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Pen design parameters for improving sheep performance in Middle East feedlots

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Abstract

The Middle East summer presents physiological challenges for Australian sheep that are part of the live export supply chain coming from the Australian winter to the Middle East summer. Extreme temperatures combined with high humidity may be experienced. From an animal welfare perspective it is important to understand what the requirements are for feed and water trough allowances, and the amount of pen space required by an animal, to cope with exposure to these types of climatic conditions.

These studies address parameters that are pertinent to the wellbeing of animals arriving in the Middle East all year round. The experimental animals were physiologically challenged, especially during the summer months.

Three prime factors (feed, water and pen space) are important regarding animal welfare (as measured by weight changes), particularly in hotter times of the year. If sheep have ideal pen parameters, they are better able to cope with difficult summer conditions. Importantly these studies have scientifically validated and more clearly defined how healthy young wethers respond to different pen parameters upon arrival in the Middle East.

Executive summary

Observations in the Persian Gulf region indicate important interactions and relationships exist between livestock performance and pen densities, feeding and water management. Many feedlots throughout the Gulf have very high numbers of animals at certain times of the year in order to cater for the increased demand for periods such as Ramadan, Eid Al Fitr and Eid Al Adha. In order to minimise weight losses and mortalities, and with the aim of improving animal welfare during these periods of peak demand, it is important to know the optimal recommendations for pen stocking density, feed and water trough allowance.

This research focused upon examination of in-market realities with the objective of quantifying the ideal pen parameters in the Gulf region for Australian sheep. The greatest challenges experienced in market are the high heat and humidity that sheep are subjected to upon arrival into their destination markets. June, July and August are traditionally and anecdotally the most environmentally and physiologically challenging months for sheep. This is exacerbated by the fact they are leaving the Australian winter and then being discharged into hot humid summer conditions. Furthermore, it is a period of peak demand therefore there may be a propensity for higher than normal stocking densities (i.e. less space per animal). The aim of this project was to better understand the impact of such exposure and attempt to determine optimal allowance without compromise to the animal's well-being.

The achievements from this project have added to increased knowledge that will subsequently underpin continual improvement in animal health, welfare and economic efficiencies of Australian sheep in the Middle East. .

The key conclusions from this investigation in the Middle East as to what constituents optimal feed and water trough length and enough pen space per animal have been identified. The recommendations are based on minimum levels for maintaining weight whilst maintaining acceptable levels of animal health and welfare.

The project comprised three separate experiments performed in the same feedlot in the ME, the first focusing on feed bunk allowance, the second on water allowance and the third on a combination of pen stocking density and feed bunk allowance. Table 3.1 summarises the treatment and background options used in each of these experiments. Each replicate within the experiments had four pens (one for each treatment) and ran for around 20 days.

The overall analyses demonstrated satisfactory animal performance for animal densities of ≥1.2 m^2/head during hot conditions (24-hour average temperatures greater than 33ºC). However the space allowance for animals could be decreased, with no demonstrated detrimental effect, to 0.6 m^2/head under milder conditions, when 24-hour average temperatures are less than 33ºC.

A length of ≥5 cm/head of feed bunk was considered optimal, as 2 cm/head showed significantly decreased animal performance. Feeding at 90% *ad libitum* (experiment 3) gave 8% higher weight gains than the more restricted feeding regime of experiment 1 which was an allocation of only 1 kg/head/day, and showed 10 cm/head was superior vs. 5 cm/head in experiment 1. Hence, optimal feed bunk length may depend on feeding regime. If feeding maintenance (1 kg/head/day) then 5 cm/head is satisfactory; if feeding 90% *ad libitum* 10 cm/head is needed.

The experiment for water trough allowance indicates that a minimum of 1 cm/head is required. However it should be noted that this experiment was conducted in relatively mild conditions, with the 24-hour average temperatures being 25 and 19ºC for the two replicates respectively. It may well be expected that larger water trough lengths will be needed in hotter conditions.

Carcass weights were determined mainly by intake weights and weight gains. Dressing % was not significantly affected by any of the applied treatments.

There was no demonstrated effect of any of the treatments on the numbers of animals which died, or were classified as unwell. However (across all the treatments) the unwell animals lost significantly more weight than the healthy animals, therefore if you have animals that are not performing it is best to remove them from the group and send them for processing as soon as possible.

Therefore best practice guidelines for management of Australian sheep in Middle East feedlots in the hot months (June, July and August) which present the greatest environmental and physical challenge is to allow feed bunk length 5 cm/head on maintenance feeding program and 10 cm/head for 90% ad lib feeding, and the space allowance per animal should be ≥1.2 m^2/head. Water trough allocation should be at least 1 cm/head with provision for more in the summer when water intake doubles. Important to note with this conclusion is 1.2m^2 is based on weight gain and not mortality. This is because the experiments did not consider length of time at each density.

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1 Background

Many thousands of live sheep are exported annually (2.3 million for 2012, Source: ABS) from Australia to the Middle East (ME). Upon arrival all the sheep are transported to feedlots. The sheep are fed, watered and housed in these feedlots for an average of 14-21 days.

It has been noted that there are few evidence-based recommendations in the literature for the design of sheep feedlots in terms of stocking density, and feed and water trough allowance. They exist for cattle but not for sheep. This is largely because the lot feeding of sheep in Australia is still in its infancy phase, whilst cattle feedlots have existed in excess of 30 years. The cattle feedlot industry has had extensive research into all these areas and their effects on production and welfare have been well documented.

The National Procedures and Guidelines for Intensive Sheep and Lamb Feeding Systems has recently been published by Productive Nutrition Pty Ltd *(Edition 2, June 2011)*, but some key differences exist between the geographically and environmentally contrasting regions of Australia and the ME. Australian sheep feedlots are often set up in paddock situations, have much more space and are run at lower stocking densities. In contrast, in the ME land is at a premium and urban expansion is already limiting the land available by ME governments for feedlots and abattoirs. Another key difference and consideration is that it rarely rains in the ME – an average annual rainfall of 70 mm that falls on 12 days of the year. June, July and August can be very hot and humid, however the humidity is generally greatest in August.

Feedlots in Australia have a focus on weight gain, while in the ME operations are aiming to maintain the sheep until slaughter, commonly for an average of 14–21 days. In general, the stocking densities for Australian paddock based feedlots are lower than maintenance-based feedlots in the ME, and this largely due to demand and quick throughput and turnover of animals shortly after arrival.

Feedlots through the ME often run between 1 to 1.5 sheep per square metre (m^2) and allow more space in summer where possible, however due to peak demand this is not always the case. Important to note however is the implementation of a blanket de-stocking management strategy across all sheep pens, to provide as much space per animal in the hot months as soon as possible. That is sheep may arrive at a feedlot and animals are processed shortly thereafter. As sheep are removed destocking can also occur on a daily basis.

Religious festivals are a key driver of pen density. Leading up to Ramadan and Eid Al Adha, feedlots are often pushed to their full capacity in order to have enough sheep when food consumption increases two to three fold for the holy month of Ramadan. Operators aim to have enough sheep for the peak consumption, however it is important that welfare is not compromised during these periods.

As Ramadan moves 10 days earlier each year, peak periods of consumption are moving further into the heat and humidity of summer, therefore feedlots have to carefully manage high numbers in hotter and more humid conditions. In 2013, Ramadan started in early July and numbers increased during June and July, which are two of the hottest months.

Anecdotal evidence suggest that high pen densities with adverse summer conditions may contribute to spikes in mortality rates and significantly contribute to morbidity and mortality in the feedlot from heat stress; however this has not been scientifically evaluated, nor has the optimal amount of space required per animal under such conditions. Research related to pen air turnover on livestock vessels indicates that more space will allow for more airflow, providing there is air movement, therefore the same could be assumed in a feedlot pen

(MLA Final Report – HOTSTUFF V5.0 – Revised Methodology). Consideration should also be given to the amount of shading in the pen. Preferably due to the intensity of the conditions, 100% shading is better. If the pen is not 100% shaded then the stocking density rate should be based on the minimum shaded area in the pen during the hottest part of the day, as on a hot day an animal's natural instinct is to seek shade. A key aim of this project is to ascertain what a suitable pen stocking density is in the ME environment.

The amount of available feed bunk space is also a limiting factor in ME feedlots, due to overstocking of sheep pens and therefore not enough bunk space for animals to access feed, as shown in Figure 1. Limited access to food is something that requires investigation and validation to determine what is the minimum requirement to optimise the opportunity for each animal to access feed, while minimising shy feeding. The term "shy feeding" refers to those animals that are unwilling to come and eat from the feed bunk. This may be for several reasons including being socially dominated by other sheep, unwillingness to compete for food in the group, and other cumulative stresses.

The Australian feed bunk length recommendation for lambs is 15-30 cm/head *(Primefacts, Feedlotting Lambs, November 2007)* which, given the limited available space for 30,000 to 40,000 sheep arriving into a ME feedlot at one time, is not feasible. It is important to remember that in Australia they are feeding for production, whilst in the ME they want to satisfactorily maintain the animals until slaughter which on average occurs within 3 weeks.

Figure 1. Inadequate feed bunk length causing aggressive feeding behaviour

A guaranteed supply of good clean water is essential in a feedlot, especially in summer in the ME as water intake at least doubles *(Primefacts, Feedlotting Lambs, November 2007)*. Normally they consume 2 litres/day/animal but in the hot months this may increase to as much as 4-5 litres/day/animal, and in extreme conditions may increase by up to 78% due to increased evaporative cooling which sheep do via panting *(Primefacts, Feedlotting Lambs,* *November 2007)*. It is also important to maintain water temperature below 37ºC – at temperatures above this sheep are less likely to consume water, therefore not eat and become sick and in some cases may die. Monitoring is critical in ME as water in some locations is supplied via desalination which is run in pipes along the ground and so is heated en route to the troughs.

The water trough allowance for lambs, as per the Australian recommendation, is that a trough be available that is a minimum 30 centimetres in length plus 1.5 cm per head for mobs or pens of sheep greater than 500 head *(Model Code of Practice for Welfare of Sheep, 2006)*. A higher allowance may be required, due to the high temperature and humidity that is experienced in the ME. A further consideration is that the majority of sheep sent to the ME are young wethers or older grown sheep, therefore it begs the question 'is the Australian best practice guideline estimate sufficient for sheep welfare in the ME environment especially in the summer months?'

The main goal of this project was to evaluate and quantify best practice management techniques of pen stocking density, water and feed bunk availability upon the welfare of Australian livestock in the Middle East and North Africa region. Currently, operators often use a best-bet "guess" approach as to how much feed, water and space the animals require in a feedlot situation. Therefore this project aimed to identify the impact of overcrowding feedlot pens, and to develop a clear list of recommendations for pen densities based on seasonal variation and the availability of suitable amounts of feed and water trough allowance. An important aspect of the research was that it was undertaken under ME conditions in importing countries to support management decisions for sheep arriving from Australia throughout the year.

2 Project objectives

The objectives developed at the commencement of this project were:

1. Determine the optimal pen density and feed and water trough length in order to decrease mortality rates and maintain the health and welfare of Australian sheep in ME feedlots.
2. Develop best practice guidelines for management of Australian livestock in ME feedlots.

3 Methodology

The project investigated three aspects of pen design, namely:

Feed bunk length. Based on the current industry "best practice" Australian guidelines, the recommendation is 15-30 cm/head for feed bunk length. Because feed bunk length is a limiting factor in the ME it was important that small lengths were also investigated: The four selected treatment levels were **2, 5, 10 and 15 cm/head**. The aim was to investigate a situation that was practical given the limitations of actual availability of feed troughs and replicate day to day operations whilst also attempting to identify "what is needed" without compromise to welfare, also considering and investigating the climatic challenges that occur at certain times of the year.

Water trough length. The "best practice" Australian sheep guidelines for water trough length is 1.3-1.5 cm/head. Again, it was important that small lengths were included, so the four selected treatment levels were **0.6, 0.8, 1 and 1.5 cm/head.** The Australian feedlot cattle requirements for water allowance not under shade are 3 cm/head and under shade are 1.5 cm/head. Therefore the maximum limit of 1.5 cm/head for a 50 kg sheep was thought by the project team to be satisfactory providing there is adequate reticulated water supply at all times.

Stocking density. The assumption was made that a 50kg merino sheep would require 1/5 of the 6 m^2 space allowance of a 250 kg steer, and it should be noted here this is based on a 100 day plus feeding program *(Australian Cattle Feedlotting Standards – National Standards for Beef Cattle Feedlots in Australia, SCRAM 2002)*. Extrapolating this cattle recommendation to sheep, the standard pen space estimated for a 50 kg merino would be 1.2 m^2. The selected treatment levels for stocking density were **0.6, 0.9, 1.2 and 1.5 m^2/head.**

The project comprised three separate experiments performed in the same feedlot in the ME, the first focusing on feed bunk allowance, the second on water allowance and the third on a combination of pen stocking density and feed bunk allowance. Table 3.1 summarises the treatment and background options used in each of these experiments. Each replicate within the experiments had four pens (one for each treatment) and ran for around 20 days.

Table 3.1. Summary of experimental details

Treatments	Experiment 1	Experiment 2	Experiment 3
Feed bunk length (cm/head)	2, 5, 10, 15	10	2, 5, 10, 15
Water trough length (cm/head)	1.5	0.6, 0.8, 1, 1.5	1.5
Density (m^2/head)	1.2	1.2	0.6, 0.9, 1.2, 1.5
Replicates (each with 4 pens)	4	2	5
Number of sheep per pen	100	100	60

Experiments 1 and 2 were designed as randomised complete blocks with four treatments and four pens per replicate. Experiment 3 used a design based on a Graeco-Latin square, with an extra (random) replicate, as outlined in Table 3.2. Whilst this design is efficient at estimating the blocking and treatment main effects, unfortunately the interaction between the feed bunk length and density treatments cannot be directly estimated (Cochran and Cox 1957).

Table 3.2. Treatment design for experiment 3. D = density (m^2/head); F = feed bunk length (cm/head)

	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5
Pen 1	$D_{0.9}$ & F_{10}	$D_{0.6}$ & F_{15}	$D_{1.2}$ & F_{2}	$D_{1.5}$ & F_{5}	$D_{1.5}$ & F_{5}
Pen 2	$D_{1.2}$ & F_{5}	$D_{1.5}$ & F_{2}	$D_{0.9}$ & F_{15}	$D_{1.2}$ & F_{10}	$D_{0.6}$ & F_{10}
Pen 3	$D_{1.5}$ & F_{15}	$D_{1.2}$ & F_{10}	$D_{0.6}$ & F_{5}	$D_{0.9}$ & F_{15}	$D_{0.9}$ & F_{2}
Pen 4	$D_{0.6}$ & F_{2}	$D_{0.9}$ & F_{5}	$D_{1.5}$ & F_{10}	$D_{0.6}$ & F_{2}	$D_{1.2}$ & F_{15}

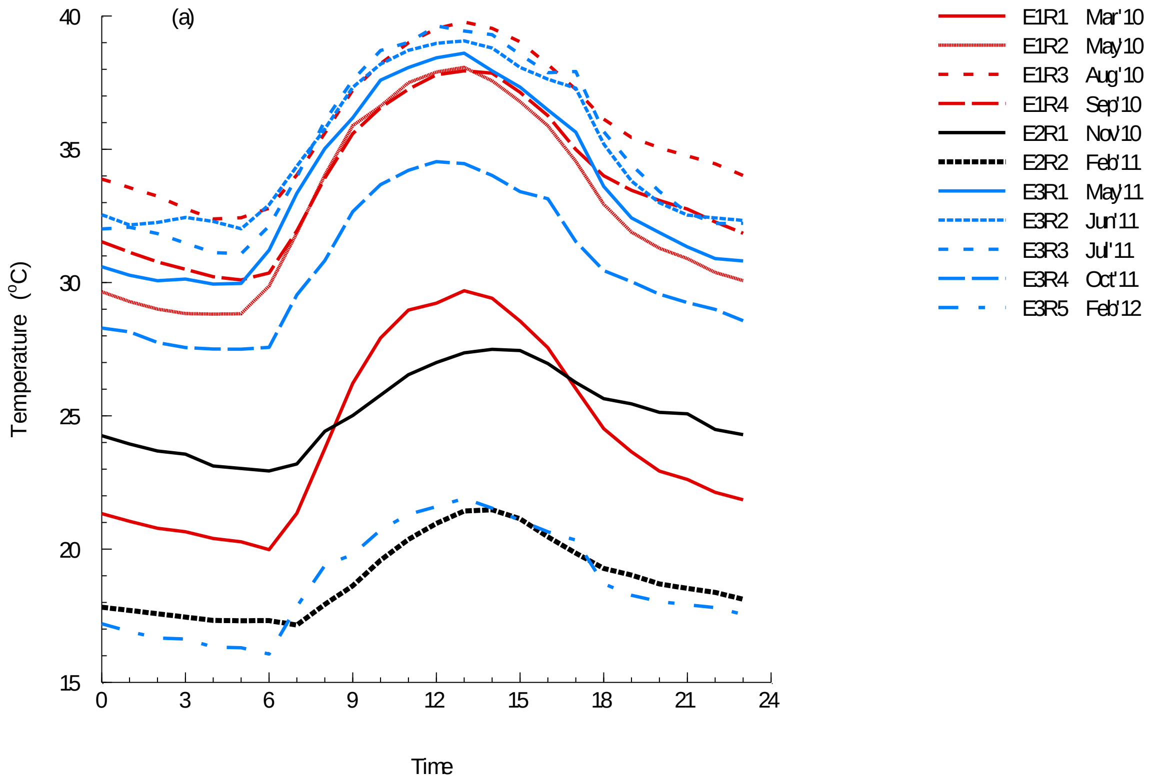
Details common to all three experiments include:

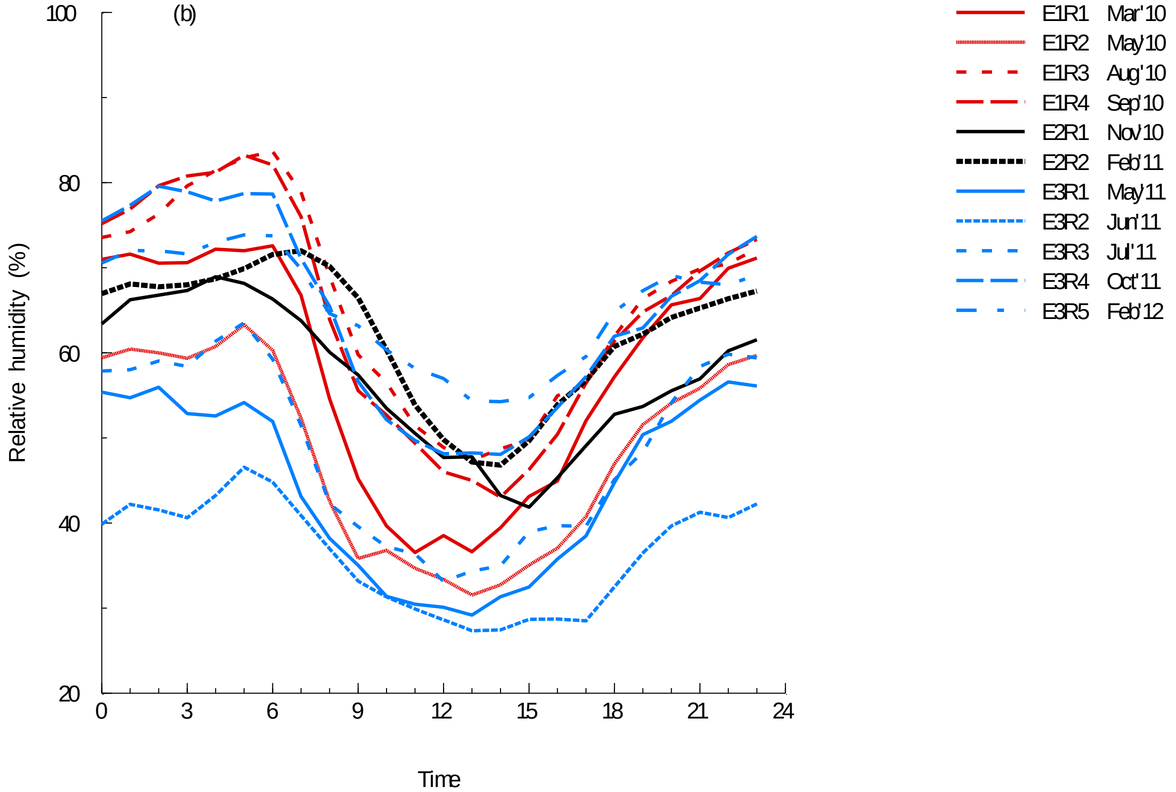
- When at any time during the experiment animal welfare of sheep became compromised, those animals were removed and taken for immediate processing
- All pens had 100% shade.
- Lines of young wethers were used and each animal was individually identified.
- Sheep were fed 1 kg/head of 10 MJ/kg DM ration, pelleted ration, the same as they consume on the ship, unless otherwise noted.
- They were fed for a period of 20 days unless otherwise noted.
- Individual weight in, weight out and carcass weight were recorded.
- Deaths were recorded
- Water troughs were cleaned at the beginning of the experiment and half way through the feeding period of 20 days, or as required.

- The animals were weighed and randomly allocated to their groups, just as occurs at a normal ship discharge. Any sick or injured animals were drafted prior to allocation to their pens so all groups were made up of healthy animals from each shipment. The purpose of this allocation was to reflect normal management on arrival and during the stay at the feedlot.

In experiments 2 and 3, pen water intake was measured using Elster V100 Volumetric water meters. Water temperature was not monitored as it was not considered to be a problem because the ambient conditions where mild. In experiment 3, pen microclimate (temperature and relative humidity data) was measured in each pen that had the stocking densities of 0.6, 0.9, 1.2 and 1.5 m^2 using Onset Hobo Data Loggers (U23-001). Experiment 3 allocated a 90% ad libitum ration, to further investigate if more feed reduces aggressive feeding behaviour and allows the less aggressive eaters to consume feed, which may subsequently allow them to also maintain their body weight. The 90% ad libitum allocation was assessed by a small quantity feed remaining in the trough two to three hours after the morning feed and the sheep were sitting and resting.

The replicates were conducted at different times of the year over a two-year period from March 2010 to February 2012, so the sheep in each experiment experienced a range of environmental conditions. Meteorological data were obtained from a local Airport Civil Aviation Authority for experiments 1 and 2, and measured within the pens for experiment 3. Figure 3.1 shows the diurnal patterns, averaged across the days for which each replicate ran. As shown in Figure 3.1(a), 7 of the 11 replicates experienced quite hot conditions, where maximum temperatures exceeded 33ºC. On the other hand, the two replicates in February experienced relatively cool conditions. The temperature-humidity index (THI) is an overall measure of environmental heat load or 'general comfort', and has been shown to be related to animal performance. THI in Figure 3.1(c) was calculated using formula 1 of *Dikmen and Hansen (2009)*. Depending on the type of animal, heat stress starts somewhere from the mid-70s *(Mayer et al. 1999; Srikandakumar et al. 2003)* to the low 80s *(Maria et al. 2007)*, and becomes progressively more severe through the 80s. As evident in Figure 3.1(c), some of the replicates experienced these quite-challenging conditions continually throughout the days of these experiments. It is also notable that THI remains fairly constant throughout the 24-hour cycle, meaning the animals get little respite at night.


(a)
Temperature (°C)
40
35
30
25
20
15
0
3
6
9
12
15
18
21
24
Time
E1R1 Mar'10
E1R2 May'10
E1R3 Aug'10
E1R4 Sep'10
E2R1 Nov'10
E2R2 Feb'11
E3R1 May'11
E3R2 Jun'11
E3R3 Jul'11
E3R4 Oct'11
E3R5 Feb'12


(b)
Relative humidity (%)
100
80
60
40
20
0
3
6
9
12
15
18
21
24
Time
E1R1 Mar'10
E1R2 May'10
E1R3 Aug'10
E1R4 Sep'10
E2R1 Nov'10
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E3R5 Feb'12

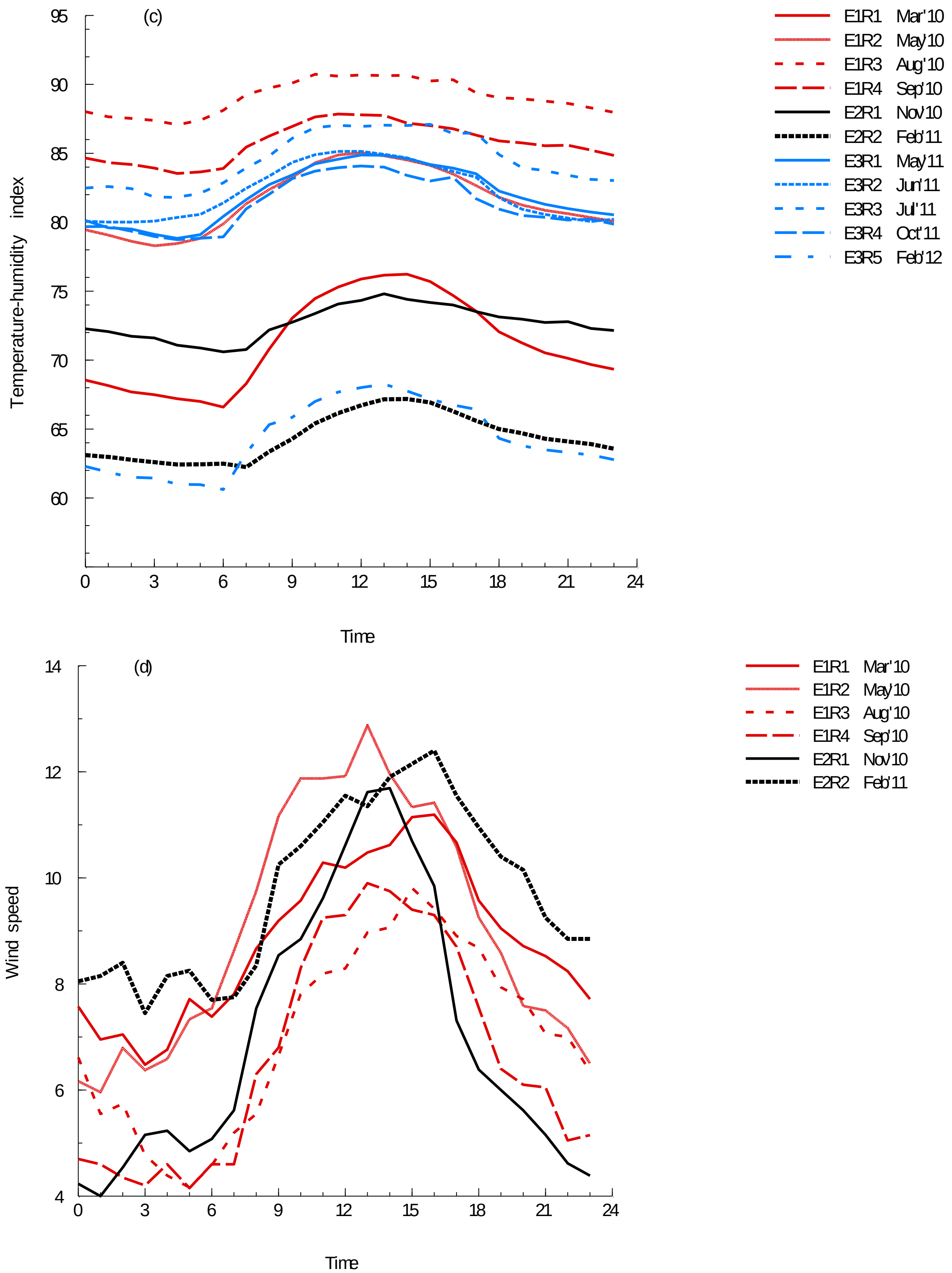

Figure 3.1. Diurnal climatic averages, by experiments (E) and replicates (R), including the month and year of each

Statistical methods

The experimental treatments (feed bunk length, water trough length and animal density) were applied to the pens, hence 'the pen' was the primary experimental unit. Other factors of interest, including frame score, weight at intake, line and health status during the experiment, are quantified for each individual animal, and hence are applicable at 'the animal' level. Hence a split-plot analysis of variance (ANOVA) was used (pens split for animals), with the treatments being tested at the whole-plot level and the animal-factors being tested at the subplot level. Parallel mixed model analyses, using residual maximum likelihood (REML) methods, were conducted to investigate the variance components. The relative variability between the lines of animals was of particular interest here. All analyses were conducted using GenStat (VSN 2011).

The basic response variables were exit and carcass weights. Preliminary analyses showed (as expected) that these were highly dependent on weight at intake and days on feed. These data were converted to 'weight change' (kg/head/day), being a standardised and easily-interpretable measure which adjusts for the confounding effects of initial weight and days on feed. Similarly, dressing percentage (100 * carcass weight / exit weight) is a useful measure which standardises for the effect of weight. All analyses of exit and carcass weights took weight at intake as a standardising covariate.

Table 3.3 gives an example of the ANOVA table from GenStat, and shows that the replicates (or blocks) were quite different for experiment 1. The between-sheep variation (s^2 = 0.0159, so standard deviation = 0.126) was markedly lower than the between-pens variation (s^2 = 0.0778, so standard deviation = 0.279). This further justifies testing the treatment effect against the residual for the pen stratum. The resultant distribution of residuals (Figure 3.2) indicates approximate normality, so no transformation was considered for weight change. Similarly, carcass weight (adjusted for intake weight) and dressing % both gave approximately normal residuals, upholding the underlying statistical assumptions of ANOVA.

Table 3.3. ANOVA table for weight change for experiment 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum					
Reps	3	1.537	0.5122	6.59	
Rep.Pen stratum					
Feed bunk length	3	1.739	0.5796	7.45	0.008
Residual	9	0.700	0.0778		
Rep.Pen.Sheep stratum					
Health status	3	8.010	2.6701	167.96	<.001
Intake weight	1	1.194	1.1938	75.10	<.001
Residual	1517	24.116	0.0159		
Total	1536	37.296			

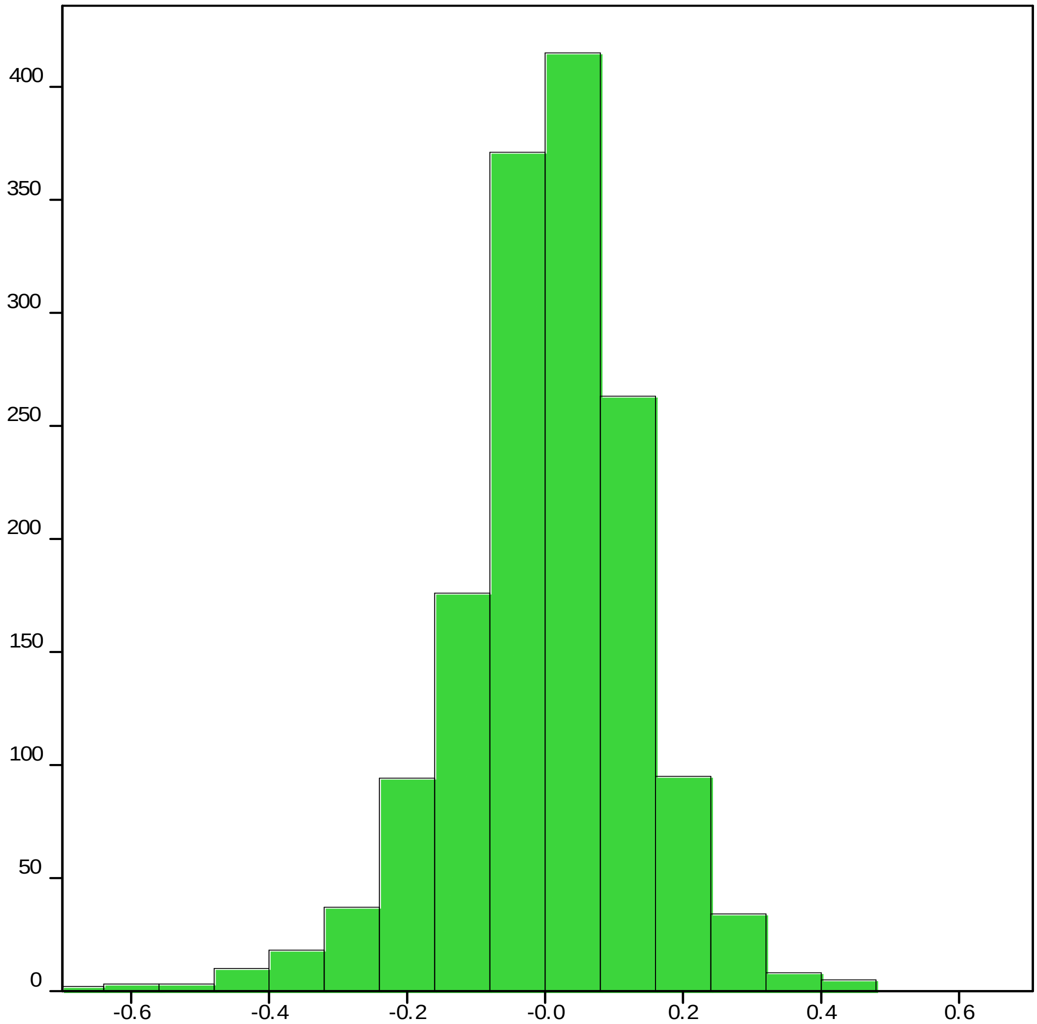

Figure 3.2. Distribution of the residuals from the ANOVA of weight changes from experiment 1

Whilst the selected treatment levels were each taken from a continuum, these were retained in the analyses as factors of fixed levels. Some exploratory analyses (as later outlined) did consider the treatments as linear contrasts, however all quoted means and standard errors are for the actual treatment levels. Where appropriate, curves of best fit, mostly of the biologically-expected asymptotic form, were subsequently added to the figures to assist interpretation.

4 Results

At the animal level, intake weights were highly associated (*P*<0.001) with frame scores, with variance ratios of 223, 179 and 386 for experiments 1 to 3 respectively. As frame score increased, so did intake weight (see Table 1 in Appendix 1). This means that these correlated terms should not both be fitted in the 'animal level' ANOVAs, and instead were taken as alternate factors.

The effects of intake weights and frame scores (estimated separately) on weight changes are listed in Tables 2 and 3 in Appendix 1. Across the three experiments, average weight changes were consistently highest for the lighter animals, which also had lower frame scores.

Similarly, Table 4 in Appendix 1 lists the fitted effects of 'health status' on weight changes. These are quite consistent across the three experiments, and show trends which may logically be expected. In each experiment, the healthy animals had the highest average weight gains, of 0.06 to 0.08 kg/head/day. These were followed, in descending order, by the animals which were recorded as unwell (due to any reason) but stayed in the experiment until the end (–0.06 to 0.02 kg/head/day); then unwell animals (mainly heat-stressed) which were removed from the experiment (–0.25 to –0.63 kg/head/day); and lastly the animals which died averaged –0.64 to –0.65 kg/head/day prior to death.

4.1 Experiment 1 – Feed bunk length

The majority of animal removals due to ill-health (primarily heat-stress) occurred in replicate 3 (Table 4.1.1), which was the most stressful (Figure 3.1) with an average temperature of 35.8ºC and THI of 89.4. In the 'unwell and removed' category, there were only six animals with reasons other than heat stress, and these few were distributed relatively evenly.

Table 4.1.1. Animal counts by replicate and health class

	Healthy	Unwell (stayed)	Unwell (removed)	Died
Rep. 1	398	0	1	1
Rep. 2	378	21	1	0
Rep. 3	334	5	60	1
Rep. 4	387	10	1	2

Health status was not related to the treatments (Table 4.1.2; $\chi^2_{(9\ d.f.)} = 7.90$; $P = 0.54$). Whilst there were too few mortalities to formally test the treatment effect on mortality rates, there was no notable trend here.

Table 4.1.2. Animal counts by treatment and health class

Feedbunk length (cm/head)	Healthy	Unwell (stayed)	Unwell (removed)	Died
2	377	5	17	1
5	379	8	11	2
10	369	13	18	0
15	372	10	17	1

Table 4.1.3 lists the variance components for weight change for experiment 1. Exit weight, carcass weight and dressing % showed similar patterns. Whilst these variance components were not pronounced in respect of their standard errors, they remain additional factors to the underlying random variation. Differences between replicates were expected, as they

experienced quite different climatic conditions. Also, lines appear ‘reasonably’ different, and showed an approximate continuum. For lines with more than five animals, the observed range was –0.22 to 0.18 kg/head/day. The other two experiments gave similar results, namely –0.11 to 0.22 kg/head/day for experiment 2 and –0.47 to 0.23 kg/head/day for experiment 3. Only one line appeared in more than one experiment, and it ranked a lowly 21st out of 23 in Experiment 2, but a relatively high 7th out of 55 in Experiment 3.

Table 4.1.3. Estimated variance components from the REML model for weight change

Random term	Variance component	s.e.
Rep	0.0009	0.0009
Rep.Pen	0.0006	0.0004
Rep.Pen.Line	0.0007	0.0004

Weight change showed a significant (*P* = 0.008) difference for treatments, however not for carcass weights (*P* = 0.159) or dressing % (*P* = 0.108). The respective means are listed in Table 4.1.4, and plotted in Figures 4.1.1 to 4.1.3.

Table 4.1.4. Treatment means and standard errors (s.e.) for weight change, carcass weight and dressing percentage in Experiment 1. Pairwise differences were tested using a protected LSD-test at *P* = 0.05 (means with a different superscript are significantly different)

Feed bunk length cm/head)	Weight change (kg/head/day)	s.e.	Carcass weight (kg)	s.e.	Dressing %	s.e.
2	0.006^{b}	0.014	19.50	0.11	45.67	0.21
5	0.097^{a}	0.014	19.91	0.11	44.81	0.21
10	0.067^{a}	0.014	19.81	0.11	45.15	0.21
15	0.064^{a}	0.014	19.80	0.11	45.24	0.21

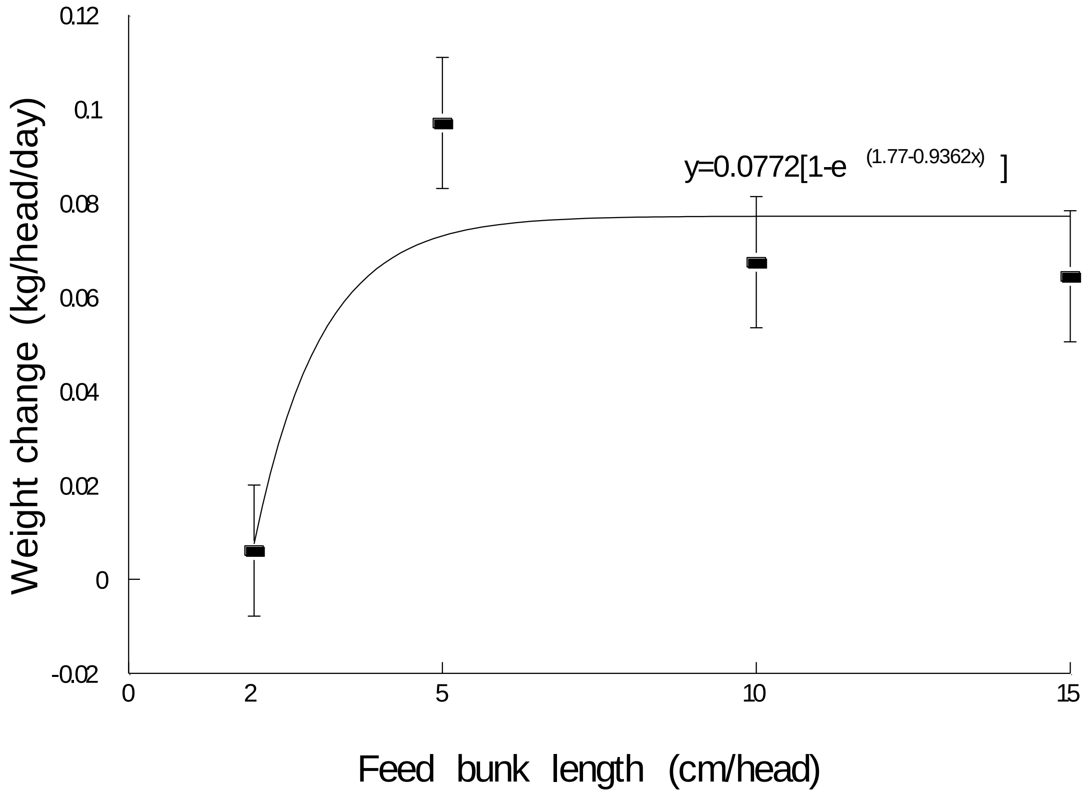

Figure 4.1.1. Relationship between feed bunk length and weight change in experiment 1 with fitted exponential curve. Standard errors are indicated by error bars

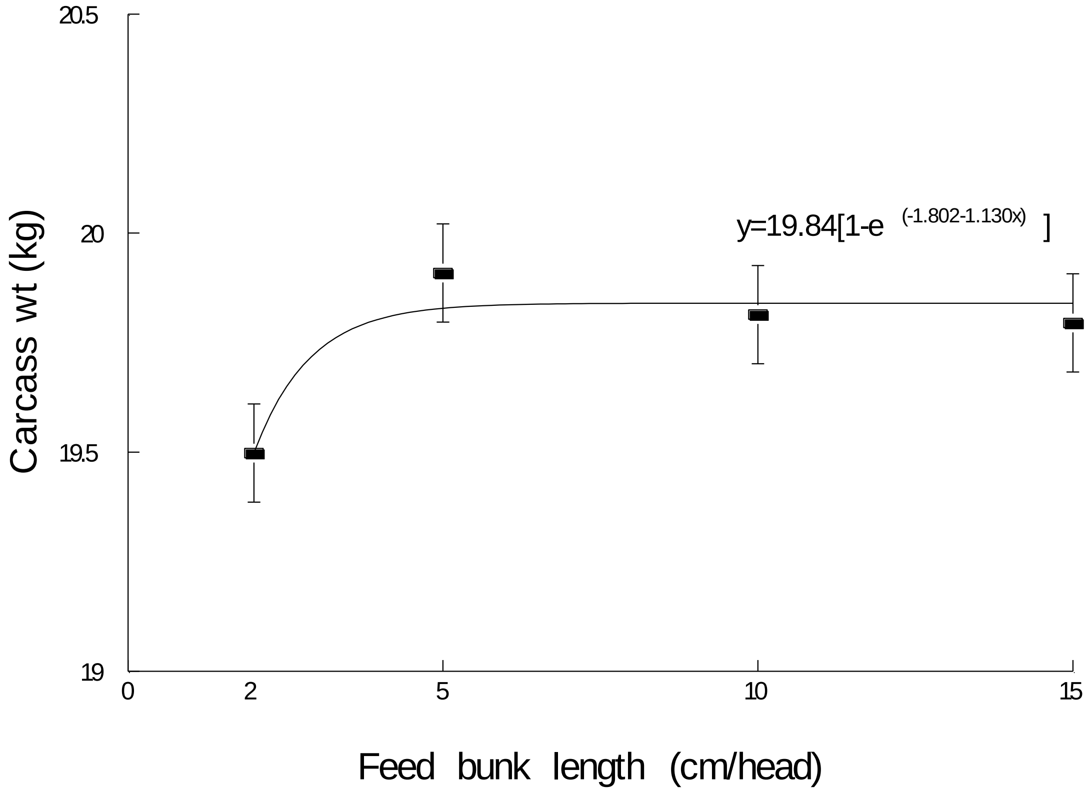

Figure 4.1.2. Carcass weights vs. feed bunk length for experiment 1, with standard errors and fitted exponential

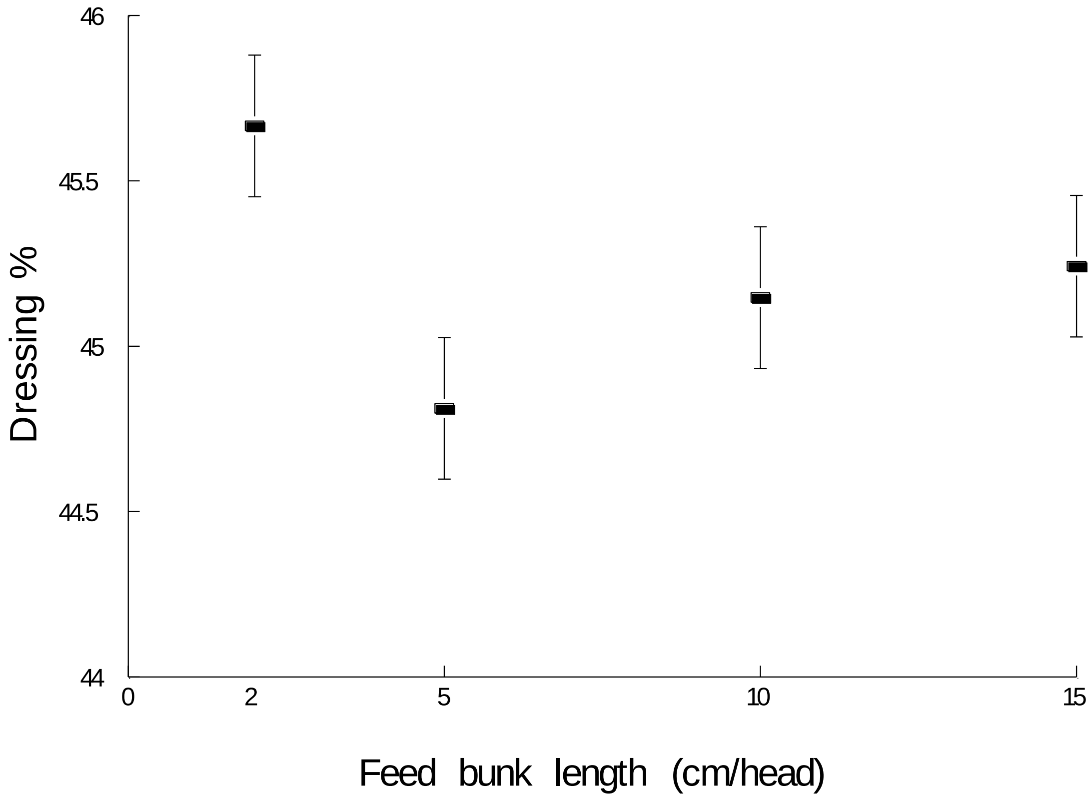

Figure 4.1.3. Dressing percentage *vs.* feed bunk length for experiment 1, with standard errors

Key findings and discussion

- Feed bunk length of 2 cm/head gave poorer performance than the other treatment levels, which were similar (*P*>0.05).
- 5 cm/head had the highest weight changes and carcass weights, but also the lowest dressing percentage, indicating higher gut fill. This could have been due to the sheep having to compete harder for feed, resulting in them eating more.
- The fitted asymptotic curve identified around 5 cm/head as being near-optimal.
- Dressing % was not affected by feed bunk length.

4.2 Experiment 2 – Water trough length

As shown in Table 4.2.1, relatively few animals were removed from this experiment.

Table 4.2.1. Animal counts by replicate and health class

	Healthy	Unwell (stayed)	Unwell (removed)	Died
Rep. 1	367	1	1	1
Rep. 2	387	9	3	0

Again, health status was not related to the treatment (Table 4.2.2; pooling the last two categories as 'removed or died' gave $\chi^2_{(6\text{ d.f.})} = 10.8$; $P = 0.093$).

Table 4.2.2. Animal counts by treatment and health class

Water trough length (cm/head)	Healthy	Unwell (stayed)	Unwell (removed)	Died
0.6	194	0	0	0
0.8	187	2	2	1
1.0	190	3	2	0
1.5	183	5	0	0

The variance components for weight change (Table 4.2.3) show similar patterns to those from experiment 1, except the replicates here were quite similar. Both were run during non-stressful times of the year (Figure 3.1), with average temperatures of 25 and 19ºC respectively.

Table 4.2.3. Estimated variance components from the REML model for weight change

Random term	Variance component	s.e.
Rep	0.0001	0.0007
Rep.Pen	0.0010	0.0011
Rep.Pen.Line	0.0006	0.0008

The analyses showed a significant difference among treatments for weight change (*P* = 0.022), carcass weights (*P* < 0.001) and water intake (*P* < 0.001), however not for dressing % (*P* = 0.97). The respective means are listed in Table 4.2.4, and plotted in Figures 4.2.1 to 4.2.4.

Table 4.2.4. Treatment means and standard errors (s.e.) for weight change, carcass weight, dressing percentage and water intake in experiment 2. Pairwise differences were tested using a protected LSD-test at *P* = 0.05 (means with a different superscript are significantly different)

Water trough length (cm/head)	Weight change (kg/head/day)	s.e.	Carcass weight (kg)	s.e.	Dress-ing %	s.e.	Water intake (L/head/day)	s.e.
0.6	0.025[b]	0.028	22.48[b]	0.14	46.68	2.49	2.47[a]	0.02
0.8	0.087[ab]	0.028	23.20[a]	0.14	46.90	2.49	2.52[a]	0.02
1.0	0.053[ab]	0.028	23.48[a]	0.14	47.72	2.49	2.02[b]	0.02
1.5	0.132[a]	0.028	23.27[a]	0.14	46.24	2.49	2.45[a]	0.02

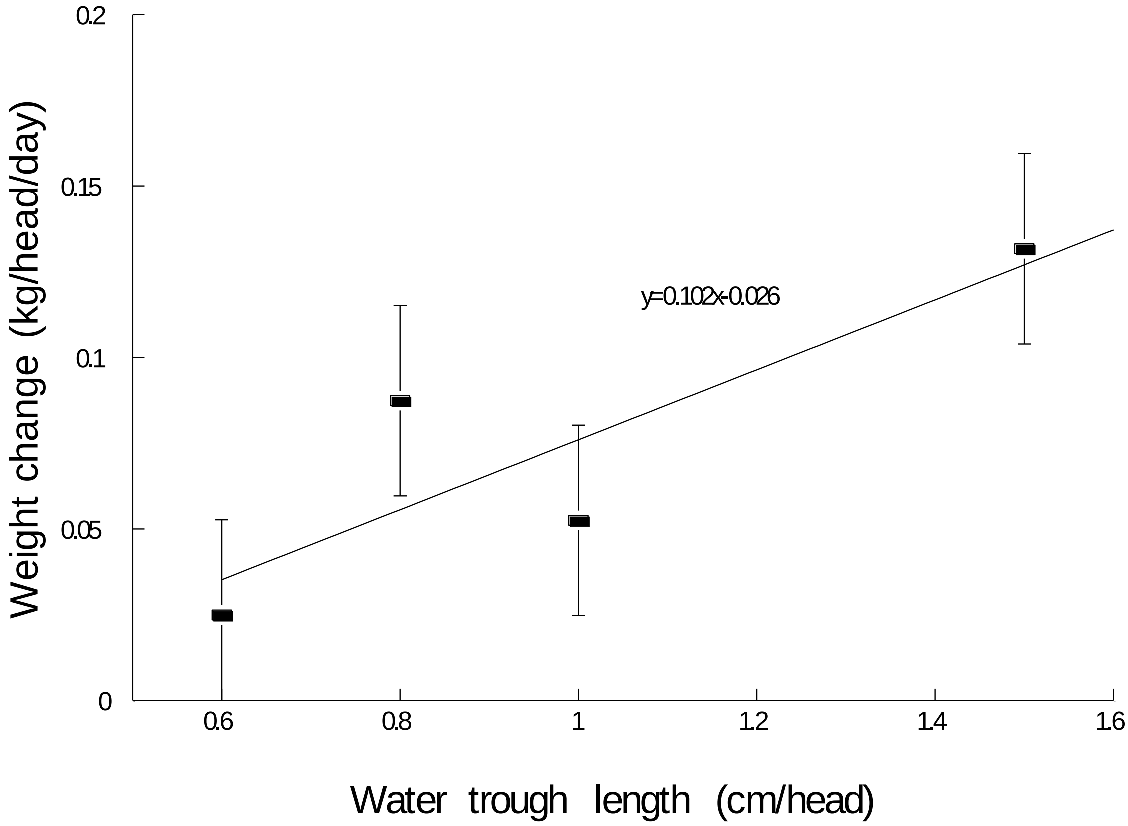

Figure 4.2.1. Relationship between water trough length and weight change in experiment 2 with fitted line. Standard errors indicated by error bars

With only two replicates in this experiment, the possible interaction of the response variables with environmental conditions could not be formally tested. The weight change responses to water trough length were reasonably consistent across these two replicates, which were run during relatively non-stressful times of the year when environmental conditions for animals were comfortable.

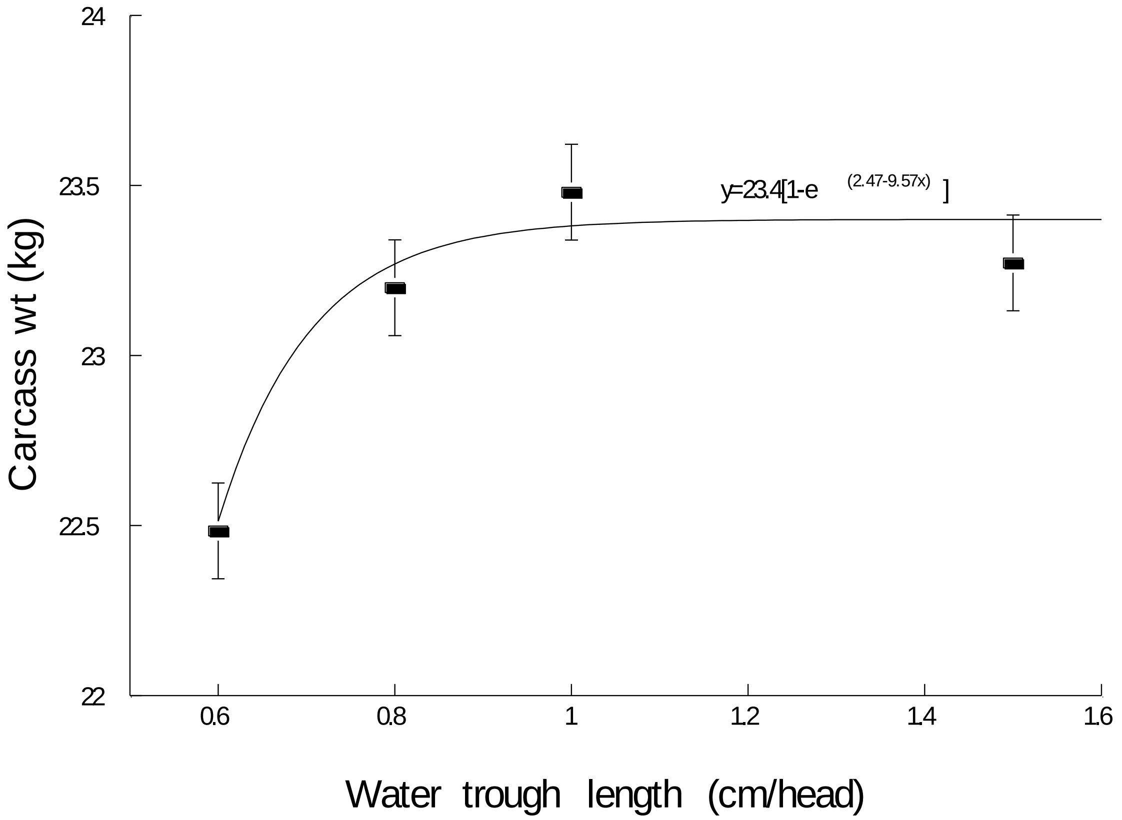

Figure 4.2.2. Carcass weights *vs.* water trough length for experiment 2, with standard errors and fitted exponential

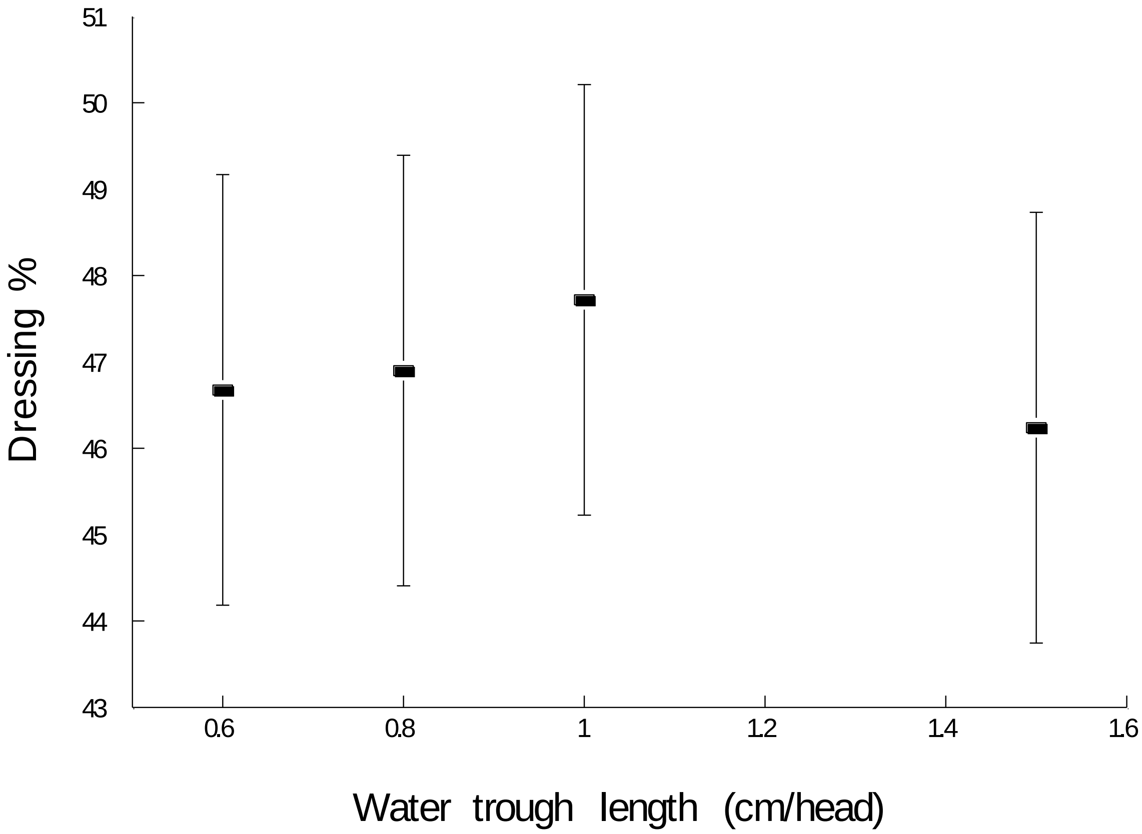

Figure 4.2.3. Dressing percentage *vs.* water trough length for experiment 2, with standard errors

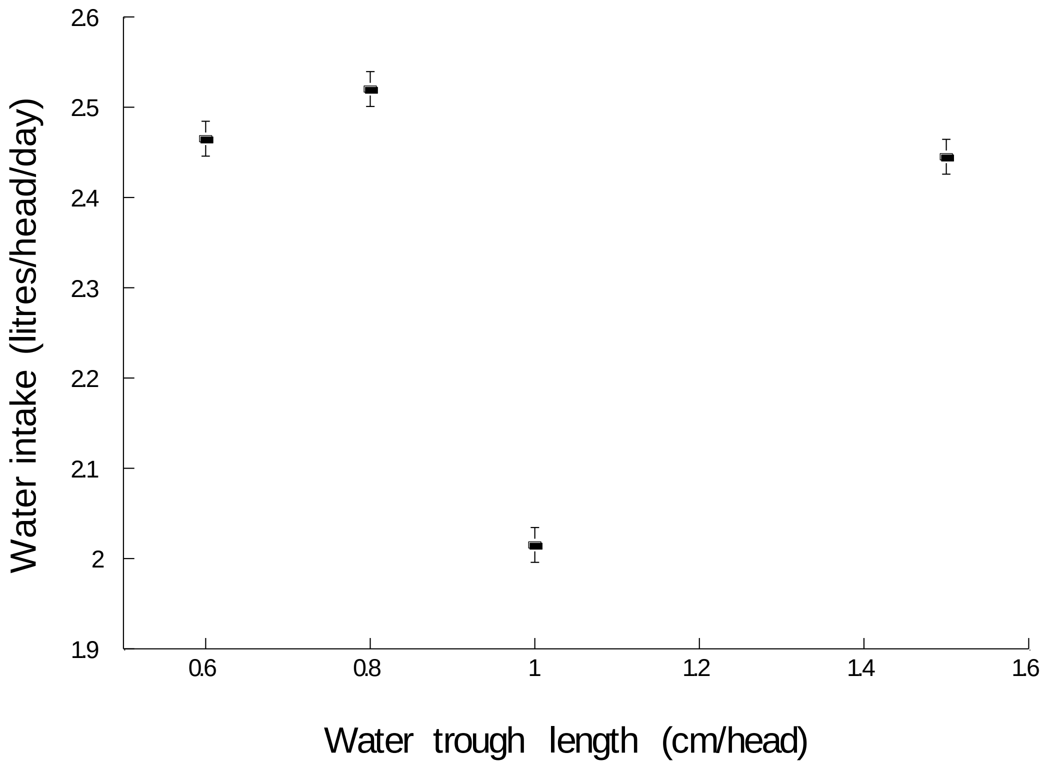

Figure 4.2.4. Water intake *vs.* water trough length for experiment 2, with standard errors

Key findings and discussion

- Water intake for the water trough length of 1 cm/head was notably low. Whilst this was evident in both replicates, there appears no logical reason for this, apart from an unfortunate random occurrence (there were only two pen-average replicate measures of this). This would probably have had a detrimental effect on weight change for this treatment level.
- The only significant treatment difference for weight change was between the lowest (0.6 cm/head) and the highest (1.5 cm/head) water trough lengths. The other two levels gave intermediate responses.
- Carcass weights differed among treatments, with 0.6 cm/head being significantly lower than the other three treatment levels. This was probably partly due to the covariate adjustment for the slightly uneven distribution of weights at intake – again probably through random chance (as there were only two replicates), this was near-significant (P = 0.12), with the water trough length of 1 cm/head having notably lower intake weights (47.0 kg, *vs*. 49.0, 48.3 and 47.6 kg for the other three treatment levels).
- In combination, these results suggest that a water trough length of ≥1 cm/head is needed.
- Note that this result comes from two replicates which experienced quite mild heat conditions (24-hour average temperatures of 25 and 19ºC respectively for the replicates; 23 and 17ºC at 5am and 27 and 21ºC at 2pm). It may well be expected that larger water trough lengths will be needed in hotter conditions.
- Dressing % was not affected by water trough length.

4.3 Experiment 3 – Feed bunk length by density

Most of the removed animals were from replicate 2 (June 2011), which had an average temperature of 35ºC and THI of 82 (Table 4.3.1). Curiously, this pattern was not observed in replicate 3 (July 2011), where conditions were slightly more stressful (average temperature of 35ºC and THI of 85).

Table 4.3.1. Animal counts by replicate and health class

	Healthy	Unwell (stayed)	Unwell (removed)	Died
Rep. 1	229	3	2	0
Rep. 2	191	12	33	1
Rep. 3	231	6	2	1
Rep. 4	217	19	3	0
Rep. 5	225	12	0	0

Health status was once again unrelated to the treatments, with $\chi^2_{(9\text{ d.f.})} = 13.0$ ($P = 0.165$) for feed bunk length and $\chi^2_{(9\text{ d.f.})} = 8.84$ ($P = 0.452$) for density (Tables 4.3.2 and 4.3.3).

The variance components (Table 4.3.4) again showed similar patterns, however as expected the replicate effect was somewhat more pronounced. With more replicates (and hence more animals and lines), the effect of lines was also more notable.

Table 4.3.2. Animal counts by feed bunk treatment and health class

Feed bunk length (cm/head)	Healthy	Unwell (stayed)	Unwell (removed)	Died
2	268	12	14	0
5	271	16	11	0
10	279	8	9	0
15	275	16	6	2

Table 4.3.3. Animal counts by density treatment and health class

Density (m^2/head)	Healthy	Unwell (stayed)	Unwell (removed)	Died
0.6	273	16	7	1
0.9	268	15	12	1
1.2	275	13	7	0
1.5	277	8	14	0

Table 4.3.4. Estimated variance components from the REML model for weight change

Random term	Variance component	s.e.
Rep	0.0225	0.0163
Rep.Pen	0.0019	0.0010
Rep.Pen.Line	0.0021	0.0010

The analyses showed only one significant effect, for the feed bunk treatment for weight change ($P = 0.042$). For this feed bunk treatment factor, the carcass weights, dressing % and water intake were all non-significant ($P = 0.12$, 0.79 and 0.72 respectively). The effect of the density treatment was non-significant for all four variables ($P = 0.76$, 0.24, 0.56 and 0.59 respectively).

As mentioned previously, the interaction between these treatments cannot be directly tested under this experimental design. An approximate test can however be constructed, using the pooled residual term from experiments 1 and 2. Under this approach, the interaction is not significant for any variable, with $P = 0.18$ for weight change, 0.42 for carcass weight and 0.48 for dressing %. A second approximate method is to consider the treatments as linear terms (rather than as discrete factors), allowing a limited number of degrees of freedom for the residual. Results from these analyses were also not significant, indicating that the interaction between these treatments is only minor at best. This effect can, however, be better tested under a combined analysis, as has been conducted in Section 4.4.

Means for the feed bunk and density treatments are listed in Tables 4.3.5 and 4.3.6, respectively. The key variables of weight change, carcass weight and dressing % are then plotted in Figures 4.3.1 to 4.3.6.

Table 4.3.5. Feed bunk length treatment means and standard errors (s.e.) for weight change, carcass weight, dressing percentage and water intake in experiment 3. Pairwise differences were tested using a protected LSD-test at *P*=0.05 (means with a different superscript are significantly different)

Feed bunk length	Weight change (kg/head/day)	s.e.	Carcass weight (kg)	s.e.	Dress-ing %	s.e.	Water intake (L/head/day)	s.e.
2	0.004^{b}	0.025	20.93	0.13	45.96	0.29	3.90	0.12
5	0.010^{b}	0.025	20.86	0.13	45.92	0.29	3.89	0.12
10	0.113^{a}	0.025	21.37	0.13	45.64	0.29	3.92	0.12
15	0.052^{ab}	0.025	21.20	0.13	46.05	0.29	4.06	0.12

Table 4.3.6. Density treatment means and standard errors (s.e.) for weight change, carcass weight, dressing percentage and water intake in experiment 3

Density	Weight change (kg/head/day)	s.e.	Carcass weight (kg)	s.e.	Dress-ing %	s.e.	Water intake (L/head/day)	s.e.
0.6	0.042	0.025	21.00	0.13	45.79	0.30	3.83	0.12
0.9	0.025	0.025	20.96	0.13	45.82	0.30	3.97	0.12
1.2	0.063	0.025	21.34	0.13	46.26	0.30	3.90	0.12
1.5	0.050	0.025	21.06	0.13	45.69	0.30	4.06	0.12

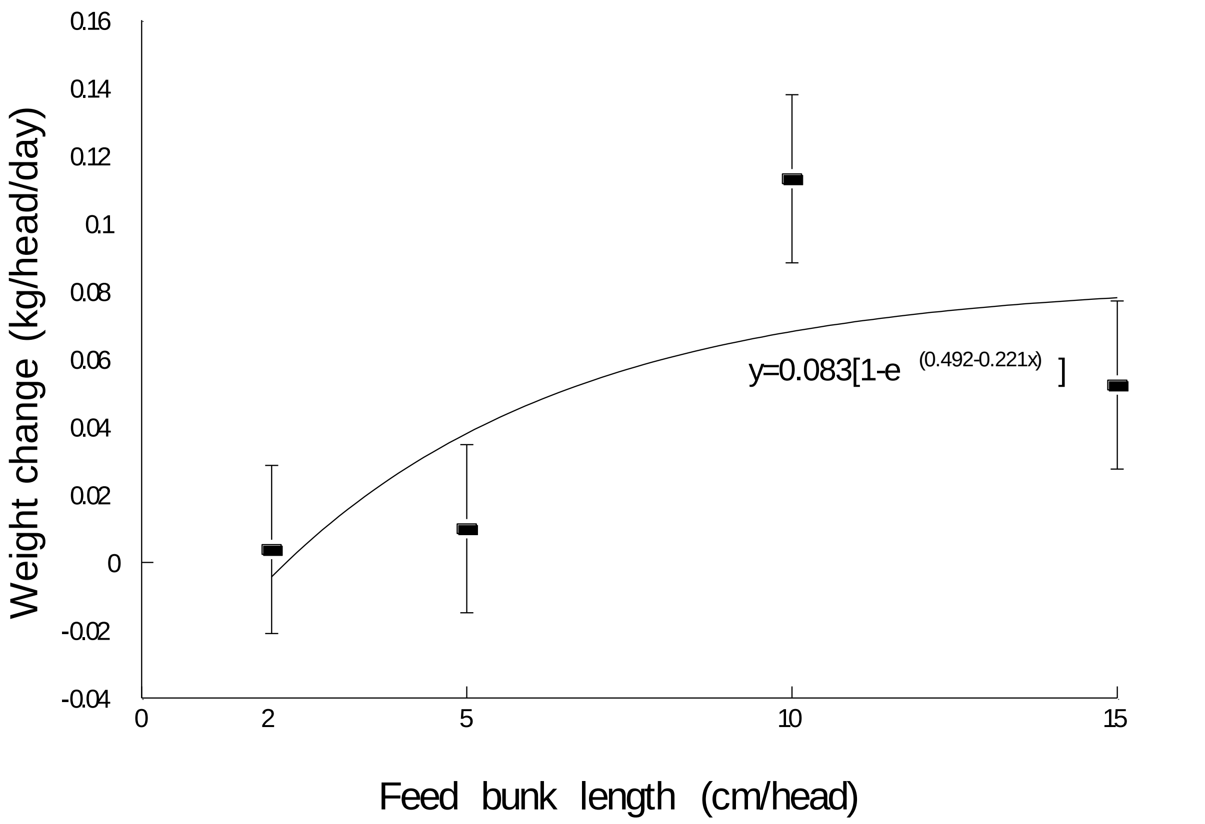

Figure 4.3.1. Relationship between feed bunk length and weight change in experiment 3 with fitted exponential curve. Standard errors are indicated by error bars

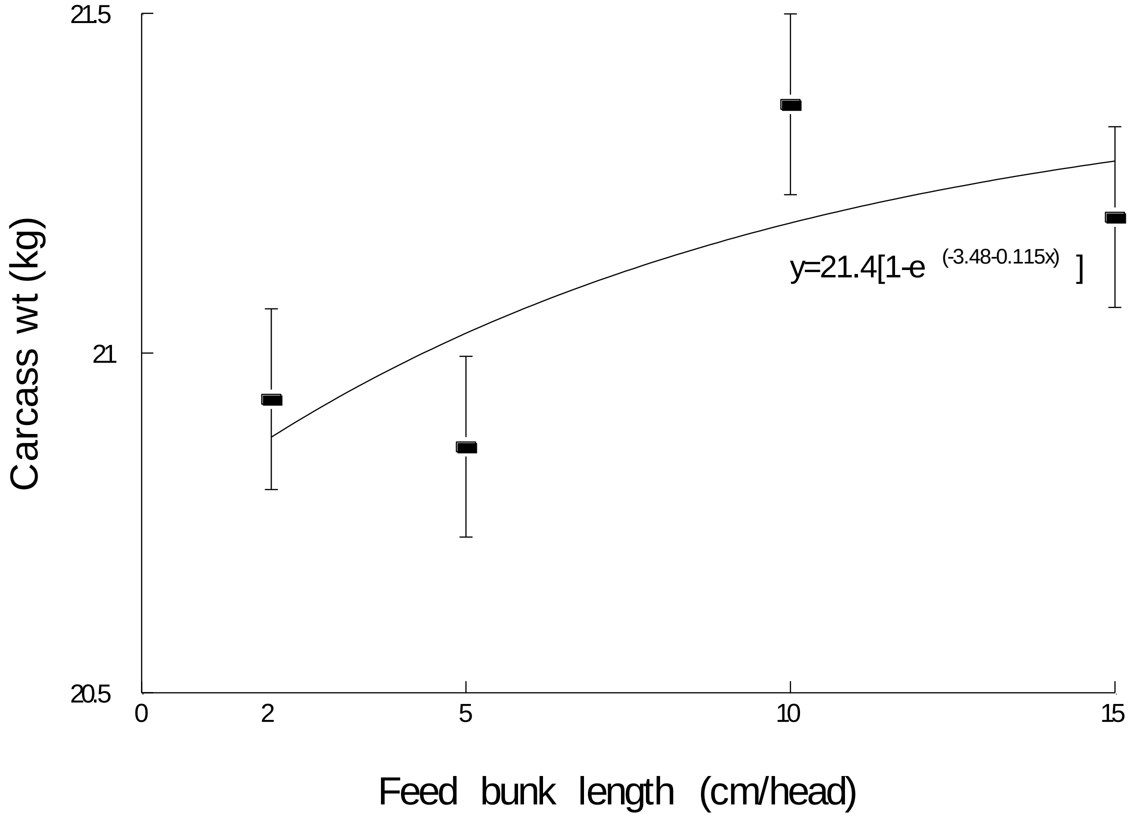

Figure 4.3.2. Carcass weights *vs.* feed bunk length for experiment 3, with standard errors and fitted exponential

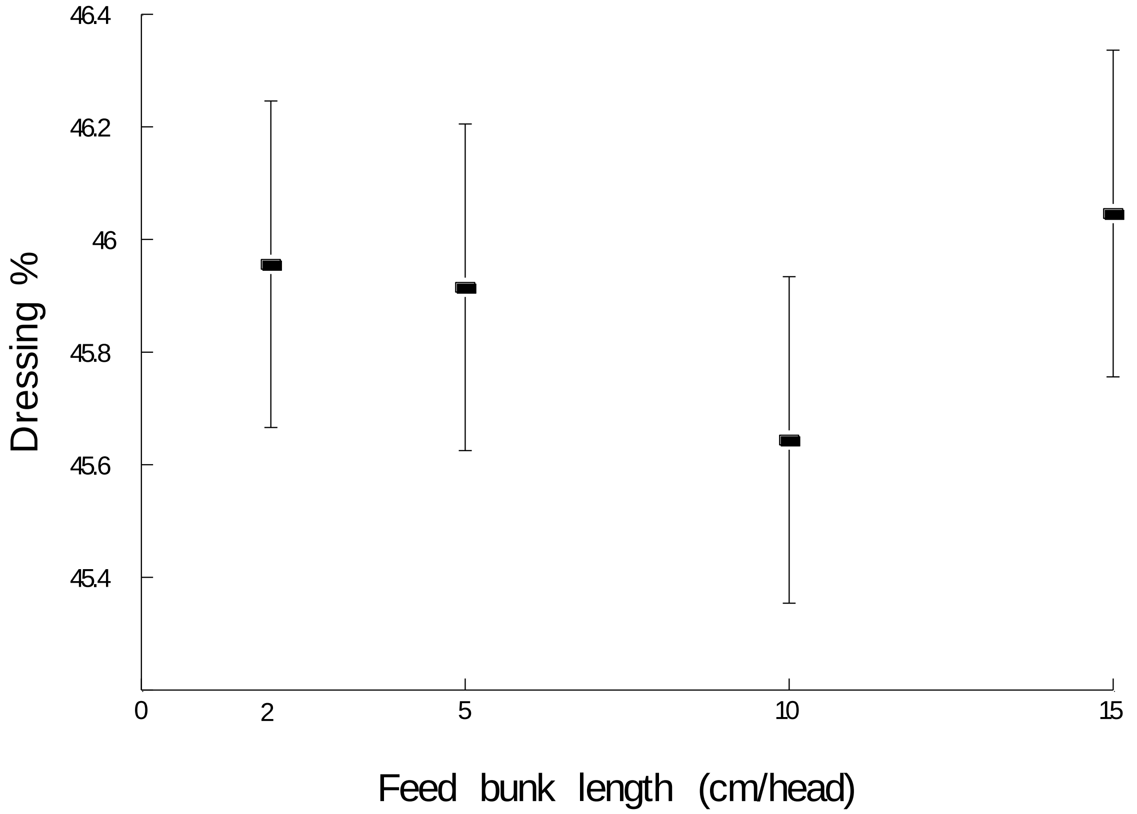

Figure 4.3.3. Dressing percentage *vs.* feed bunk length for experiment 3, with standard errors

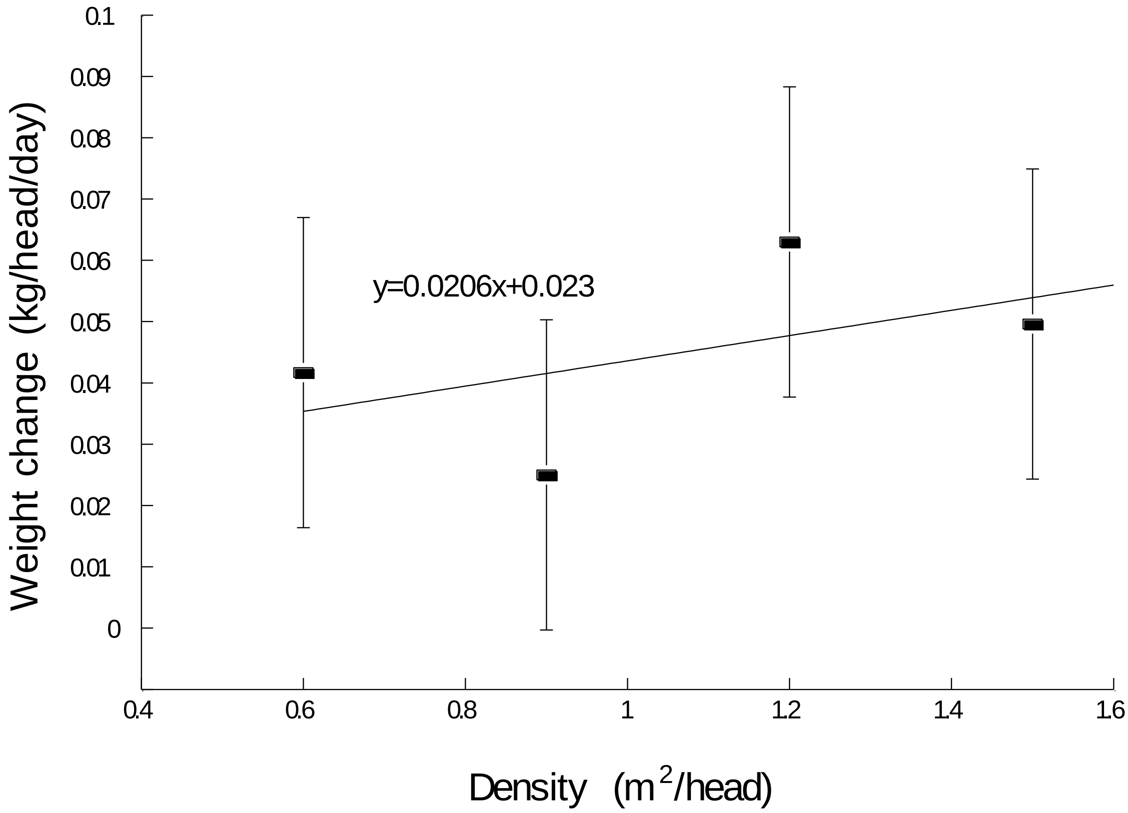

Figure 4.3.4. Weight changes *vs.* animal density for experiment 3, with standard errors and fitted line

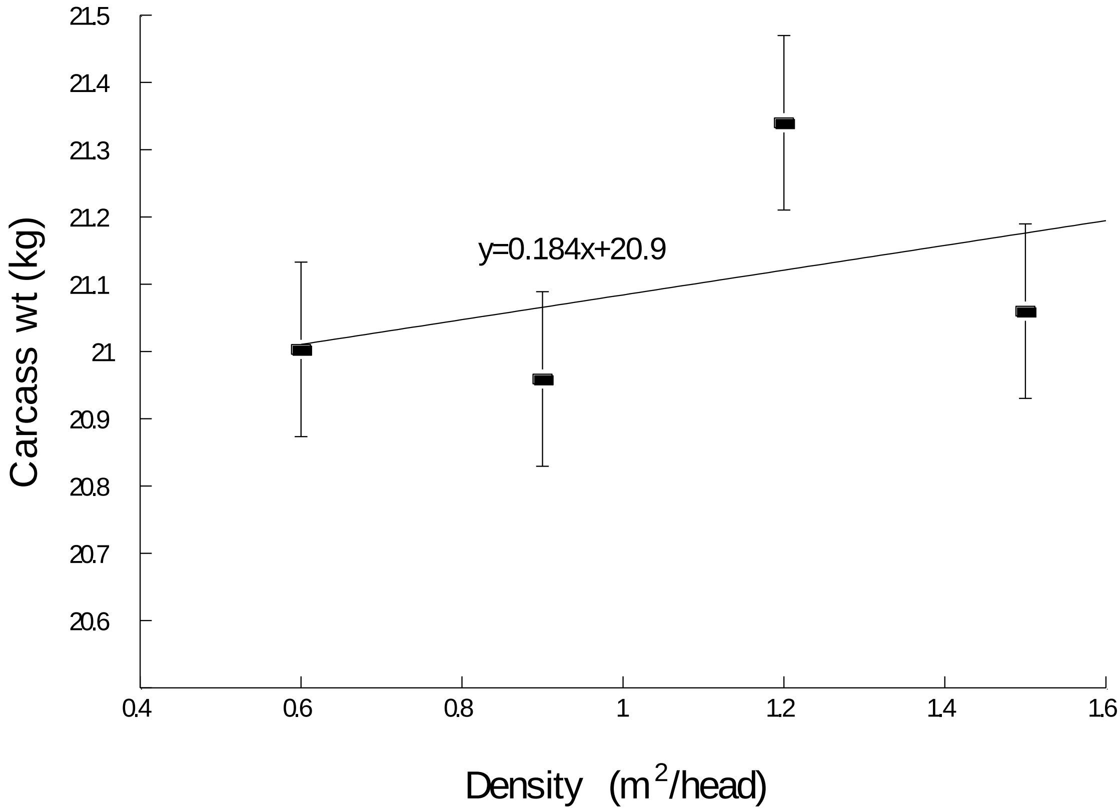

Figure 4.3.5. Carcass weights *vs.* animal density for experiment 3, with standard errors and fitted line

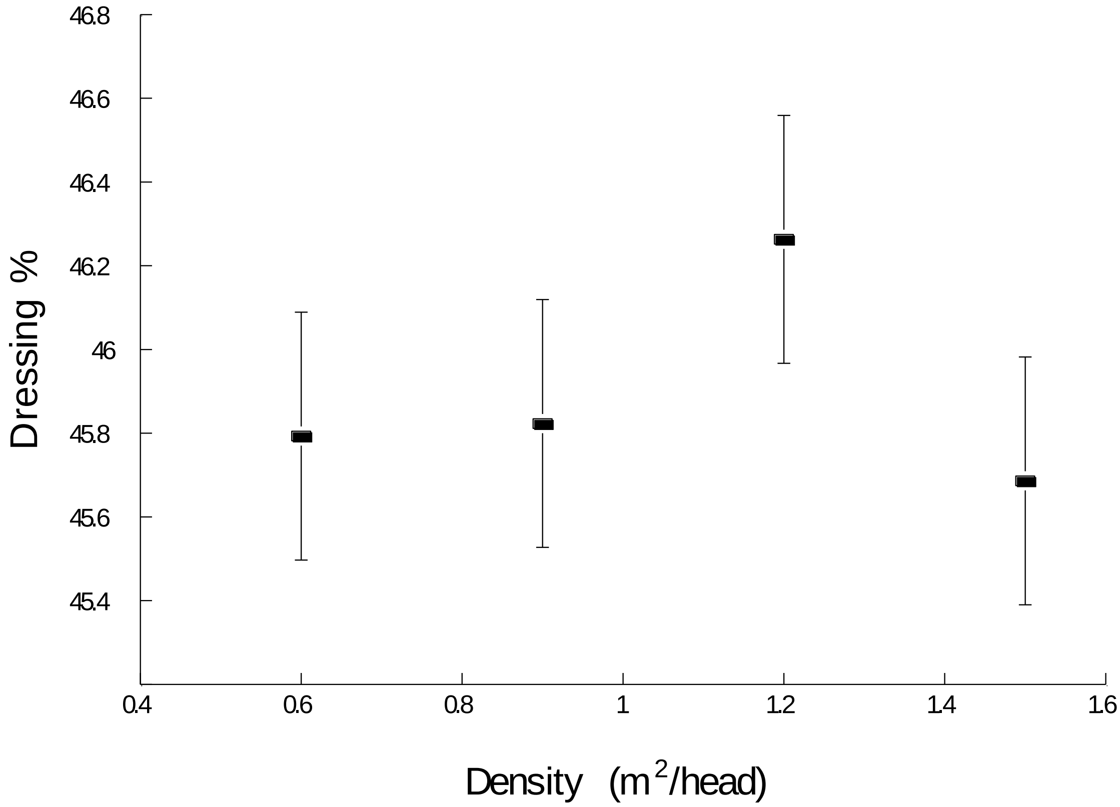

Figure 4.3.6. Dressing percentage *vs.* animal density for experiment 3, with standard errors

Key findings and discussion

- Feed bunk lengths of 2 and 5 cm/head gave significantly lower weight changes than a length of 10 cm/head. In this experiment (with feeding levels close to *ad libitum*), 10 cm/head had the highest weight change and carcass weight and also the lowest dressing percentage – which again may indicate gut fill.
- Weight gain and carcass weight for 15 cm/head was intermediate (statistically), but near the fitted respective asymptotes.
- Hence the fitted asymptotic lines indicate that a feed bunk length of 10 cm/head is near-optimal.
- The fitted asymptote for weight gain, of 0.083 kg/head/day, is 8% higher than the asymptote from experiment 1, and this reflects the higher feeding regime. These values compare well with other studies of sheep in hot environments – Australian wether lambs in Kuwait in a 'hot' treatment (average THI of 83) gained 0.14 kg/head/day *(Ilian et al. 1988)*, and better-adapted Mexican cross-breeds averaged 0.21 kg/head/day at THI levels averaging 85 *(Marcias-Cruz et al. 2010)*.
- There was no significant effect of density on weight gain or carcass weights, however the trend of better performance for more space per animal was noted.
- Dressing % was not affected by either treatment.

4.4 Cross-experiments meta-analysis

All data from experiments 1 and 3, and the water trough treatment of 1.5 cm/head from experiment 2, were included in an overall analysis for feed bunk length and density (as all of these pens had a water trough length of 1.5 cm/head). The purpose of this overall 'feed bunk length by density' analysis was threefold – firstly by consolidating all replicates we get more powerful tests for the treatment effects and more stable estimates of their means; secondly this approach provides sufficient degrees of freedom to conduct a formal test of the interaction between the density and feed bunk length treatments; and thirdly to also consider and estimate the effects of the environmental conditions and possible interactions with the treatments.

To quantify the environmental effects, the cross-treatment response variates (weight change, carcass weight, dressing %, water intake) were obtained for each replicate (four from experiment 1, two from experiment 2, and five from experiment 3). These were compared against the key environmental variables of temperature, relative humidity and the THI. Each of these climate variables were calculated as 24-hour averages, along with the 2pm and 5am values (the approximate times of the day that the maximum and minimum values occur). Wind speeds were not available for experiment 3, however across experiments 1 and 2 these had considerably less effect than the other environmental variables. Water intakes were only from experiments 2 and 3, so were based on fewer observations.

Table 4.4.1 lists the (linear) correlation coefficients amongst the variables. The remainder of this correlation matrix, listing the correlations amongst the climate variables, has not been included but (as expected) did show consistently high values. Overall, these results show:

- For weight change, alternate environmental variables give approximately the same degree of fit. Somewhat surprisingly, temperatures were slightly superior to THI.
- There were no secondary variables (in a multiple regression) that added any reasonable improvement. Hence any of the ‘best’ single variables can be used to adequately quantify environmental heat stress.
- Carcass weight was negatively correlated with environmental stress. However, given the additional variation due to the differences in intake weights and the relatively low degree of (pen) replication, these correlations were not statistically significant.
- Dressing % was not significantly related to environmental stress.
- As expected, water intake (based on only seven values) was highly correlated with environmental stress.

Table 4.4.1. Correlation coefficients (r) among animal responses and climate variables. Bolded values are significant (*P* < 0.05)

	Weight change	Carcass weight	Dressing %	Water intake
Carcass weight	0.18			
Dressing %	–0.01	**0.79**		
Water intake	–0.74	–0.59	–0.06	
Temperature (avg.)	**–0.78**	–0.50	–0.11	**0.96**
Temperature 2pm	**–0.77**	–0.52	–0.11	**0.96**
Temperature 5am	**–0.80**	–0.48	–0.10	**0.94**
RH% (avg.)	0.58	–0.13	–0.20	**–0.76**
RH% 2pm	**0.63**	–0.06	–0.28	**–0.79**
RH% 5am	0.38	–0.32	–0.27	–0.61
THI (avg.)	**–0.71**	–0.56	–0.16	**0.93**
THI 2pm	**–0.72**	–0.58	–0.17	**0.95**
THI 5am	**–0.73**	–0.55	–0.16	**0.92**

For the key variable of weight change, temperature at 5am had the highest linear correlation. This relationship appears nonlinear (Figure 4.4.1), with the fitted linear-plus-exponential explaining 68.3% of the total variation. From these patterns, three ‘temperature groups’ were identified to stratify the environmental conditions, as shown on Figure 4.4.1. Table 4.4.2 summarises all of the climate variables for these nominated groups.

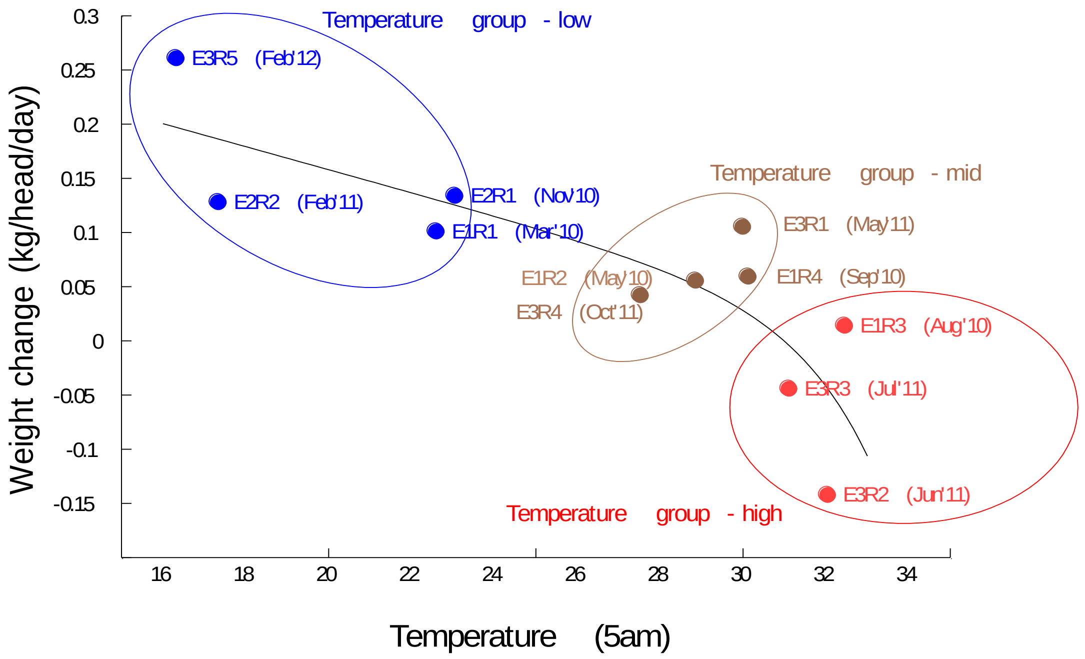

Figure 4.4.1. Combined experiments, weight changes *vs.* temperature, with fitted linear-plus-exponential line

Table 4.4.2. Climate means for the nominated temperature groups

	Temperature group		
	Low	**Mid**	**High**
Temperature (avg.)	21.7	32.7	35.2
Temperature 2pm	24.9	36.8	39.2
Temperature 5am	19.8	29.1	31.8
RH (avg.)	60.6	55.6	50.4
RH 2pm	45.4	38.8	37.0
RH 5am	69.4	69.8	64.3
THI (avg.)	68.4	83.0	85.5
THI 2pm	71.2	84.9	87.4
THI 5am	66.1	80.1	83.4

Due to the data structure, an unbalanced analysis of variance was used to analyse the response variables, using Type-I significance tests. Temperature group was fitted first (to account for the largest effect), and temperature (5am) was retained as a covariate to adjust for differences within these groups. Next the treatments (feed bunk length and density) were added to the ANOVA, followed by the interactions between the three factors.

For each response variable, temperature group and feed bunk length generally had dominant effects, as outlined in Tables 4.4.3 and 4.4.4. The standard errors differ due to the unbalanced nature of the data. No testing of significant differences between the temperature groups has been conducted, as these groups were created from the observed patterns in the data. The patterns in carcass weights generally followed those in weight gains with feed bunk length of 2 cm/head having significantly (P = 0.019) lower weight gains compared with the length of 5 cm/head; for carcass weights this was not quite significant (P = 0.066). Again, there were no significant effects on dressing %.

Table 4.4.3. Mean animal responses and standard errors (s.e.) for the temperature groups

Temperature group	Weight change (kg/head/day)	s.e.	Carcass weight (kg)	s.e.	Dressing %	s.e.
Low	0.146	0.074	21.49	0.61	45.04	1.31
Mid	0.075	0.021	21.04	0.17	46.55	0.38
High	–0.025	0.042	19.59	0.34	44.63	0.75

Table 4.4.4. Mean animal responses for the feed bunk lengths, standard errors (s.e.) and protected LSD-testing at *P*=0.05 (means with a different superscript are significantly different)

Feed bunk length (cm/head)	Weight change (kg/head/day)	s.e.	Carcass weight (kg)	s.e.	Dressing %	s.e.
2	–0.018[b]	0.027	20.21	0.21	46.18	0.48
5	0.080[a]	0.026	20.81	0.21	45.11	0.46
10	0.083[a]	0.022	20.83	0.18	45.79	0.39
15	0.102[a]	0.025	20.92	0.22	45.07	0.44

Again, visual representation of the response surface along with meaningful lines (where appropriate) can assist interpretation, and these are shown in Figures 4.4.2 to 4.4.4.

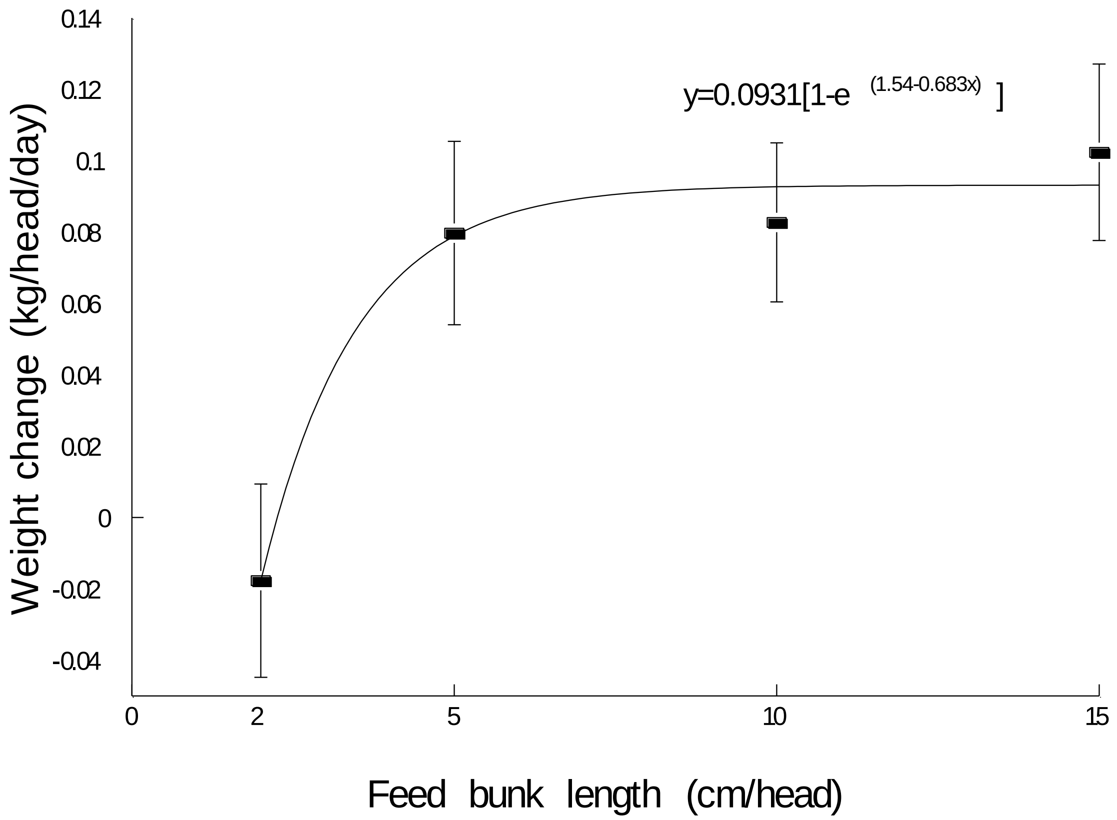

Figure 4.4.2. Combined experiments, weight changes *vs.* feed bunk length, with standard errors and fitted exponential

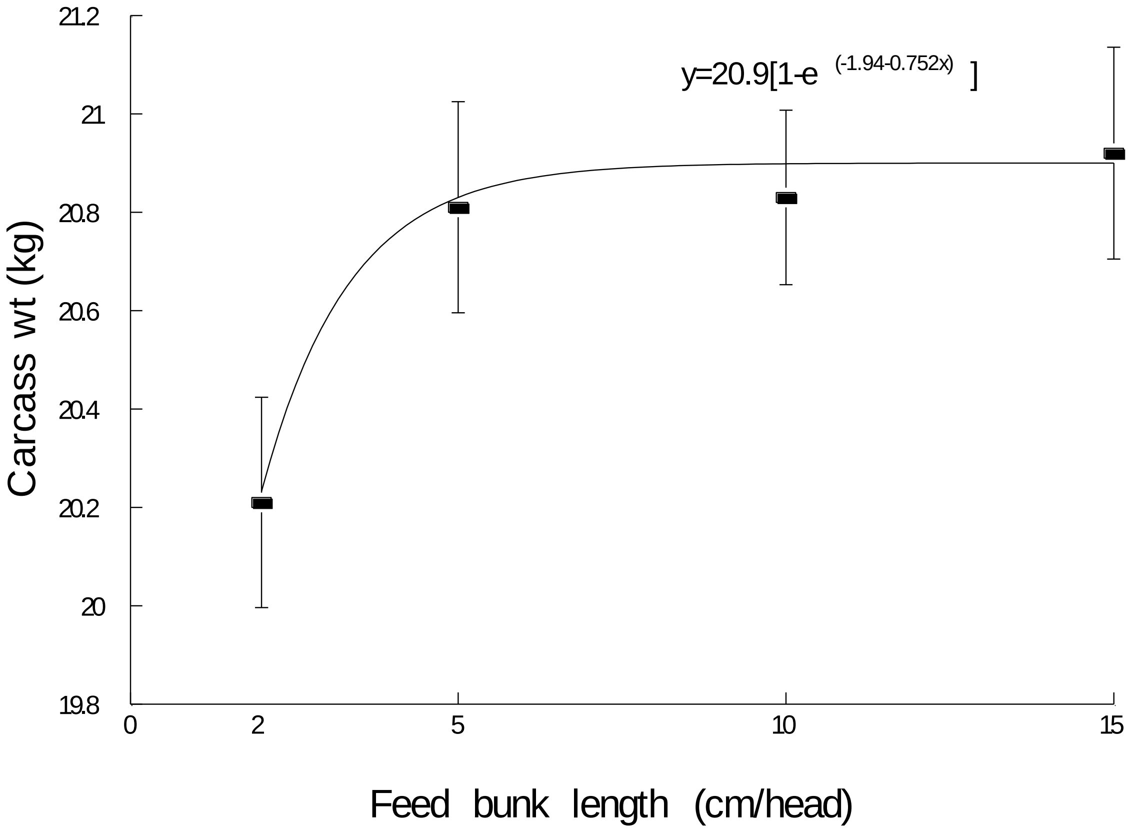

Figure 4.4.3. Combined experiments, carcass weights *vs.* feed bunk length, with standard errors and fitted exponential

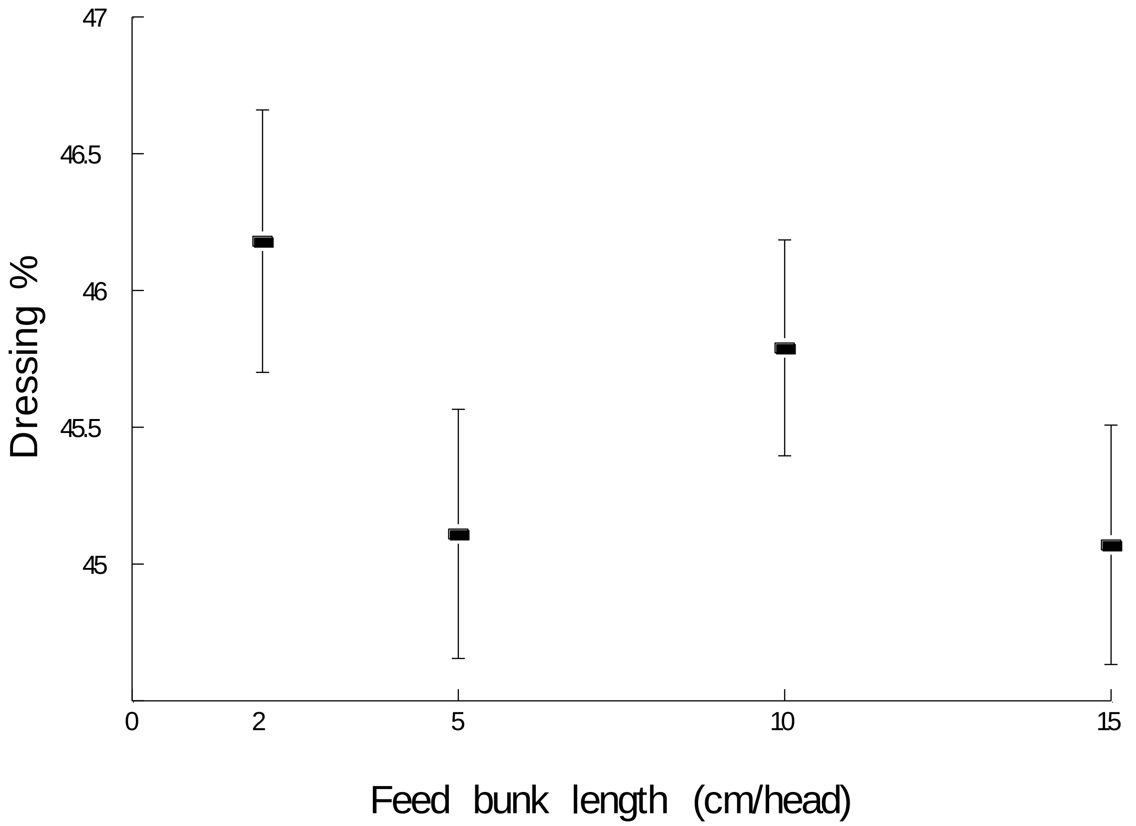

Figure 4.4.4. Combined experiments, dressing percentage *vs.* feed bunk length, with standard errors

The density by feed bunk length interaction showed very little effect. Even when taking these two treatments as linear variates, the ‘more powerful’ test of this interaction (being based on a single degree of freedom) showed that the probability level (*P*) was only 0.59 for weight change. The interaction between temperature group and feed bunk length was also not significant ($P > 0.05$) and minor for all analyses. Hence the estimated feed bunk effect appears to be consistent across the animal densities and the climatic conditions in these experiments.

The strongest interaction (near-significant for weight change at P=0.079) was between temperature group and density, and is shown in Table 4.4.5 and Figure 4.4.5. Similarly, Tables 4.4.6 and 4.4.7, and Figures 4.4.6 and 4.4.7, show the corresponding results for carcass weights and dressing % respectively. The fitted lines in these figures adopt the prior assumption that increasing the space for the animals should not have a detrimental effect on performance, so $y = y_{mean}$ is plotted when there is no increasing trend.

Table 4.4.5. Mean weight change (kg/head/day) and standard errors for the interaction between density treatment and temperature group

Density (m^2/head)	Means – Low temp.	Mid temp.	High temp.	Standard errors – Low	Mid	High
0.6	0.254	0.108	–0.115	0.116	0.062	0.064
0.9	0.314	0.047	–0.147	0.135	0.050	0.063
1.2	0.093	0.078	0.015	0.058	0.026	0.048
1.5	0.179	0.050	–0.020	0.133	0.051	0.064

Table 4.4.6. Mean carcass weight (kg) and standard errors for the interaction between density treatment and temperature group

Density (m^2/head)	Means – Low temp.	Mid temp.	High temp.	Standard errors – Low	Mid	High
0.6	22.15	21.54	19.24	1.05	0.49	0.60
0.9	22.26	21.13	18.95	1.10	0.41	0.63
1.2	21.18	20.91	19.80	0.46	0.20	0.38
1.5	21.46	21.08	19.58	1.08	0.41	0.50

Table 4.4.7. Mean dressing % and standard errors for the interaction between density treatment and temperature group

Density (m^2/head)	Means – Low temp.	Mid temp.	High temp.	Standard errors – Low	Mid	High
0.6	43.51	46.73	46.49	2.07	1.10	1.14
0.9	42.97	47.30	46.28	2.40	0.90	1.13
1.2	45.96	46.21	43.93	1.03	0.46	0.86
1.5	44.40	47.23	44.35	2.37	0.91	1.14

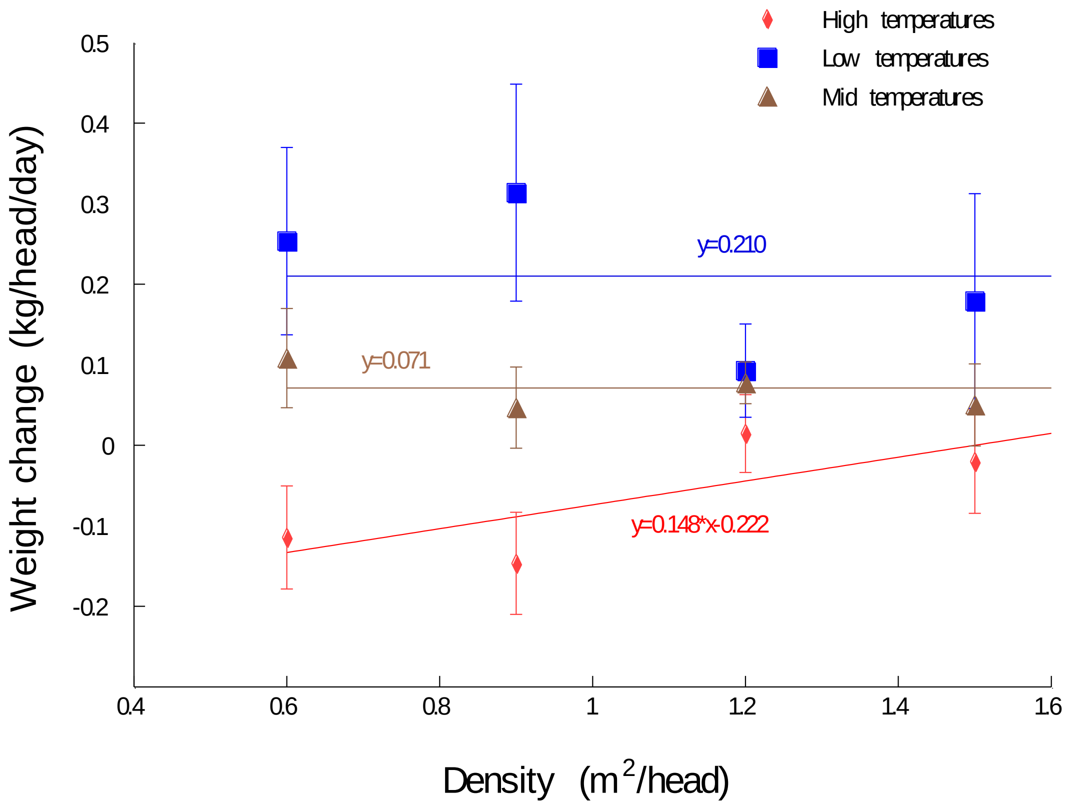

Figure 4.4.5. Combined experiments, weight changes *vs.* animal density by temperature groups, with standard errors and fitted lines

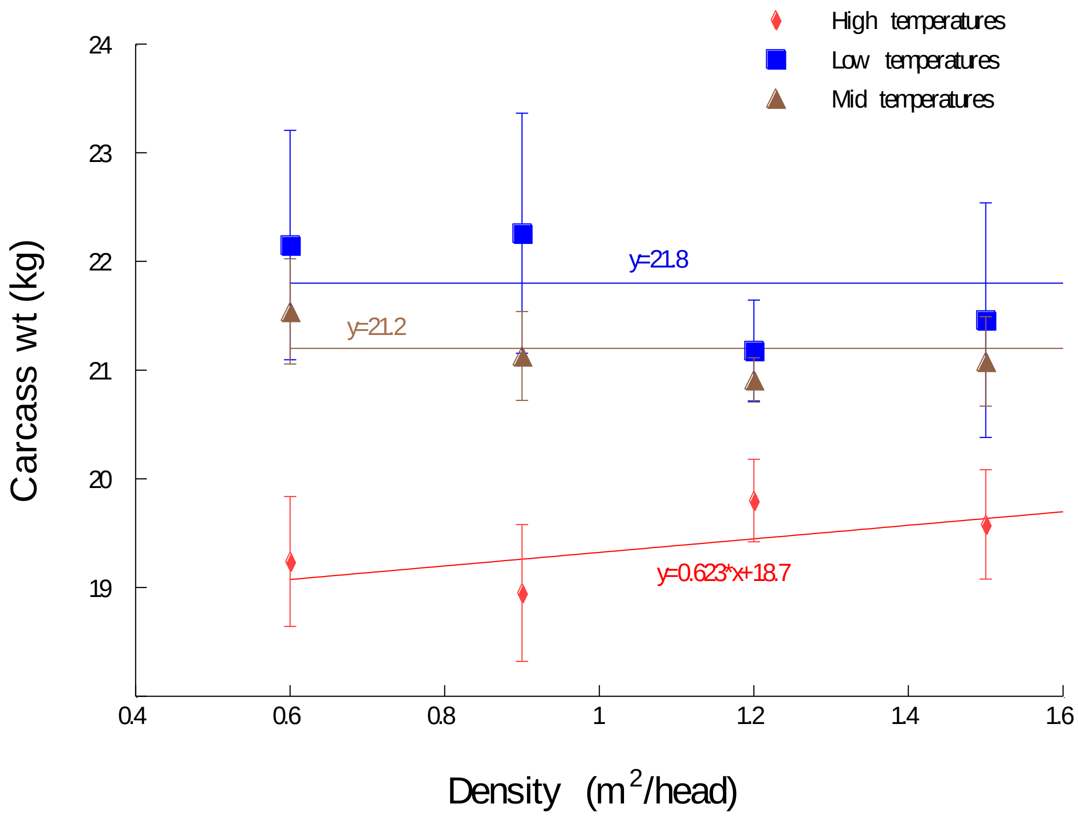

Figure 4.4.6. Combined experiments, carcass weights *vs.* animal density by temperature groups, with standard errors and fitted lines

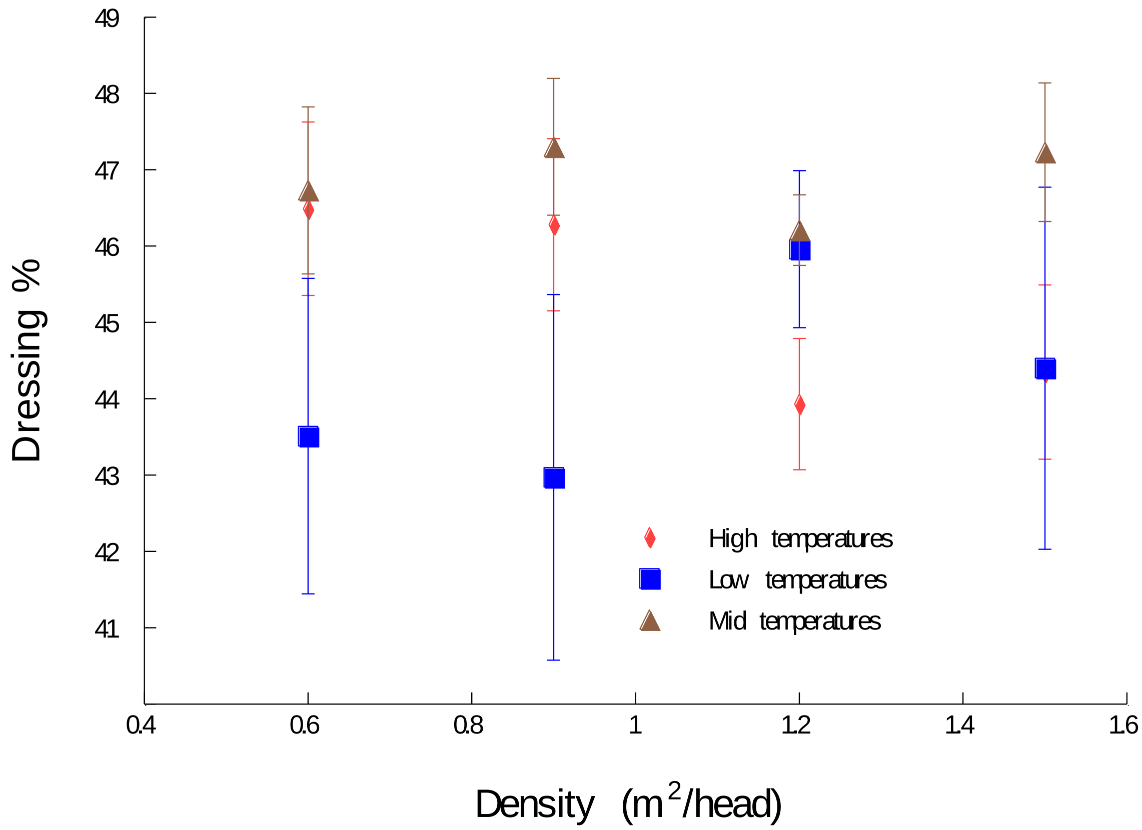

Figure 4.4.7. Combined experiments, dressing percentage *vs.* animal density by temperature groups, with standard errors

Key findings and discussion

- Feed bunk length of 2 cm/head gave poorer performance than the other levels, which were similar ($P > 0.05$). The fitted asymptotic curves approached the optimum at between 5 and 10 cm/head of feed bunk length. This result was consistent across the observed climatic conditions.
- The effect of density depended on climate – at low and mid temperatures (up to about 29ºC with RH 70% at 5am, 37ºC with RH 40% at 2pm, and a 24-hour average of 33ºC with RH 60%) there was no noted effect, but at temperatures higher than these, spacing allowances of ≥1.2 m^2/head gave better animal performance.
- Feed bunk length and density both had no effect on dressing %.

5 Success in achieving objectives

A series of statistically-sound feedlot experiments in the Middle East was conducted, which determined the optimal pen density and feed and water trough length requirements for maintaining animal weights.

Whilst these treatments had no demonstrated effect on mortality or ill-health rates, the recommended levels appear adequate for maintaining good health and animal welfare of Australian sheep in ME feedlots.

Best practice guidelines for management of Australian livestock in ME feedlots have been recommended, as outlined in section 7.

6 Impact on meat and livestock industry – now and in five years time

The main goal of this project was to evaluate and quantify best practice management techniques of pen stocking density, and water and feed bunk availability upon the welfare of Australian livestock in the ME and North Africa region. Having achieved this, it has already had an impact in the ME feedlots. Managers are more aware that more feed bunk allowance combined with adequate allocation of feed reduces shy feeders, morbidity and mortality.

The effect of feed bunk length was shown to be consistent across the other experimental factors as well as environmental conditions. Therefore animal health and welfare benefits are evidenced in this report by providing at least 5 cm however better results were achieved with an allocation of 10 cm per head.

Water delivery is critical, with the aim of a good constant *ad libitum* supply (with good pressure and flow) and at a temperature less than 37ºC *(Savage et al., 2007)*. Superior water delivery in the summer months are critical as sheep that don't drink, don't eat and can get sick and potentially die.

This project also identified adequate pen densities, based on seasonal variation.

The long and short term outcome of this study has been continuous improvement in health and welfare and reduction in morbidity and mortality of Australian sheep in the Middle East. This will strengthen and defend the position of the industry, whilst contributing to the sustainability of a trade that provides a valuable market to livestock producers and exporters, and supplies protein to developing countries.

7 Conclusion

The recommended minimum levels for density, and feed bunk and water trough length in ME feedlots for maintaining weight whilst maintaining acceptable levels of animal health and welfare, are:

1. **Density.** Superior animal performance was achieved at densities **≥1.2 m^2/head during hot conditions** (24-hour average temperatures greater than 33ºC). Based on the civil aviation data collected temperatures of this nature occur during the months of June, July and August. However the space allowance for animals could be decreased, with no demonstrated detrimental effect, to **0.6 m^2/head under milder conditions.**
2. **Feed bunk length.** A length of **≥5 cm/head** is required. Feeding at 90% *ad libitum* (experiment 3) gave 8% higher weight gains than the more restricted feeding regime of experiment 1 which was an allocation of only 1 kg/head/day, and showed 10 cm/head to be optimal compared with 5 cm/head in experiment 1. Hence, optimal feed bunk length may depend on feeding regime. **If feeding maintenance (1 kg/head/day) then 5 cm/head is satisfactory; if feeding 90% *ad libitum* 10 cm/head is required.**
3. **Water trough length.** The results indicate that a **minimum of 1 cm/head** is required. However it should be noted that this experiment was conducted in relatively mild conditions, with the 24-hour average temperatures being 25 and 19ºC for the two replicates respectively. It may well be expected that **larger water trough lengths will be needed in hotter conditions.**

Carcass weights were mainly influenced by intake weights and weight gains. Dressing % was not significantly affected by any of the applied treatments.

There was no demonstrated effect of any of the treatments on the numbers of animals which died, or were classified as unwell. However these animals lost significantly more weight than the healthy animals, therefore if you have animals that are not performing it is best to remove them from the group and send them for processing as soon as possible.

8 Appendices

8.1 Appendix 1. Animal-level factors for the three experiments

Table 1. Mean intake weights (kg) by frame scores

Frame score	Experiment 1	Experiment 2	Experiment 3
40	31.9		
50	38.0	41.9	38.5
60	43.0	46.9	44.2
70	47.4	51.6	51.2

Table 2. Mean weight changes (kg/head/day) by frame scores

Frame score	Experiment 1	Experiment 2	Experiment 3
40	–0.023		
50	0.062	0.055	0.071
60	0.035	0.073	0.046
70	0.039	0.082	0.027

Table 3. Mean weight changes (kg/head/day) by intake weights (kg)

Intake weight	Experiment 1	Experiment 2	Experiment 3
35	0.098	0.078	0.097
40	0.072	0.076	0.071
45	0.046	0.075	0.045
50	0.020	0.073	0.019
55		0.072	

Table 4. Mean weight changes (kg/head/day) by health status

Health status	Experiment 1	Experiment 2	Experiment 3
Healthy	0.074	0.080	0.062
Unwell (stayed)	0.001	–0.062	0.020
Unwell (removed)	–0.252	–0.625	–0.390
Died	–0.646	(none)	–0.640

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