

# final report

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Dr Darryl Savage Dr John GaughanB
Dr Ian GodwinA & Professor John NolanA
University of New England & The University of Queensland
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# Post Discharge Induction Procedures for Sheep in the Middle East

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# Abstract

In-market research of the post-discharge phase of the livestock trade to the Middle East region has identified that feedlot induction procedures could be improved, assisting in the management of heat stress and inanition and improving the overall welfare of sheep and cattle.

Specifically, it is a widely held view in the Middle East region that free access to feed and water on induction to the feedlot increases the risk of sheep mortality. As a consequence, sheep may be curfewed from water and feed on arrival into the feedlot.

This report presents a review of the literature associated with feedlot induction with specific reference to inanition in sheep and cattle in hot climates. Based on consultation (Appendix 2) with industry stakeholders and the review of literature, 'best practice' guidelines for (post-discharge) feedlot induction procedures and recommendations for future research, development and education are presented.

# **Executive summary**

Australia exports sheep and cattle to the Middle East region contributing to an industry worth \$1.8 billion annually. Upon arrival in the Middle East, almost all sheep are inducted into feedlots. Sheep are housed in these feedlots for an average of 15 days post-discharge, ranging from 1 day to 60 days.

Ambient temperatures in the Middle East region during the summer months (> 42°C) are higher than those experienced in the regions from which Australian sheep are typically sourced. The religious festivals creating the greatest demand for sheep meat (*Ramadān* and *Eid Al Fitr*) currently coincide with the cooler months in Australia and the hotter months in the Middle East. The situation will become more intense over the next 5 years as the start of *Ramadān* (10 days earlier each year) moves into July and August, the hottest and most humid of the summer months.

It is a widely held view of feedlot operators in the Middle East region that free access to feed and water on induction to the feedlot increases the risk of sheep mortality. As a consequence, sheep may be curfewed from water and feed on arrival into the feedlot after discharge from the ship.

Research indicates that heat stress increases the risk of inanition, which has been reported as a major contributor to sheep mortality in the live export trade. This review of the literature suggests that modification of the current feedlot induction practices in the Middle East region may reduce the risk of inanition, assist in the management of heat stress and improve overall animal welfare.

Consequently, 'best practice' guidelines for feedlot induction of sheep and cattle in the postdischarge phase of the live export trade were developed and are presented in this report. This report also identifies key animal welfare-related education and training initiatives and recommends their inclusion in the existing industry programs.

This review identified a lack of research-based information relating to drinking water temperature and feeding management strategies for intensively housed sheep in hot conditions and therefore further research into these areas, resulting in the development of industry guidelines, is recommended.

The primary beneficiaries of this information are feedlot operators and service providers to the live export trade between Australia and the Middle East region. It is likely that the findings presented in this report also have relevance to sheep feedlot operators in Australia, particularly those in locations susceptible to hot climatic conditions.

# Contents

		Page
1	Background	5
2	Project objectives	5
3	Literature Review	5
3.1	The relationship between induction procedures and the incide inanition	ence of 6
3.1.1	Feeding behaviour	6
3.1.2	Managing the risk of acidosis	8
3.1.3 <b>3.2</b>	Summary Management interventions for heat stress	12 <b>12</b>
3.2.1	Shade and ventilation	12
3.2.2	Feeding management	14
3.2.3	Diet manipulation	16
3.2.4	Wetting	17
3.2.5 <b>3.3</b>	Summary The importance of drinking water temperature	18 <b>18</b>
3.3.1	The importance of drinking water temperature for sheep	19
3.3.2	The importance of drinking water temperature for cattle	21
3.3.3 <b>3.4</b>	Summary Physiological and metabolic responses to heat stress	22 <b>23</b>
3.4.1	Thermoregulation	23
3.4.2	Endocrinological effects of heat stress	29
3.4.3	Selective brain cooling	29
4	Guidelines for sheep feedlot induction in the M East	liddle 31
5	Recommendations for further RD&E	33
6	Bibliography	34
7	Appendices	45
7.1 7.2	Appendix 1 Feedlot shade structures Appendix 2 People and organisations consulted	45 50

# 1 Background

Millions of live sheep are exported annually (4.2 million for 2008, Source: ABS) from Australia to the Middle East region. Upon arrival in the Middle East, almost all sheep are inducted into feedlots. Sheep are housed in these feedlots for an average of 15 days post-discharge, ranging from 1 day to 60 days (Savage 2007). Periods of peak demand (and therefore shipment) for Australian sheep coincide with the periods immediately prior to the four annual Islamic religious festivals, *Ramadān*, *Eid Al Fitr, Eid Al Adha* and *Muharram*.

During these periods immediately prior to religious festivals, the average post-discharge period that sheep are housed in feedlots is increased as importers "stock-pile" sheep in preparation for increased demand. The religious festivals creating the greatest demand for sheep meat (*Ramadān* and *Eid Al Fitr*), currently coincide with the tail end of the summer months in the Middle East and the winter months in Australia. *Ramadān* started on 1<sup>st</sup> September in 2008 and lasts for 30 days. *Eid Al Fitr* runs 3 days immediately following *Ramadan*. As a consequence, most of the sheep currently transported to satisfy peak demand in the livestock trade are departing Australia in the cooler months and arriving in the Middle East during the hotter months. As *Ramadan* starts 10 days earlier each year, the situation will become more intense over the next 5 years with July and August the hottest and most humid of the summer months.

Ambient temperatures in the Middle East region during the summer months (> 42°C) are higher than those experienced in the regions from which Australian sheep are typically sourced. The extreme climatic conditions (high ambient temperature, high humidity and low wind speed) typical of Middle Eastern summers can result in heat stress in Australian Merino sheep in the postdischarge phase of the livestock trade to the Middle East region. Heat stress is an acute compromise of animal welfare and contributes to mortality rates of Australian sheep.

# 2 **Project objectives**

The objectives of this report were to:

- 1. Review the published and unpublished literature and guidelines related to feedlot induction procedures for sheep and cattle.
- 2. Develop "best practice" guidelines for sheep feedlot induction in the Middle East
- 3. Provide recommendations and justification for further RD&E.

Additionally, the literature review will include the following key issues:

- The relationship between induction procedures and the incidence of inanition
- Management interventions for heat stress in intensively housed sheep and cattle
- The importance of drinking water temperature on heat stress responses in sheep and cattle
- Thermoregulation processes in sheep and cattle
- Physiological and metabolic responses of sheep and cattle to heat stress

The review will summarise the key outcomes with particular application to the Middle East.

# 3 Literature Review

The information presented below represents a review of the literature relevant to developing recommendations for feedlot induction in the post-discharge phase of the livestock trade to the

Middle East region. Key areas identified as requiring specific attention related to inanition and heat stress and, therefore, these topics are the primary focus of the review.

#### 3.1 The relationship between induction procedures and the incidence of inanition

The process of discharging sheep at their port of destination in the Middle East can take several days, depending on the rate of discharge (sheep/hour) and number of sheep to be discharged. For example, a discharge of 24,000 sheep at a rate of 1000 sheep/hour will take 24 hours. While feed is generally provided *ad libitum* while shipboard, prior to arrival at the port of discharge, the provision of feed will be stopped as this has been found to increase the rate of discharge (Holden *pers. comm..* 2008). Consequently, it is possible that on arrival at the feedlot, sheep have been without feed for up to 48 hours in this example of a 24,000 sheep discharge.

Feedlot induction procedures in the Middle East region are inconsistent. Additionally, perceptions that sheep need to be curfewed from water and feed on arrival at the feedlot are potentially contributing to increased incidence of inanition. There is clearly a need for feedlot induction guidelines, specific to the Middle East post-discharge context.

#### 3.1.1 Feeding behaviour

Sheep exported from Australia to the Middle East region are offered a consistent feed pellet on arrival at the pre-export "feedlot" or holding facility in Australia and throughout the duration of the sea voyage. Observations of feeding behaviour of sheep are undertaken at the pre-export holding facility to assist in identifying animals that do not readily accept the feed pellet. Therefore, when sheep arrive in the Middle East, they have been exposed to (and consumed) the feed pellet for a minimum of two weeks. Prior exposure to feedstuffs is one of the most effective management strategies for minimising the incidence of inappetence and consequently, inanition in sheep (Lynch and Bell 1987).

The average Middle East post-discharge period for sheep (the time from arrival in the Middle East to slaughter) is two weeks (Savage 2007). Therefore, induction procedures should be designed to maximise the likelihood and rate at which sheep accept feed on offer.

When sheep arrive at the feedlot post-discharge, they will have been without feed for a minimum of 24 hours. Rumen bacterial populations reduce activity within 12 hours if a constant feed source is not provided (Nolan and Leng 1989). The most effective method for re-establishing rumen fermentation and motility is the provision of a roughage source (Annison and Lewis 1959).

A longer curfew off feed will increase the risk of inappetence (McDonald 1986). A curfew period of 96 hours resulted in 29% sheep demonstrating inappetence compared to a curfew of 48 hours resulting in only 2% inappetence. Time off feed prior to arrival at the pre-export handling facility has also been shown to be a factor increasing the risk of inanition in live export sheep (Norris *et al.* 1989).

Levels of inappetence in lamb finishing operations in Australia are reported to range between 1% and 20% (Bowen *et al.* 2006). It is worth noting that lower rates of inappetence are reported when an *ad libitum* source of roughage is offered in addition to the grain-based ration (Kirby *et al.* 2004, Seymour 2006, Savage *et al.* 2008a). In situations such as these, it is likely that sheep have substituted grain components of their diet with roughage.

#### Prior exposure to feedstuffs and feed delivery systems

Introduction of a new feedstuff to sheep on arrival at the post-discharge feedlot will increase the risk of inanition (Kahn *et al.* 2000). Prior experience with a novel feed has been shown to expedite the acceptance of that feed later in life, overcoming the fear of new foods, which is a trait of ruminant species (Lynch and Bell 1987). Moreover, further improvements in novel food acceptance are possible if initial exposure is undertaken in the presence of social partners (Green et al. 1984, Lynch and Bell 1987) or dams who have prenatal (Schaal *et al.* 1995) or postnatal (Saint-Dizier *et al.* 2007) experience of the novel feed (Figure 1).

Environmental factors such as the feed delivery method and trough space have all been shown to influence feed intake variability (Bowman and Sowell 1997). For example, Holst et al. (1994) reported higher variation in supplement intake between individuals when the supplement was offered in a self-feeder rather than being offered in a more familiar context such as being trail fed on the ground. Arrival in the post-discharge feedlot, represents a significant change in the feeding environment of Australian sheep. Therefore, ensuring that water and feed trough space and feed provision are optimised is a recommended induction practice (refer to Guidelines, Section 4 of this report).



**Figure 1**. Interaction between pre-feedlot feeding treatment and feeding period on percentage of time eating during the initial 10 min period post-feeding. *Control*; these lambs had no previous exposure to the feedlot pellet. *Ground-fed*; the dams of these lambs were offered 200g of the feedlot pellets on two occasions, along the ground, while lambs were atfoot. *Trough fed*; the dams of these lambs were offered 200g of the feedlot pellets on two occasions, in the feedlot troughs, while lambs were at-foot (Savage *et al.* 2008a).

The above results highlight the strength of social models in the transmission of feeding behaviour and food acceptance and also suggest that socially acquired information was more efficient than trial and error learning in the development of feeding behaviour and food acceptance (Veissier *et al.* 1998). In the context of either supplementary feeding or intensive finishing of sheep, it appears that

the introduction of pre-weaning exposure of lambs to a novel feed/supplement, together with their experienced dams, in order to expedite the acceptance of such feeds later in life, has considerable practical and economic merits. All the above is relevant to pre-export feedlots, but by the time sheep get to the ME they have been on pellets for 2-3 weeks....

The risk of inanition may also be reduced by selection of sheep with desirable temperament traits including slow flight time, low blood cortisol, high lymphocyte proliferative activity and high Immunoglobulin A (IgA) concentration (Fell *et al.* 1999). While this is not a management option for post-discharge feedlot operators, it may be a consideration for selection of animals in Australia that are destined for live export.

Whilst social order or dominance hierarchies are not as obvious in sheep as they are in other genera, it may become more evident in competitive situations when feed trough space or feed allocations are limited (Lynch *et al.* 1992). While there is little published data examining the effect of social order on feeding behaviour in sheep, research with cattle has shown significant influences on feeding behaviour that are likely to be exacerbated during increased competition for the feed (e.g. reduced trough or bunk space) (Hasegawa *et al.* 1997, Olofsson 1999). The correlation between feeding behaviour (and competition) and feed intake is not so clear. Considering this, it is generally recommended that animals are grouped according to age and body size.

#### 3.1.2 Managing the risk of acidosis

Acidosis can occur when sheep are introduced to a high starch diet without an adequate introductory period. Acidosis has been recognised as a risk associated with grain feeding (Bigham and McManus 1975; Ikin and Pearce 1978). A survey of Australian farmers who were lot feeding sheep in drought conditions found that 19 per cent of the farmers identified acidosis as the main cause of deaths (Langman and Ashton 2000). Observations of feedlots in the Middle East region indicate that clinical and sub-clinical acidosis are major contributors to poor performance, morbidity and mortality of sheep.

Description of the metabolic disturbances associated with acidosis can be easily sourced in the literature. Therefore, this review of acidosis is focussed on options for its management, with specific reference to lot-feeding in the Middle East environment.



**Figure 2** Control points for various management interventions in the control of acidosis for grain-fed ruminants (source: UNE Animal Science Database).

Strategies for the management of acidosis include feed selection, feed introduction practices and the use of feed additives (Figure 2). Feed selection and feed introduction strategies aim to reduce the level of fermentation substrates entering the rumen and thereby decrease the risk of acidosis. The use of feed additives aims to decrease lactate production or increase lactate utilisation.

#### Feed selection

The selection of a grain and method of processing should aim to provide a feed that suits the digestive capacity of the animal (Table 1). Differences between grains are based not only on the macro nutrients such as starch, lipid and protein, but also on components such as non-starch polysaccharides (NSP), which can have a negative effect on intestinal digestion, and lignin which reduces fermentative digestion (McDonald *et al.* 2002). The characteristics of starch granules and the endosperm matrix also have important effects on digestibility and response to processing, and must be considered when designing processing techniques.

Digestibility	Maize	Sorghum	Barley
(% of starch intake)			
Cattle	93	87	93
Sheep	100	97	100
Pigs		100	99
Chickens	100	99	100

Table 1 Differences between livestock species in their ability to digest cereal grains (adapted from Rowe et al. 2002).

Examples of grain processing methods include:

- Cracking, dry rolling, grinding
- Reconstitution (high moisture treatment followed by rolling)
- Pelleting
- Extrusion (moisture, high temperature and pressure aim to achieve gelatinisation)

- Ensiling
- Chemical treatment (formaldehyde-treated protein)
- Steam flaking

Steam flaking is a very effective form of grain processing since it acts to break the seed coat and endosperm and also to gelatinise the starch. It is clear that grains such as barley, wheat and oats, which have a naturally high fermentation and intestinal digestion when ground or dry–rolled, are not affected as much by steam flaking as are grains like sorghum and maize. The review by Owens *et al.* (1997) indicates there is a small but significant improvement in productivity in beef cattle associated with steam treatment of wheat, whereas consistent and significant benefits can be obtained for sorghum and maize by steam treatment and re–constitution procedures.



**Figure 3** Effect of steam flaking on rumen fermentation and post– ruminal digestion of different grains in cattle (adapted from Huntington, 1997).

Figure 3 illustrates the potential of both sorghum and maize for manipulation with respect to site of digestion, since both parameters are significantly increased by the physical and chemical transformation that take place during steam pelleting. Sorghum and, to a lesser degree, maize, are far less extensively fermented in the rumen than barley or wheat and this characteristic provides the potential for feeding systems which deliver unfermented starch to the small intestine. The problem with both sorghum and maize is that starch escaping the rumen is only around 60–70% digested in the small and large intestines. The potential challenge is, therefore, to find processing treatments which are effective in improving post ruminal digestion without increasing the extent of rumen fermentation. The same concepts apply to sheep; however the response in terms of overall degradation and site of digestion due to processing is not as great as found in cattle (Rowe *et al.* 

1999). This is likely a consequence of increased mastication (breaking of seeds due to chewing) in sheep.

#### Introducing dietary changes

Due to the risk of acidosis when feeding ruminants cereal grain-based diets, it is recommended that the grain component of the diet is gradually introduced. A typical introductory regime is described below in Table 2. Gradual introduction of the grain allows the rumen bacterial population to adjust to an increased availability of fermentable substrate and the associated shift in bacterial population allows the inevitable increase in lactate production to be utilised.

Studies have indicated that post-ingestive feedback is an important determinant for the acceptance of new feeds (Provenza 1995). Consequently, a sudden drop in rumen pH associated with excess ingestion of cereal grain can contribute to increased risk of inappetence and inanition.

 Table 2 A typical introductory feeding regime for grain feeding sheep (adapted from NSW DPI 2008

http://www.dpi.nsw.gov.au/ data/assets/pdf file/0016/101338/grain-poisoning-of-cattle-and-sheep.pdf)

Day	% in ra	tion	
	Cereal grain	Hay	
1 – 5	20	80	
6 – 10	40	60	
11 - 15	60	40	_

The use of feed pellets that resemble those offered to sheep and cattle shipboard along with the provision of good quality hay (such as Rhodes grass hay or Lucerne hay) is recommended for the introduction of sheep to the feedlot environment and diet.

#### Feed additives

Feed additives are rarely used in the Middle East context. Consultation with industry stakeholders indicates that public perception in the Middle East region of such products is negative. In addition to this reason, the cost associated with the inclusion of feed additives was occasionally cited.

Some examples of additives that have been used in cereal grain-based diets for sheep and cattle include:

- Ionophores such as monensin these modify the rumen to decrease the amount of lactic acid produced. It is important to note that the use of monensin for sheep is not permitted in some countries.
- Virginiamycin is a selective antibiotic that reduces the risk of acidosis by reducing the numbers of lactate-producing rumen bacteria. This is an antibiotic that is applied directly to the feed. The use of this antibiotic is banned for animal use in some countries.
- Sodium bicarbonate or sodium bentonite is often applied directly to the diet (usually at a rate of 2%). There is limited scientific evidence to support the use of these products for prevention of acidosis (Table 3).

Treatment	Incidence of acidosis
	(% of animals)
Control	55
Bicarbonate	48
Bentonite	45
Avoparcin	3

**Table 3** Comparison of the effectiveness of sodium bicarbonate (2% of grain) and the antibiotic feed additive, avoparcin (0.04% of grain) in lowering the incidence of acidosis in sheep dosed with ground wheat (Rowe unpub. data).

The percentage of sheep with diarrhoea was reduced from 65% to 15% with the addition of virginiamycin, when fed Barley on a weekly basis. When the same sheep were fed Barley twice-weekly, the incidence of diarrhoea was reduced from 19% to 3% by the addition of virginiamycin (Godfrey et al. 1993). The addition of monensin to grain-based diets reduces the incidence (or degree) of acidosis. For example, in beef cattle fed diets to induce acidosis, the addition of monensin (1.3 g/kg liveweight) increased rumen pH (from 4.3 to 5.2, 8 hours post-ingestion) and reduced L-lactate production from 406 to 105 mg/dl (Nagaraja *etal.* 1982).

## 3.1.3 Summary

Rapid adaptation to grain feeding will maximise intake and reduce the variation in feed intake between individual animals. In comparison to cattle, the period of time sheep spend in feedlots in the post-discharge phase is very short, so rapid acceptance of grain is particularly relevant. In the short-term, the impact of social interaction on inappetence can be reduced by adopting recommendations for trough spacing and induction guidelines for feed provision (refer to Guidelines, Section 4 of this report). In the future, selection of animals for behavioural indicators and early life exposure of live export pellets may prove valuable strategies for minimising the risk of inanition through the livestock trade supply chain.

## 3.2 Management interventions for heat stress

## 3.2.1 Shade and ventilation

Every post-discharge phase feedlot in the Middle East region has shade for livestock. The aspects of variation between locations relate to shade design and total shade area per pen (Figure 4). A review of the literature on the production benefits of shade for sheep and cattle shows conflicting views. While there is no consensus on the production benefits from shade, the evidence of improvements in animal welfare, measured as reduced heat load or positive changes in animal behaviour is more compelling.



Figure 4 Photos of some typical shade designs used in feedlots in the Middle East region

Johnson (1991) investigated shade seeking behaviour of sheep exposed to a maximum ambient temperature range of 28 - 41 °C. He reported that the sheep that used shade for 6% of the day or 39% of the day had the same body temperatures (Johnson 1991). This may have arisen because animals had different rates of evaporative cooling (respiratory rates, sweating) or possibly different rates of heat production. Similarly, the use of shade did not effect feeding times, ruminating times or drinks per day.

Sheep in the shade stood for 2 hours longer per day than sheep in the sun, though they behaved similarly at night. Thus shade use by sheep was not apparently related to patterns of feeding or watering, but was associated with postural modifications that probably have thermoregulatory consequences (Johnson 1987). Studies have noted that a simple iron shelter is of little benefit to sheep in hot environments, because the hot iron sheeting will impose a long wave radiation load on the sheltering animals (Ingrain and Dauncey 1985; Johnson 1991).

Consistent, detectable improvements in beef feedlot cattle performance due to the provision of shade in hot environments have not been found. Clarke and Kelly (1996) reported that provision of shade gave no improvement in feed intake, average daily gain, feed efficiency or meat characteristics of feedlot cattle. While Mader et al. (1997) and, Brown-Brandl et al. (2005) reported inconsistent results on feed intake for cattle with access to shade.. In dairy cows however, provision of shade has consistently resulted in increased milk yield and reproductive efficiency (Buffington et al. 1983). There is general agreement in the literature that shade can reduce heat load (Blackshaw and Blackshaw 1994, Mader et al. 1999b, Davis et al. 2003) and therefore represents an improvement in animal welfare. Most of the research in this field was conducted in the USA (Nebraska and Texas) and Australia (Queensland) where heat and humidity are not as continuously high as some parts of the Middle East region. This point has particular relevance for the live export context as the literature indicates that as environmental conditions become more extreme (hotter and more humid), the benefit of heat stress management strategies (including shade) become more pronounced (Blackshaw and Blackshaw 1994, Brosh et al. 1998, Beatty et al. 2006). Therefore, it is reasonable to assume that the provision of shade for cattle in the Middle East region will provide animal welfare benefits and due to the extreme of climate during the summer months, is more likely to provide production benefits than in Australian cattle feedlots.



Figure 5 An example of a shade designed to maximise ventilation. (Source: Meat and Livestock Australia, www.mla.com.au)

A most critical component of shade provision is design. The principles of shade design include:

- Size
- Location
- Orientation
- Type of material used
- Maximising ventilation (Figure 5)

A description of the factors to be considered in designing shade for feedlot cattle has been produced by Meat and Livestock Australia. A version of the publication is provided in Appendix 1.

## 3.2.2 Feeding management

Feeding management is discussed on the basis of what is known for feedlot cattle during periods of high heat load. It is not clear if beef feedlot feeding strategies outlined below will be applicable to sheep. Clearly there is a need for research in this area.

While altering the microclimate by providing protection from the environment is one of the most useful tools helping animals cope with hot conditions (Mader *et al.* 1997 and 1999) it may not be economically viable for stress elimination. Adjustments in feeding management may be the least expensive and most beneficial strategy to use for feedlot cattle challenged by environmental conditions (Hahn, 1995; Brosh *et al.* 1998; Mader *et al.* 1999b).

Managed feeding programs for feedlot cattle, when used by themselves or in combination with facility additions or changes, can aid in stress alleviation. Studies have shown consistent lower core body temperature of *Bos taurus* cattle exposed to high heat load, when feed intake has been regulated (e.g. Gaughan *et al.* 1996; Davis *et al.* 2003). Feeding programs are designed to reduce the period of peak metabolic load coinciding with peak environmental heat load. The feeding programs used include; split feeding, where a percentage of feed is fed in the morning and the remainder in the afternoon e.g. 60% AM and 40% PM, managed intake systems, where cattle are fed their full allocation in the afternoon (Gaughan *et al.* 1996; Brosh *et al.* 1998; Davis *et al.* 2003) and clean bunk at midday feed intake management program (Lawrence 1998). Another option often

used is the provision of "storm" rations. These rations are usually formulated to have a higher roughage content, and a lower energy content. The use of these rations reduces the metabolic load on the animal, resulting in lower body temperature (Mader *et al.* 1999b). These strategies have resulted in less DMI variation, and have reduced the decline in DMI in commercial feedlots during periods of hot weather (Lawrence *pers. comm.* 2008).

Restricted feeding techniques are one form of dietary manipulation in which feed intake is restricted to a percentage of the intake of a control pen of cattle offered feed *ad libitum* or restricted to a percentage of projected *ad libitum* intake. Restricted feeding increases the efficiency with which cattle convert feed into live weight gain (Plegge, 1987; Hicks *et al.* 1990; Murphy and Loerch, 1994) however, restricted feeding also tends to decrease liveweight gain. Consequently, hot carcass weights are reduced or if animals are fed to similar final weights, days on feed are increased (Plegge, 1987; Hicks *et al.* 1990; Murphy and Loerch, 1994).

One mechanism by which cattle reduce metabolic heat load is through a reduction of feed intake following exposure to high heat load (Carstens *et al.* 1989; Mader *et al.* 2002). During periods of high heat load DMI reductions can be as high as 40%, although falls of 10 - 20% are more common. There is anecdotal evidence that feedlot cattle that have been adversely affected by a heat challenge may not return to previous DMI levels following the cessation of the heat event. It has been suggested by Mader *et al.* (2002) that restricted feeding programs in summer can avoid adversely affecting animal performance if used on a short-term (21 to 42 days) basis to manage heat stress<sup>1</sup> (Figure 6). This strategy allows mangers to control DMI in a way that reduces large variations in DMI as seen in systems where feed intake is not managed (Mader *et al.* 2002).



**Figure 6** Tympanic temperature of cattle offered a grain-based diet on an *ad libitium* (ADLIB) basis; restricted fed for 21 days (RES21) or restricted in feed intake for 42 days (RES42), with average daily maximum temperature of 29°C and 84% relative humidity. (Source: Mader *et al.* 2002).

Problems in managing cattle exposed to elevated climatic temperatures may be further complicated if cattle are being fed high-energy diets (Brosh *et al.* 1994; Reinhardt and Brandt, 1994; Gaughan *et* 

<sup>&</sup>lt;sup>1</sup> During the study reported by Mader et al. (2002) the temperature humidity index ranged from 64.2 to 79.4.

*al.* 1996), which also contributes to elevated metabolic heat load. Reducing metabolisable energy ME intake through feed restriction could lower heat production (Purwanto *et al.* 1990) and enhance feed conversion (Hicks *et al.* 1990; Murphy *et al.* 1994; Murphy and Loerch, 1994).

In general, it is recommended that roughage inclusion rates are increased during periods of hot conditions due to increased risk of acidosis (Gaughan *et al.* 2002). The decrease in feed intake associated with the onset of heat stress can result in aggressive feeding behavior following the excessive heat load period.

#### 3.2.3 Diet manipulation

Diet manipulation and in particular, the use of feed additives to alleviate heat stress has been widely researched and aggressively promoted by commercial interests. Published findings of the benefits associated with the inclusion of feed additives for managing heat stress in lot-fed ruminants rarely reach a consensus on the level of benefit achieved. While many forms of diet manipulation and feed additives are available commercially, those of relevance and with practical implications for the Middle East context include:

- Betaine
- Fat
- Salt

Consequently, these three feedstuffs are the focus of the review.

While to use of Betaine supplements has been shown to have numerous animal health benefits in poultry (Emmert *et al.* 1996, Augustine *et al.* 1997, Kidd *et al.* 1997), the evidence is not so compelling for its use in alleviating heat stress in sheep or cattle (Ali *et al.* 2006). Sodium betaine (also known as trimethylglycine) has been found to be effective against salt stress in plants (Yin *et al.* 2002) and in animals with hyperhomocysteinemia or endoplasmic reticulum stress (Ji and Kaplowitz 2003). However it has not been found to be effective at reducing stress associated with transport or reducing heat load in cattle or sheep (Ali *et al.* 2006).

Hot environmental conditions can be a problem in feedlot cattle causing large productive losses, particularly for cattle consuming high energy diets (Mader *et al.* 1999, Gaughan *et al.* 2002, Mader 2003).

During periods of high heat load, reductions in feed intake helps bring metabolic heat production in balance with the animal's capacity to dissipate heat. However, this has a negative affect on performance. In an effort to maintain energy intake with decreasing fed intake, fat is often added to diets in an effort to increase energy density.

Dietary fats have a low heat increment in comparison to carbohydrates and proteins. The lower heat increment of fat is due to a greater efficiency of utilisation (Baldwin *et al.* 1980). High efficiency results in lower heat production in the rumen when fats are used. However, inclusion is limited in ruminants on the basis that diets with more than 5% total fat suppress ruminal starch digestion (Montgomery *et al.* 2008). The inclusion of dietary lipids in dairy cow diets has resulted in a reduction in heat load (Beede and Collier, 1986; Huber et al., 1994). However, others have shown little benefit (Knapp and Grummer, 1991; White et al., 1992; West, 1997).

Salt (NaCl) is a common feed ingredient, which can be used to regulate feed intake, particularly at levels of 5% or more on a dry matter basis. However, when included at less than 1% on a dry matter basis, salt will tend to stimulate intake (La Manna *et al.* 1999). Levels of salt that stimulate or

restrict feed intake may vary depending on feeding conditions and the amount of environmental stress to which cattle are exposed.

The effects of switching cattle from low-salt, low-fat diets to diets containing elevated levels of salt and/or fat are unknown. In addition, the effects of supplemental salt and fat when fed to feedlot cattle exposed to cold stress or heat stress are largely unknown (Table 4).

**Table 4** Dry matter intake (DMI, kg/d), daily water intake (L), rectal temperature (RT,  $^{\circ}$ C) and respiration rate (RR, breaths/min) of Angus steers under thermoneutral (TN, 19 – 23°C) and hot (HOT, 25 – 36°C) conditions. (Source: Gaughan *et al. in press*)

		Treatment		
Item	Control	Salt	Salt-fat	SEM
<u>TN</u>				
DMI <sup>1</sup> , kg <sup>c</sup>	5.33	5.80	6.12	0.68
DWI <sup>2</sup> , L	18.16	20.13	22.80	1.2
RT, ⁰C	38.8	38.6	38.7	0.1
RR, bpm <sup>3</sup>	53.7 <sup>a</sup>	53.8 <sup>a</sup>	60.1 <sup>b</sup>	3.4
HOT				
DMI, kg <sup>c</sup>	4.04	3.58	3.71	0.89
DWI, L	38.95 <sup>a</sup>	40.55 <sup>a</sup>	46.13 <sup>b</sup>	1.8
RT, ⁰C	39.5 <sup>a</sup>	39.5 <sup>a</sup>	40.0 <sup>b</sup>	0.1
RR, bpm	98.3 <sup>a</sup>	110.2 <sup>b</sup>	112.7 <sup>b</sup>	1.7

<sup>ab</sup>Means within a row with unlike superscripts differ (P < 0.05).

<sup>c</sup>Diet treatment by climate period interaction (P < 0.05).

Decreases in dry matter feed intake, of 0.7 to 1.0 kg/d, as a result of fat supplementation have been reported (Drackley *et al.* 2003). The mechanisms by which supplemental fat sometimes depresses feed intake are not clear, but could involve the effects of fat on ruminal fermentation and gut motility, palatability of diets containing added fat, release of gut hormones, and oxidation of fat in the liver (Allen 2000; Grummer *et al.* 1993). Even though added salt plus fat lowered feed intake under hot conditions, data from Gaughan and Mader (2009) suggest that switching to diets containing the combination of added salt and fat may elevate body temperature, which would be detrimental in the summer but beneficial in winter (Table 4).

## 3.2.4 Wetting

Application of water to heat stressed cattle may provide immediate relief and prevent death (Gaughan *et al.* 2004) and may even improve overall feedlot performance (Nicholls *et al.* 1982). Water applied directly to beef cattle suffering heat stress can rapidly lower body temperature and respiration rate (Gaughan *et al.* 2004) (Table 5). The application of water may even maintain feed intake and reduce thermoregulation energy demands. The effects however may be reduced when there is limited air flow, where relative humidity is high or where the water temperature is close to the animal's body temperature.

**Table 5** Mean (kg/d) and rate (%/h) of feed intake for NONWET and WET heifers during days 4 and 5 of exposure to hot conditions (31°C) (Source: Gaughan *et al.* 2004).

	Treatr	nents	s.e.m.	P-value
	NONWET	WET	_	
Dry matter intake	4.43	5.49	0.31	0.03
Consumption rate	4.72	7.33	0.61	0.01

There are some important caveats for effective application of water for cooling cattle that have particular relevance for the Middle East situation. As cattle are continuously exposed to elevated ambient temperatures, adaptations such as reduced feed intake and reduced metabolic activity allow survival in extreme conditions (Hahn 1999). Cattle are cooled by water application do not initiate coping mechanisms, or acclimatize to the prevailing conditions. It is therefore important that once application of water to reduce heat stress in cattle has been initiated, the timing and duration remain consistent for the duration of exposure to the hot conditions. Failure to do so may result in increased susceptibility of cattle to heat stress (Gaughan *et al.* 2008).

Situations observed in the Middle East region that present such risks include high pen stocking densities (preventing all cattle getting consistent exposure to wetting), prolonged periods of excessive heat load (therefore requiring dedication and commitment to the wetting procedures from employed staff) and high financial costs associated with the purchase of water (as all water has been desalinated).

The wetting of sheep for management of heat stress is not recommended.

#### 3.2.5 Summary

The use of shade will provide a degree of relief for sheep when they are exposed to high heat load. However there are no data available to develop recommendations for the area of shade required per animal, height and orientation of shade or shade material for the Middle East.

There are no research-based recommendations for feeding sheep in hot climates. Consequently there is no evidence that the strategies and methods presented here for feedlot beef cattle during periods of high heat load will be useful for sheep in the Middle East.

Therefore it is recommended that research be undertaken in order to develop recommendations for shade requirements and structures, and nutritional management (including ingredients and feeding programs) for sheep in hot climates.

## 3.3 The importance of drinking water temperature

Drinking water temperature has been shown to play an important role in the management of heat stress in intensively housed beef cattle, dairy cattle, goats, pigs and chickens. Preliminary studies (Savage *et al.* 2008b) indicate that drinking water temperature may also be important for sheep; however more work is required to understand its importance so that industry recommendations can be developed.

#### 3.3.1 The importance of drinking water temperature for sheep

Most of the 4.2 million (ABS 2008) sheep exported are transported from Australia in the cool winter months and arrive in the Middle East during the hot summer months. The average change in ambient temperature during the transportation of most sheep is approximately 18°C to 42°C (during the 12-day journey) and may result in sheep displaying signs of heat stress. Upon arrival in the Middle East, almost all sheep are inducted into feedlots where they are held for 1 day to 60 days (average 15 days) (Savage 2007). During the summer months, drinking water temperatures exceeding 40°C have been measured (measured by author). The importance of drinking water temperature for heat stress management in sheep is not well understood. There is little scientific information about the importance of drinking water temperature and water restriction in sheep for the management of heat stress and welfare.

#### Water intake and thermoregulation in sheep

When sheep suffer heat stress, their increased water intake has been attributed to an increased requirement for evaporative heat dissipation (Appleman & Delouche, 1958; Baker, 1989; Dahlanuddin & Thwaites, 1993). However, the temperature of the drinking water offered to sheep in high ambient temperatures has rarely been documented, despite evidence that water temperature influences thermoregulation and digestive function (Silanikove, 1992).

In cold climates (-12°C), water consumption of sheep was the same at drinking water temperatures of 0, 10, 20 or 30°C. It is worth noting, that these sheep (Cheviot cross wethers) had higher rectal temperatures when consuming water at 0°C than 30°C (Bailey *et al.* 1962). Consumption of water at 0°C has also been shown to reduce rumen microbial activity compared to drinking water temperatures of 10, 20 and 30°C (Brod *et al.* 1982). Frustratingly, this study did not report ambient temperature or water intake data.

While there is very little information relating to the effects of hot drinking water (>30°C) on sheep in hot climatic conditions, it is useful to review the effects of cold drinking water on sheep in hot climates. When 2 L of water at 0 - 1°C was delivered to sheep in a range of ambient temperatures (0, 10, 20, 30 and 40°C), it was found that the sheep demonstrated increased 'heat-seeking' behaviour (voluntarily standing under heaters) at all ambient temperatures except 40°C. For those sheep housed at 10°C, the cold water reduced hypothalamic temperature (Figure 7)(Baldwin 1975).While this evidence indicates that delivery of freezing cold water to sheep will reduce rumen and anterior hypothalamic temperature and encourage heat seeking behaviour in sheep at temperatures up to 30°C, the effect of cold water consumption on the body temperature of sheep is unclear.



**Figure 7** The effects of hypothalamic temperature on loading the rumen of sheep housed at ambient temperature of 10°C with 1 or 2 L of water at 0 to 1°C (top and middle graphs) or 2 L of water at body temperature (bottom graph). The arrow indicates the time of loading (Baldwin 1975).

The only published evidence relating to the consumption of hot water by sheep in hot climates appears to be the recent preliminary studies conducted in Armidale, Australia.

Sheep were housed in two rooms of different temperature and consistent relative humidity (60%). In the cool environment ( $20^{\circ}$ C), drinking water temperature (20, 30 and  $40^{\circ}$ C) did not affect water intake; however, in the hot environment ( $40^{\circ}$ C day-time and  $30^{\circ}$ C night-time), there was a trend for daily water intake to increase as water temperature increased (Table 6). Within the hot environment, sheep drank more water at  $40^{\circ}$ C (9913 g/d) than  $20^{\circ}$ C (6591 g/d), with water intake at  $30^{\circ}$ C (8491g/d) being intermediate.

**Table 6** Mean liveweight change, daily dry matter intake (DMI) and water intake (WI) of sheep housed in a cool room (20°C) or a hot room (40°C daytime; 30°C nighttime) and offered drinking water at 20°C, 30°C and 40°C (Savage *et al.* 2008b).

		Cool room			Hot room			SED	Roo	Wate	Room x
		20°C	30°C	40°C	20°C	30°C	40°C		m	r	Water
Livewt A	(kg)	-0.9	-1.7	-1.2	0.2	-0.4	-1.2	0.9	0.38	0.69	0.92
DMI	(g/d)	1515 <sup>ab</sup>	1620 a	1475 <sup>a</sup>	1096 <sup>c</sup>	1211 <sup>b</sup> د	1073 <sup>°</sup>	156	<0.01	0.68	0.97
WI	(ml/d)	5237 <sup>a</sup>	5822 a	5575 <sup>ª</sup>	6591 <sup>b</sup>	8491 <sup>b</sup> c	9913 <sup>c</sup>	1121	<0.01	0.41	0.52

Within rows, means with a common superscript are not significantly different (P<0.05)

When sheep in the Hot room had a choice between 30°C and 20°C water, they drank more 30°C water than 20°C water. In contrast, in the cool room, sheep drank more 20°C water than 30°C water (Figure 8).



**Figure 8** Mean daily water intake of sheep housed in a hot room (ambient temperature 30 to 40°C) or cool room (ambient temperature 20°C) and offered a choice of drinking water at 20°C or 30°C (Savage *et al.* 2008b).

The lack of response in water intake of sheep to water temperature in a cool environment and a tendency for water intake to increase as water temperature increases in a hot environment are counter-intuitive outcomes. The finding from a third study reported in the same paper, that higher intakes of hot water in conditions led to lower respiration rates, suggests that the increase in water consumption with increasing water temperature, observed in all three studies, may be a thermoregulatory response. Increased water consumption in sheep has been identified in other studies as a response to heat stress (Johnson 1987), however the relationship with water temperature in sheep has not been previously established. Increased water intake in humans exercising, suppresses rise in body temperature, independent of water temperature. However, water temperature influences the mechanism of suppression. The direct cooling effect is dominant during consumption of cool water (1°C and 16°C) whereas evaporative heat loss was dominant during consumption of warm water (37°C) (Niwa 1997).

## 3.3.2 The importance of drinking water temperature for cattle

The importance of drinking water temperature for alleviating heat stress in cattle has been previously reviewed in the Meat and Livestock Australia publication, *Cooling Water for Lot-fed Cattle, FLOT.322* in 2004. This review recommended that cattle should be offered drinking water between 16 and 18°C and not above 25°C.

The most cited publication relating to drinking water temperature for beef cattle in a hot environment is Lofgreen (1975). This study compared the performance, feed intake and water intake of *Bos taurus* and *Bos indicus* cross cattle offered drinking water at 18°C or 32°C in average daily maximum ambient temperatures of approximately 40°C. This study found that *Bos taurus* cattle performed better when consuming cool water than hot water. The increased performance of the *Bos taurus* cattle was due to increased feed intake (associated with consuming cooler water). Conversely, the *Bos indicus* cross cattle did not benefit from cool drinking water and it depressed feed intake. Additionally, cattle drank less cool water (18°C) than warm water (32°C). The above

review (MLA 2004) reported increased water intake from cool drinking water, citing Lofgreen (1975).

It is important to note that improvements in cattle performance from ingestion of cooler water (Lofgreen 1975) were directly related to lower heat production, allowing for increased feed consumption. A related study on lactating dairy cows in a hot environment (average daily maximum of 37°C) found that milk production and feed intake were higher when cows drank water at 10°C than 28°C (Milam *et al.* 1986). In this study, drinking water temperature (10°C or 28°C) had no discernable effect on rectal temperature or respiration rate, however the cooler drinking water did reduce tympanic temperature for longer.

Like the outcome of studies reported for sheep (Section 4.3.1) and goats (Olsson and Hydbring 1995), cattle tend to have a preference for warmer water (Lofgreen 1975, Jones 1999). Increasing water consumption is an innate strategy for heat stress management in many species (Knapp and Robinson 1954, Brown and Lynch 1972, Purwanto *et al.* 1996). Lactating animals, may even hyperhydrate (cattle; McDowell *et al.* 1969, sheep; Thompson *et al.* 1981, goats; Olsson and Hydbring 1995). Hyperhydration may lead to health problems such as haemodilution and hyponatraemia, (Olsson *et al.* 1996). However water loss is an important thermoregulatory process for animals in hot climates. Therefore increased water consumption is usually desirable and decreased water consumption undesirable.

While studies of the effect of drinking-water temperature on the productive performance and physiological responses of cattle have been undertaken, a basic understanding of the importance of drinking water temperature on thermoregulation is limited. This has particular relevance to the Middle East context where production outcomes such as high daily weight gain or milk production are less common targets than liveweight maintenance. The limited research on the effectiveness of chilled drinking water for the elimination of excessive heat load in cattle (Purwanto *et al.* 1996) suggests that chilled drinking water (10°C) is not effective for reducing heat load in excessively hot conditions, typical of a Middle East summer.

#### 3.3.3 Summary

There are no research-based recommendations for drinking water temperature in hot climates for sheep. These findings suggest that research aimed at developing recommendations for management strategies for sheep in hot climates should include consideration of water temperature as a means of improving production and welfare outcomes.

Current evidence to support chilling water for cattle in extreme conditions typical of a Middle East summer is not compelling. Delivery of cool water (< 18°C) for cattle as the only heat stress alleviation strategy is likely to be ineffective in the Middle East context. However, cool water provided in addition to other recommended heat stress management strategies such as the provision of shade, feeding management interventions and ventilation is more likely to be beneficial than detrimental.

## 3.4 Physiological and metabolic responses to heat stress

#### 3.4.1 Thermoregulation

Body temperature is maintained constant as a balance of heat flows to and from the environment. Basically, if the body takes in or produces more heat than it loses then the body temperature rises until heat stress eventuates. One of the heat inputs into the animal is that of endogenous heat production, both from metabolic processes and from microbial fermentation in the gut.

The thermoneutral zone is defined as the range of ambient temperatures between which temperature regulation is achieved by non-evaporative physical processes (Bligh and Johnson 1973). These processes include postural and behavioural changes as well as shifts in blood flow patterns (Stonewell and Bickert 1996). The upper and lower limits of the thermoneutral zone are termed the upper and lower critical temperatures. For sheep, the lower critical temperature is between 18 and 25°C depending on wool cover (Yousef 1985b).

Defining the upper critical temperature is more complex. It is the ambient temperature when a) the metabolic rate increases; b) evaporative heat loss increases; or c) tissue thermal insulation is minimal (Silanikove 2000). Under natural conditions this temperature is difficult to define, so many researchers suggest that the upper critical temperature occurs when the animal begins to use panting as a form of evaporative heat loss (Silanikove 2000) and ranges from 25 °C for growing lambs to 31 °C for fully fleeced ewes (Hahn 1985). Hahn (1985) suggests the term 'acceptable temperature range" should be used where there are minimal losses in production and efficiency. For shorn ewes this ranges from 20-27 °C with optimal production performance occurring between 21 and 25 °C. Various animal factors such as acclimatisation, breed, wool cover and body condition will have quite large influences on the 'acceptable temperature range', however very little consistent information is available on these factors. A major failing in the scientific literature is that most studies do not take into account humidity and simply present dry bulb temperatures (Whan *et al* 2006).

#### Heat Balance

A constant body temperature (homeothermy) requires that heat gain and loss are equal. This can be summarised by the heat balance equation of Robertshaw (1985):

#### M = K + C + R + E

where:

M = Metabolic heat production

- K = Conductive heat exchange
- C = Convective heat exchange
- R = Radiative heat exchange
- E = Evaporative heat exchange

#### Metabolic Heat Production

Metabolic activity produces heat. The basal metabolic rate is defined as the heat produced in resting, fasted, unstressed animals (Graham 1974). It has recently been challenged that these conditions cannot fully be met in a ruminant animal as they never truly meet post-absorptive conditions during fasting (Glazier 2005). Nevertheless, the basal metabolic rate of sheep has been measured as between about 2.6 and 3.1W/kg<sup>0.75</sup> (refs).

Robinson (2002) noted that heat production by individual organs may vary substantially, particularly that produced by the gut. Heat is produced during the digestion of food, from digestive secretions, movements and absorptive processes and also from the specific dynamic action of the absorbed nutrients. Generally diets higher in fibre generate higher heat production (Lee 1950). Muscular work (exercise) is also a major source of heat production, with skeletal muscle accounting for as much as 80% of the total metabolic heat (Andersson and Johansson 1993).

Metabolic heat production may also increase during heat stress as the metabolic rate of tissues increases with increasing body temperatures. This is termed the Q10 effect (Whittow and Findley 1968). The additional energy costs of panting, sweating and work associated with increased heart rate also contribute to metabolic heat production (Kibler 1957, Bianca 1968). Ames *et al* (1971) estimated that the Q10 or the Vant Hoff effect is responsible for 23% of the increase in metabolic rate at ambient temperatures of 35°C and 41% at 45°C. This increase occurs despite reductions in thyroid function during heat stress.

#### Conductive Heat Exchange

Conductive heat gain is generally minor in a standing animal with only the hooves touching the ground. However, in an animal lying down some degree of conductive heat transfer will ensue. The rate of heat gain will depend on the temperature difference between the ground and the animal and the degree of solid contact between the ground surface and the animal (Robertshaw 1985). In shadeless conditions, where the ground temperature is high, sheep generally stand rather than lie to minimise the conductive heat gain (Macfarlane *et al* 1958). It should also be noted that taller animals (such as cattle) will gain or lose less heat than shorter animals simply due to the distance of their bodies from the ground (Thwaites 1985).

#### Convective Heat Exchange

When air temperature is greater than body temperature, there is a gain of heat to the animal by convection (Silanikove 2000). The temperature gradient can be influenced by the degree of air movement and also the shifts in blood flow patterns to the skin of animals allowing changes in skin temperature (Hales *et al* 1985).

#### Radiative Heat Exchange

Most radiative heat load to sheep is directly from sunlight although radiation is also reflected from nearby objects (Thwaites 1985). The horizontal stature of sheep generally ensures that they gain heat from sunlight, often exceeding their metabolic heat production by as much as four fold (Stafford Smith *et al* 1985). Animals use shade seeking behaviour and body orientation shifts to reduce radiative heat loads. Normally the underside of a standing sheep does not receive solar radiation, but may receive heat load from very hot ground (Macfarlane *et al* 1958).

Radiative heat loss and gain are greatly reduced by the presence of wool. Radiative heat loss is negligible in woolly sheep. It should also be noted that recently shorn sheep tend to have a whiter coat colour, which helps reflect some of the incoming solar radiation (Macfarlane et al 1958).

#### Evaporative Heat Loss

Evaporative heat loss is the major mechanism of cooling in a large variety of animals. The mechanisms range from evaporation of sweat, respiratory secretions and the spreading of saliva (Robertshaw 2006). Evaporative or insensible losses of water in sheep increase from about 1L/d to 3L/d when the temperature is raised from 25 to 40°C (Blaxter *et al* 1959, Rahardja 1995). Once ambient temperature rises above body temperature the only form of cooling available to the animal is evaporative heat loss. The rate of evaporative heat loss is dependent on the difference between the vapour pressure on the animal surface and the surrounding air (Mount 1979). When humidity is

high the vaporisation of water at the animal surface is reduced. Increasing air movement over the vapour-laden surface close to the animal with relatively drier air may substantially increase the rate of evaporation (Ingram and Mount 1975).

#### Blood Flow

Movement of heat from the internal body organs, where it is mostly generated, to the skin surface where it can be lost is largely achieved by convective heat transfer in blood. Blood flow shifts away from the internal organs to the skin and more peripheral regions such as the legs and ears during high temperatures (Webster and Johnson 1964). The increased skin blood flow leads to substantial convective and radiative heat losses from the extremities (Blaxter *et al* 1959).

The mechanism of increased skin blood flow during hot conditions is via vasodilation of arterioles in the dermal vascular beds. Arteriovenous anastomoses in the vascular plexuses of the skin, ears and limbs also open, substantially increasing peripheral blood flow. These arteriovenous anastomoses are responsive to changes in core body temperature rather than ambient temperature. Dilation of the arteriovenous anastomoses occurs when core body temperature rises from 38 to  $42^{\circ}$ C (Hales *et al* 1985). However, in an experiment where core body temperature was maintained below normal, despite skin temperatures as high as  $44^{\circ}$ C, there was no dilation of arteriovenous anastomoses (Hales *et al* 1985). When core body temperature is elevated then skin temperature does influence the degree of dilation (Hales *et al* 1985). The increased blood flow to the skin also maintains skin temperature at about  $40^{\circ}$ C, preventing potential thermal damage to the skin itself.

During exercise under heat stress conditions, there is substantial competition between muscle and skin for blood perfusion. This competition is largely met by an increase in cardiac output and a decrease in perfusion of the other organs such as the gut (Hales *et al.* 1984).

A hypothesis suggested by Hales and Sakurada (1998) states that severe heat stress may lead to induction of fever. The hypothesis suggests that when blood is shunted away from the gut to the more peripheral areas, gut wall integrity can become compromised. The ischemic gut then becomes permeable to bacterial endotoxins which initiate a fever type response. The shifts in blood flow that occur when this pattern of events occurs, together with the associated pathologies can be summarised in the following figure (Hales and Sakurada 1998)(Figure 9).



**Figure 9** Proposed scheme of the interacting sequence of events occurring from the beginning of exercise and exposure to a hot environment to death from heat stroke BF = Blood Flow; CO = Cardiac Output; CBV = Central Blood Volume; CVP = Central Venous Pressure; DIC = Disseminated Intravascular Coagulation; el = Electrolytes; ex = exercising; Fl= Fluids; kid = Kidney; M = Muscle; PVB = Peripheral Blood Volume; Sk = Skin; spl = Splanchnic; TBV = Toatal Blood Volume; Tc = core temperature; V = Volume (Adapted from Hales and Sakurada 1998).

The exact role of endotoxins in driving the pathologies seen in "heat stressed" sheep is unknown, but it is plausible that much of the "heat stress" mortality noted in the live sheep trade may well be accounted for by this explanation.

#### Sweating

Sweat glands in sheep are associated with the primary hair follicles. These glands produce sweat at a maximum rate of about 1g/kgW/h (Hofmeyr *et al* 1969). However, sweat gland discharge is not continuous and varies depending on ambient temperature. The maximal rate of secretion occurs when ambient temperature exceeds about 38°C (Ames *et al* 1971, Hofmeyr 1969) but the maximal secretion rate can only be maintained for a few hours before the glands become fatigued and reduce their secretion (Alexander and Williams 1962). They generally recover after an overnight period of cooling and resume normal activity the next day (Hofmeyr *et al* 1969). Hence, under conditions of continual exposure to high temperatures, sweat gland secretion will only be of importance during the first few hours of heat exposure.

Thwaites (1985) noted that sweating played only a minor role in heat loss from sheep, compared to the evaporative cooling from the respiratory tract. In this respect sheep differ substantially from cattle, which have a much higher density of sweat glands, higher gland volumes and higher secretion rates than sheep (Macfarlane 1968).

#### Respiratory Heat Loss

Evaporation of moisture from the respiratory surfaces provides an efficient heat loss mechanism in sheep. Hales and Brown (1974) suggested that respiratory heat loss may be as high as 80% of total heat loss.

The normal respiratory frequency for resting sheep is between about 20 and 40 breaths/min (Hales and Brown 1974, Bhattacharya and Hussain 1974). During periods of high heat load, respiratory frequencies of greater than 350-400 breaths/min have been recorded (Starr 2007, Marai *et al* 2007). Panting scores for cattle have been developed through work supported by Meat and Livestock Australia (Sparke et al 2001). Panting scores in cattle range from 0 (normal) to 4.5 (animal severely stressed). Industry recommendations using these scores include; a) if more than 10% of cattle are exhibiting panting scores of 2 or above, all handling and movement of the affected cattle should be stopped and only resumed when conditions become cooler and cattle have returned to normal and b) cattle with a panting score of 3.5 or greater are in danger of death if they do not receive some form of relief from the hot conditions. A four point panting score has been used to assess heat load in sheep (McCarthy 2005, Stockman 2006). Relating this scoring system to the Heat Load Index (HLI) (Gaughan et al 2004) and the Temperature Humidity Index (THI) (Sparke et al 2001) will require more research to refine cut-offs appropriate thresholds (Stockman 2006).

Ames *et al* (1971) found no increase in respiratory heat loss after the respiratory frequency reached 240 breaths/min. This was probably due to the increased metabolic cost (heat production) of panting, although the sheep appears to be very efficient compared to other animals (Hofman and Riegle 1977).

Sheep exhibit two types of panting, termed first and second phase panting. First phase panting involves rapid shallow breathing, whereas second phase panting is characterised by a slower deeper panting (Hales and Webster 1967).

The stimulus for panting appears to be more related to the ambient temperature than to core body temperature (Ames *et al* 1971). Receptors located in the bare skin area between the hind legs and scrotum and in the nose appear to respond to increased environmental temperatures by stimulating panting (Waites 1962, Bligh 1963, Hales and Hutchinson 1971, Phillips and Raghaven 1970), even if the core body temperature is normal (Hales and Webster 1967). Elevation in core body temperature will also lead to an increase in first phase panting, with rises in core body temperature of more than 1°C leading to the initiation of second phase panting (Hales and Webster 1967).

Panting generally involves a low tidal volume with an increased respiratory frequency. In first phase panting there is a slight rise in respiratory minute volume. The rise in respiratory minute volume is largely confined to the respiratory dead space, preventing the alkalosis normally seen with hyperventilation. The aim of first phase panting is to move air backwards and forwards over the moist surface of the nasal cavity. The reduced tidal volume ensures that the respired air is limited to the dead space regions (Hales and Webster 1967, Thompson 1985). If gas exchange obligations are not met then the occasional deep breath suffices (Hales and Webster 1967).

First phase panting simply involves diaphragmatic breathing whereas second phase panting involves the use of intercostal muscles and excursion of the thorax. Second phase panting thus requires more metabolic input (and heat generation) (Hales and Brown 1974) which correlates with the increased blood flow to the respiratory muscles that occurs during second phase panting (Hales 1973). Second phase panting is characterised by open mouth breathing with increased tidal volumes, but with lower respiratory frequencies than seen in first phase panting (Hales and Webster 1967). Hence the respiratory minute volume is substantially larger than during first phase panting and this volume is not confined to the respiratory dead space (Thompson 1985). Minute volumes may increase 10 fold with alveolar ventilation increasing to as much as 5 times that seen in animals at thermoneutral conditions, leading to severe respiratory alkalosis (Hales and Webster 1976).

Sheep undergoing second phase panting often have their tongues protruding and their necks extended (Hales and Webster 1967). The secretion of saliva which provides a major source of buccal moisture during heat stress has not been measured in sheep and may be a limiting factor for evaporative heat loss, especially during dehydration. Sheep do not appear to exhibit drooling which is often seen in heat stressed cattle (Beatty *et al* 2006).

A simple indicator of moderate heat stress in sheep is the onset of first phase panting and for severe heat stress is the onset of second phase (open mouth) panting. The measurement of respiratory frequency as a simple index of heat stress would be inappropriate unless the differences in first and second phase panting are taken into account. In Hales and Webster's (1967) study, respiratory frequencies approaching 300 breaths/min were recorded after only 1 h of exposure to 28°C. Ames *et al* (1971) found sheep exposed to 45°C for 1.5 h had respiratory frequencies of only 240 breaths/min. Hence it is suggested that respiratory frequency may not be a reliable indicator of the degree of heat stress.

Silanikove (2000) suggested that heat stress was related more or less linearly to respiratory frequency and that severe heat stress was occurring when respiratory frequency above 200 breaths/min were recorded. A simple linear relationship like this is inappropriate as it does not take into account the existence of second phase panting and the increases in metabolic heat production that this entails. It also does not allow for the disturbances in acid/base balance that occur during second phase panting. A panting score has been developed for cattle and is now widely used as an indicator of heat stress (Sparke *et al* 2001, PIRSA 2006).

Second phase panting leads to respiratory alkalosis due to the enhanced alveolar ventilation and the consequent loss of  $CO_2$  (Hales and Webster 1967). Arterial pH shifts from 7.48 to 7.59 and p $CO_2$  from 35 to 25mmHg have been measured in sheep during second phase panting (Hofman and Riegle 1977). The set point for arterial p $CO_2$  is decreased or the regulatory system gain is increased during hyperthermic exercise in sheep. This mitigates the conflict between thermoregulatory and chemoregulatory drives and facilitates increases in respiratory minute volume and hence evaporative heat loss (Entin *et al* 2005). Maskrey *et al* (1981) also showed that enriching the inspired air (42°Cdb, 39°Cwb) of panting sheep with  $CO_2$  led to a reduction in panting frequency and an increase in tidal volume, suggesting that the threshold for the chemoreceptor response to  $CO_2$  was lowered by hyperthermia.

The renal response to respiratory alkalosis is generally to excrete  $HCO_3^-$ , thus normalizing the ratio of  $CO_2$  to  $HCO_3^-$ . During heat stress Hofman and Riegle (1977) noted a decrease in arterial  $HCO_3$  from 25 to 23 mmol/L, presumably due to increased renal excretion.

If heat stress is suddenly removed and the animal no longer hyperventilates, the blood  $pCO_2$  rapidly rises due to metabolic processes, swinging the ratio of  $CO_2$  to  $HCO_3$  into acidotic values. The acidosis then becomes a mix of both respiratory and metabolic due to the increased  $pCO_2$  and the decreased  $HCO_3$ . This phenomenon has been observed in cattle following abrupt cessation of 15 days high heat load (Beatty *et al* 2006). Schneider *et al* (1988) also observed respiratory alkalosis during the day and metabolic acidosis at night in cattle exposed to hot day and cold night temperatures.

## 3.4.2 Endocrinological effects of heat stress

Thyroid hormone is one of the major hormones regulating metabolic rate in animals and hence heat production. Heat exposure decreases thyroid hormone secretion (Hoersch *et al* 1961, Hafez 1968). The concentration of thyroid hormones declines by about 25% in cattle exposed to heat stress (Beede and Collier 1986). It is assumed that a decline in thyroid hormone levels plays a role in body temperature regulation, by lowering the metabolic rate and hence lowering heat production. For example, Ross *et al* (1985) showed that both tropical and British breeds of sheep show a reduction in serum thyroid hormone under heat stress. However, cross bred animals from these two groups exhibited no change in serum thyroid hormone levels, indicating that heterosis for thyroid gland function in regard to heat tolerance is substantial. Thyroid hormone may also play an indirect role in heat generation by either influencing food intake or the turnover of gut contents (Weston 1977).

The adrenal corticosteroids, particularly the glucocorticoids play a lead role in the general response to stress (Fell *et al* 1985). Hales (1973) showed that during severe heat stress in sheep, where core body temperature had risen by more than 2°C, adrenal blood flow was substantially increased. Short term heat stress leads to an increased plasma cortisol level in cattle; however, longer term heat exposure in cattle leads to a decrease in plasma cortisol (Yousef 1979). The longer term decline in cortisol may be an adjustment mechanism that enables the animal to reduce its metabolic heat production. The exact roles of cortisol and the various "stress hormones" such as endorphins, enkephalins and adrenocorticotropin in heat stress need further investigation.

The food intake regulating hormones, most of which have only been discovered in the past 10 years, are almost certainly affected by heat stress. The inanition symptoms seen in heat stressed sheep are largely unexplained, but reflect a range of factors impinging on the hypothalamic drive to eat. Among the hormones known to influence food intake, leptin (produced by adipose tissue) and ghrelin (produced by the stomach) are likely to be influenced by heat stress. Leptin levels depend to a large extent on the body fat mass of animals (Daniel et al 2002). As mentioned earlier the body condition of animals may well influence their ability to tolerate heat stress (Norris and Norman 2002). Ghrelin, secreted by the walls of the stomach stimulates appetite and water intake (Mietlicki *et al* 2008) and may well be influenced by changes in blood flow to the gut that occur during heat stress and dehydration (Hales and Sakurada 1998).

During heat stress in goats, plasma prolactin is dramatically increased (Sergent *et al* 1985). When prolactin secretion was inhibited by bromocryptine, the rectal temperature of male goats was substantially increased (Sergent *et al* 1988). The exact role that prolactin plays in thermoregulation has not been established.

## 3.4.3 Selective brain cooling

Selective brain cooling (SBC) refers to the cooling of the brain tissues below arterial blood temperature (IUPS 2001). As neuronal tissue is well-known to be damaged by overheating, SBC is

believed to provide protection for brain tissue from heat injury, especially during exercise (McKinley *et al* 1983).

It is well known that, when sheep are exposed to ambient temperatures of 45-50° C, respiratory rate increases 5-10 times (Baker and Haywood 1968). These workers also found that the temperature difference between central and cerebral arterial blood (i.e. SBC) increased. There are two mechanisms that enable SBC. One uses the cooler venous blood that drains from the evaporative surfaces external to the cranial cavity, whereas the other uses venous blood to cool the brain directly (Caputa 2004). Sheep, cattle and goats have a well-developed carotid rete, a vascular structure within the cranium in the cavernous sinus located at the base of the skull that facilitates counter-current heat exchange.

The rete is a compact network of intertwined, anastomosing arteries that lies in the path by which the major arteries supply the brain. By injecting latex into the facial venous system of sheep, Baker and Haywood (1968) demonstrated there is a venous pathway from the nasal mucosa to the cavernous sinus that contains the rete; they concluded that venous blood returning to the cavernous sinus from the nasal mucosa and the skin of the head cools the arterial blood in the carotid rete. This cooler blood then cools the brain itself. The upper respiratory cooling effect is considerable. Laburn *et al.* (1988) showed that hypothalamic temperature was 1°C lower than rectal temperature in both normothermic and hyperthermic sheep. However, the temperature difference was not present in sheep breathing via a tracheal fistula and so bypassing the upper respiratory surfaces.

Maloney *et al* (2007) studied the role of the rete by implanting thermometric data loggers in five conscious, unrestrained, sheep at an ambient temperature of 20-22°C. They measured the temperature of arterial blood before entering and after leaving the carotid rete, as well as hypothalamic temperature, every 2 min for up to 12 days. On average, carotid arterial blood and brain temperatures were the same as might be expected in normothermic animals. There was a decrease in blood temperature of 0.35°C across the rete; but a temperature increase of a similar magnitude between that of blood leaving the rete and the brain tissue. In this case, rete cooling of arterial blood was occurring at temperatures below the threshold for selective brain cooling. Retia are not, however, a prerequisite for SBC; other animals, e.g. humans, horses and birds have no carotid rete but also achieve SBC. Humans, for example, achieve brain cooling by perfusing blood draining from the nose and head surfaces through a system of dural sinuses (Caputa 2004).

As well as preventing thermal injury to neuronal tissue, SBC may have additional roles. Maloney *et al* (2001) have hypothesised that 'selective brain cooling serves to modulate thermoregulation, rather than to protect the brain from overheating. Implementation of selective brain cooling reduces hypothalamic temperature and therefore attenuates heat loss effectors'. Similarly, Jessen (2001) notes that, during severe exercise hyperthermia in humans, the venous return from the nasal area bypasses the cavernous sinus so that brain cooling is suppressed. He argues that this is inimicable with the idea that SBC protects the brain from thermal damage. Instead he suggests that SBC could be part of a control system linking thermoregulation and water saving by reducing evaporative heat loss in animals under hot ambient temperatures.

Fuller *et al.* (2007) have taken this idea further, hypothesising that SBC may cool the hypothalamus during hyperthermia, reduce the drive on evaporative heat loss effectors, and thereby saving body water. To investigate whether SBC was in sheep deprived of water, these workers measured brain and carotid arterial blood temperatures in 9 female Dorper sheep at 5-min intervals for 9 days. The animals were housed in a climatic chamber at 23°C and exposed to temperatures of 40°C for 6 h

each day. Drinking water was removed on the third day and returned 5 days later. After 4 days without water, sheep had lost 16% of their body weight.

Carotid blood temperature increased during heat exposure in all sheep but the threshold temperature for onset of SBC (about 39.2°C) did not differ between euhydrated and dehydrated animals. Above the SBC threshold, the mean slope of lines of regression of brain temperature on carotid blood temperature was significantly lower in dehydrated (0.40) than in euhydrated animals (0.87). They concluded that for any given carotid blood temperature, heat exposed sheep when dehydrated exhibit up to 3-fold greater SBC than that when euhydrated.

Our understanding of the roles and importance of SBC is still evolving. Caputa (2004) has concluded 'that SBC integrates both thermal and non-thermal regulatory functions. There is a common mechanism of control of SBC intensity. Reduced sympathetic activity leads to simultaneous dilation of the angular oculi veins, supplying the intracranial heat exchangers, and constriction of the facial veins, supplying the heart. Therefore, SBC is enhanced during heat exposure, endurance exercise, relaxed wakefulness and non-rapid-eye-movement sleep, and vanishes in the cold and during emotional distress. SBC is a multifunctional effector mechanism: it protects the brain from heat damage; it intensifies in dehydrated mammals, thereby saving water; it helps exercising animals delay exhaustion.'

Many of these facets of SBC may be relevant to sheep in the export post-discharge phase. These sheep may be subject to heat exposure, exercise and emotional distress, all of which may invoke the SBC regulatory functions.

## 4 Guidelines for sheep feedlot induction in the Middle East

The recommended guidelines for sheep feedlot induction in the post-discharge phase of livestock export to the Middle East region are presented below. These guidelines are based on current industry and scientific information and reflect "best practice" animal husbandry practices. The guidelines should be reviewed as new research information on strategies for improving animal welfare and husbandry become available.

Category	Criteria
1. Pre-induction activities	<ul> <li>Feedlot pen flooring should be cleaned of all rubbish and excess faceal material removed before every new receival.</li> </ul>
	<ul> <li>Feed troughs and water troughs should be cleaned before every new receival.</li> </ul>
	<ul> <li>Pen infrastructure (shade, water troughs, feed troughs, fencing) should be inspected and necessary repairs undertaken prior to arrival of sheep.</li> </ul>
	<ul> <li>d) The receival area should be inspected and any identified obstacles to the unloading of sheep removed or repairs undertaken.</li> </ul>
	<ul> <li>e) Provision of fresh feed and clean water (as described in Categories 4 and 5)</li> </ul>
2. Facilities	a) Receival facilities should be designed to handle the number of sheep with
	a minimum of stress and injury.
	<ul> <li>Floors of loading ramps, races, yards and pens should have non-slip surfaces.</li> </ul>

	<ul> <li>c) Lighting should be installed to facilitate receival of sheep during the night and should be situated to avoid creating shadows that may disrupt the unleading process.</li> </ul>
	unioading process.
	d) A pen should be located adjacent to the race to allow isolation of sick or
	injured sneep with a minimum of stress (preferably, this activity would be
	undertaken during the unloading process).
	e) Sufficient shade should be provided to enable all animals to be shaded
	concurrently.
	f) All obstructions to ventilation should be removed where possible.
3. Sick or injured	<ul> <li>Every animal should be inspected on arrival at the feedlot and sick or</li> </ul>
sheep	injured animals isolated and allocated to a dedicated pen.
	<ul> <li>b) Isolated sheep should be closely observed for feeding and drinking</li> </ul>
	behaviour and shy feeders identified and isolated for immediate slaughter.
	c) If the condition of the sheep is unlikely to improve, the feedlot veterinarian
	should be contacted for immediate treatment.
	d) If the cause of sickness or injury is not obvious, the feedlot veterinarian
	must be contacted.
4. Provision of	a) Sheep should have access to feed immediately upon arrival at the feedlot.
feed	b) Preferably, the feed should resemble the pellets fed shipboard. Sheep
	should be offered good quality roughage (eg. Rhodes grass hay or
	Lucerne hay) for the first 24 hours and gradually introduced to the grain-
	based ration.
	c) If the feedlot ration exceeds 50% grain content, the recommended period
	of adaptation is a minimum of 7 days.
	d) A minimum allocation of feed is 3% of liveweight. (For example, for a 50 kg
	sheep, this represents 1.5 kg of feed per day.)
	e) Sufficient feed trough spacing should be provided. The recommended
	minimum feed trough spacing is 20 cm per sheep during feedlot induction.
5. Provision of	a) Sheep should have ad libitum access to fresh, clean water on arrival at the
water	feedlot.
	b) Sufficient water trough spacing should be provided. The recommended
	minimum water trough spacing is 1.5 cm per sheep.
	c) There should be sufficient backup storage or a contingency plan to ensure
	continuity of supply at peak demand for two (2) days.
	d) Water troughs should be kept clean.
6. Stocking	a) The recommended minimum space requirement for sheep is 0.5 m <sup>2</sup> per
density	sheep.
	b) During the summer months it is recommended that sheep are provided
	with more space than the recommended minimum to assist in reducing the
	risk of heat stress.

# 5 Recommendations for further RD&E

Based on consultation with industry stakeholders and review of the related literature, the following initiatives are recommended:

## **Research and Development**

- Development of recommendations for drinking water temperature for intensively housed sheep and cattle in the Middle East region. There are currently no recommendations for sheep and this report indicates that current recommendations for cattle need to be reviewed.
- Development of recommendations for feeding management strategies of intensively housed sheep in hot conditions.

## Extension and Education

- The recommended induction practices (Section 5 of this report) should be added to the *Feedlot Management Training Pack, Middle East* for inclusion in the in-market MLA Education and Training Program for Middle East and Africa regions.
- Shade design information from Meat and Livestock Australia (and provided in Appendix 1 of this report) should be added to the *Feedlot Management Training Pack, Middle East* for inclusion in the in-market MLA Education and Training Program for Middle East and Africa regions.
- Training of port and feedlot staff in the Middle East on heat stress management practices should be a component of the in-market Animal Welfare and Education and Training projects for MLA's Middle East and Africa program.

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# 7 Appendices

## 7.1 Appendix 1 Feedlot shade structures





Figure 2: Feedlot iron sheet shade structure Photo courtesy of Sandalwood Feedlot, Dalby, Queensland

tensioned cables are involved, and the fixing details for the corrugated iron sheeting.

#### Sizing of shade structures

A relationship between shaded area, stocking density, and cattle performance has not been defined in the available literature. However, general recommendations have been made by some researchers.

The minimum requirement is that the shade structures must create a shadow on the ground of sufficient size to cover all animals. Guidelines relating to the ideal amount of shade that should be provided vary. Recommendations derived from US dairy research suggest that cattle should be provided with anywhere from 1.9 to 6.0m<sup>2</sup> of shade per head.

The size of the shadow is most affected by the angle (or slope) of the shade material. The height of the structure does not change the size of the shadow, but does affect the rate at which the shadow moves across the ground. Higher shade structures also provide more cool air for cattle and studies have shown that cattle show a preference for higher shade structures. However, higher structures typically cost more to construct as they are subject to greater wind loads.

#### Positioning of shade structures

It is important to locate shade structures so that their shadow covers an area of the ground that is easily accessible by the animals. This is the primary reason that shade structures are typically erected towards the centre of feedlot pens. This ensures that cattle are able to occupy the shaded area as it moves across the pen during the day.

The orientation of shade structures will also affect their performance. Structures orientated with the long axis in a north-south direction have the advantage of providing dryer pen surfaces as the shadow provided by the shade moves over a greater area than that of structures orientated eastwest. Shade structures constructed with an east-west orientation require openings between the sheeting, to allow the shaded area to move during the day.

Allowing the shaded area to move within the pen throughout the day has a number of advantages including:

- + improved drying of the pen surface
- breaking up of social groupings within the pens to reduce dominance

Determining the ideal orientation also requires consideration of the prevailing winds, which should be utilised to assist in ventilation and cooling.

#### Shade materials

At present a wide range of materials are used in the construction of shade structures. The most common materials used in Australian feedlots are galvanised sheeting or shadeoloth, due to availability and relatively low

#### Practical design issues for feedlot shade structures

(Comments from Industry shade system survey)

- Shadeoloth is not the preferred roofing material as the stitching can deteriorate, requiring replacement of the oloth or stitching every three to five years. New technologies are now offering life spans of up to 10 years.
- Shadecloth can be affected by hail damage, bird chewing or pen cleaning machinery exhaust pipes that can burn holes in the cloth. Cloth must be placed well above machinery.
- Corrugated iron sheets on some shade structures were still considered to be in the same condition as when erected, five years later. Ammonia levels increase with manure moisture content. As ammonia is a corrosive agent, particularly in humid climates, this may also reduce the life of corrugated iron in wet humid climates.
- Galvanized iron sheets can be very dangerous if they work loose in high winds or a storm. Some stock have been killed by flying sheet metal.
- Designs have incorporated concrete pillars to protect the base of the main steel posts from corrosion caused by manure on the pen floor.
- Maintenance of pen floors under shade can be problematic. Shaded areas do not dry as well as unshaded areas, which can contribute to greater wear on the pen surface and increased maintenance costs, aside from problems such as holes being formed, which can trap water and become odourous.
- If shadecloths are removed and stored during the winter mice can damage the stored material.
- An ideal shade structure would have no posts in the pens, would be durable, cheap, and able to be taken down easily and folded for storage in winter.

cost. The effectiveness of shade structures is highly dependent on the type of material used.

Any material that intercepts direct solar radiation will heat up. If the lower side of the shade material becomes hot it will then radiate heat to the air and the animals below. An advantage can be gained by having shade structures that are reflective on the top surface, absorptive on the bottom surface, and allow free airflow.

In dairies it has been suggested that the most effective shade roof is an aluminium or white coloured galvanised metal roof that is fitted with insulation directly beneath the roofing to reduce the radiation heat load. Figure 3 below shows the radiation energy balance for an artificial shade structure.



Figure 3: Radiation energy balance of a horizontal shade structure (adapted from Owen, 1994 and Esmay, 1978)

#### Ventilation

Air movement is an important factor in the relief of heat stress in cattle. The design of shade structures should ensure that ventilation is not restricted. Natural air movement under a shade structure is affected by its size (height and width), the slope of the roof and the ease with which air can move through the structure. Shadecloth has the advantage of allowing air to pass directly through the material, whilst structures constructed from galvanised sheeting require openings to assist air movement.

The heating of shade material by incoming solar radiation causes the air immediately beneath the shade material to become considerably hotter than the surrounding air, and therefore it rises. This 'buoyancy' can be used to passively create air movement beneath shade structures by allowing hot air to slide upwards on the inside of a sloping roof. As this air moves upward, it draws air in from the side of the structure. Rate of upward movement is related to the slope of the roof, buoyancy of the air, and roughness of the material. It is generally recommended that slopes of three horizontal to one vertical be used. This equates to a slope of 18°. It is known that for larger roof structures, slopes of 10–15° will utilise this phenomenon to similar effect. It is important to note that shade slopes over 15–20° may have a net negative effect on shaded areas.

#### Height

Meat & Livestock Australia (MLA) funded research projects have proven that many existing shade structures restrict air

movement beneath the structure. Most existing structures are about four metres high. These effects can be profound. To combat the restricted ventilation the structures should be higher and the stock more spaced out to allow air movement in and around the cattle. While increasing the height of the structure will improve ventilation, it will also result in increased wind loads.

#### Management of shaded areas

The use of shades will result in a moist area beneath the shade due to the deposition of urine and faeces. This area, if not well managed to limit manure accumulation and moisture build up, may result in increased humidity and elevated ammonia levels within the pen and beneath the shade.

Repair and maintenance of the pen surface will also be high in this area. It is strongly recommended that areas beneath shade structures be regularly cleaned of wet manure to limit odour production and ammonia emissions. Increasing the height of a proposed shade structure will provide both a greater exposure of the pen to drying by morning to midday sun, and a greater movement of shade which will act to limit the occurrence of shade related wet pen conditions.

#### **Key tips**

- The provision of shade should be considered for susceptible cattle being housed in feedlots located in areas prone to high temperatures and radiation loads.
- In dry arid areas, shades should be placed on a north-south axis.
- In hot humid areas, shades should be placed on an east-west axis.
- Shades should be constructed to maximise ventilation, afternoon shade and a cool aspect.
- Manage shaded pen areas to limit potential increases in repairs, maintenance and environmental problems.
- Seek engineering advice on the design of the shade structure.

# Structural design of shade systems

#### Wind loads

The movement of wind against a solid structure results in directional loads on the structure. If wind is moving against a wall it causes a **static side load**. As wind moves up and over a roof structure it causes a **download** on the front face of the roof and an **upload** on the downwind face as a result of an induced area of low pressure over the inclined surface. These forces must be taken into account when designing a shade structure, especially if the shade itself is sloped to obtain advantages in shading and ventilation. A sloping shade structure will act either as a wing or as an aerofoil depending upon the direction of the wind. These forces are shown in figure 4.



Figure 4: Static direction loads for wind

#### Dead loads

A 'dead load' is the load supported by a structure and is equivalent to the mass of the materials held by the structure. The load is applied vertically downward due to gravitational force. This means that the load is passed either vertically downward through a support column or is restrained from movement downward by horizontal forces through systems such as tension cables. This is shown in figure 5. The dead load of galvanised sheeting is greater than that of shadecloth. Consequently, the support structures holding up galvanised iron shading need to be more substantial.



Figure 5: Tension cables

#### **Dynamic loading**

A dynamic load is a load that varies in character. It typically results from movement of a structural component or other variable or oscillating force. Wind gusts cause dynamic loading of structures. In the case of shade structures, wind driven movement of the shade will cause dynamic loading through swinging of the structure or alternating uplift or down draft loads.

The ability of the structure to shed load and dampen out oscillations becomes important when taking account of dynamic loads. The weight of the moving section is also of critical importance as the energy contained in movement of the part is the squared function of its mass and velocity. Consequently, a heavy moving structure becomes difficult to constrain.

#### The ideal design

By drawing on the theoretical outcomes of research and practical experience, a new generation of shade structures



Figure 6: Conceptual shade design

can be formulated. A conceptual design is presented in figures 6 and 7.

The design is based on a feedlot with pens 60m deep and 63m wide, containing 250 bullocks at a stocking density of about 15m<sup>2</sup>/head.

The shade is located as a strip that runs across the feedlot pens in a north-south direction. The shade is pitched with the 'eave' towards the west. The upper side of the material is white and the bottom side is matt black. It is assumed that the material is a heavy-duty shadecloth that will allow high winds and rainfall to pass through the material.

Because the shade is on an angle its profile to winds will either make it an aerofoil or wing. Structural design to counter these aerodynamic features becomes important and the pervious nature and lightness of shadecloth provides this material with design efficiencies over coloured galvanised iron. The use of galvanised iron in this type of structure would significantly increase loading rates and thus the size of support structures.

Because the shade material is high and pitched, the shade will move across the pen quickly. Shade providing the largest area per animal is most important late in the afternoon when stock have been accumulating heat for the longest and daytime temperatures are at their greatest. Research has found that the highest daytime temperatures often occur between 2–4pm EST and that typically heat stress occurs in the period between 2–6pm, with cattle often showing most stress in the period between 3–5pm EST.

Some care needs to be taken in the location of the shade structure to ensure that shade is kept within the pen during the afternoon. By 4pm (EST) 20 January the throw of the shade from the  $15^{\circ}$  shade will be 10.75 metres (9.3 metres for  $10^{\circ}$ ), and by 6pm (EST) the throw will be 41.2 metres (36 metres for  $10^{\circ}$ ). This gives reason to place the shade on the western side of the pen.

Conflict with the placement of the water trough needs to be avoided because this is an area where moisture accumulates. It is recommended that in earth-based yards, troughs are located away from shaded areas to limit the build up of wet manure.

Figure 7 shows a simple plan of the position of the shade as described. It is located 15m off the western fence line allowing sufficient room to place a water trough on the dividing fence line whilst providing some distance between the pen gate and the trough, and the trough and shade structure. The throw of the shade at 6pm would result in the shade being cast onto the feed bunk if the pitch of the shade was 15°.



Figure 7: Conceptual shade location within a feedlot pen

# Conceptual shade design specifications

- The western 'eave' is 5m (or higher) off the ground to improve airflow through the side of the shade system.
- The shade is 12m wide, which allows for effective use of materials as most are provided in 6m widths or lengths.
- If the pitch is 15° the top of the shade is 3.1m above the lower eave of the shade. If the slope is 10° the upper edge is 2m higher than the western edge.
- The 12m wide strip of shade will have an 11.6 or 11.8m planar width, given the pitch of 15° or 10° respectively. This equates to a shade cover of 2.92 m<sup>2</sup>/head or 2.97m<sup>2</sup>/head if the sun were immediately overhead.
- In the afternoon an increase in shaded area due to the western pitch will become available to cattle. Based on the position of the sun on 20 January at Toowoomba between 3–4pm the average increase (over the hour) in shaded area is 28.5% (15°) or 18.4% (10°). Therefore the shaded area increases to 3.75m<sup>2</sup>/head or 3.51m<sup>2</sup>/head, respectively.

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#### The bottom line

Shade structures can be used in feedlots to improve cattle comfort and to decrease the risk of reduced productivity due to excessive body heat loads. Shades should be designed to maximise ventilation and afternoon shade. It is recommended that engineering advice be sought in the design and placement of feedlot shade structures.

#### **Further information**

This *Tips & Tools* is part of a series on understanding, recognising and managing heat load in feedlot cattle. For a copy of *Heat load in feedlot cattle* call MLA on 1800 675 717 or email publications@mla.com.au

#### Key contact

Des Rinehart, MLA Ph: 07 3620 5236 Email: drinehart@mla.com.au



Level 1, 165 Walker Street, North Sydney NSW 2060 Ph: +61 2 9463 9333 Fax: +61 2 9463 9393 www.mla.com.au

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## 7.2 Appendix 2 People and organisations consulted

Between April 2007 and June 2008 numerous meetings, workshops and site visits were conducted throughout the Middle East region at ports of discharge, feedlots and abattoirs. While these activities were financed by sources other than the current project, they provided invaluable incountry experience and information, which has contributed to the production of this report.

Country	Affiliation	Primary contact
Oman	Al Batina Livestock Company	Tariq Mahmood Butt
	Ma'alem Barka Trading Company	Ahmed S. Yahmadi
	Arabian Livestock (formerly Buraimi Livestock)	Navid Abodabaker
Qatar	Mawashi Livestock Company	Abdulsalam Ahmad
Kuwait	Livestock Transport and Trading (KLTT)	Ahmed A. Khallaf
Bahrain	Bahrain Livestock Company	Mustapha Mohammed
	Meat and Livestock Australia	Peter Dundon
Israel	Bakar Tnuva, Pituach Shean	Omer Rimshon
	Kibbutz Ein Ha Shofet (Moadon La Chaver)	Eitzik Shafran
	Dabach, Dir El Assad	Fadi Dabach
	Austrade	Eric Goldberg
Jordan	Hijazi and Ghosheh	Hani Hijazi
United Arab	Office of Veterinary Services, Mushrif	Hisham al Fahami
Emirates (UAE)	Municipality abattoir, Al Qusais	Tareq Aziz Saeed
	Livestock Transport and Trading (KLTT)	Hesham H. Ghazal
Egypt	Ain Sokhna	Richard Leitch
Australia	Holden Agricultural Services	Boyd Holden