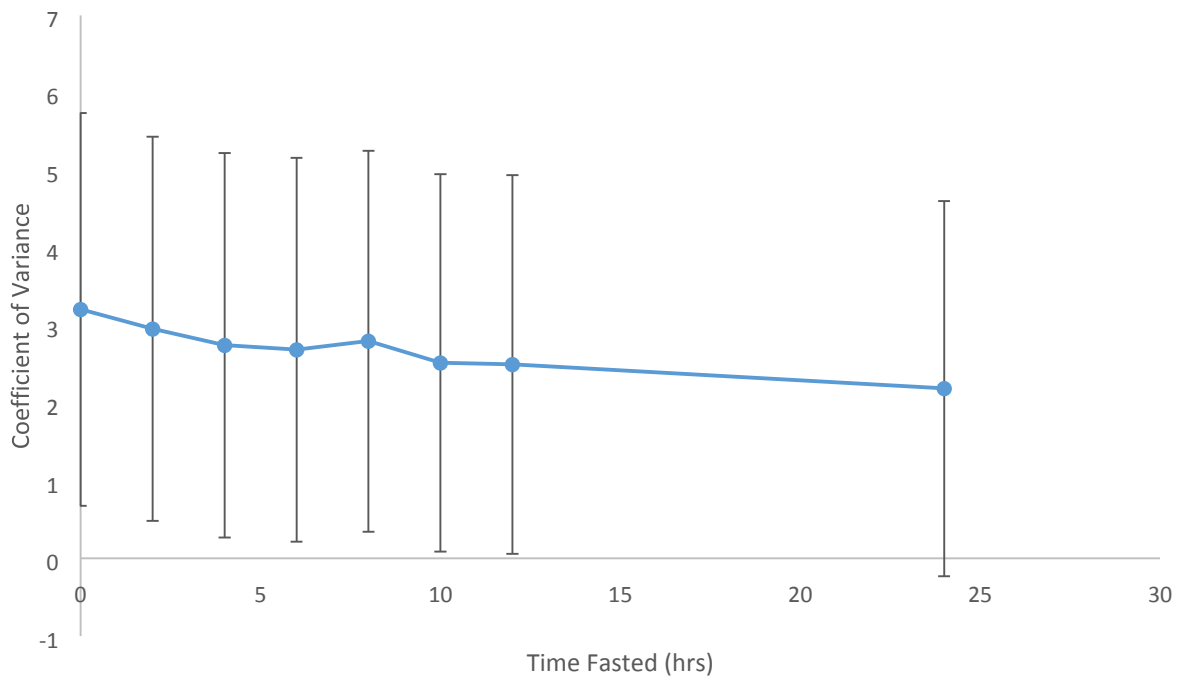


Figure 4.8: The overall coefficient of variation (\pm s.e.m) of the proportion of measured live weight is of true live weight relative to time fasting time from feed and water (hrs) for 24 ewes.

4.2.2 Experiment 2

The co-efficient of variation for the live weight loss as a percentage of initial live weight for experiment two, for May and July relative to fasting time is given in Figure 4.9. The coefficient of variation decreased from 1.9% and 0.3% at 0hr fasted to 0.3 and 0.2% at 24hrs fasted.

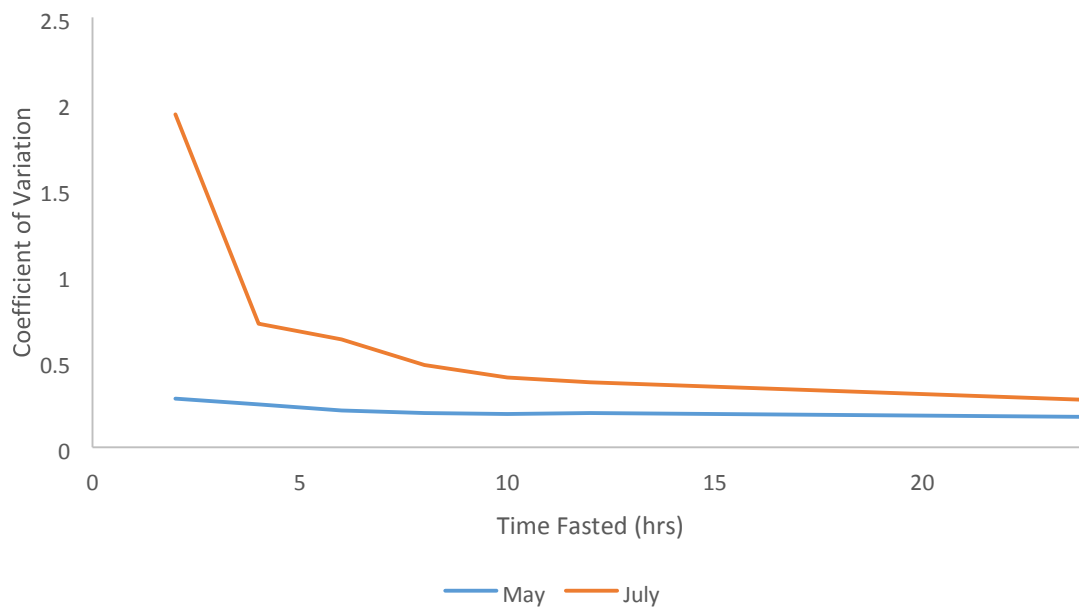


Figure 4.9: The Coefficient of variation for the live weight loss as a percentage of initial live weight for experiment two, May and July

4.3 Rank Comparison of initial live weight less the true live weight ranking

4.3.1 Experiment 1

The initial live weight less true live weight ranking of live weight loss (kg) is plotted against live weight loss (kg) at fasting times 2, 4, 6, 8, 10, 12 and 24 for experiment one (24 ewes) in Figure 4.10. Overall there was a relatively strong positive relationship, with the greatest correlation found at 10hr fasted with a regression equation of $y=0.9578x$ ($R^2=0.6476$). The weakest relationship was found at 8hr fasted with a regression equation of $y=0.911x$ ($R^2=0.2755$).

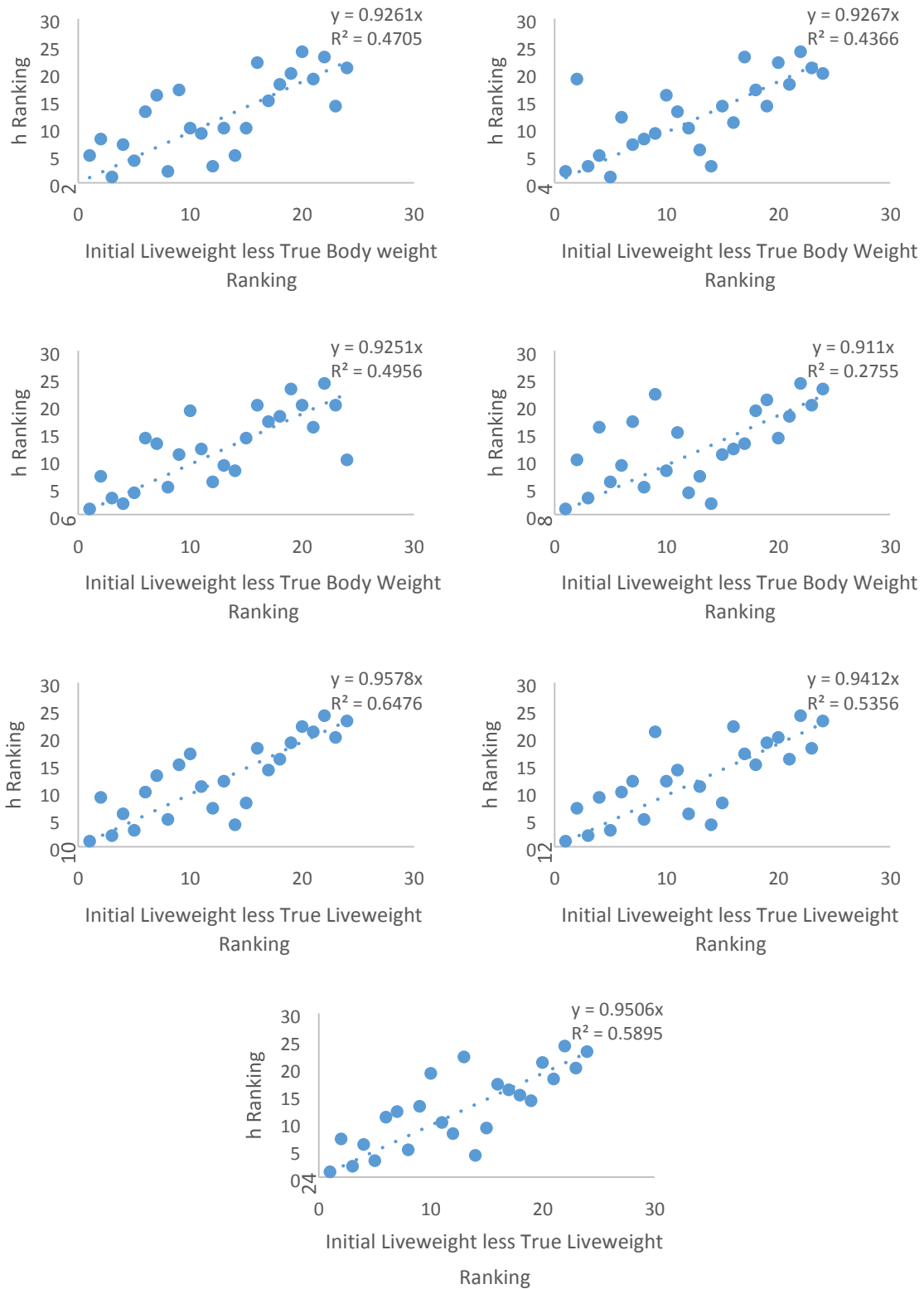


Figure 4.10: Rank Comparison of initial live weight less the true live weight ranking with ranking of live weight loss (kg) for fasting times 2, 4, 6, 8, 10, 12, 24 hours for experiment one (24 ewes)

4.4 Relationship between Live weight Loss and 24hr Loss

4.4.1 Experiment 1 absolute (kg)

The relationship between live weight loss (kg) ranking at 24 hours fasted and the live weight loss (kg) at fasting times 2, 4, 6, 8, 10, 12 for experiment 1 (24 ewes) is given in Figure 4.11. The positive linear relationship improved as fasting time increased. The strongest relationships was found at 10hr fasted $y=0.9839$ ($R^2=0.8637$). The weakest relationships were seen at 8hr fasted $y=0.9212x$ ($R^2 = 0.3551$);

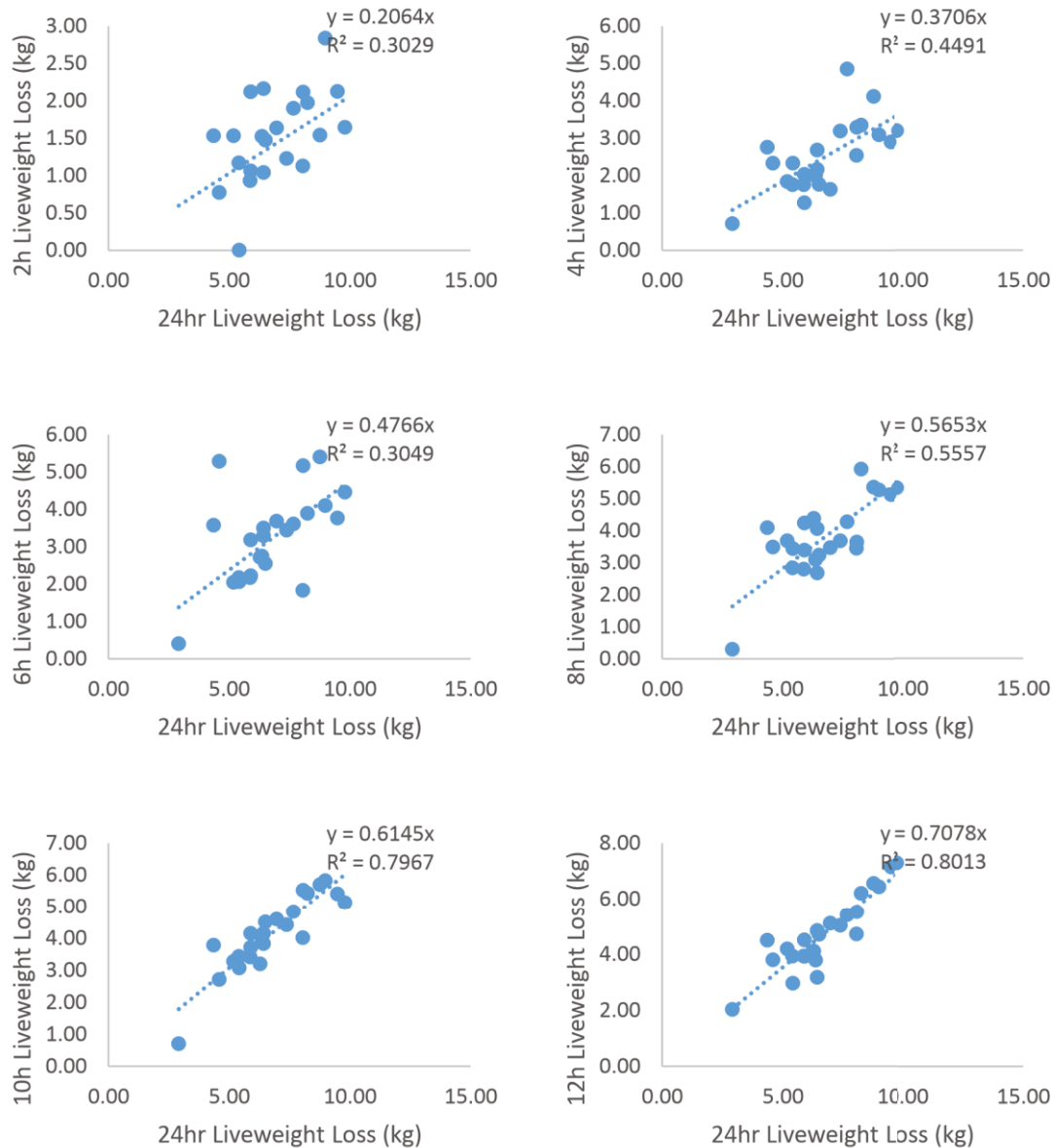


Figure 4.11: 24hr Live weight Loss (kg) comparison with live weight loss (kg) for fasting times 2, 4, 6, 8, 10, 12, 24 hours for the 24 ewe experiment

4.4.2 Experiment 2 absolute (kg)

The relationship between live weight loss (kg) ranking at 24 hours fasted and the live weight loss (kg) at fasting times 2, 4, 6, 8, 10, 12 for experiment 2 (May and July) is given in Figure 4.12. A positive linear relationship got stronger as fasting time increased. The weakest relationships were found at: May experiment: 2hr Fasted $y=0.8897$ ($R^2=0.2378$) and July Experiment: 2hr Fasted $y=0.8433x$ ($R^2=0.008$). The strongest relationship was seen in the May experiment at: 12hr Fasted $y=0.9878x$ ($R^2=0.8976$) and July Experiment: 12hr Fasted $y=0.9567x$ ($R^2=0.6623$).

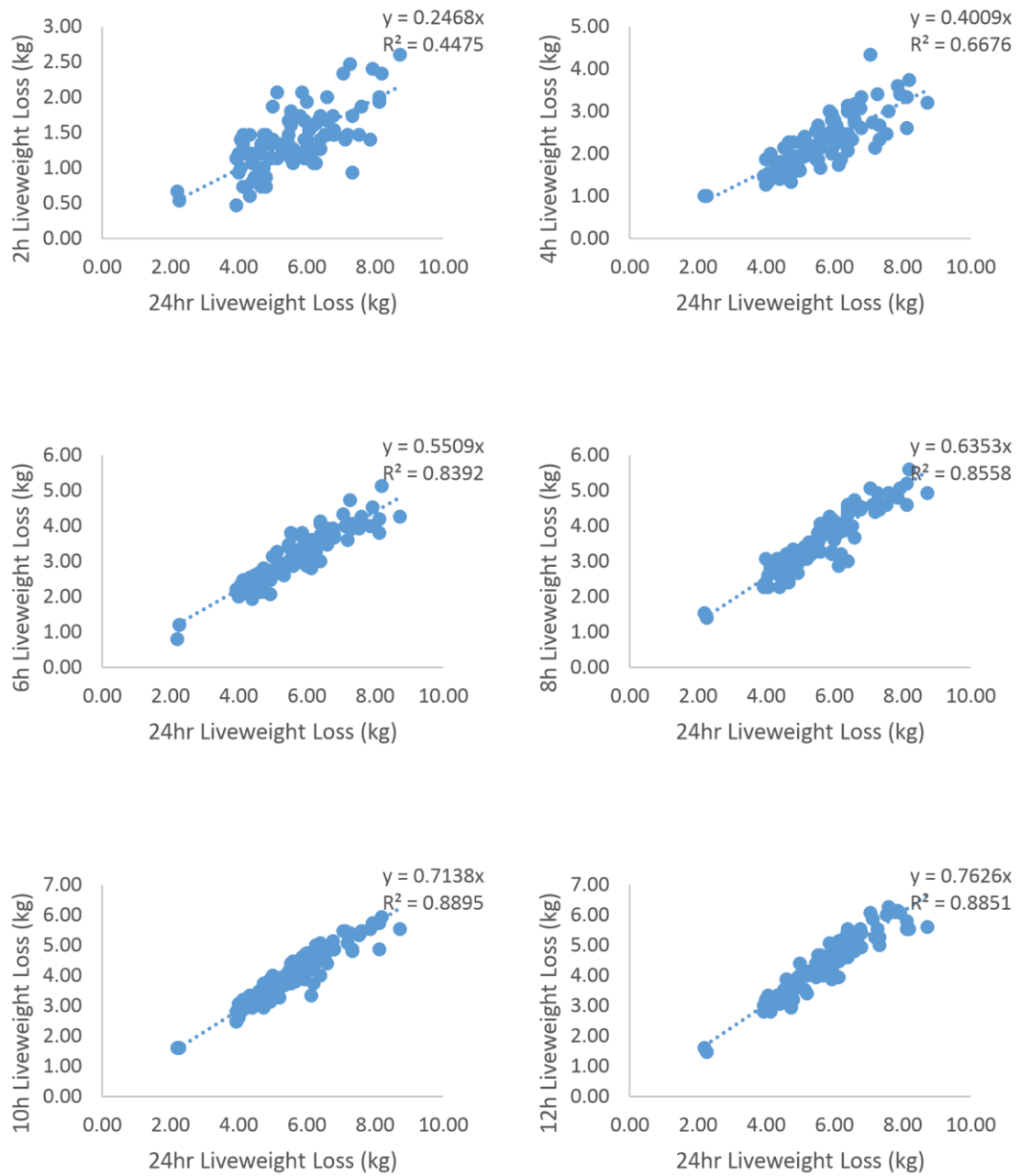


Figure 4.12: 24hr Live weight Loss (kg) comparison with live weight loss (kg) for fasting times 2, 4, 6, 8, 10, 12, 24 hours for experiment two (May).

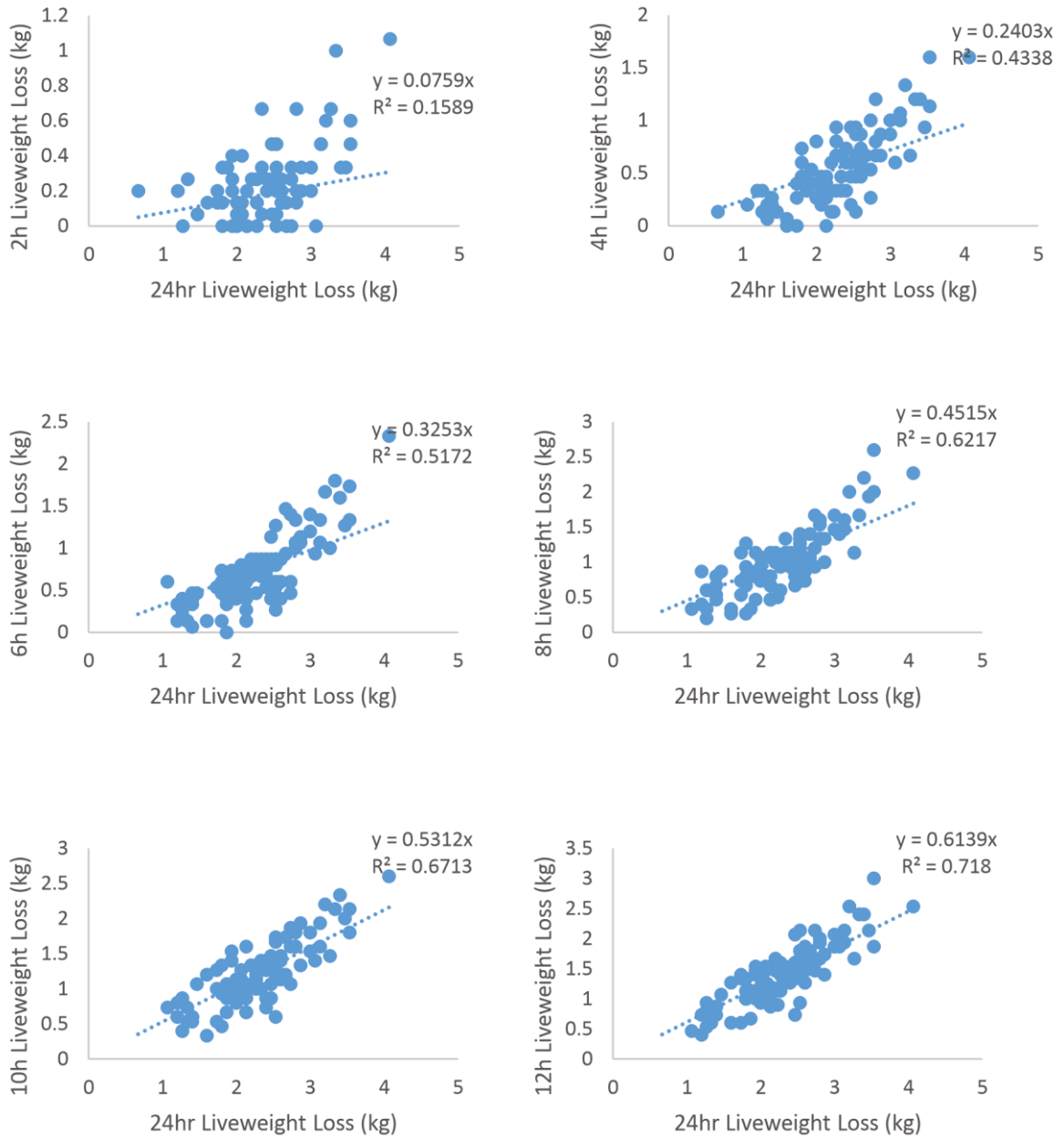


Figure 4.13: 24hr Live weight Loss (kg) comparison with live weight loss (kg) for fasting times 2, 4, 6, 8, 10, 12, 24 hours for experiment two (July).

4.4.3 Experiment 1 (%)

The relationship between live weight loss (%) at 24 hours fasted and the live weight loss (%) at fasting times 2, 4, 6, 8, 10, 12 for experiment one (24 ewes) is given in Figure 4.14: 24 hours live weight loss proportion of initial live weight (%) comparison with live weight loss proportion of initial live weight (%) for fasting times 2,4,6,8,10,12 24 hours for experiment 1. The strongest relationships was found in Experiment 1: 12hr Fasted $y=0.7078x$ ($R^2 =0.8013$). The weakest relationship was seen in; Experiment 1 at 2hr Fasted $y=0.2064x$ ($R^2 = 0.3029$).

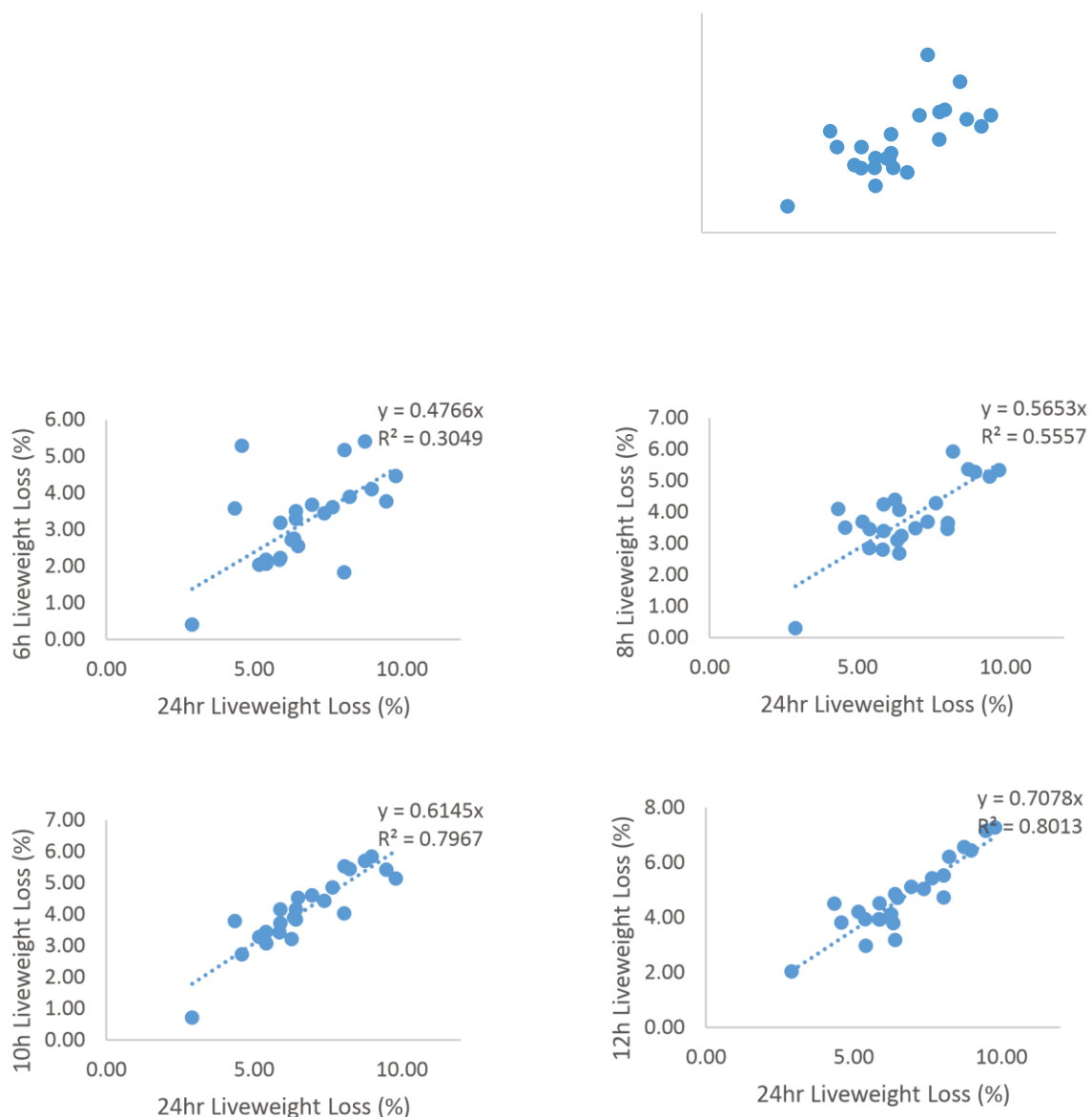


Figure 4.14: 24 hours live weight loss proportion of initial live weight (%) comparison with live weight loss proportion of initial live weight (%) for fasting times 2,4,6,8,10,12 24 hours for experiment 1.

4.4.4 Experiment 2 (%)

The relationship between live weight loss (%) at 24 hours fasted and the live weight loss (%) at fasting times 2, 4, 6, 8, 10, 12 for experiment two (May and July) is given in Figure 4.15. The strongest relationship was found for experiment 2 (May): 10hr Fasted $y=0.716x$ ($R^2=0.8578$) and experiment 2 (July): 10hr Fasted $y=0.8895x$ ($R^2=0.8895$). The weakest relationship was found for experiment 2 (May): 2hr Fasted $y=0.2489x$ ($R^2=0.3909$) and experiment two (July): 2hr Fasted $y=0.2468x$ ($R^2=0.4475$).

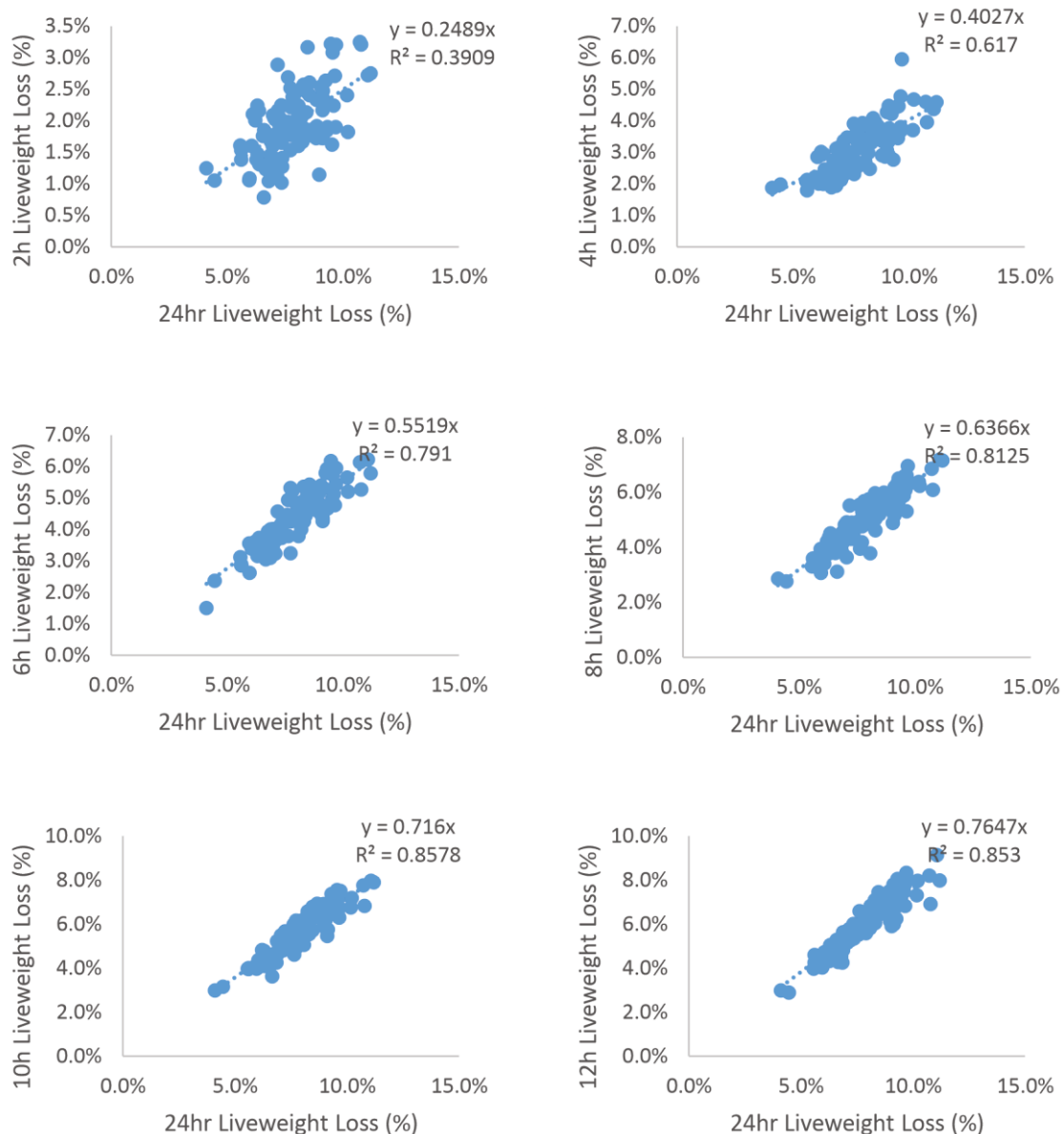


Figure 4.15: 24hr Live weight Loss proportion of initial live weight (%) comparison with live weight loss proportion of initial live weight (%) for fasting times 2, 4, 6, 8, 10, 12, 24 hours for experiment two (May).

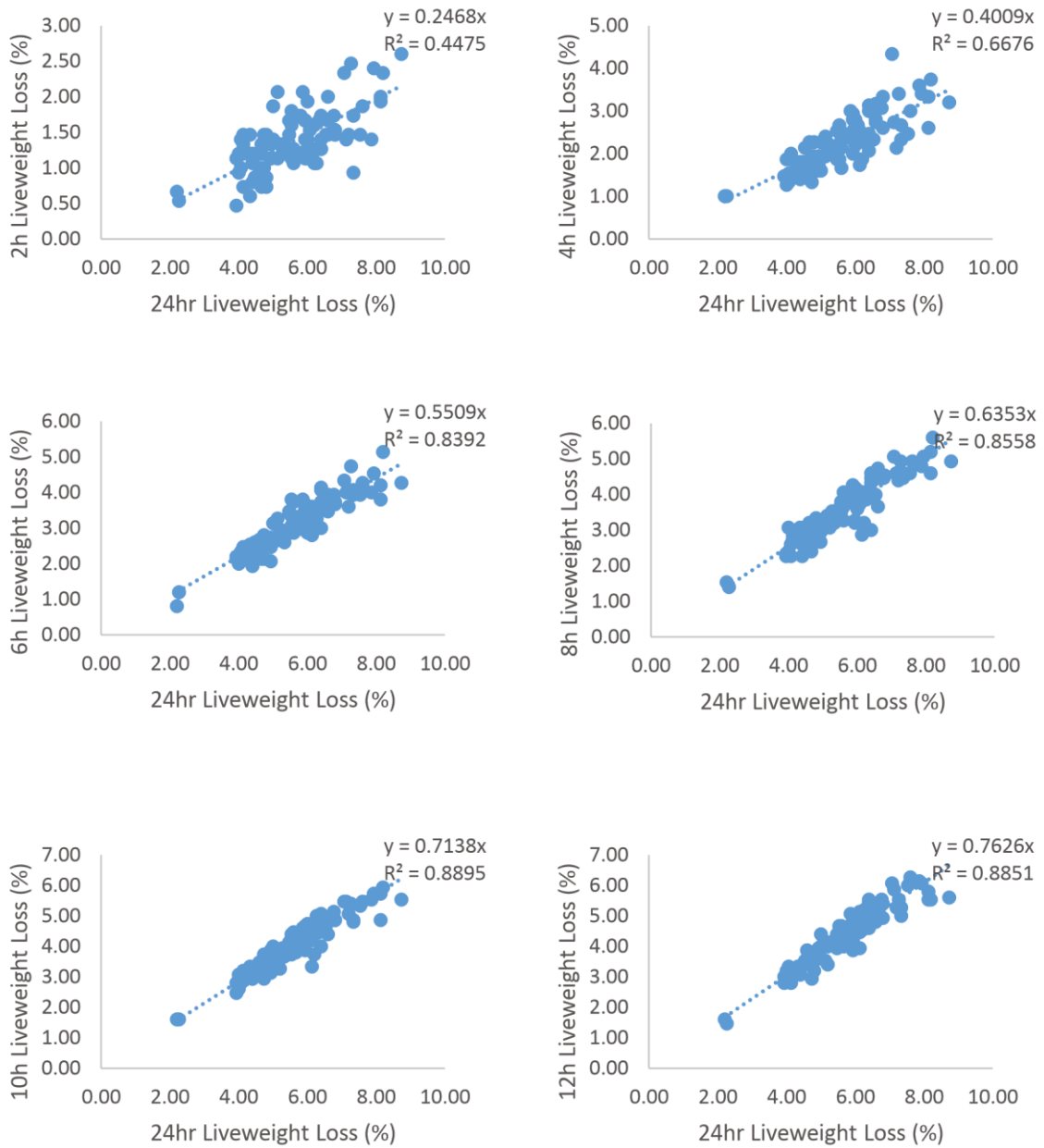


Figure 4.16: 24hr Live weight Loss proportion of initial live weight (%) comparison with live weight loss proportion of initial live weight (%) for fasting times 2, 4, 6, 8, 10, 12, 24 hours for experiment two (July).

4.5 Ranking at 24 hours fasted and ranking at various fasting times

4.5.1 Experiment 1

The relationship between ranking at 24 hours fasted and the ranking at fasting times 2, 4, 6, 8, 10, 12 for experiment one is given in Figure 4.17. The strongest relationship was found at 10hr Fasted $y=0.9839x$ ($R^2=0.8637$); The weakest relationship was seen at 8hr fasted $y=0.9212x$ ($R^2=0.3551$);



Figure 4.17: Rank Comparison of 24 hour live weight loss (kg) ranking against ranking of live weight loss for fasting times 2, 4, 6, 8, 10, 12, 24 hours for experiment one (24 ewes).

4.5.2 Experiment 2

The relationship between ranking at 24 hours fasted and the ranking times 2, 4, 6, 8, 10, 12 for experiment two (May and July) is given in Figure 4.18 and Figure 4.19, respectively. The strongest relationships were found at experiment two (May): 12hr Fasted $y=0.9878x$ ($R^2 =0.8976$) and experiment two (July): 12hr Fasted $y=0.9567x$ ($R^2 =0.6623$). The weakest relationships were seen in experiment two (May): 2hr Fasted $y=0.8897x$ ($R^2 =0.2378$) and experiment two (July): 2hr Fasted $y=0.8433x$ ($R^2 =-0.008$).

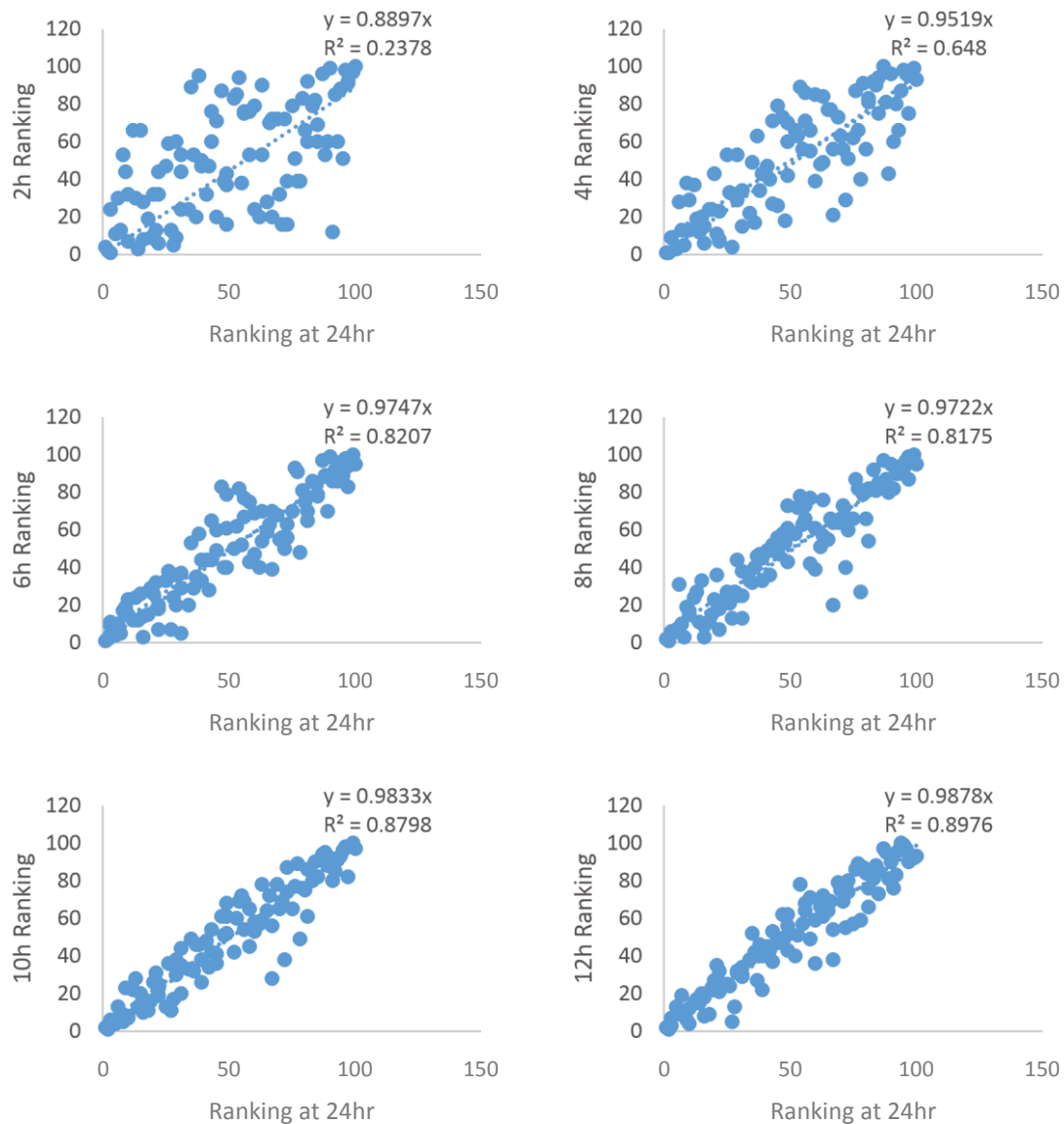


Figure 4.18: Rank Comparison of 24 hour live weight loss (kg) ranking against ranking of live weight loss for fasting times 2, 4, 6, 8, 10, 12, 24 hours for the 100 ewe May experiment.

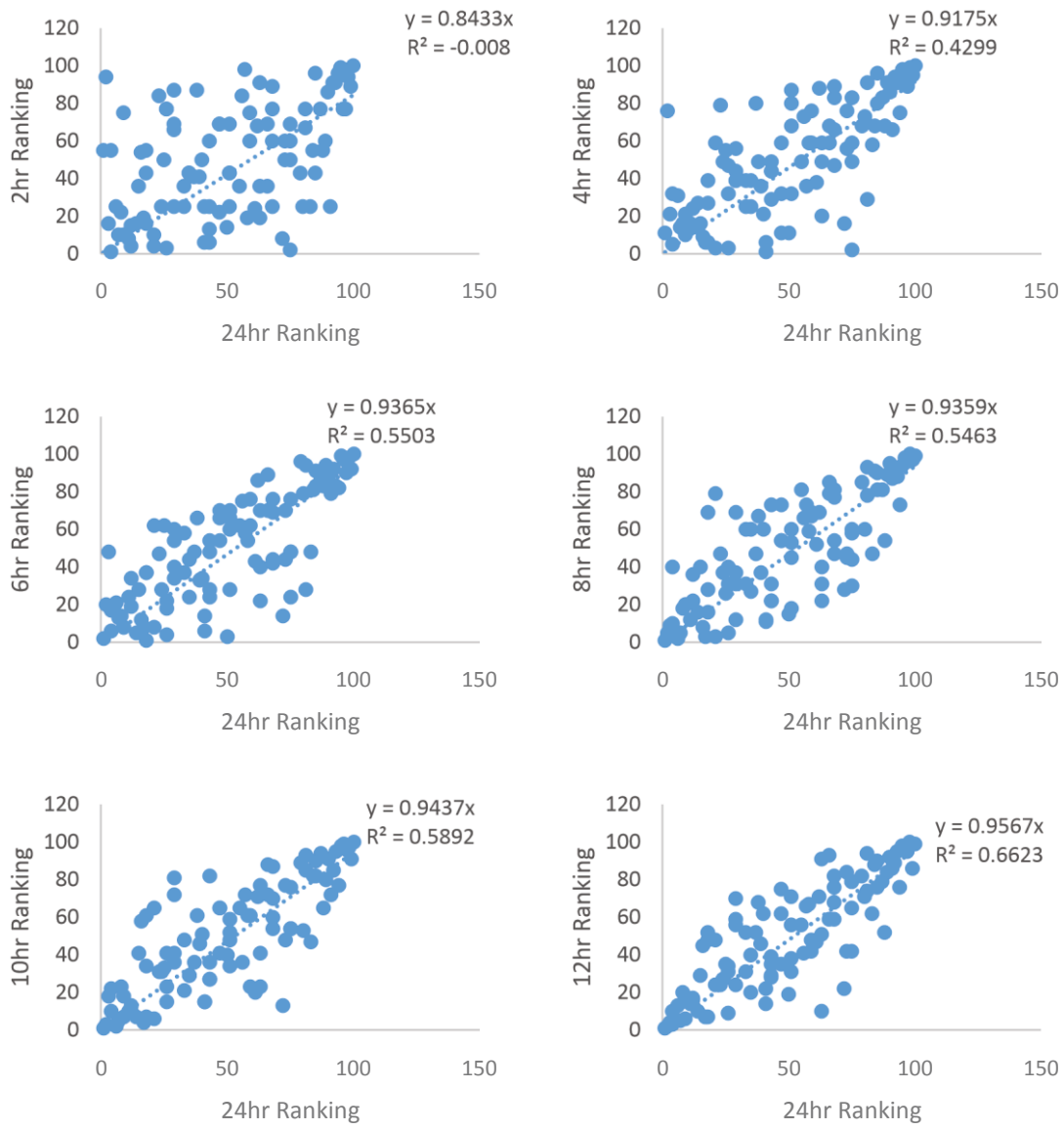


Figure 4.19: Rank Comparison of 24 hour live weight loss (kg) ranking against ranking of live weight loss for fasting times 2, 4, 6, 8, 10, 12, 24 hours for the 100 ewe July experiment.

4.5.3 Comparison across Experiments 1 and 2

A comparison of the regression co-efficient and gradient for experiments 1 and 2 (May and July) as depicted are given in Table 4.5.1, Table 4.5.2 and Table 4.5.3.

Table 4.5.1: 24 Hour Ranking Data: Live weight Loss (kg) of 24hr

Fasting Time	R-Squared		Gradient	
	Mean	S.E.M	Mean	S.E.M
2	0.303 ^a	0.083	0.1764 ^a	0.052
4	0.517 ^{ab}	0.076	0.337 ^{ab}	0.049
6	0.554 ^{ab}	0.155	0.451 ^{bc}	0.066
8	0.678 ^{ab}	0.091	0.551 ^{bc}	0.054
10	0.786 ^b	0.063	0.620 ^c	0.053
12	0.802 ^b	0.048	0.695 ^c	0.043

Table 4.5.2: Live weight Loss (%) of 24hr

Fasting Time	R-Squared		Gradient	
	Mean	S.E.M	Mean	S.E.M
2	0.380 ^a	0.042	0.234 ^a	0.014
4	0.578 ^{ab}	0.066	0.391 ^b	0.010
6	0.645 ^{ab}	0.171	0.526 ^c	0.025
8	0.741 ^{ab}	0.094	0.612 ^{cd}	0.024
10	0.848 ^b	0.027	0.681 ^{de}	0.033
12	0.847 ^b	0.024	0.745 ^e	0.019

Table 4.5.3: 24 Hour Ranking Data

Fasting Time	R-Squared		Gradient	
	Mean	S.E.M	Mean	S.E.M
2	0.287 ^b	0.188	0.893 ^a	0.030
4	0.525 ^{ab}	0.064	0.935 ^{ab}	0.010
6	0.638 ^{ab}	0.091	0.947 ^{ab}	0.014
8	0.573 ^{ab}	0.134	0.943 ^{ab}	0.015
10	0.778 ^{ab}	0.094	0.970 ^b	0.013
12	0.761 ^{ab}	0.071	0.970 ^b	0.009

4.6 Probit Analysis of data within 95% of 24hr weight

4.6.1 Experiment 2

The data range (kg) within 95% of the 24hr weight over the time 2, 4, 6, 8, 10, 12 hours fasted for experiment two May and July is given in Table 4.6.1. At 0 hours fasted, 95% of the ewes were within 6.3 (± 1.5) kg of their 24 hour liveweight. As time fasted increased, the liveweight range reduced to 95% of weights being 2.2 (± 0.3) kg within the 24h fasted weight by 12h fasting. There was no significant difference between the liveweight range from 0, 2 and 4 hours fasted; 4, 6, 8 hours fasted and 6, 8, 10, 12 hours fasted as indicated in Table 4.6.1: The range of live weight (kg) (\pm s.e.m) within 95% of 24hr weight (kg) for average of 3 weights with time fasted 2, 4, 6, 8, 10 and 12 hours for experiment two May and July.

Table 4.6.1: The range of live weight (kg) (\pm s.e.m) within 95% of 24hr weight (kg) for average of 3 weights with time fasted 2, 4, 6, 8, 10 and 12 hours for experiment two May and July.

	0	2	4	6	8	10	12
Mean	6.316	4.833	3.98	3.364	2.952	2.361	2.212
Standard error of mean =	1.486	0.947	0.722	0.517	0.48	0.314	0.329
Significant Differences	a	ab	abc	bc	bc	c	c

4.7 Live weight relative to multiple weighing

4.7.1 Experiment 1

The R^2 values for the measured live weight plotted against the animal's true live weight for 1 weighing, the average of two and three weighings in Table 4.7.1. Generally the R^2 values increased from an average of 0.977 to 0.99 over the 24 hour fasting time period. The greatest difference is seen at 0 hours fasting where there is a 0.08 difference between one weight measured and the average of two weights. However, there was no significant difference between R^2 values between taking one weight and a two or three weight average. There was also no significant difference when fasting time was blocked. The gradient for the line of best fit is for the plot against true live weight verses measured live weight is given in Table 4.7.2. There is no statistical difference in gradient between the number of times an animal is weighed.

Table 4.7.1: R^2 Values for Best Fit Regression for the estimated live weight vs. true liveweight over multiple weighing: one weight, average of 2 and 3 weights for the 24 ewe experiment.

<u>Fasting Time</u>	<u>Weight 1</u>	<u>Average 2 Weights</u>	<u>Average 3 Weights</u>
0	0.972	0.980	0.979
2	0.981	0.983	0.982
4	0.986	0.986	0.985
6	0.987	0.988	0.987
8	0.980	0.984	0.984
10	0.988	0.988	0.988
12	0.986	0.987	0.987
24	0.989	0.990	0.990

Table 4.7.2: Gradient Values for Best Fit Regression for the estimated live weight vs. true live weight over multiple weighing: one weight, average of 2 and 3 weights for experiment one.

<u>Fasting Time</u>	<u>Weight 1</u>	<u>Average 2 Weights</u>	<u>Average 3 Weights</u>
0	0.850	0.861	0.853
2	0.865	0.872	0.865
4	0.874	0.874	0.874
6	0.880	0.880	0.881
8	0.887	0.886	0.886
10	0.889	0.890	0.890
12	0.894	0.894	0.894
24	0.933	0.936	0.912

4.8 Probit Analysis data within 95% of average of three weight

4.8.1 Experiment 2

The data range (kg) within 95% of the average of 3 weight measurement over the time 2, 4, 6, 8, 10, 12 and 24 hours fasted for experiment two May and July is given in Figure 4.20. As expected the liveweight (kg) within 95% decreased from 1.3 (± 0.5) kg and (± 0.9) for one weight and the average of two weights at 0hrs fasted to 0.6 (± 0.1) and 0.3 (± 0.1) kg for weight one and average of two weights. There was only a significant difference between one weight and the average of two weight at 10 hours fasted, $p = 0.03$.

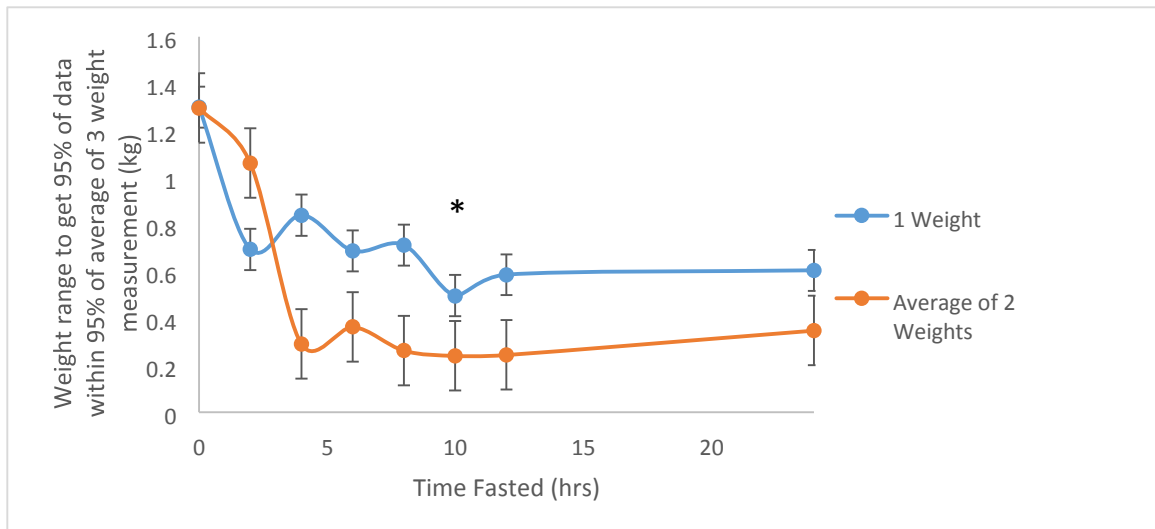


Figure 4.20: The range of live weight (kg) (\pm s.e.m) within 95% of the average of three live weight mean 24hr weight (kg) for average of 3 weights with time fasted 2, 4, 6, 8, 10 and 12 hours for the 100 ewe experiment May and July.

5 Discussion

An animal's true live weight is considered to be digesta-free live weight, an estimate of which was unachievable due to the considerable variation in digesta weight. As may have been expected, the result of fasting improved the closeness of measurements to the 'true' live weight (digesta-free live weight), however there was still considerable variation, which did not reduce with fasting time. The longer an animal was fasted, the greater the opportunity was to lose gutfill, which is the main determinant of live weight loss as animals are fasted over 24 hours. In experiment one, animals reached on average $91 \pm 0.004\%$ of their true live weight, an increase from $85 \pm 0.006\%$ at 0 hours fasted. It is assumed that it would take more than 24 hours fasted to completely empty the digestive tract of an animal, however fasting for greater than 24 hours may lead to tissue losses. Gutfill contributed, on average, 15% of an animal's starting live weight, ranging from 10-20% and 8.9% (613%) of the 24hr fasted measured live weight. This is in accordance with Lawrence et al. (2002) which found digesta can make up to 23% of total live weight. However, the animals were unable to reach 100% of their true live weight as there was still a considerable proportion of gutfill that was making up their live weight. The proportion the digesta weight was of true live weight in experiment one ranged from 6.29-15.4%. This shows the considerable variation in digesta between animals that was not able to be substantially reduced in the 24 hours fasting. Fasting did not extend beyond 24 h in the current study as live weight loss has been observed beyond 24 hours fasted (Thompson et al., 1987; Cole, 1995), 3% loss between 24-48 hours and a total of 9.9% loss. Fasting beyond 24 hours may result in subsequent adipose and protein tissue losses. Further, in practice it is unlikely that fasting over 24 hours will be carried out and therefore the effects of fasting to give a reliable estimate of a 24 hour fasting weight has been analysed to optimise a weighing protocol that best represents what is likely to be utilised in practice.

Weighing animals multiple times does not significantly reduce error associated with live weight measurements, suggesting that one weight is sufficient enough to obtain an estimate of animal live weight. It has been suggested that more than one measurement should be taken in order to take a reliable live weight measurement of an animal (Bean, 1946). Taking more than one measurement supposedly reduces variation as there is less reliance on one single measurement. This was evident in experiment one, which showed no significant difference between taking one weight and averaging two or three weights for true live weight verses measured live weight for one measurement or the average of two or three weights. R-squared values ranged between 0.972 – 0.990 and gradient varied between 0.880-0.936. The weight range to get 95% of data within 95% of

the average of three weights reduced from 1.3 kg to 0.6 kg for one weight measurement and 1.3kg to 0.3kg for the average of two weights over 24 hours fasted. However, there was little difference between taking one weight and averaging two weights with the only significant result found at 10 hours fasted, where the standard error of mean was particularly small for the one weight average. These results are in agreement with Bean, (1946; 1948) and Baker et al, (1947) which also showed no significant difference between multiple weighing particularly over a three day average. By comparison, Galwey et al (2013) used the same method in comparing variation to the best estimate, average of three weight and. found a greater accuracy in the average of two weight measurement. These authors reported a 0.3 kg difference between one live weight measured and the average of two live weight measurements for the data within 95% of the best estimate at 0 hours fasted and 0.17 kg at 24 hours fasted (Galwey et al., 2013), which is considerably greater than the 0.004 kg difference at 0hr fasted and 0.25 kg at 24 hours fasted from experiment two data in the current study. The difference between multiple weighing was not obvious in the experiments performed, and at least for these animals, it appears multiple weighing does not substantially improve the accuracy of live weight measurements.

Fasting proves to be a suitable method in improving the accuracy of an animal's live weight. As mentioned earlier the animals in experiment one increased to their true live weight from 85% at 0 hours fasted up to 91% at 24 hours fasted. However it was clear that a true estimate of live weight is not achievable as there is still a considerable level of gutfill and variation of gutfill in the rumen and intestinal tract. The next best live weight estimate is the 24 hour fasted live weight. However as live weight loss shows a curvilinear response there is a point at which live weight loss is minimised. As live weight loss plateaus the level of accuracy reaches a peak, further fasting does result in an increase in accuracy but the margin of increase is not significant, following the law of diminishing returns. The range of live weight within 95% of the 24hr weight for average of three weights improved by 23% at 2 hrs fasted, 37% at 4hrs, 47% at 6hrs, 53% at 8 hrs, 63% at 10 hrs and 65% at 12hrs. As time fasted increased there was only a small increase in precision beyond 8 hours fasted suggesting that there is limited benefit in fasting beyond this time. Other evidence from live weight loss (kg) of 24 hours showed there was no significant difference between the regression coefficients and gradient at 8 hours fasted compared with 12 hours fasted across experiment one and experiment two, (May and July). There was also no significant difference between 8-12hrs fasted for the regression co-efficient and 8-10hrs fasted for gradient values when live weight loss of 24hr fasted was expressed as a percentage.

Live weight is a well-used measure of production on-farm, however live weight is only an estimated value and is prone to some degree of error. Future production measurements are likely to occur in the sheep industry on an individual bases with the use of EID tags. One particular area of interest is identifying the elasticity of ewes, as the highest performing ewes have been shown to mobilise their energy reserves over lactation (Mathias-Davis et al., 2013). Live weight and the change of live weight could be used to identify such animals. Fasting such animals before measuring for 8hrs could improve the accuracy of live weight measurements, which is beneficial when ranking the highest portion of ewes in a flock. Other areas of use for such information in this dissertation could be used in scientific research, as animals are often fasted before treatments.

An area of further research is investigating the relationship between body condition changes and the effect on live weight. This would allow live weight to be used as an indicator of body tissue reserves. As identified in 2.11, body condition score and live weight relationship, there is an indisputable relationship between BCS and live weight. There is a large difference across breeds as expected, due to differing mature frame size. However Greer et al., (2013) also identified considerable variation within breeds shown by the change in live weight per condition score in the Coopworth and Rosebank data. It should be noted that the suggestions given in this review are specific to fasting from 2 hours after sunrise. Further investigation should be made into the effect of fasting at various hours after sunrise to account for difference in diurnal variation. Further analyses on the rate of live weight loss on different feed types could also be useful in practice.

If the experiment was to be conducted again it is suggested that more information should be gathered in terms of the live weight loss. In order to gain a broader understanding of live weight losses. It is suggested to hold animals in a digestibility grate to measure urine and faeces output, therefore any live weight lost can be accounted.

In summary live weight is an estimated measurement that is vastly used in the sheep production and research industry. The measurement of liveweight can be improved with the method of faster, however an animal will not get within its true liveweight in 24 hours. Through the series of experiments it is determine that there is little benefit in fasting beyond 8 hours.

6 Acknowledgements

I would like to sincerely thank my supervisor Dr Andrew Greer for his support and guidance. I am very grateful for the significant practical and theoretical contribution he has made over the past year.

My thanks also goes to Chris Logan and Colin Pettigrew, along with the Ashley Dene workers for their practical assistance in gathering data.

I am thankful for Amy Smaill and the work she has put in for the CT scanning process.

My thanks also goes to the French intern students Thomas and Vincent for their contribution and data collection throughout the trials.

My thanks also goes to Nikki Brown who severely helped me with my formatting issues.

I would like to express my thanks to all those that have given assistance and guidance during this dissertation.

7 Discussion

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