1.0 GENERAL INTRODUCTION

The Australian feedlot industry has sufficient capacity to feed approximately 870 000 head (ALFA Lotfeeding 1997) and contributes approximately 25% of total beef production in Australia. The industry is composed of feedlots incorporated into vertically integrated companies, custom feedlots, pastoral operations and opportunity feedlots. Custom feedlots feed and market cattle for other owners, the pastoral operations value add and retain control over breeding programmes and opportunity feedlots feed cattle on a opportunistic basis when market conditions, eg. feed costs, cattle costs and selling price, are economically beneficial.

The objective of feeding grain to cattle under intensive conditions is to provide meat products that consistently meet specific market specifications throughout the year. The major market for grain fed beef is Japan (see Table 1.1 for Australian grain fed market destinations, September 1997)

Table 1.1: Grain fed beef market destinations, September 1997 (ALFA Lotfeeding 1997)

Market	destination of grain fed cattle (%)
Japan	59.9
Korea	1.3
other export	0.9
Domestic	35.8
Unknown	2.1

Each market has its own carcass composition specifications and the feedlot designates particular live animal characteristics which best enable it to successfully meet the requirements. Feedlots feeding for the Japanese market generally require British bred cattle, in particular Angus, Murry Grey and their crosses. These breeds are preferred due to their higher marbling ability. These animals are on feed from 150 to 300 days. Cattle fed for the domestic market, ie. supermarkets and local butcher trade are on feed for up to 120 days and are mainly European, *Bos indicus* types and their crosses.

Australia uses a beef carcass grading system based on AUS-MEAT (Australian Uniform Standards for Meat). These standards provide general carcass composition specifications required to meet specific beef markets and are summarised in table 1.2. Assessment of carcass specifications are based on both objective and subjective measurements. Dentition, fat depth (P8 site) and hot carcass weight are all measured, marbling score (level of fat deposition within the exposed rib eye, *Longissimus dorsi*), meat and fat colour are all subjectively measured. Level of marbling, meat and fat colour are described by a number system, the higher the number the greater level of marbling and colour. Individual abattoirs use the AUS-MEAT standards, eg. teeth, fat depth (P8 site) and hot carcass weight, to form a price grid to determine payment on each carcass (see table 1.3 for an example of a price grid for short fed market)

Table 1.2: AUS-MEAT carcass specifications and example of feedlot live animal specifications

Market	Domestic	Korean	Japan-Grainfed
Carcass Specifications			
Sex	all	steer/heifer	steer/ox
Dentition	all	all	4 teeth max
Fat (P8)	6-18	8-20mm	15-32mm
Hot carcass wght (kg)	200-300	180-280	280-380kg
Marbling	nill requ	-	score 2 min
Meat colour	1,2,3	-	1,2,3
Fat colour	1,2,3	-	1,2
Eye muscle area	no limit	-	56 sq cm
Live Animal Specifications			
Age (yrs)	<6	< 6	1.5-2
Weight (kg)	260-320	350-400	380-520
Feeding period (days)	70-90	100	150-300

Table 1.3: Price grid standard for short fed market

	Fat depth (P8) max mm			
Hot carcass weight max kg	6	29	35	> 35
279	-0.35 $/kg	-0.35	-0.35	-0.35
299	-0.35	-0.05	-0.10	-0.15
400	-0.35	0	-0.05	-0.10
460	-0.35	-0.35	-0.35	-0.35
> 460	-0.35	-0.35	-0.35	-0.35

Problems and constraints facing the industry are price fluctuations for purchase of feed and cattle, variation in quality of feed and cattle, retaining and increasing export market share, minimising incidence of meat residues, identification of animals that consistently perform and environmental issues concerning effluent, manure, dust and odour control.

The two most significant costs to the feedlot industry are associated with the purchase of cattle and feed. In general, these costs tend to offset one another, eg. during good seasons cattle prices increase as graziers hold on to cattle and feed costs decrease, during dry seasons, graziers offload cattle depressing price, however feed costs increase. Feedlots attempt to offset price fluctuations by forward contracting and developing relationships with growers and breeders. Feeding costs can further be reduced by incorporating byproducts of other industries into rations, eg. molasses, cotton byproducts, straw, citrus pulp and supplementing requirements with feed grown by the feedlot, eg. hay and silage.

Another factor significantly contributing to feedlot cost is cost of weight gain. Factors which influence cost of weight gain include, feed conversion efficiency, variation in pen performance and health status. The manner in which cattle are fed, ie bunk management, has a significant impact on cost of gain (Pritchard 1993). Feed bunk management monitors animal response to diet quality, quantity and time of feed delivery (Doyle 1996). The objective of bunk management is to provide sufficient quantity of feed to achieve a desired level of production and health (Doyle 1996).

Several bunk management strategies are used in the feedlot industry including *ad lib*, frequent feeding, restricted feeding and clean bunk management strategies. A*d libitum* feeding has been the preferred method of feeding cattle. Feeding *ad libitum* is designed to maximise feed intake by providing a continuous supply of feed to cattle throughout the day and allowing every animal in the pen adequate opportunity to feed. However, associated with this feeding method is the tendency of animals to exhibit large fluctuations in feed intake (Slyter 1976), predisposing animals to the risk of digestive disorders (Slyter 1976) and depressed performance (Huber 1976 ; Wiryawan and Booker 1995 ; Foster and Woods 1970 ; Montgomery 1985 ; Brink et al 1990), thereby significantly contributing to cost of production and cost of gain (Hicks et al 1990a).

In an attempt to reduce feed intake variation and associated depression of performance, other bunk management strategies were developed. Increasing feeding frequency is a strategy used to stimulate intake (Gibson 1981) and stabilise rumen fermentation (Goetsch and Galyean 1983) however, associated with this strategy are high labour and machinery costs (Goetsch and Galyean 1983). Restricted feeding strategies were developed to improve feed utilisation and reduce costs associated with faecal output, feed mixing and transport and feed wastage (Loerch 1990 ; Eng 1995 ; Hicks et al 1990a). However, restricted feeding strategies require precise bunk management to avoid interruptions in feed delivery, feeding errors and variation in diet specifications. A clean bunk management feeding strategy is not designed to restrict intake. It is designed to encourage animals to clean the bunk of feed at least once per day and yet provide sufficient feed to satisfy animals level of satiety over a 24 hour period by using a range of indicators (Doyle 1996). These indicators include the quantity of feed remaining in the bunk and animal response to morning feed delivery. A clean bunk management strategy aims to optimise feed intake by providing appropriate quantities of fresh feed that is synchronised with the animals natural feeding activity period (Doyle 1994).

The objective of the experimental work described in this thesis was to compare a range of bunk management strategies, in terms of feeding costs, health and performance during the summer period under commercial conditions in a large feedlot.

2.0 REVIEW OF LITERATURE

2.1 Scope of Review

The manner in which feedlot cattle are fed, ie. bunk management, has a significant impact on cost of production (Pritchard 1993). The success of bunk management is related to the ability of the operator to integrate all factors which affect feed intake including animal health, animal behaviour and environmental conditions, to achieve market goals and minimise cost.

The purpose of this review is to detail the knowledge of digestive physiology and digestive disorders related to feeding grain based diets. It also considers the environmental effects on animal production and the social and feeding behaviour related to feedlot production. The final section of the review introduces the concept of bunk management and the importance of integrating health, behaviour and environmental aspects into a successful bunk management strategy.

2.2 DIGESTION IN THE RUMINANT

2.2.1 The Digestive Tract

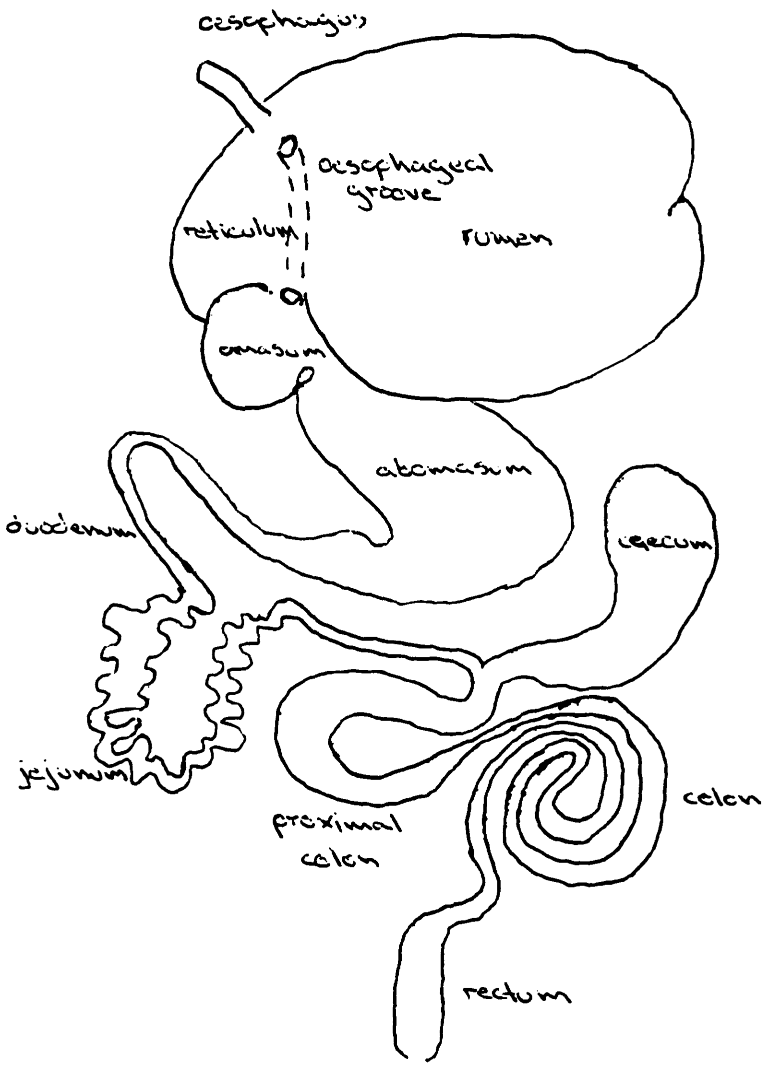
The digestive tract of the ruminant is characterised by the large reticulo-rumen, containing an immense anaerobic microbial population responsible for extensive pre-gastric fermentation. Major organs involved in digestion include the rumen, abomasum and small intestines. Absorption occurs in the rumen, small intestines and large intestines. A basic diagram of the ruminant digestive system is provided in Figure 2.1.

Digestion in the ruminant, as with other animals, begins in the mouth. Consumed feed undergoes mechanical breakdown and chemical digestion by chewing and mixing with saliva. The process of chewing reduces particle size and increases surface area exposed to salivary enzymes, eg. alpha amylase and lysozyme responsible for digestion of starch, glycogen and related poly- and oligo-saccharides. Saliva plays an important role in swallowing, provides nutrient recycling, eg. urea and buffers for the rumen environment to protect against changes in rumen pH. Production of saliva depends on the physical characteristics of the diet (Huck et al 1997). Table 2.1 shows the effect of feed characteristics on saliva production.

Table 2.1: Feed type and effect on saliva production rates (McDonald et al 1988)

	Salivary Production	
Diet	g/g of food	ml/min
Pellets / Grain	0.68	243
Silage	1.13	280
Hay	3.63	254

Figure 2.1: The ruminant digestive system (Webster 1987)



The rumen is the largest organ of the ruminant digestive tract. It is composed of two parts, the reticulum, involved in rumen motility, and the rumen, involved in pre-gastric fermentation. Ruminal microbes possess enzymes capable of carbohydrate digestion. The major end products of carbohydrate fermentation by rumen microbes are volatile fatty acids (VFA) and microbial cells. The major VFAs include acetic, propionic and butyric acid and to a lesser extent isobutyric, isovaleric and valeric acid. Acetic acid and propionic acid are derived from the fermentation of structural and storage carbohydrates respectively (Bath and Head 1961). Butyric acid can also be derived from non carbohydrate fermentation, ie. amino acids and protein (Balch and Rowland 1957) and isobutyric and isovaleric acids are derived from the fermentation of branched chain amino acids (Hegarty 1989). Adenosine trinucleotide phosphate (ATP) is produced during VFA production and is used by rumen microbes for maintenance and growth.

VFAs are absorbed across the rumen wall and metabolised to various extents in the rumen epithelium. Acetic acid metabolism in the rumen epithelium is limited. It is utilised by the animal for ATP production and fat synthesis. Propronic acid is partially metabolised in the rumen epithelium to lactate, the remainder is converted to glucose in the liver. Butyric acid is extensively metabolised within the rumen epithelium to ketone bodies. These are used in lipid synthesis, as an energy source and for ATP production via the citric acid cycle.

When fermentation rate is stable the rumen provides an ideal environment for microoganisms. It is essentially an anaerobic environment with a stable pH, consistent temperature and relatively continuous food supply. Mixing ensures continuous contact between microbes and digesta and microbial growth is maintained by absorption of waste products across the rumen epithelium and passage down the gastro intestinal tract (GIT).

Motility of the reticulo-rumen plays a vital role in maintaining efficient fermentation and particle size reduction. The main types of motility involved in particle size reduction are mixing and rumination. Eructation involves motility concerned with the removal of ruminal gas. Mixing ensures contact between rumen microbes and digesta and separates digesta by particle size and density (Evans et al 1973). Particles of small size and high density concentrate in the omasal orifice region (Welch 1982) and thereby leave the rumen more quickly (Kaske et al 1992) than large low density particles which remain in the rumen for further degradation. Rumination involves re-gurgitation, re-mastication, mixing with saliva and swallowing. The re-gurgitated bolus is chewed resulting in extensive maceration and mixing with saliva and an increase in the surface area exposed to microbial attack. Salivation that occurs during rumination hydrates feed particles of the bolus and increases particle density (Welch 1982 ; Welch 1986). It is the combined action of rumen microbial activity and rumination that reduces particle size and alters density (Welch 1982). These patterns of motility ensure microbial access to rumen digesta and feed particle size reduction, thereby maintaining supply of nutrients to the GIT.

The omasum links the reticulo-rumen with the abomasum. The surface of the omasum consists of a large number of laminae. Each lamina has many small papillae which are arranged to promote flow towards the abomasum. The omasum acts as a filter ensuring particles greater than 3-4mm remain within the omasum. The primary function of the omasum is to absorb water, VFAs, ammonia, potassium, sodium and hydrogen bicarbonate ions. The absorption of these reduce the buffering capacity of the digesta to enable more efficient gastric digestion.

The abomasum is concerned with gastric digestion. The secretion of gastric juice is relatively continuous due to the steady flow of ingesta into the abomasum. Gastric juice is composed of pepsin, acid and lysozyme. Pepsin and lysozyme act together in the digestion of microbial cells and increase the digestive rate of dietary and microbial protein. Rapid digestion is important due to the relatively short period in which digesta remains in the abomasum.

The small intestine is concerned with the digestion of starch, protein and lipids and the absorption of amino acids, glucose and lipid. Digesta entering the small intestine is initially neutralised by biliary and pancreatic secretions. Starch is hydrolysed by a range of enzymes secreted by the pancreas and intestinal mucosa, eg. alpha amylase, maltase and isomaltase. Small intestinal enzymes responsible for hydrolysis of starch appear to have low activity and are secreted in limited quantities (Nocek and Tamminga 1991 ; Owens et al 1986 ; Huntington 1997). The apparent low activity and level of secretion of these enzymes is possibly a function of the limited amounts of starch that reach the small intestine of animals consuming forage based diets. The majority of starch is hydrolysed in the rumen (Hill 1961). However, of the starch hydrolysis that occurs in the rumen, amylase associated with the intestinal mucosa is most rapid (Owens et al 1986). Glucose produced at this site is efficiently absorbed due to its close proximity to the surface layers of the intestinal wall (Owens et al 1986).

The ruminant large intestine is spiral and is made up of the colon and caecum. These organs are responsible for absorption of water, minerals and fermentation products (Van Soest 1994). The large intestine is the major site of sodium absorption. Other minerals absorbed include potassium, calcium, phosphorus, cobalt, manganese, magnesium, copper and zinc (Hoover 1978).

2.2.2 Digestion of Forages

Forage based diets consist mainly of structural carbohydrates, eg. cellulose, other non starch polysaccharides (NSP) and lignin. The rate at which structural carbohydrates are fermented in the rumen is considerably slower than storage carbohydrates such as starch. The slower rate of fermentation in conjunction with large particle size and slow rumen digesta turnover rate ensures a majority of fermentation occurs in the rumen, minimising quantities of sugars reaching small and large intestines.

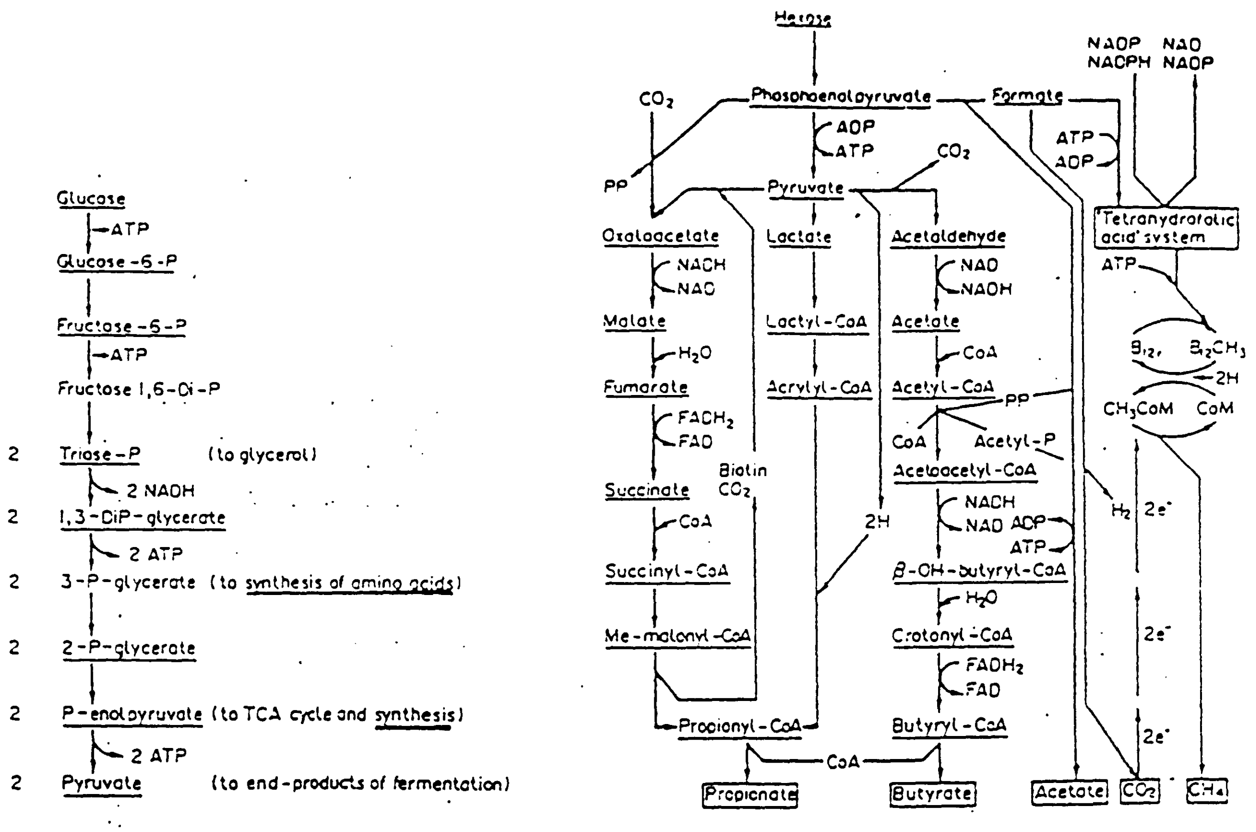
The rumen microbial population of forage based diets is dominated by cellulytic bacteria possessing enzymes necessary to digest structural carbohydrates, ie. cellulose and NSP. The VFAs produced from the fermentation of these carbohydrates, mainly acetic, propronic and butyric acids, are weak acids and minimise disruption to rumen pH, ie rumen pH > 6.5. The stability of rumen pH is further maintained by the larger rumen pH is further maintained by the larger particle size, ie > 4mm, characteristic of forage based diets. The large particle size significantly contributes to rumination activity (Chandler 1997) by stimulating mechanical and tension receptors located in the wall of the reticulo-rumen (Leek 1987). Coarse feed material coming into direct contact with rumen epithelium provides strong stimulus for rumination and saliva production (Huck et al 1997). Saliva contains bicarbonate ions which provide a buffer against potential changes in rumen pH. The slower rate of fermentation and production of VFAs, in conjunction with slow rumen digesta turnover rate and rumination activity provides a stable and therefore controlled rumen environment.

2.2.3 Digestion of Cereal Grains

Diets containing high levels of cereal grain are not natural feeds for ruminants. The feeding of such diets changes rumen microbial population, fermentation rate, digesta flow rate, rumen motility and sites of digestion and absorption.

Feeding high levels of cereal grain initiates changes in the rumen microbial population as a result of increased supply of starch and rapid fermentation. These changes alter the rumen microbial population and the production of VFAs . Fermentation of storage carbohydrates, referred to as readily fermentable carbohydrates (RFC), results in net hydrogen production, forcing fermentation pathways towards pathways that are net users of hydrogen, ie. propionic and lactic acid production (Baldwin 1964). Figure 2.2 illustrates the major pathways of carbohydrate fermentation in the rumen. The rumen microbial population is transformed from fibre fermentors, ie cellulytic bacteria, to starch fermentors, ie. amylolytic bacteria (Mackenzie 1967).

Figure 2.2. Carbohydrate fermentation pathways of rumen microbes (Baldwin 1964)



Feeding cereal based diets limits the buffering capacity of the rumen by reducing rumen motility due to small particle size (Leedle 1993). The diet's small particle size does not provide sufficient stimulation for mechanical and tension receptors in the reticulo-rumen (Howie 1997). A reduction in rumination activity reduces saliva production and in turn reduces buffering capacity of the rumen. Maintaining rumination activity and saliva production plays an important role in buffering the rumen against production of large amounts of organic acids associated with the fermentation of RFC. Cereal grain based diets include a roughage to provide tactile stimulation and increased rumination activity.

Digestion and absorption sites are also altered when feeding cereal based diets due to small particle size and rapid rumen turnover rates (Branine 1996). The small intestine's absorption ability has the capacity to adapt to increased supply of dietary starch (Huntington 1997) and does not appear to be limited (Owens et al 1986b ; Huntington 1997). However, utilisation of glucose by the gut wall limits available glucose for absorption (Owens et al 1986a ; Theurer et al 1987).

The ruminant large intestine's fermentation potential is also stimulated when feeding cereal based diets. Rapid digesta passage rate increases presentation of starch to the large intestine (Hoover 1978). Microbes of the large intestine rapidly respond to increases in supply of carbohydrates by increasing numbers and VFA production (Hoover 1978). Owens et al (1986b) reported 33 to 62% of starch leaving the rumen is fermented in the large intestine. Orskov (1986) suggested that increasing digestion post ruminally, through intestinal absorption of glucose, avoids energy losses associated with methane and heat production which can account for 12-20% of energy loss. The advantages in large intestine fermentation exist with the recovery potential and use of fermentation byproducts. The VFAs produced may serve as an energy source for the active transport of sodium and increase water and urea absorption (Hoover 1978). However increased starch fermentation in the large intestine increases the loss of microbial nitrogen and fermentation products in the faeces (Spicer et al 1986 ; Hoover 1978 ; Van Soest 1994 ; Orskov 1986). The increase in starch fermentation in the large intestines also increases the risk of the animal suffering from diarrhoea as pH is reduced and osmotic pressure increases (Hoover 1978).

The ability to maintain fermentation stability relies on rumination and thereby saliva production (Hibbard et al 1995). However, rapid rates of fermentation, poor tactile stimulation (Howie 1997) and low cation exchange capacity of cereal based diets reduce buffering potential (Garret et al 1961 ; Chandler 1997) and can reduce rumination activity and saliva production (Leedle 1993). These factors increase the risk of digestive disorders and consequently depression in performance (Koers et al 1976 ; Ahrens 1967). The health of the rumen depends on maintaining an equilibrium between production and utilisation of fermentation products. The potential of RFC to initiate rumen imbalances, digestive disorders (Koers et al 1976 ; Ahrens 1967) and depressed performance (Huber 1976 ; Wiryawan and Booker 1995 ; Foster and Woods 1970 ; Montgomery 1985 ; Brink et al 1990) is primarily due to the rapid rate at which fermentation products are produced (Mackenzie 1967).

Feedlot cattle are initially fed a series of "starter" diets to allow the rumen microbial population to adapt to RFCs. The adaptation period involves a gradual change from forage to grain. However, even after animals are established on cereal based diets, disruptions to feeding pattern and feed intake variation can induce digestive disorders (Slyter 1976). Feed intake patterns of animals that are allowed free access to cereal based diets are highly variable (Hicks et al 1990a ; Glimp et al 1989 ; Aronen 1992) due to changes in rumen acid load (Slyter 1976). Fluctuating feed intakes reduce energy intake, predispose animals to digestive disorders (Slyter 1976) and thereby depress performance (Huber 1976 ; Wiryawan and Booker 1995 ; Foster and Woods 1970 ; Montgomery 1985 ; Brink et al 1990). Bunk management plays an important role in maintaining a consistent level of feed intake (Doyle 1996 ; Preston 1995 ; Galyean 1996) by using indicators, eg. quantity of feed remaining in the bunk and level of feeding activity, to determine the amount of feed required to meet animals level of satiety (Doyle 1994).

2.2.3.1 Changes in Rumen Environment with Grain Feeding

Rumen pH and modification of rumen microbe population

When RFC are fermented a rapid rate of VFA production results in a initial reduction of rumen pH. VFAs accumulate in the rumen when rate of acid production exceeds the rate of absorption (Owens et al 1998). The depression in rumen pH is a normal occurrence when feeding RFC, however a reduction to less than 5.5 may result in disruption to rumen function (Kaufman et al 1980). Figure 2.3. illustrates changes in VFA production and their effect on rumen pH.

During rapid fermentation of RFCs, rumen pH decreases and free amylase activity increases resulting in accumulation of glucose in the rumen (Slyter 1976 ; Owens et al 1998). The presence of free glucose stimulates growth of lactate producing bacteria, eg. *Streptococcus bovis*, *Lactobacillus spp*, *Butyrivibrio fibrisolvens* and *Lachnospira muiltiparus*. The production of lactate increases ruminal osmolarity, inhibiting VFA absorption and further contributing to depression in rumen pH (Owens et al 1998). As ruminal pH decreases, (< 6.0) the numbers of protozoa, cellulytic and methagenic bacteria diminish, resulting in a modification of rumen microbe population and potential instability. The balance between lactate producers and lactate utilisers determines whether lactate accumulates in the rumen, however lactate utilising bacteria, *Megasphaera elsdenii*, *Veillonella spp* and *Selenomonas ruminantium* are sensitive to low rumen pH and most lactate producing bacteria prefer low rumen pH (Owens et al 1988). During periods of rapid fermentation, lactate producing bacteria dominate (Slyter 1976). High rumen acidity enhances the activity of lactate dehydrogenase and pyruvate hydrogenase, increasing conversion of pyruvate to lactate (Owens et al 1998). Endotoxin releasing coliforms, amino acid decarboxylating (Owens et al 1998) and lipopoly-saccharide producing (Glock and DeGroot 1998) bacteria also proliferate under conditions of low rumen pH. Production of lactic acid and its slow rate of absorption is primarily responsible for increasing ruminal hydrogen ion concentration, pH depression and disruption to rumen function (Owens et al 1998). Figure 2.4. illustrates the sequence of events associated with the induction of ruminal lactic acidosis.

Rumen osmotic pressure

Ruminal osmolality normally ranges from 280 to 300mOsm/L feeding forage based rations, however, with grain based rations osmolarity can reach 515mOsm/L under acidotic conditions (Owens et al 1998). A reduction in rumen pH and accumulation of lactic acid in the rumen (Huber 1976) causes rumen fluid to become hypertonic to blood plasma. Under these conditions water from blood is drawn rapidly inward through the rumen wall (Brent 1976) disturbing electrolyte balance (Brent 1976). A range of receptors throughout the body respond to elevated rumen osmotic pressure. Reticulo-rumen receptors inhibit feed intake, liver receptors inhibit rumen motility and brain receptors inhibit salivation (Owens et al 1998). High ruminal osmotic pressure also inhibits bacterial activity causing ruminal stasis (Owens et al 1998). These factors combined with distension of the abomasum, through inhibition of outflow, restricts removal of fluid and acid from the rumen (Owens et al 1998).

Rumen motility

Rumen stasis initially protects the animal against continued absorption of organic acids (Slyter 1976) and other potential toxins produced under conditions of depressed rumen pH (Dunlop 1972 : Huber 1976 ; Cricklow and Chaplin 1985). However, a reduction in rumen motility reduces saliva production and consequently buffering capacity (Slyter 1976) against increasing concentration of lactic acid in the rumen and increased damage to the rumen epithelium (Owens et al 1998). Rumen stasis is associated with a reduction/cessation in feed intake (Owens et al 1998).

Figure 2.3: Ruminal fermentation products as influenced by pH (Branine 1996)

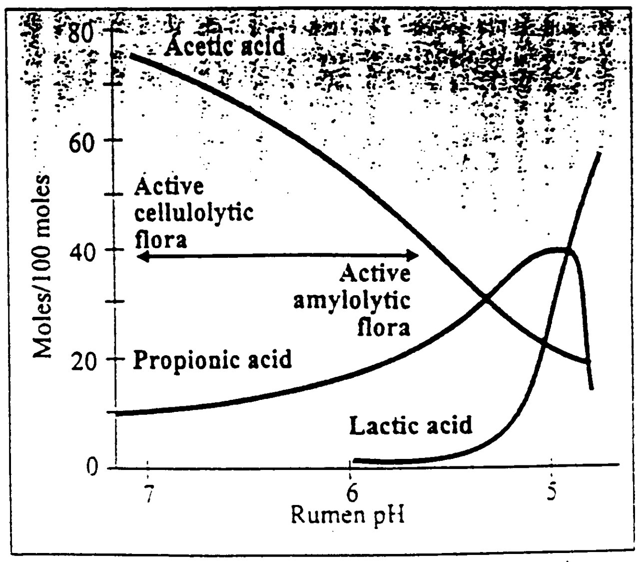
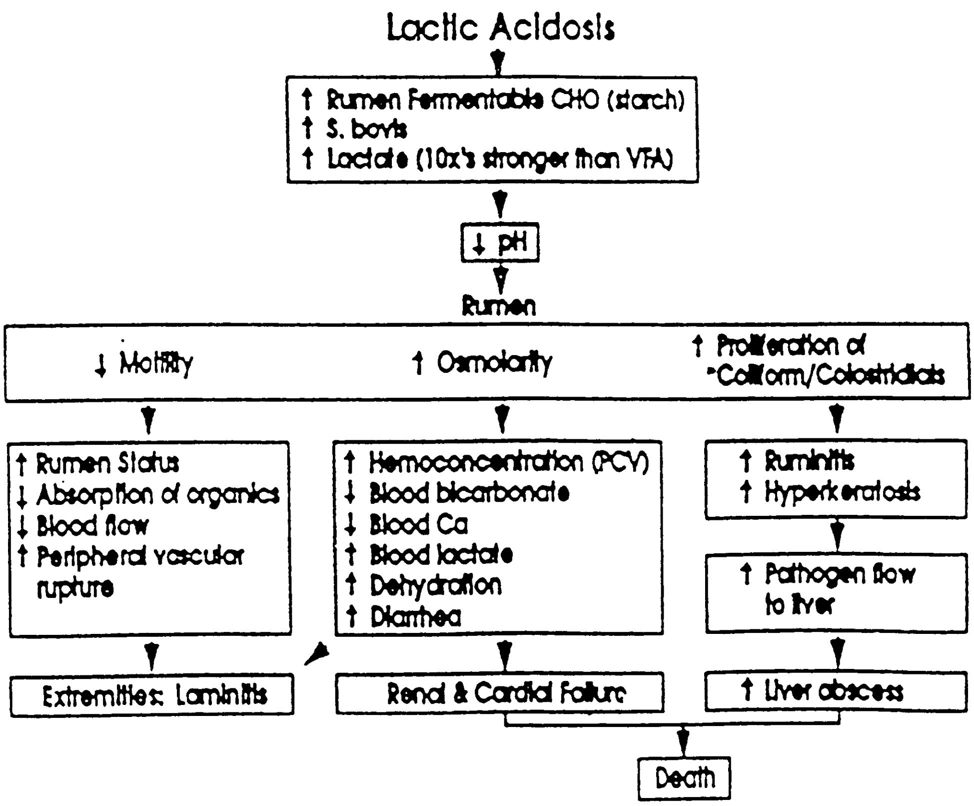


Figure 2.4: Sequence of events associated with induction of ruminal lactic acidosis (Nocek 1996)



2.2.3.2 Acidosis and Physiological Dysfunction

The increased concentration of lactic acid in ruminal fluid causes a series of physiological stresses as the animals regulatory mechanisms attempt to restore stability. Under stable rumen conditions VFAs and lactic acid are absorbed passively across the rumen epithelium. However, at low rumen pH and active rumen motility (Dunlop 1972), VFAs (Leedle 1993) and lactic acid (Mackenzie 1967 ; Dunlop 1972) become undissocitated and are absorbed at a more rapid rate (Owens et al 1998). Rapid absorption increases lactic acid content of the blood (Huber 1976 ; Dunlop 1972) and disturbs blood acid-base balance (Mackenzie 1967). Blood acid-base balance is regulated by the respiratory system via removal of carbon dioxide and increasing the ratio of bicarbonate to carbonic acid (Harmon 1996), muscular activity and kidney function, ie. excretion of acids (Owens et al 1998). High blood lactic acid concentration prevents kidney function from removing adequate acids, thereby placing additional stress on the blood bicarbonate pool (Owens et al 1998).

Reduced availability of bicarbonate ions limits metabolic pathways that utilise lactic acid, eg. conversion of lactate to propionate via succinate in the liver (Dunlop 1972). The livers ability to metabolise lactate may be further overloaded by lactate originating from both tissue metabolism (Godfrey et al 1992) and digestive tract absorption (Owens et al 1998) contributing further to lactic acid content of the blood (Huber 1976).

The respiratory centre is stimulated by increasing levels of carbon dioxide derived from restricted circulation due to dehydration associated with rumen osmolartiy (Dunlop 1972). The respiratory centre attempts to maintain acid-base status by rapid removal of carbon dioxide (Huber 1976). However, as lactic acid level of the blood increases, carbon dioxide level depresses the respiratory centre, decreasing blood pressure and blood pH (Huber 1976). As blood pressure decreases, so does renal blood flow, thereby compromising further the ability of the kidney to compensate the bicarbonate pool and hydrogen ion secretion (Owens et al 1998).

The accumulation of lactic acid in rumen and in blood, reduces blood pressure, compromising acid-base and electrolyte balance (Mackenzie 1967), hydrogen ion secretion and bicarbonate reabsorption (Huber 1976). These factors in conjunction with lactate overload of the liver and kidney can result in hypovolemic shock and death of the animal (Glock and DeGroot 1998). However, in non-fatal cases, factors associated with the development of digestive disorders in ruminants may cause damage to the liver and rumen and thereby depress performance (Owens et al 1998).

The initial sign of animals suffering from acidosis is reflected in changes of feeding pattern. Animals exhibit a reduction in feed intake, fluctuating feed intake patterns and changes in normal feeding behaviour (Stock and Britton 1993). Animals change from meal eaters to nibblers, slowing rate of intake in response to high ruminal acid load (Slyter 1976). Even when feed intake is reduced, ruminal pH can remain low illustrating the inability of the rumen to adjust once acidosis has occurred (Stock and Britton 1993).

Acidosis is diagnosed into one of two categories: acute and subclinical. Acute acidosis (pH<5.0) is diagnosed when the animal exhibits noticeable signs of illness. Subclinical acidosis (pH<5.5) reduces feed intake and performance, however the animal may not appear ill (Owens et al 1998). Nocek (1996) reported that subclinical acidosis causes greatest economic loss. Edwards (1996) analysed feedlot records and reported of total morbidity 3 to 7% was due to digestive disorders linked to acidosis. Although digestive disorders may only represent a small proportion of total morbidity, expenses associated with medication, labour, treatment, and the cost of reduced performance during and after illness can exceed the financial cost if the animal dies (Smith 1998).

Rumenitis and liver abscess

During periods of ruminal acidosis, increased rumen osmolarity (Owens et al 1998), reduced motility, opportunistic bacteria, endotoxin production (Nagaraja and Chengappa 1998) and prolonged exposure to acidic ruminal contents (Brent 1976) damages the rumen epithelium (Elam 1976 ; Brent 1976 ; Owens et al 1998). The rumen epithelium is also damaged by prolonged exposure to low rumen pH (Brent 1976), foreign objects in feed (Nagaraja and Chengappa 1998 ; Brent 1976) and bacteria (Dirksen 1970). These damaged sites develop into abscesses, a condition known as rumenitis. Rumenitis provides access of ruminal microbes into the blood stream (Owens et al 1998 ; Nagaraja 1993a ; Dirksen 1970). Nagaraja and Chengappa (1998) reported that rumenitis caused by acidosis is a predisposing factor for liver abscesses. Liver abscess is part of a disease complex known as rumentitis-liver abscess (Nagaraja 1993a).

Bacteria responsible for rumentitis-liver abscess are primarily _Fusobacterium necrophorum_ and secondarily _Actinomyces pyogenes_ (Lechtenberg et al 1988 ; Nagaraja and Chengappa 1998). These bacteria are normal inhabitants of the ruminal micro-flora (Lechtenberg et al 1988 ; Nagaraja 1993b). However, under acidotic conditions the number of _F. necrophorum_ increase dramatically as lactic acid is its major energy substrate (Nagaraja and Chengappa 1998). Rumenitis allows invasion and colonisation of _F. necrophorum_ within the rumen wall (Nagaraja 1993b). After colonisation, _F. necrophorum_ enters the blood stream and subsequently the portal circulation, passing to the liver and leading to infection and abscess formation (Nagaraja and Chengappa 1998). Contributing to _F. necrophorum's_ virulent nature is its production of toxins, eg. leukotoxin and endotoxic lippopoly-saccharide, that participate in the penetration and colonisation of the ruminal epithelium and subsequent entry and establishment of infection in the liver (Nagaraja and Chengappa 1998 ; Nagaraja 1993b). Liver abscesses are composed of degenerating hepotocytes and leucocytes which initially form lesions and gradually change from a liquid to encapsulated abscess (Nagaraja and Chengappa 1998).

The development of abscessed liver has direct effects on cattle performance and carcass quality (Nagaraja and Chengappa 1998) especially in grain fed cattle where frequency of liver abscess is highest (Lechtenberg et al 1988). Incidence of liver abscess in grain fed animals in the US averages 12-32% (Nagaraja and Chengappa 1998) and in Australia 1-3% (Elanco 1996). Damage to the epithelium layer caused by rumenitis reduces absorptive ability of the rumen (Stock and Britton 1993 ; Owens et al 1998) and thereby compromises potential performance. Foster and Woods (1970), Montgomery (1985), Brink et al (1990) and Nagaraja and Chengappa (1998) all reported that abscessed livers results in reduced gain, poor feed conversion and low dressing percentage.

Laminitis

Nutritional laminitis is initially derived from the effects of pH reduction in the rumen and blood causing damage to rumen epithelium, liver and GIT, consequently resulting in vascular destruction (Nocek 1996). The definition of laminitis is an aseptic inflammation of the dermal layers inside the foot (Nocek 1996). Laminitis or founder was initially thought to occur as a result of high levels of histamine production (Dirksen 1970 ; Slyter 1976 ; Huber 1976). Histamine and endotoxins are released by bacteria within the gut and add further to increased vascular constriction and dilation (Nocek 1996). It is thought that arterial-venous (AV) shunts are produced in the foot due to vascular changes (Nocek 1996) and that these AV shunts increase blood pressure resulting in seepage through vessel walls which are eventually damaged, limiting nutrients and oxygen reaching epidermal cells. More recent evidence in horses suggests that there is direct damage to the basement membrane and that this causes the separation of the hoof from the pedal bone (Pollitt 1996). Eventually, nutrients can not access epidermal cells and the epidermal layers breakdown and separation of tissue layers occur (Nocek 1996). Nocek (1996) reported lameness derived from subclinical acidosis ranged from 5.5 to 30%, and of the total types of foot lesions observed in grain fed animals, 62% were derived from laminitis. The cost of hoof disorders is estimated at between $150 - 300 per treated case (Seymour 1998). Animals with founder become tender footed, consequently reducing free movement of the animal. This condition can be exacerbated by wet and boggy pen conditions (Hoffman and Self 1970).

PEM (Polioencepahalomalacia)

An acidotic rumen provides conditions conducive to the production of thiaminase. There are two thiaminase enzymes responsible for the onset of PEM, a condition that affects the nervous system by inhibiting phosphyalation reactions and ion transport in nerve tissue (Brent 1976). Thiaminase II reduces thiamine level in the rumen and thiaminase I creates thiamine analogs capable of acting as thiamine antimetabolites (Brent 1976). Bacteria that proliferate at low rumen pH, such as *Clotstridium sporogenes* in association with high concentrations of histamine (Slyter 1976 ; Brent 1976) add to the condition. Thiamine is essential for pathways of energy utilisation by the brain and its deficiency leads to brain damage and death. Animals suffering from PEM are unsteady on their feed and very lethargic. The reduction in thiamine adds further to lactic acid accumulation in the rumen by inhibiting pyruvate oxidation (Brent 1976 ; Mackenzie 1967).

Bloat

Bloat results from excessive gas retention in the rumen. As gas accumulates, the expanding rumen exerts pressure on the diaphragm and lungs, thereby impairing respiration and ultimately causing death (Cheng et al 1998). Ruminal gas is removed from the rumen via eructation. Eructation requires a complex series of muscular contractions, initiated by the presence of free gas in the dorsal sac of the rumen, which forces gas through the cardia and released via the oesophagus (Leek 1987). Ruminal conditions associated with acidosis inhibit rumen motility (Huber 1976) and consequently increase ruminal gas retention (Cheng et al 1998). Movement of ruminal gas is further reduced by the presence of ruminal foam (Cheng et al 1998), stabilised by cell lysis (Dirksen 1970 ; Glock and DeGroot 1998) and the release of foam stabilisers, eg. mucopolysacchardes. The majority of feedlot bloat cases are caused by frothy bloat (Cheng et al 1998). The mortality from bloat ranges from 0.1 - 0.2%, however financial loss incurred from culling, treatment and lost production often exceed cost of mortality (Cheng et al 1998).

2.2.4 Grain Feeding and Production

The objective of feeding grain to cattle is to optimise intake of a highly digestible feed and thereby improve performance, however a fine line exists between maximising production and maintaining animal health (Nocek 1996). Digestive disorders have a detrimental effect on animal performance. An acidotic rumen causes fluctuations in feed intake, may result in lameness (Nocek 1996) and an animal may take several weeks to recover from dehydration associated with changes in rumen osmolarity (Huber 1976). Reductions in weight gain (Wiryawan and Booker 1995 ; Nocek 1996) and poor feed conversions as a result of rumen epithelium and liver damage are also associated with an acidotic rumen (Foster and Woods 1970 ; Montgomery 1985 ; Brink et al 1990).

High risk periods for digestive disorders include starting cattle on feed, increasing grain proportion, weather changes, long periods on finishing diets (Stock and Britton 1993) and errors in feed preparation and feeding problems leading to uneven supply (Elam 1976). The risk of digestive disorders during these periods is primarily due to the opportunity of the animal to over consume feed and thereby disrupt rumen environment (Owens et al 1998). Large fluctuations in feed intake increase the risk of digestive disorders. Feeding strategies (Bunk Management) are aimed at regulating feed intake and rumen fermentation and minimising digestive disorders. It is evident that Bunk Management can have a significant impact on the profitability of the feedlot operation.

2.3 ENVIRONMENTAL EFFECTS ON ANIMAL PRODUCTION

Cattle are homoeothermic and exhibit a relatively constant body temperature over a wide variety of environments (Hahn 1989). The ability of cattle to adapt to changes in their environment is centred on the animals ability to make both rapid behavioural and slower metabolic changes (Young 1992) via the animals regulatory systems. The animals regulatory systems detect and interpret environmental challenge and initiate changes to maintain homeostasis (Young et al 1989). Prior to these changes being activated the animal can become stressed, reducing performance and health status (DeDios and Hahn 1994). In Australia, the summer months provide the greatest environmental challenge to feedlot cattle. Feeding management and an understanding of animal behaviour can be utilised to reduce the severity of this challenge and its effect on animal performance and health.

2.3.1 Environmental Adaptation Mechanisms

Cattle have a range of temperatures in which they are comfortable, known as the thermal neutral zone (TNZ). The TNZ is delineated by a lower critical temperature (LCT) and an upper critical temperature (UCT). Depending on diet and previous climatic exposure the TNZ of feedlot cattle is approximately -10°C to 25°C (Hahn 1995a). Figure 2.5 illustrates the basic concept of the TNZ.

Animals gain heat via metabolic processes and from the environment and are capable of dissipating heat via the excretion of metabolic end products and interaction with the environment by modes of heat transfer. When an animal is confronted with an environment that challenges its thermal regulation, its initial response is to attempt to maintain its body temperature within its TNZ. In hot conditions the animals first available defence is to alter its behaviour, eg. seek shade, alter feeding times, reduce feed intake and increase water consumption. Behavioural changes aid in heat transfer from the animal to the environment. Heat transfer mechanisms available include convection, radiation, conduction and evaporation. Figure 2.6 illustrates thermodynamic pathways of heat exchange between an animal and its environment.

Figure 2.5: TNZ concept

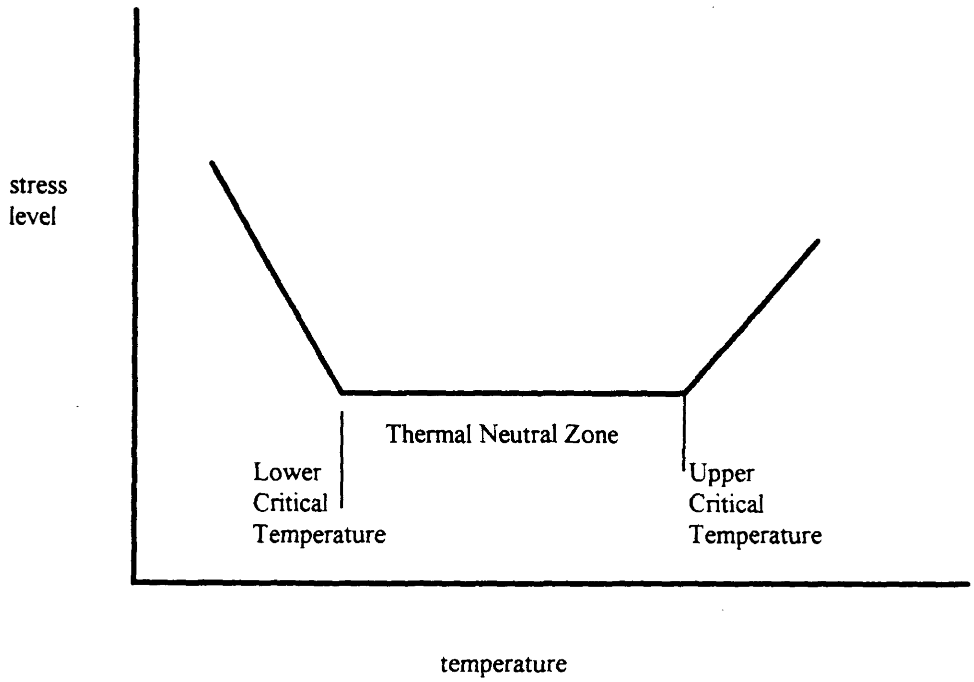
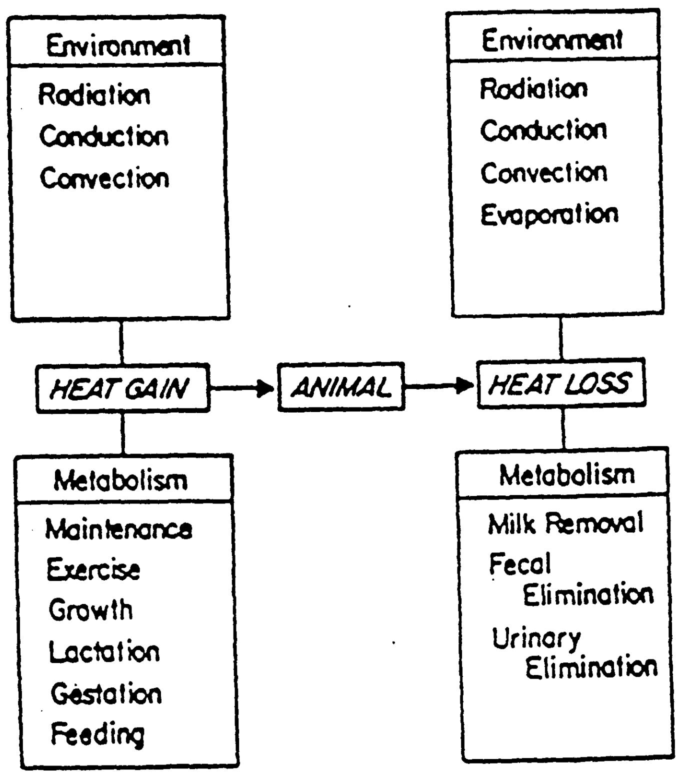


Figure 2.6: Thermodynamic pathways of heat exchange between an animal and its environment (Ray 1991)

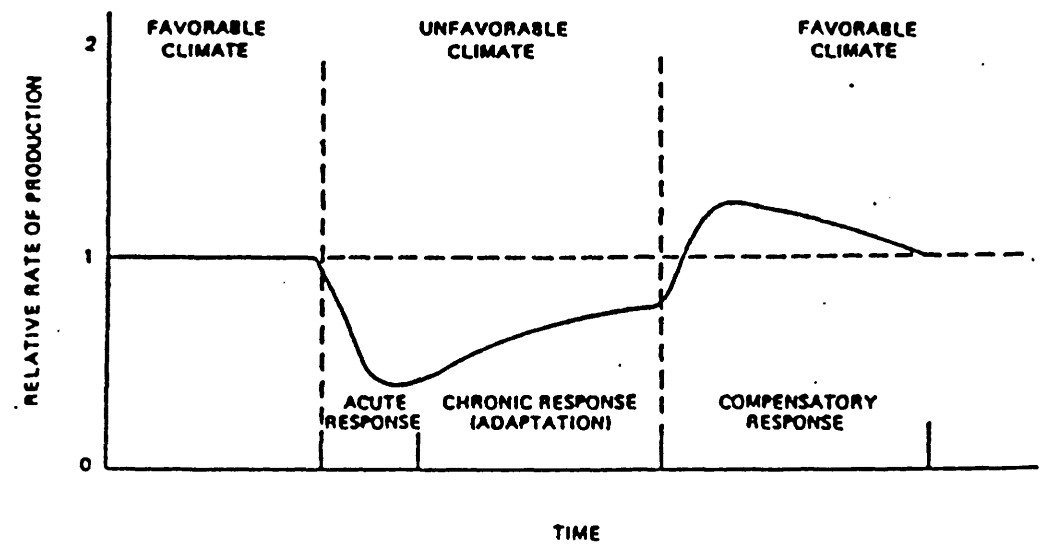


During the day, the animal gains a net heat load, the majority of which is gained from direct and indirect radiation (Ray 1991 ; Ames and Ray 1983 ; Finch 1986). This heat load is "stored" within the animal (Mendel et al 1971 ; Finch 1986 ; DeDios and Hahn 1994) during the day and dissipated to the environment during the cooler night (Hahn 1995b), allowing the animal to maintain a constant body temperature for 2 to 5 hours (DeDios and Hahn 1994) during periods between maximum and minimum air temperatures (Ray 1991 ; Ames and Ray 1983 ; Finch 1986). Radiation provides an important means of heat loss whenever the surrounding air is cooler than the animals surface. Mendel et al (1971) reported that 6 hours of cooling, at 21°C, during the evening, 4 - 10 pm, was as effective as 12 hours cooling during the day. Physical characteristics of the animal that effect its ability to carry a net heat load include body mass, specific heat of tissue, temperature distributions in the body and temperature sensitivity of tissues (Finch 1986 ; Young 1993). High temperatures during the day and night reduce the effectiveness of radiation as a means of heat dissipation. Under these conditions the heat capacity of the animal is reduced and evaporative cooling is the only means by which animals can reduce heat load (Fuquay 1981). The presence of high humidity and low air movement (Sharma and Kehar 1961 ; Morrison 1983) reduce the effect of evaporative cooling and can further inhibit the ability of the animal to transfer heat.

Heat stress occurs when the animal is unable to dissipate sufficient heat to the environment. Sudden increases in ambient temperature and body temperature result in the highest levels of stress as the animal attempts to maintain homeostasis. Ray (1991) proposed three phases of adjustment animals move through when confronted with environmental stress. Figure 2.8 illustrates these phases and their effect on production.

The initial phase is known as the acute phase. The acute phase represents the greatest challenge on the animals thermoregulation. Performance of non acclimatised animals exposed to relatively low levels of thermal stress can be significantly effected. (DeDios and Hahn 1994 : Hahn 1995a). This phase is represented by an obvious fall in performance as the animal attempts to maintain homeostasis by changes in its behaviour.

Figure 2.7: Theoretical animal response to periodic climatic change (Ray 1991)



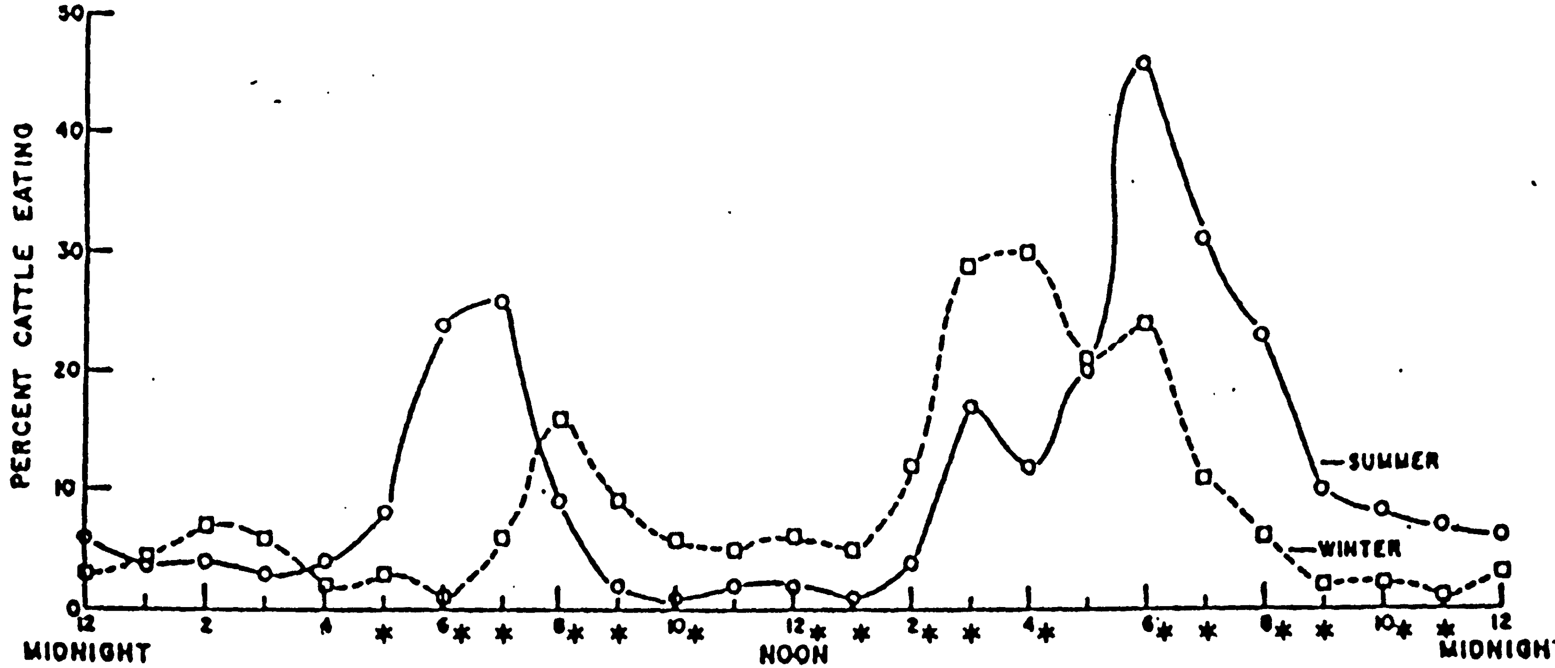
Behavioural changes generally include alignment of body with solar radiation, shade seeking, reduced feed intake, change in feeding pattern, refusal to lie down, crowding water trough, increased water consumption and concentrating in coolest areas of the pen (Fell et al 1993 ; Hermel 1996 ; Young 1993). During the acute phase animals also adjust their respiration rate. An increase in respiration rate occurs before body temperature rises and is therefore a primary defence in maintaining homeothermy (Hahn et al 1997). During the acute phase, respiration rate remains high at night, as animals attempt to dissipate heat and correct the imbalance between metabolic heat production and heat dissipation (Hahn et al 1997). Respiration rate increases range from 2.8 breaths per minute (bpm)/°C to 9 bpm/°C (Hahn et al 1997).

The second phase is known as the acclimation and adaptation phase. Acclimation develops in response to prolonged or repeated exposure to stress (Young 1992 ; Ray 1991 ; Hahn 1995a). Animals require three to five days to balance heat production with heat dissipation capabilities (Hahn and Mader 1997 : Hahn 1995a). Peak body temperatures decline at a rate of 0.1 - 0.4 °C / day (Hahn 1995b) before the diurnal body rhythm stabilises at a new elevated mean. Acclimation relies on metabolic changes controlled by the CNS via thermal sensors in the skin and brain. The hypothalamus is the principle thermoregulatory control centre (Hahn 1989). Temperature variations occur among different sites within the body due to differing levels of metabolic activity (Hahn 1989). When a certain threshold is reached, compensating mechanisms are initiated and act via neural and endocrine systems to maintain homeostasis (Young et al 1989). The processes responsible for heat redistribution in the body are complex. These processes attempt to maintain the stability of the body core temperature (Hahn 1989). Changes in the endocrine system reduce energy metabolism and increases water and electrolyte conservation (Beede and Collier 1986). A reduction in the concentration of metabolic hormones such as thyroxine, various growth hormones and corticoids aid in slowing metabolism (Beede and Collier 1986). Acclimation results in a gradual shifting of the TNZ. (Young 1992 ; Hahn 1995b) improving performance to a higher level than acute phase but lower than under normal conditions.

The final phase indicated in Figure 2.7 is the compensatory phase. It has been shown that when conditions became favourable, animals have the ability to exhibit a compensatory response where performance is better than normal for a period of time (Ray 1991 ; Morrison 1983). The ability of the animal to exhibit this response depends on the severity of the stress. Animals affected by mild heat stress recover within a few weeks, however severely stressed animals may never regain lost production (Morrison 1983).

2.3.2 Changes in Feeding Behaviour in Response to Heat Challenge

Behavioural changes allow the animal to make rapid adjustments to environmental stresses. These rapid changes are based on avoidance behaviour and an attempt to reduce metabolic heat load via a reduction in feed intake (Hicks et al 1990b ; Hahn 1995b). In association with these rapid changes are more subtle feeding behaviour changes that occur over a longer period initiated by photoperiod and temperature (Ray 1991 ; Hicks et al 1990b ; Hahn 1995 ; Ray and Roubicek 1971). Ray and Roubicek (1971) reported during summer, feeding began 2 hours earlier in the morning and 2 hours later in the afternoon than compared to winter. These time changes were correlated closely with changes in sunrise and sunset time differences between summer and winter. These changes in feeding behaviour are characteristic of both feedlot and grazing cattle. Fuquay (1981) observed during summer, 75% of grazing activity occurred at night and little feeding activity took place during the mid part of the day (Ray 1991). Figure 2.8 illustrates the effect of seasonal changes on feedlot cattle feeding behaviour.



Seasonal influence on diurnal eating activity of yearling steers in the feedlot. An asterisk (*) indicates a significant ($P<.001$) difference between seasons.

Figure 2.8: Seasonal influence on diurnal eating activity of yearling steers in the feedlot (Ray and Roucibek 1971)

2.3.3 Heat Stress and Performance

2.3.3.1 Feed intake

As environmental temperatures approach and exceed the animals UCT, level of feed intake falls and feeding behaviour is altered. Hahn and Mader (1997) reported a strong association between feeding behaviour and pattern of body temperature. Altered daily rhythms of body temperature in hot conditions was accompanied by reduced feed intake (Hahn and Mader 1997 ; Hahn 1995) and more frequent feeding with less feed consumed during each individual feeding event (Hahn and Mader 1997).

Sudden increases in temperature beyond the animal's TNZ significantly effect feed intake. Finch (1986) reported that feed intake reduction enabled animals to reduce their metabolic rate and maintain body temperature stability. Feedlots have reported up to a 30% reduction in feed intake under these circumstances (Hahn 1995 ; Silanikove 1992). Hicks et al (1990b) reported changes in weather conditions only caused short term erratic variation in feed intake and had little effect over the entire feeding period. However an evaluation of 15 years of data from the Texas Panhandle area of commercial feedlots reported that year and season interactions was a major factor influencing cattle performance (Schake 1995). Schake (1995) reported that year and season had a significant ($P<0.0001$) effect on daily gain, feed conversion efficiency, death loss, medication cost and cost of gain.

The effect of environmental conditions on feed intake will depend significantly on the severity of conditions and physical characteristics of the animal. Feed intakes of heavier cattle are depressed more than lighter cattle (Hicks et al 1990a) as a result of greater insulation in the heavier cattle increasing resistance of heat exchange (Finch 1986). Coat characteristics correlate strongly with performance. Sleek dense coats are associated with lower body temperatures than deep woolly coats. Coat colour also effects heat exchange rate. Heat absorption of black is 16% greater than brown and 58% greater than white (Finch 1986).

A reduction of feed intake in response to heat is part of the acclimation and adaptation process. During the adaptation phase the animal needs to balance heat gain from the environment and metabolism with heat loss. Metabolic heat contributes only one third of the total heat load of an animal, however the ability of the animal to remove metabolic heat efficiently is extremely important for maintenance of a steady body temperature (Finch 1986). Heat derived from rumen fermentation also contributes significantly to metabolic heat (Sharma and Kehar 1961) and reducing feed intake reduces heat produced from both fermentation and metabolism (Webster et al 1975 ; Ames and Ray 1983 ; Beede and Collier 1986 ; Silanikove 1992 ; Young 1992). A direct effect on the appetite centre of the hypothalamus may also exist (Beede and Collier 1986). DeDios and Hahn (1994) reported feed intake will remain depressed until the animal can synchronise its daily heat production with heat loss.

2.3.3.2 Water consumption and electrolyte balance

Heat stress increases animal water requirements (Kelly et al 1968 ; Ray and Roubicek 1971 ; Beede and Collier 1986) as the animal maximises evaporative heat loss via respiratory tract and skin. Beede and Collier (1986) evaluated the response of dairy cattle in heat chambers, 30°C vs 18°C, and reported that water consumption increased by 29%, faecal water loss declined by 33% and that water lost via urine, skin and respiratory evaporation increased by 15, 59 and 50% respectively.

Electrolyte balance of the blood can be compromised during periods of thermal stress due to reduced feed intake and prolonged periods of evaporative cooling. Ruminant sweat is high in potassium and hormones involved in conservation of water and electrolytes, eg. aldosterone, can change significantly during heat stress (Beede and Collier 1986). Beede and Collier (1986) found that with prolonged exposure to 35°C, plasma aldosterone concentrations of non lactating cows were 40% less than at 20°C. Aldosterone is responsible for resorption of sodium, potassium loss from urine and is linked to urine electrolyte excretion (Beede and Collier 1986). Supplementation of sodium and potassium during periods of heat stress have shown to significantly improve performance. Beede and Collier (1986) reported supplementation of these minerals during heat stress increased milk yield of dairy cattle by 3 to 11%.

2.3.3.3 Digestion and absorption

Processes of digestion and absorption are also altered in response to heat stress due to reduced feed intake and endocrinology changes. High ambient temperatures have been shown to depress rumen contractions (Atterbery and Johnson 1969 ; Beede and Collier 1986 ; Silanikove 1992), rumination time (Christopherson and Kennedy 1983) and saliva secretion (Silanikove 1992). These changes are in response to reduced secretion of thyroid hormone slowing metabolism and also reducing rumen motility (Beede and Collier 1986 ; Silanikove 1992). Rumen contractions were smaller and more irregular at ambient temperatures of 38°C than at 25°C (Atterbery and Johnson 1969 ; Silanikove 1992). Reduced rumen motility contributes to a reduction in feed intake (Beede and Collier 1986 ; Silanikove 1992), increasing residence time of digesta in the rumen and whole tract (Morrison 1983 ; Beede and Collier 1986 ; Silanikove 1992). Beede and Collier (1986) reported that the reduced volume of the GIT and an increase in rumen volume combined to slow digesta passage rate and increase digestibility of feed (Silanikove 1992 ; Atterbery and Johnson 1969 ; Fuquay 1981). However, any advantage gained from an increase in digestibility is lost due to higher energy requirements associated with maintaining homeostasis and reduced nutrient availability through depressed feed intake (Beede and Collier 1986).

2.3.3.4 Energy availability and utilisation

A close relationship exists between thermal stress, feed intake, the availability of energy and the efficiency of its utilisation (Young 1992 ; Ames et al 1980 ; Ames and Ray 1983). Heat stress causes a general depression in performance as a result of reduced feed intake, nutrient availability (Beede and Collier 1986) and an increase in maintenance energy requirement of the animal (Young 1992). The increase in maintenance requirement is due to the additional energy required to maintain homeostasis (Fuquay 1981 ; Morrison 1983 ; Young 1992) via increased respiration rate (Young 1992 ; Fuquay 1981). Beede and Collier (1986) and Hermel (1996) reported that elevated respiratory activity increases maintenance requirement by between 7 - 25%. Table 2.2 shows the depressing effect summer conditions have on the performance of feedlot steers even though feed intake remains the same.

Heat stress has been reported to adversely effect daily gain (Young 1992 ; Morrison 1983 ; Ray 1991), feed conversion (Young 1992 ; Fuquay 1981 ; Ray 1991) and milk production (Morrison 1983 ; Kelly et al 1968). Ray (1991) found that for every 2°C increase in temperature above 21.1°C, daily gain decreased by 0.07kg/hd/d for cattle fed a 90% concentrate ration and Ray et al (1969) reported daily gain and feed conversion were depressed by up to 25% and animal response to growth promotants was depressed.

Table 2.2: Seasonal effects on performance of steers in a feedlot (Ray 1991). All figures are averages taken from a feeding period of 120 days.

Season	Live weight gain (kg/d)	Daily feed intake (kg/d)	Feed : Gain (kg/kg)
Winter	1.25	9.60	7.66
Summer	1.00	9.68	9.66
Change between summer and winter (%)	-20%	+1%	+26%

2.3.4 Heat Stress and Animal Health

In extreme situations heat stress can result in death (Hahn 1995). The onset of open mouthed, laboured panting and excessive salivation suggests failure of the animal's regulatory system (Hahn et al 1997). Under such extreme environmental conditions the animal is unable to dissipate heat and death occurs when body temperatures reach 43 to 45°C (Young 1992).

As animals attempt to maintain homeothermy changes in metabolic function can compromise animal health, particularly when animals are consuming grain based diets. Cattle consuming diets high in readily fermentable carbohydrates (RFC) rely on rumination activity to stimulate saliva production to maintain adequate rumen buffering capacity. Heat stress however, reduces rumen movement (Christopherson and Kennedy 1983), saliva production (Silanikove 1992) and challenges the respiratory system (Hahn and Mader 1997). Respiration rate increases from 30 to 70 bpm to peaks of 170 bpm and can be sustained at rates of 120 bpm (Hahn and Mader 1997). The respiratory system plays an important role in maintaining the acid-base balance in the blood. Under heat stress conditions and elevated respiration rates, the base component of the blood can be reduced causing metabolic acidosis (Owens et al 1998 ; Beede and Collier 1986 ; Howie 1996), PEM and urinary calculi formation due to changes in urine pH (Howie 1996).

2.3.5 Management Strategies that Reduce the Effect of Heat Stress on Animal Performance and Health

There are several strategies available to reduce the effect of heat stress on performance and health of feedlot cattle. Strategies discussed include structures and physical means, genetic selection, environmental adaptation, nutrition and bunk management.

2.3.5.1 Structural and physical

The use of structures, eg. shade (Garrett et al 1962 ; Ray 1991 ; Fuquay 1981 ; Morrison 1983 ; Fell et al 1993 ; Busby and Loy 1996 ; Hermel 1996), maximising air movement (Ray 1991 ; Morrison 1983 ; Busby and Loy 1996), cooled drinking water (Lofgreen et al 1975 ; Ray 1991 ; Fuquay 1981 ; Morrison 1983 ; Beede and Collier 1986), sprays and sprinklers (Ray 1991 ; Morrison et al 1973 ; Morrison 1983) and artificial lighting (Ray 1991) are designed to reduce absorption of radiation, maximise heat loss via radiation, convection and conduction and modifying natural behaviour.

2.3.5.2 Genetic selection and environmental adaptation

Morrison (1983) reported significant advantages in performance when utilising animals tolerant to heat, eg. *Bos indicus* type cattle. Animals previously adapted to heat or raised in warmer climates were not effected to the same degree of those cattle raised in cooler areas (Morrison 1983). Ames and Ray (1983) reported animals acclimatised to heat stress were more effective panters than cattle not exposed to previous episodes of heat stress.

2.3.5.3 Nutrition

Performance depression associated with animals experiencing heat stress is primarily associated with increased maintenance requirement and reduced feed intake. Manipulation of diet components can reduce the effect of stressful environments on performance. Diet components associated with reducing heat of fermentation and maximising diet energy density play an important role in achieving this goal. Reducing fibre levels in the diet have been shown to reduce rumen heat of fermentation (Morrison 1983 ; Fuquay 1981) and improve feed intake (Fuquay 1981) of heat stressed animals. Beede and Collier (1986) and Ray (1987) reported the importance of maximising energy density of diets to maintain performance during periods of heat stress. Fat inclusion maximises energy intake and has minimal effect on rumen heat production compared to carbohydrate energy sources (Morrison 1983 ; Beede and Collier 1986 ; Atterbery and Johnson 1969) because the major component of fat, long chain fatty acids, are not fermented in the rumen.

2.3.5.4 Bunk management

Animals alter their natural periods of feeding and level of feeding activity in response to changes in the environment. In response to these changes, there are distinct differences in feeding activity between summer and winter (Ray 1991 ; Ray and Roubicek 1971). During the summer period, the greatest feeding activity is concentrated at sunrise and sunset with minimal feeding activity during midday (Ray 1991 ; Ray and Roubicek 1971). The morning feeding period is only of short duration but high activity as compared to the evening feeding period which has a longer duration and less intense feeding activity. The aim is to provide sufficient feed in the morning to satisfy cattle hunger and enable the animals to consume feed before the heat of the day. Advancing morning feed delivery time allows all cattle of the feedlot be fed before conditions inhibit feeding activity. By restricting feed intake in the morning, metabolic heat production is reduced, which is important during the summer months when the ambient temperature is high. Minimising feed availability during the midday period maintains feed freshness (Hermel 1996 ; Howie 1996 ; Coppock et al 1981) as feeding behaviour during this time is minimal (Ray 1991 ; Ray and Roubicek 1971). Therefore, bunk management strategies can be tailored to deliver feed in amounts that match natural feeding behaviour (Ames and Ray 1983 ; Ray and Roubicek 1971) and minimise the detrimental effects of high ambient temperatures on feed intake.

2.4 ANIMAL BEHAVIOUR

Cattle have specific social and feeding behavioural patterns which are exhibited in both grazing and intensive production systems. These behavioural patterns aim to maximise availability of resources to the group and reduce confrontations, thereby minimising energy wastage (Siegal and Gross 1973). Behavioural patterns of individual animals within a group are controlled by a dominance hierarchy (Brouns and Edwards 1994) which assists in maintaining a stable social group. The structure of the social hierarchy is generally linear, ie one dominant animal is superior over the other subordinate animals (Wierenga 1990 ; McPhee et al 1964). However, in intensive production systems when many cattle from different origins are grouped together, several linear hierarchies can exist (Beilharz and Mylrea 1963).

Variation in behavioural patterns can occur in response to changes in environment, management practises (Wierenga 1990) and resource limitations (Friend et al 1977 ; Siegal and Gross 1973 ; Wierenga 1990 ; Fraser 1981). Modifications of behavioural patterns are most relevant in intensive production systems (Fell and Clarke 1993). An understanding of basic social and feeding behaviour aids in maximising production by ensuring even resource distribution, reducing stress and allowing animals to express natural behaviour.

2.4.1 Social Behaviour

2.4.1.1 Social order

Social organisation of cattle is based on a dominance hierarchy. This type of hierarchal system is common in domestic animals (McPhee et al 1964). The dominant animal within a group is the one that has the ability to behave as it would under natural conditions (Wierenga 1990 ; Beilharz and Zeeb 1982 ; Crook 1970). Dominant hierarchal group structures originate from aggressiveness of animals toward one another during competition for mating. The role of a dominant hierarchal system is to dissipate this aggressiveness (McBride et al 1964 ; Crook 1970) and prevent injury to weaker animals on occasions when strength is used to assert dominance (Beilharz and Zeeb 1982). In domestic situations dominant-subordinate relationships are rarely settled by strength and dominance and aggression are rarely performed by the same animal (Wierenga 1990). Beilharz and Zeeb (1982) defined aggression as a motivated behaviour that results in repelling another animal through physical means, whereas dominance is the ability of one animal to inhibit another animals behaviour purely through its presence (Seigal and Gross 1973).

Characteristics of animals that influence social ranking varys widely. Beilharz and Mylrea (1963) found that temperament is a poor measure of social ranking. Greater emphasis is based on physical characteristics. Animal characteristics which influence social ranking include age (Beilharz and Mylrea 1963 ; Friend and Polan 1974 ; Arave and Albright 1981 ; Beilharz and Zeeb 1982 ; Wierenga 1990 ; Mench et al 1990), weight (McBride et al 1964 ; Dove et al 1974 ; Friend and Polan 1974 ; Arave and Albright 1981), height (Beilharz and Mylrea 1963 ; McPhee et al 1964 ; Dove et al 1974 ; Friend and Polan 1974), size (Beilharz and Mylrea 1963), familiarity and residence time in the group (Beilharz and Zeeb 1982 ; Friend and Polan 1974 ; Wierenga 1990) and presence of horns (Beilharz and Zeeb 1982). Other characteristics that influence group position include breed (Mench et al 1990) and pregnancy status (Beilharz and Zeeb 1982). Interactions of these physical characteristics commonly play a role in social ranking. McPhee et al (1964) reported that wither height of steers had a greater effect than weight in social ranking and Dove et al (1974) found that dominance status of sheep correlated significantly with body weight, wither height and height of hock and that age had little effect.

An established social group rarely exhibits direct threats to subordinate animals. The stability of a social group relies on individuals capacity to learn, recognise and remember other individuals (Siegal and Gross 1973). Once the dominant-subordinate relationship is established tension within the group is minimised and any individual interaction will have a pre-determined outcome (Siegal and Gross 1973 ; Wierenga 1990).

2.4.1.2 Establishing social order

The establishment of a social order involves individuals locating their social position within the group. It is during the establishment phase that the highest frequency of confrontations between individuals occur (Siegal and Gross 1973 ; Beilharz and Zeeb 1982). The time period for a group to establish a social order depends mainly on the number of individuals within the group (Tennessen et al 1985) and the frequency in which new animals are introduced (Mench et al 1990). Establishment of social order within a group is important as it aids in the regulation and distribution of available resources (Syme 1974 ; Wierenga 1990). Large groups of animals do not establish a strict linear hierarchal order (Beilharz and Mylrea 1963), instead relationships between pairs (Tennessen et al 1985) and small groups (Craig 1986) of animals develop. The ability of animals to develop social alliances with each other (Arave and Albright 1981 ; Craig 1986) further reduces confrontation frequency. Relationships between small groups are encouraged to occur as animals do not associate with more individuals than can be remembered (Arave et al 1974 ; Craig 1986).

All animals exhibit competitive behaviour that identifies and separates the dominant individuals from the subordinates (McBride et al 1964). McPhee et al (1964) observed cattle established their social order through bunting competitions. However animals will avoid confrontations if possible and dominant - submissive roles can be determined without physical contact, even when animals are not familiar with each other (McPhee et al 1964). Once social order is established, individuals learn to accept their rank, confrontations are minimised (Beilharz and Zeeb 1982) and the group develops resistance to change (Siegal and Gross 1973). Confrontations may still occur but are often isolated to animals of similar ranking (McPhee et al 1964). The nature in which the social group is established and ordered upon aids in the maintenance of social order.

2.4.1.3 Maintaining social order

Maintaining social order is based on communication (Siegal and Gross 1973) and the ability of individual animals to learn and remember their position within the group (Beilharz and Mylrea 1963). Communication between animals is highly formalised (McBride et al 1964) and centres on posture (Siegal and Gross 1973), eye contact (McBride et al 1964), smell (Klemm et al 1984 ; Fell and Clarke 1993), space (Siegal and Gross 1973 ; McBride et al 1964) and other subtle signals (Brouns and Edwards 1994). The display of certain postures that define rank of an individual to the group reduces confrontations by providing space control between animals (Siegal and Gross 1973) and organises the distribution of animals within the yard (Beilharz and Mylrea 1963 ; Dove et al 1974).

The ability of animals to learn and remember their social position within the group assists in maintaining social order. Social affiliations between small groups of animals aids in learning and maintaining social position (Fraser 1981). Beilharz and Mylrea (1963) reported that once an animal submits to another the relationship is cemented and will remain stable until there is a reason to learn a new relationship. Arave and Albright (1981) reported that short separation has little effect on social order as individual animals remember their ranking within the group. These factors take time to develop but enable the group to function without the necessity for confrontations when group members encounter each other (McBride et al 1964 ; Beilharz and Mylrea 1963 ; Arave and Albright 1981 ; Brouns and Edwards 1994).

2.4.1.4 Disruption to social order

Competition for available resources (McPhee et al 1964 ; Friend et al1977 ; Wierenga 1990) and the introduction of unfamiliar animals into an established group (McBride et al 1964) are the main factors that result in disruption to social group order. Competition for resources increase confrontation frequency as resource distribution becomes limited (McPhee et al 1964 ; Friend 1977 ; Arave et al 1974) and introduction of unfamiliar animals increases stress as the group must re-establish its social order. Increased stress

(Friend et al 1977 ; Siegal and Gross 1973) and reduced performance (Friend and Polan 1978) can result from disruption to social order (McBride et al 1964 ; particularly in feedlots (Brouns and Edward 1994) where location of water points and feed bunk capacity can limit resource availability (Wierenga 1990) and mixing of cattle is common.

- Crowding and resource competition

Social crowding is a function of density (Dove et al 1974), communication and contact (Friend 1977). Reducing space to a point where crowding occurs increases frequency of confrontations as animals are forced to move into the personal space of other individuals and movement is inhibited as animals attempt to avoid personal space conflicts (Arave et al 1974). Animals that can interact closely are more adaptive to space restrictions (Siegel and Gross 1977) and maintain social stability (Dove et al 1974 ; Brouns and Edward 1994).

A reduction in space increases antagonistic behaviour (Arave et al 1974 ; McPhee et al 1964 ; Friend et al 1977 ; Siegel and Gross 1973 ; Wierenga 1990 ; Fraser 1981) as access to resources become limited. The role dominant relationships play in competitive situations remains unclear. Wierenga (1990) found when feed is restricted and crowding occurred, dominance played a limited role in individual feed intake suggesting social dominance is only important in making animal interactions predictable. However subordinate animals are consistently disadvantaged by resource limitation (Wierenga 1990 ; Brouns and Edwards 1990 ; Beilharz and Zeeb 1982 ; Friend and Polan 1978 ; McPhee et al 1964) suggesting dominant-subordinate relationships play an active role.

- Mixing

The introduction and mixing of unfamiliar individuals or groups of animals disrupts social order (McBride et al 1964 ; Mench et al 1990 ; Tennessen et al 1985 ; Arave and Albright 1981 ; Brakel and Leis 1976). The degree of disruption depends on age (Tennessen et al 1985 ; Mench et al 1990), breed (Mench et al 1990), animal density (Tennessen et al 1985 ; Dove et al 1974) numbers of animals introduced and size of group (Dove et al 1974 ; Arave and Albright 1981 ; Tennessen et al 1985). The disruption to social order increases antagonistic behaviour within the group and towards "alien" animals (McBride et al 1964 ; Mench et al 1990 ; Tennessen et al 1985 ; Brakel and Leis 1976) as the new group attempts to re-establish social order. Re-establishment of social order takes time and it is during this adjustment period that stress increases and animal performance can suffer (Mench et al 1990).

Dominance rankings can be established within two hours of new animals entering a group (Arave and Albright 1981). However the period of time required for social order to re-adjust can range from a week (Brakel and Leis 1976 ; Mench et al 1990) to ten days (Tennessen et al 1985). Age of cattle and space are important factors that influence the adjustment period. Tennessen et al (1985) and Mench et al (1990) reported older cattle are less aggressive and establish a more stable social order in less time and Tennessen et al (1985) and Dove et al (1974) observed that greater allocations of space allow "alien" animals to avoid antagonistic behaviour.

Dominance pattern of the new group can alter significantly after mixing (Arave and Albright 1981) and the ranking of "alien" animals is most affected. Newly introduced animals are generally lower ranked (McBride et al 1964 ; Mench et al 1990 ; Wierenga 1990 ; Arave and Albright 1981), initiate less and receive more aggression (Mench et al 1990) even when those animals have a higher rank prior to mixing (Arave and Albright 1981 ; McBride et al 1964).

2.4.2 Buller Syndrome

The "buller" syndrome is a behavioural characteristic specific to feedlot cattle (Fell and Clarke 1993 ; Edwards 1996) and is characterised by an expression of female like behaviour by the "buller" steer. The "buller" becomes sexually attractive to other steers and is continually mounted until exhausted (Irwin et al 1979). Edwards (1996) describes two types of "bullers", the true "buller" and the "picked on steer". The true "buller" is the steer that assumes a position and stands to be ridden as a female in heat. The "picked on steer" is a steer that becomes ridden as a result of circumstance, eg. new addition to pen, carrier of strange odour. Although the reasons behind this behaviour are not fully understood, it appears to be a combination of social pressure and hormonal imbalance (Irwin et al 1979).

Factors that appear to increase bulling include seasonal effects, weather changes, poor bunk management, feeding of oestrogenic containing forages and the use of certain hormonal implants (Peirson et al ; Taylor 1996). Research has concentrated on oestradiol and testosterone levels in "bullers" (Edwards 1996). Variation in hormonal concentration is reported to be a contributing factor to the sexual attractiveness of the "buller". Stimulation of riding may derive from olfactory origin associated with the release of pheromones by the "buller", however visual stimulus of the "bullers" stance may also play a role in stimulating riding behaviour (Irwin et al 1979). Hormonal variation is not the only cause to the syndrome. Irwin et al (1979) reported bulling occurs in feedlots that do not use hormonal implants and total serum oestradiol and testosterone levels were depressed during bulling and on recovery levels returned to normal.

Periods of high social stress, eg. introduction to pen, mixing with unfamiliar cattle and extending period to close pen increases "buller" incidence suggesting "buller" syndrome is related to levels of social pressure (Peirson et al 1976 ; Taylor 1996 ; Irwin et al 1979). Highest incidence of bulling occurs during the initial introductory period (Peirson et al 1976 ; Taylor 1996). However, Irwin et al (1979) reported the time interval between entry into feedlot and onset of bulling varied greatly with a range of 1 to 221 days. This long potential "buller" period may be explained by Fell and Clarke (1993) who proposed that feedlot cattle may experience boredom and express this in abnormal behaviour. Age and weight are factors that effect "buller" incidence. Taylor (1996) reported older animals have a earlier "buller" peak and more rapid decline than younger animals. A significant relationship exists between "buller" incidence and number of head in a pen (Peirson et al ; Irwin et al 1979 ; Taylor 1996). However, Irwin et al (1979) suggested crowding per se is not a key factor and suggested the submissive behaviour of the "buller" may be the result of the adverse effect of the intensity of social interaction.

The incidence of "buller" syndrome in feedlots in the US and Australia ranges from 1 to 3% (Edwards 1995) and represents a significant cost to the industry. The majority of feedlots separate "bullers" from pen mates, thereby requiring additional pens. In addition "bullers" add 1% to mortality rate and can reduce carcass yield as a result of deep muscle wounds acquired from riding injuries (Edwards 1996).

2.4.3 Feeding Behaviour

2.4.3.1 Feed intake

Feed consumption by grazing cattle is related to forage nutrient quality and quantity. In cases when these are low, grazing cattle can be forced to feed throughout the night and day (Adams 1985). Consumption of feed by feedlot cattle however, is concentrated to approximately 7% of the day, ie 1.5 to 2 h/d (Fell and Clarke 1993). The actual time cattle spend at the feed bunk can be much greater but has no relationship to level of feed intake (Friend et al 1977). Prawl et al (1997) studied the effect of feed access on animal performance. Feed access times included 1.5, 3, 6, 9, and 24h over a 120 day feeding period. Prawl et al (1997) reported animals restricted to 9 hours feeding had the highest daily gain, dressing percentage and superior feed conversion, with no significant difference in carcass performance. Chase et al (1976) and Vasilatos and Wangsness (1980) observed the consumption of feed accounted for only 60% of the time cattle remained at the bunk. The remaining time was spent resting and ruminating (Vasilatos and Wangsness 1980).

Animals adjust feed intake by varying the number of meals per day and / or average meal size (Chase et al 1976 ; Vasilatos and Wangsness 1980). Forbes (1993) reported ruminants take between five and twenty discrete meals each day with an average meal duration of approximately 20 minutes (Chase et al 1976 ; Vasilatos and Wangsness 1980). The rate of feed intake can be increased, but at some point the rate of feed intake plateaus resulting in an increase in feeding time (Chase et al 1976). Physical nature of feed (Putman et al 1962 ; Putman and Davis 1963 ; Forbes et al 1972), behavioural characteristics specific to individual animals (Vasilatos and Wangsness

1980 ; Fell and Clarke 1993) and social group pressures (Grant and Albright 1997) have a greater influence on meal duration and rate of intake than animal characteristics such as body weight (Chase et al 1976) or period on feed (Laudert 1995).

Animal feeding patterns can be established within 7 to 14 days from entry into the feedlot (Putman and Davis 1963). The establishment of feeding patterns is aided by maintaining specific feeding times thereby conditioning animals to begin feeding on feed delivery. Baily et al (1988) reported that steers can remember where they foraged and how much feed they found at that location.

Maintaining feed freshness and avoiding faecal contamination reduces feed refusals and maximises feed intake. Sensory input from smell (Bell 1984) and taste (Curtis and Houpt 1983) provides a strong stimulus in acceptance or rejection of feed and cattle can readily detect faecal contamination (Bell 1984). Curtis and Houpt (1983) suggested that cattle can associate specific tastes to illness and learn to avoid feed that results in sickness. Bunk management strategies that minimise feed residue in the bunk aid in maintaining freshness and palatability of feed and reduce the likelihood of mould, especially during wet and humid periods.

2.4.3.2 Feeding behaviour and social interaction

Social hierarchy controls an individual animal's access to feed and determines feeding time and rate of intake. Dominant steers spend more time feeding, have fewer meals and eat for longer periods than lower ranked cattle (Friend et al 1977 ; Stricklin and Gonyou 1981 ; McPhee et al 1964 ; Kenwright and Forbes 1993 ; Friend and Polan 1974). Lower ranked feedlot steers compensate for reduced feeding time by feeding more frequently (Kenwright and Forbes 1993). When large groups of cattle are maintained in a confined area, the formation of several hierarchal groups each with their dominant animal will affect animal interaction, particularly during feeding when all animals are bought together to a specific area of the pen.

The method of feeding, eg. stall versus bunk, influences feeding behaviour. Bunks allow animals to feed with their herd mates (Schmisseur et al 1966) where as feeding from stalls restricts the feeding area and increases social interaction and competition for feeding sites (Friend and Polan 1974 ; Metz 1981). Hierarchies based on access to feed do not always reflect those based strictly on social interactions (Hughes 1977 ; Mench et al 1990), however the differences observed may be due to means in which feed is supplied. Stricklin and Gonyou (1981) observed animals paired when feeding from a stall and pairing was more common to animals further apart in dominance. This behaviour contradicts social behaviour where social alliances are common between animals of similar ranking. As a result of this apparent relationship subordinate cattle gain access to feed over dominant cattle by use of subtle signals and persistency (Stricklin and Gonyou 1981 ; Friend and Polan 1974). Dominant cattle do not prevent subordinate cattle access to stall (Stricklin and Gonyou 1981), however Friend and Polan (1974) observed dominant cattle displayed territorialism for certain stalls which lower ranked cattle did not occupy. At the feed bunk however, definite dominance hierarchies are established which can affect feed intake and productivity (Grant and Albright 1997).

Contradictory reports remain over whether animals prefer to feed at specific sites and wether social rank plays a role in feeding order. McPhee et al (1964) concluded social rank showed no relationship with movement to the bunk, preferred section (Laudert 1995) or which animals appeared adjacent to each other (Friend and Polan 1974). However, Schmisseur et al (1966) observed animals had preference for certain eating places over others and Fell and Clarke (1993) reported pen riders commonly observed favourite locations within the pen for individual animals with the most aggressive animals congregating at the end in which feed delivery begins.

A reduction in feeding space increases competition for feeding places by preventing all animals gaining access to feed sites. Social organisation may have a detrimental effect on performance of lower ranked animals when competition for feed exists (Corkum et al 1994 ; Brouns and Edwards 1984). Corkum et al (1994) evaluated the effect of feed competition on feed intake, stress levels and performance. Stress levels did not differ between treatments, suggesting animals were capable of adjusting to competitive feeding by altering feeding rate and duration. Grant and Albright (1997) reported animals can adapt feed intake to competition level without altering level of feed consumed. As competition level increases animals adjust by feeding for shorter periods, increase number of visits to the bunk and increase feed intake rate. Corkum et al (1994) found no significant difference in weight gains between treatments and Zinn (1989) reported that increasing bunk space did not affect daily gain or feed conversion. Competition appears to encourage animals to approach feeders and increase feed intake (Corkum et al 1994 ; Coppock et al 1981). This response has a social origin and is known as social facilitation (Curtis and Houpt 1983 ; Hsia and Wood-Gush 1984). Social facilitation describes the response of one feeding animal stimulating other animals to feed whether they are hungry or not (Hsia and Wood-Gush 1984; Fell and Clarke 1993). Grant and Albright (1997) reported the effect of social facilitation in lambs and its ability to increase feed intake.

2.4.3.3 Feeding behaviour and environmental interaction

Environmental conditions directly influence cattle feeding behaviour. The greatest influence is derived from photoperiod and sunrise and sunset times. Cattle prefer to consume the majority of their feed during daylight hours (Putman et al 1968 ; Chase et al 1976 ; Putman and Davis 1963 ; Vasilatos and Wangsness 1980 ; Ray and Roubicek 1971 ; Gonyou and Stricklin 1984), however if prevailing environmental conditions prevent feeding during preferred periods cattle adjust feeding behaviour (Arave and Albright 1981 ; Ray and Roubicek 1971 ; Fell and Clarke 1993 ; Gonyou and Stricklin 1984 ; Wilson and Flynn 1979 ; Putman and Davis 1963). Some feeding activity can occur at night, particularly during winter as animals compensate for short day length (Wilson and Flynn 1979 ; Adams 1985 ; Gonyou and Stricklin 1984) and during hot days (Fell and Clarke 1993). However, feeding activity during the night lacks the intensity and duration daylight feeding (Wilson and Flynn 1979 ; Forbes 1993). Radiation intensity also modifies feeding behaviour. Ray and Roubicek (1971) observed during summer the migration of cattle under shade begins early morning as radiation levels increase, with all cattle remaining under shade until late afternoon.

Peaks in feeding activity are strongly associated with times of sunrise and sunset (Adams 1985 ; Ruckebusch and Bueno 1978 ; Chase et al 1976 ; Ray and Roubicek 1971 ; Gonyou and Stricklin 1984 ; Chase et al 1966 ; Fell and Clarke 1993). Ray and Roubicek (1971) observed feeding pattern remained the same for summer and winter, however the initiation of feeding during the different seasons reflected the changes in sunrise and sunset times (Gonyou and Stricklin 1984). Feeding intensity and duration changes with season. Ray and Roubicek (1971) observed hot summer conditions modified feeding behaviour pattern by dramatically decreasing frequency of eating activity during midday, the majority of cattle at this time remained under shade, delaying the afternoon peak and increasing the frequency of feeding during the early evening hours. Gonyou and Striklin (1984) observed the initiation of eating during summer was high at sunrise and represented the most intense feeding period of the day with little feeding activity occurring midday and Morrow-Tesch et al (1997) observed most morning activity was composed of feeding behaviour and evening activities were primarily social. Figure 2.9 highlights the changes in feeding behaviour of feedlot steers with season. The delivery of feed provides the highest feeding stimulus (Fell and Clarke 1993 ; Vasilatos and Wangsness 1980), particularly in the morning. The response to afternoon feed delivery depends on the time and environmental conditions. Gonyou and Stricklin (1984) observed feed added to the bunk in the afternoon was left uneaten until sunset during the summer period.

2.4.4 Bunk Management, Animal Behaviour and Implications to Animal Performance

The incorporation of cattle social and feeding behaviour into bunk management systems has the potential to maximise cattle performance under variable environmental conditions. The development of bunk management systems that prevent feed limitations and meet the animals natural feeding pattern provides the opportunity for all animals to satisfy their nutrient requirements, minimises disruption to social order, encourage feed intake and minimise performance depression during stressful environmental conditions.

2.5 FEEDING MANAGEMENT OF GRAIN-FED CATTLE

2.5.1 The Allocater

The allocater in a feedlot operation is the person responsible for estimating the amount of feed a pen of cattle will consume over a 24 hour period. To estimate the correct amount of feed required consistently and repeatedly, the allocater needs to be a keen observer of animal behaviour and cattle responses to diet, feeding and environment (Doyle 1994). The estimated amount of feed is referred to as a "call". The allocater has several indicators which can aid in the prediction of potential intake and the amount of feed required. These indicators include breed of cattle, number of cattle in the pen, weight of cattle, prevailing weather conditions, cattle behaviour, timing of feeding, energy density of diet, dry matter of diet, bunk score, aggression score, days on feed and peak feed level. A good allocater can anticipate changes in pen feed intakes and relies on cattle behaviour to indicate these changes. The two indicators which provide the best information are bunk score and aggression score. Tables 2.3 and 2.4 define the scoring system for aggression and bunk assessment respectively. The allocater uses the aggression of animals to the morning feed delivery and the quantity of feed remaining in the bunk to make the call (Doyle 1996 ; Horton 1996). The best time to make an assessment of aggression is during the morning feed (Doyle 1994) as this is characterised by the greatest intensity of feeding activity (Ray and Roubicek 1974). The ideal bunk rating is a 3B or 3C (Doyle 1994).

Table 2.3: Scale used to define aggression score

Score	% of cattle at the feed bunk after feed delivery
1	0 - 10
2	10 - 30
3	30 - 50
4	50 - 80
5	80 - 100

Table 2.4: Definition of bunk conditions used to define bunk score

Score	Definition
A	licked clean, no feed left in bunk, slick
B	clean with few grains scattered in bunk
C	scattered quantities of feed left in bunk (<2.5 cm lining bottom)
D	feed lining bottom of bunk (>2.5 cm)
E	large quantities of feed in bunk

The allocater can develop an understanding of changes in feed intake pattern by relying on the pattern of feed consumption of each pen. This pattern of consumption is reinforced by allocating at the same time and by the same route each day (Doyle 1994 ; Horton 1996). The timing of allocation is flexible, providing animals have sufficient time to satisfy their feed requirements before the next allocation begins, ie. 2 hours after feed delivery (Doyle 1996). Any changes to allocation and feeding start times are best made gradually, ie. 30 min each week, to avoid disrupting feeding pattern and reduce the risk of digestive disorders. When the allocater has assessed the bunk and other relevant information, a decision is made on the amount of feed for the pen. Increasing the allocation is known as "challenging". Table 2.5 provides a guide to the level of challenging depending on days on feed and diet characteristics.

Table 2.5: Feed challenge guide, where the feed challenge (kgDM/hd/d) is the amount by which the feed offered can be increased on any one day.

Diet	Days on feed	Feed challenge
starter diet 1	0 - 7	0.05 - 2.00
starter diet 2	7 - 14	0.05 - 1.50
starter diet 3	14 - 21	0.25 - 1.00
grower	21 - 100	0.25 - 0.75
finisher	> 100	0.25 - 0.50

The objective of bunk assessment and feed allocation is to establish a consistent feed intake pattern and maximise feed consumption. The allocater attempts to anticipate feed intake and the skill of the allocater is illustrated when the call coincides with intake swings. Over feeding is disruptive to feed intake and may lead to the development of mould and feed wastage. Under feeding increases cattle aggression level and the risk of digestive disorders. Feed that remains in the bunk for longer than 24 hours needs to removed. Maintaining feed freshness by avoiding mould and faecal contamination reduces feed refusals and reduction in feed intakes. Changing weather patterns continually cause difficulty for bunk management. Cattle are sensitive to changes in barometric pressure (Elam 1976). An approach of a cold or wet front stimulates feed intake, however this effect is often temporary and can result in many full bunks and feed wastage if changes in weather conditions are not anticipated.

Allocating feed for starter cattle provides the greatest challenge. These animals are unpredictable and initially do not have a consistent feed intake pattern. The unpredictable nature of these cattle is due to stress associated with transport, induction, a new diet and establishing a social order (Tennessen et al 1985). Consequently, starter cattle tend to consume feed on an individual bases rather than as a group and the allocater is often faced with feed remaining in the bunk at time of allocation. Successfully anticipating increases in feed intake aids in managing the unpredictable behaviour and minimises the risk of digestive disorders.

Other responsibilities of the allocater involve ration changes and ensuring feed delivery drivers feed in a manner that does not disadvantage performance of cattle. Preston (1995) observed the greatest swings in feed intake are most evident during ration changes. To reduce variation, rations are changed over three days, with the higher energy diet fed in the afternoon when cattle are less aggressive. The allocater must estimate the amount of feed a pen will consume and relies on the pattern of feed consumption for making feed calls. For this reason, it is critical that the amount of feed delivered to each pen is as close as possible to the allocated amount (Horton 1996 ; Craig 1997). The manner in which feed is delivered to the bunks can influence both performance and health. Feed needs to be adequately mixed to prevent sorting and delivered evenly and accurately across the entire length of the bunk. Observation of cattle feeding behaviour has shown that animals tend to feed from the same location along the bunk each day (Doyle 1994 ; Horton 1996 ; Craig 1997) and are unlikely to move from their bunk location when feed is no longer available (Doyle 1994 ; Horton 1996 ; Craig 1997). Uneven deliveries increase the opportunity for waste in areas of the bunk where feed amounts are too large to be consumed in on day. The risk of digestive disorders is minimised by avoiding disruption in feeding schedule and ensuring all animals have equal opportunity to consume feed (Horton 1996). Variation in these areas can result in variation in feed intake and performance.

2.5.2 Natural Feeding Behaviour and Bunk Management

A feed bunk management program aims to encourage animals to consume more feed and at a more consistent level than when self regulated (Doyle 1994), thereby achieving improved performance and health (Doyle 1994 ; Preston 1995 ; Galyean 1996). To maximise intake, cattle feeding behaviour requires modification, ie. develop an association between feed delivery and feed consumption. Modification of feeding behaviour relies strongly on the ability to maintain regular and consistent feeding times (Doyle 1994 ; Horton 1996 ; Gaylean 1996 ; Craig 1997). Feeding at regular and consistent times of the day strengthens the association between feed delivery and the act of feed consumption (Doyle 1996). The modification of feeding activity is particularly important in large feedlots where it is difficult to feed all cattle within their natural feeding period, ie. some cattle are fed before and some fed after the preferred feeding period. Maintaining regular feeding times and modification of feeding activity aids in animals adapting to the bunk management strategy and reduces the risk of digestive disorders. This association develops into a conditioned response. Driver and Forbes (1981) offered feed to sheep regularly at the same time each day. They observed that animals become conditioned to feeding times and expected to be fed at these times. The intensity with which animals exhibit this conditioned response to feed delivery can be used as an indicator of potential feed intake (Doyle 1996). During summer, the intensity of this response or “aggression” level is best monitored during the morning feeding (Doyle 1996). Social facilitation plays an important role in the conditioned response to feed delivery and has the potential to stimulate feed intake (Corkum et al 1994 ; Coppock et al 1981 ; Curtis and Houpt 1983 ; Hsia and Wood-Gush 1984 ; Fell and Clarke 1993). Corkum et al (1994) and Coppock et al (1981) reported competition appeared to encourage animals to approach feeders and increase feed intake. Clifton and Della-Fera (1981) reported that feeding competition also altered meal size and their tendency to selectively feed (Pritchard and Statelar 1997). Cattle are selective feeders and their ability to sort corn cobs and stones from feed is evidence that their ability to select is high. Selective feeding of animals higher in the social order could influence the effective diets of all cattle in the pen, as feed remaining can vary considerably in nutritional content from formulated diet specifications (Pritchard and Statelar 1997). Bunk management strategies that encourage animals to exhibit some aggression of feeding are less selective, thereby providing improved performance or less variable performance within a pen. Grant and Albright (1997) reported that by encouraging intense feeding behaviour, feed intake and production were maximised.

Conditioning the animals to initiate feeding activity with feed delivery is best achieved by recognising that animals have preferred feeding times. This preferred feeding pattern is evidence that animals prefer to consume feed at specific times during the day (Ketelaars and Tolkamp 1992). Whitt et al (1996) compared feeding times of three feeding treatments, *ad lib* fed two times a day, 90% *ad lib* fed three times a day and 90% *ad lib* fed two times a day, and found that the act of feeding occurred in similar patterns, even though feed was provided at different times of the day and in different proportions. Feed intake of animals adapted to scheduled feeding systems is related strongly to the conditioned response of feed delivery. The ability to synchronise feed delivery with the animals natural feeding period is a critical aspect of bunk management (Doyle 1994 ; Doyle 1996). Factors that may limit the ability to deliver feed within daylight hours, eg. mill production capacity, diet dry matter and labour availability, need to be taken into consideration as daylight hours and thereby feeding behaviour changes with season. The peak feeding periods of sunset and sunrise are characterised by different patterns of feeding behaviour intensity and duration. Morning feeding behaviour is characterised by a high intensity and a short duration and afternoon feeding behaviour is characterised by low intensity and long duration (Ray and Roubicek 1971) with little feeding activity occurring during the middle part of the day (Gonyou and Stricklin 1984). Providing feed during natural feed consumption periods has the potential to improve performance and health of feedlot cattle.

2.5.3 Bunk Management Strategies

Factors to be considered when selecting a bunk management strategy are management skill, labour availability, and feed production and delivery capacity. These factors will determine the success of any bunk management strategy. There are several bunk management strategies in use in the feedlot industry today, these include *ad libitium*, restricted feeding, feeding frequently and clean bunk.

Ad libitium feeding

Providing feed *ad libitium* is the traditional method of feeding lot fed cattle. *Ad libitium* feeding allows all animals continual access to feed and is assumed to maximise feed intake and growth rate with minimal bunk management. However, associated with *ad libitium* feeding are high costs, particularly feed wastage, machinery costs and labour requirements (Goetsch and Galyean 1983). Digestive disorders are also commonly associated with *ad libitium* feeding (Slyter 1976) as animals exhibit large fluctuations in feed intake pattern. Galyean et al (1992) evaluated the effects of varying intake patterns on performance of feedlot steers fed a 90% concentrate diet. Treatments included constant feed intake, 10% daily feed intake fluctuations and 20% weekly feed intake fluctuations. Galyean et al (1992) reported that the 10% daily feed intake fluctuation treatment decreased daily gain by 6.5% and increased feed to gain ratio by 6.9%. Providing feed *ad lib* increases feeding costs (Hicks et al 1990 ; Glimp et al 1989 ; Aronen 1992) and decreases feed utilisation and efficiency (Hicks et al 1990 ; Glimp et al 1989 ; Aronen 1992 ; Meissner et al 1995). Stock et al (1995) concluded that fluctuations in feed intake associated with *ad lib* feeding are the primary cause of both digestive disorders and depressed performance.

Restricted feeding

Attempts to reduce costs while maintaining performance have resulted in alternative feeding strategies being developed. One method used to achieve this aim is to restrict feed availability during specific days on feed. A predetermined level of feed is provided to meet specific growth rates and target feed intake levels for certain days on feed. The overall objective of these strategies is to reduce feed intake fluctuations, avoid excessive wastage and increase efficiency of feed utilisation (Eng 1995). Restricted feeding has been shown to significantly improve feed conversion efficiency (Eng 1995 ; Sainz et al 1995 ; Hicks et al 1990a ; Glimp et al 1989 ; Sainz 1995 ; Aronen 1992) through a reduction in maintenance energy requirements due to decreased size of liver and small intestine (Pekas 1995), easier bunk management, less feed wastage and greater digestibility (Eadie et al 1969 ; Pothoven et al 1975 ; Eng 1995 ; Hicks et al 1990a ; Glimp et al 1989 ; Sainz 1995). Tables 2.6 and 2.7 highlight the improved performance of restricted fed animals when compared with *ad lib* fed animals. Hicks et al (1990a) reported that improvements in efficiency associated with restricted feeding include improved bunk management, greater control over feed inventories, reduced labour requirements, reduced feed wastage, reduced feed haulage, less manure handling and greater control over despatch dates.

Table 2.6: Performance of restricted fed heifer calves compared to *ad lib* feeding (Peters 1995).

	Feeding Regime	
Item	Limit fed	*Ad lib*
Initial weight (kg)	290.90	294.10
Final weight (kg)	493.20	471.40
Daily gain (kg/d)	1.27	1.14
Daily feed intake (DMkg/d)	7.54	8.69
Feed/gain	5.92	7.65

Table 2.7: Performance of restricted fed steers compared to *ad lib* feeding (Hicks et al 1990a).

	Feeding Regime	
Item	Limit fed	*Ad lib*
Initial weight (kg)	374.00	375.00
Final weight (kg)	572.00	587.00
Daily gain (kg/d)	1.27	1.36
Daily feed intake (DMkg/d)	10.13	11.98
Feed/gain	8.66	9.46

To maximise the potential of restricted methods of feeding, bunk management needs to be well defined due to higher aggression level expressed by animals compared to *ad lib* or clean bunk management strategies. Restricted feeding is limited in its ability to absorb feeding interruptions which are an ever present problem when feeding large numbers of cattle. To avoid digestive problems associated with the aggressive nature, sufficient bunk space must be made available to allow all animals access to feed at one time. Delivery of feed must also be provided regularly and at consistent times to avoid excessive aggression. Restricted feeding programs are most commonly used during the starter period as this period is characterised by large fluctuations in feed intake. Restricting feed provides control over level of feed intake (Peters 1995) and avoids large intake fluctuations.

Several different strategies have been developed in response to performance gains achieved by restricted feeding. eg. program, multiples of maintenance and plateau feeding. These strategies differ by the means in which upper feed intake limits are calculated.

- Programme feeding

Programme feeding uses an intake prediction equation based on initial weight of the animal to regulate daily DM feed intake (Peters 1995). As animals progress through the feeding period, weight based feed intake stages are set and animals are encouraged to reach these predetermined levels. Programme feeding maintains a consistent intake over the feeding period with the opportunity of maximising intake during the last 80 days on feed and improving feed efficiency (Peters 1995). Table 2.8 describes the performance differences between programme fed and *ad lib* fed steers.

Table 2.8: Performance of programme-fed steers compared to *ad libitum* feeding (Peters 1995).

	Feeding Regime	
Item	Programme fed	*Ad lib*
Initial weight (kg)	352.00	342.00
Final weight (kg)	549.00	545.00
Days on feed	134	149
Daily gain (kg/d)	1.47[a]	1.36[b]
Daily feed intake (DMkg/d)	10.04[a]	9.54[b]
Feed/gain	6.84[a]	7.00[b]

subscripts signify significance at 5%.

Dry matter intakes for desired stages on feed are derived from the following equation: Dry matter intake = $W^{0.75}$ (0.1493 x NEm - 0.046 x NEm^2 - 0.0196)

Where W is feeding weight = (required end weight - initial weight) / 2 + initial weight and Nem is net energy for maintenance provided by the diet.

- Multiples of maintenance

Multiples of maintenance (MM) is a similar feeding strategy to programme feeding, however programme feeding does not prevent over feeding (Preston 1995). MM is based on actual and predicted body weight as well as energy content of feed (Xiong et al 1991).

The following equation is used to determine the required dry matter feed intake to meet a specific MM level: Dry matter intake = {(MM x $0.077W^{0.75}$) / NEm diet}

Where W is feeding weight = (required end weight - initial weight) / 2 + initial weight and Nem is net energy for maintenance provided by the diet.

The objective of MM is to reduce variation in feed intake and control feed intake peaks (Xiong et al 1991 ; Bartle and Preston 1992 ; Preston 1995) particularly during the starter period. Bartle and Preston (1992) reported that steers with high intakes during the starter period were more likely to develop severe liver abscess and consequently reduced performance. Using MM feeding during the starting period reduced fluctuations in feed intake when compared to ad lib feeding (Preston 1995) but did not significantly effect carcass characteristics (Bartle and Preston 1992 ; Preston 1995). However, MM provided little benefit over *ad lib* feeding once animals were established on feed (Bartle and Preston 1992). Feeding MM during the first four weeks on feed have shown to improve daily gain and feed conversion compared to *ad lib* feeding (Xiong et al 1991 ; Bartle and Preston 1992 ; Preston 1995). Bartle and Preston (1992) and Xiong et al (1991) concluded improvement in performance was derived primarily from reduced digestive disorders during early period on feed.

- Plateau feeding

Plateau feeding is based on both programme and MM strategies. A level of feed intake is set for animals to reach at specific periods during time on feed.

The following equation is used to pre-determine the required dry matter feed intake levels: DM intake = $\{(0.077W^{0.75}) / NEm + (dg / 15.4 \times W^{-0.6837})^{1.0967}) / NEg\ diet\}$

Where W is feeding weight = (required end weight - initial weight) / 2 + initial weight, Nem is net energy for maintenance provided by the diet, dg is the daily gain required to meet the stage on feed and Neg is net energy for gain provided by the diet.

This regime is designed to restrict feed intake and is based on the hypothesis that feed restriction improves cell efficiency and metabolism (Peters 1995). Table 2.9 describes the performance differences between programme fed and *ad lib* fed steers.

Table 2.9: Performance of plateau fed steer calves compared to *ad libitum* (Peters 1995)

	Feeding Regime	
Item	Plateau fed	*Ad lib*
Initial weight (kg)	261.00	252.00
Final weight (kg)	515.00	510.00
Days on feed	184	204
Daily gain (kg/d)	1.38^{a}	1.26^{b}
Daily feed intake (DMkg/d)	8.31^{a}	8.13^{b}
Feed/gain	6.03^{a}	6.44^{b}

subscripts signify significance at 5%

Feeding frequency

The objective of increasing feeding frequency is to stimulate feed intake and therefore improve performance. Increasing feed consumption when feeding frequently is achieved by conditioning animals to approach the bunk as feed is delivered and through the provision of increased availability of fresh palatable feed (Prtichard and Knutsen 1995 ; Fletcher et al 1968). Research into the effects of feeding frequency has examined a number of different frequencies including twice a day (Bragg et al 1986 ; Goetsch and Galyean 1983 ; Knox and Ward 1961 ; Goonewardene et al 1995 ; French and Kennelly 1984 ; Campbell and Merilan 1961), three times (Goonewardene et al 1995), four times (Robinson and Sniffen 1985 ; Campbell and Merilan 1961), seven times (Campbell and Merilan 1961), eight times (Bragg et al 1986 ; Goetsch and Galyean 1983 ; Knox and Ward 1961) up to twenty two times a day (Gill and Castle 1983). However, the value gained from increasing the frequency of feeding needs to be balanced against the additional costs associated with machinery and labour requirements (Goetsch and Galyean 1983).

The response to feeding frequency will alter with the ability of the feedlot operator to provide feeding times regularly and within the natural feeding behaviour period of the animal. Increasing feeding frequency outside these boundaries may result in little advantage. Pritchard and Knutsen (1995) noted that although animals can be conditioned to move to the bunk and feed outside their normal feeding behaviour, which may increase feed intake, the efficiency with which this feed is utilised is unknown. Galyean (1996) compared four treatments of specific feeding times and frequency. In treatment 1 animals were fed once daily at 8am, in treatment 2 feeding was once daily at 5pm, in treatment 3 feeding was twice daily at 8am and 5pm and in treatment 4 animals were fed three times daily at 8am, 12:30pm and 5pm. All treatments received a 85% concentrate diet programme fed to provide for a daily gain of 0.8kg/d. Time of day at which feed was provided and frequency of feeding had no significant effect on feed intake, daily gain or feed conversion efficiency.

Increasing feeding frequency has been reported to stabilise rumen fermentation and improve digestive efficiency (Horton 1964 ; Sniffen and Robinson 1984 ; Robinson and Sniffen 1985 ; Sutton et al 1986 ; Bragg et al 1986 ; Goonewardene et al 1995 ; French and Kennelly 1984 ; Clark and Keener 1962 ; Burt and Dunton 1967). Greatest gains are derived from increasing feeding frequency of *ad lib* concentrate based diets (Gibson 1981) due to large fluctuations in feed intake (Hicks et al 1990 ; Glimp et al 1989 ; Aronen 1992) as well as restricted feeding strategies (Clark and Keener 1962 ; Burt and Dunton 1967 ; Goonewardene et al 1995). Diets high in roughage maintain a stable fermentation rate and gain little from increased feeding frequency (Robinson and Sniffen 1985 ; Sutton et al 1986 ; Renton and Forbes 1974 ; Johnson 1979 ; Gill and Castle 1983 ; Thomas and Kelly 1976 ; Raleigh and Wallace 1965 ; Stanley and Morita 1967 ; Ruiz and Mowat 1987 ; Charmely et al 1991). Feeding concentrate based diets more frequently reduces peaks of rumen fermentation products (Kaufmann 1976 ; Knox and Ward 1961 ; Michalowski 1979 ; French and Kennelly 1984 ; Ruiz and Mowat 1987) which are significantly correlated with feeding periods (Charmely et al 1991). Increasing feeding frequency of concentrate based diets have shown to stabilise rumen pH (Kaufmann 1976 ; Sutton et al 1986 ; Bragg et al 1986 ; Goetsch and Galyean 1983 ; Burt and Dunton 1967 ; Kaufmann et al 1980 ; Goonewardene et al 1995 ; French and Kennelly 1984 ; Ruiz and Mowat 1987 ; Charmley et al 1991), reduce diurnal fluctuations of VFA concentration (Sutton et al 1986 ; Bragg et al 1986 ; Goetsch and Galyean 1983 ; Burt and Dunton 1967 ; Kaufmann 1976 ; Michalowski 1979 ; Knox and Ward 1961 ; French and Kennelly 1984), stabilise carbohydrate and protein fermentation rates (Sniffen and Robinson 1984 ; Ruiz and Mowat 1987) and reduce rumen ammonia concentration variation (Bragg et al 1986 ; Goetsch and Galyean 1983 ; Burt and Dunton 1967 ; Michalowski 1979 ; Thomas and Kelly 1976 ; Ruiz and Mowat 1987 ; Charmley et al 1991). Reducing fluctuations of these fermentation products improves microbial protein synthesis and utilisation efficiency (Sniffen and Robinson 1984 ; Michalowski 1979 ; Attar et al 1976 ; Kaufmann et al 1980).

Improvements in animal performance with increased feeding frequency have been attributed to the reduction in rumen metabolite variation (Robinson and Sniffen 1985 ; Sutton et al 1986). Increasing feeding frequency has shown improvements in daily gain (Gibson 1981 ; Campbell et al 1963 ; Clark and Keener 1962), feed conversion efficiency (Gibson 1981 ; Fletcher et al 1968), milk fat percentage (Johnson 1979 ; Kaufmann 1976 ; French and Kennelly 1984), milk production (Campbell and Merilan 1961), feed intake (Campbell and Merilan 1961 ; Kaufmann 1976 ; Stanley and Morita 1967), and digestibility (Campbell and Merilan 1961) in both *ad lib* and restricted fed animals. Goonewardene et al (1995) however, reported increasing feeding frequency from once to twice and three times a day of a concentrate *ad lib* fed diet reduced rumen metabolite variation but had no significant effect on daily gain or feed efficiency.

Clean bunk

Clean bunk management strategies provide feeding flexibility and the potential for an equivalent level of animal performance achieved by the other bunk management strategies already discussed. Its flexibility lies in its incorporation of all factors that affect feeding and animal response to feeding and the environment. Slyter (1976) reported that *ad libitum* feeding increased the risk of acidosis due to over eating. Clean bunk management reduces the opportunity of animals to over consume by providing appropriate quantities of feed sufficient to satisfy animals level of satiety by using indicators, eg. quantity of feed remaining in bunk and animal response to morning feed delivery. Encouraging animals to clean bunk of feed at least once during a 24 hour period minimises feed wastage and labour requirements and maximises the availability of freshly delivered feed (Doyle 1994 ; Horton 1996 ; Craig 1997).

Encouraging animals to clean the bunk at midday further reduces potential feed wastage as the midday period corresponds with minimal animal feeding behaviour and natural resting behaviour (Gonyou and Stricklin 1984). Animals can be encouraged to clean the bunk of feed by midday by altering feed delivery proportions to meet quantities consumed during natural feeding activity. The natural feeding activity of cattle is characterised by peaks in activity at sunrise and sunset (Ray and Roubicek 1971). These peaks in activity are characterised by different patterns of feeding behaviour intensity and duration. The morning feeding behaviour is characterised by a high intensity and a short duration and the afternoon feeding behaviour is characterised by low intensity and a longer duration (Ray and Roubicek 1971). By altering feed delivery proportions, eg. 30-40% of total feed delivered in the morning, and the remainder of feed delivered in the afternoon, animal feed consumption can be satisfied and bunks clean for allocation by mid morning to midday. Minimising feed availability during the midday period may also encourage animals to ruminate as a strong correlation exists between resting behaviour and rumination (Wilson and Flynn 1979 ; Ruckebusch and Bueno 1978). Rumination and the consequent production of saliva plays an important role in buffering the rumen against the rapid rate of fermentation associated with grain based diets (Hibbard et al 1995 ; Galyean 1996 ; Ketelaars and Tolkamp 1992).

2.5.4 Bunk Management and Production

Growth rate and feed intake

Restricted feeding has been shown to improve daily gain and feed efficiency (Glimp et al 1989 ; Eng 1995a ; Lofgreen et al 1987 ; Murphy and Loerch 1994). Eng (1995a) reported that 15% restriction improved feed efficiency by 0.6% for every 1% restriction. However, the effect of restricted feeding on performance depends on the degree of restriction, energy content of the diet, period of restriction and at what stage in the feeding period restriction is implemented. High energy diets allow higher levels of restriction without reducing performance, however at some point intake restriction will result in depressed performance. Glimp et al (1989) compared three levels of restriction, 92.5%, 89.5% and 84% of a 90% concentrate diet fed to 9 month old Rambouillet ewe and wether lambs weighting 37.6kg. The optimum restriction level was found at 92.5%, at 89.5% feed efficiency was improved with no gain effect and at the 84% level feed efficiency was unaffected and gain was depressed. Lofgreen et al (1987) restricted feed intake to 90% and 80% of a 85% concentrate based diet fed to 318kg beef steers with no significant effect on daily gain or feed conversion and Albin and Durham (1967) restricted intake to 90% *ad lib* of a cracked sorghum diet to 111 mixed bred steers weighing 236kg resulting in a reduction in daily gain. Adjusting the period in which feed restriction is implemented provides flexibility in achieving increases in performance. Murphy and Loerch (1994) compared restriction levels on a corn silage based grower diet and a high concentrate finishing diet. Feeding regimes included *ad lib*, 80% and 90% restriction. Feed restriction at the 80% level for the finishing period (84 days) provided the best feed efficiency and daily gain. Sainz (1995) reported that limit feeding during the growing phase (237-327kg) improved feed efficiency by 27% and that final live weight gain over the finishing stages (327 - 481kg) was also improved. Hill et al (1996) restricted feed to 83% of *ad lib* for steer calves fed to a weight of 140kg after which animals received *ad lib* access to feed. During the restricted period on feed animals gained slower when compared to *ad lib* feeding, however during the *ad lib* period animals converted feed to body weight more efficiently than animals that were continually fed *ad lib* and there were no differences in carcass characteristics.

Digestion

The improvements in animal performance gained by restricting feed intake have been reported to be derived from increasing the efficiency with which available nutrients are utilised both in the rumen and GIT. Traditional methods of feeding, ie *ad lib*, are based on ensuring constant feed availability to maximise feed intake and thereby nutrient intake. Maximising feed intake increases passage rate of digesta, thereby reducing feed digestibility in the GIT (Leaver et al 1969 ; Merchen et al 1986 ; Zinn and Owens 1983 ; Zinn 1995) and increasing maintenance requirement of digestion and absorption (Zinn 1995). Koong et al (1985) reported that maintenance energy requirements for digestion and absorption is related to internal organ size. Maximising energy intake increases the mass of GIT and liver (Birkelo 1996). Heat production of liver and GIT can represent 20 to 50% of total body maintenance energy requirements (Koong et al 1985 ; Birkelo 1996 ; Cant et al 1996). Therefore, animals adapted to intakes above maintenance have a higher fasting heat production and maintenance requirement. Birkelo (1996) reported that actual maintenance energy requirement and fasting heat production increased by 13.6% and 6.8% respectively for each increase in metabolisable energy intake above maintenance. Although increasing feed intake increases energy intake, a greater proportion is utilised for maintenance (Huntington and Prior 1983).

Improvements in performance of restricted fed cattle are associated with increases in lean to fat ratio, reduction in maintenance energy requirements due to decreased liver and small intestine size (Pekas 1995 : Flauharty and McClure 1997) and improved digestibility (Murphy and Loerch 1994 ; Murphy et al 1994a ; Murphy et al 1994b). Restricting feed intake has been shown to increase retention time of rumen

(Zinn 1995), reduce rumen turnover rates and increase rumen ammonia concentrations (Murphy et al 1994a).

Carcass composition

Restricting feed is reported to reduce final live weight and total numbers reaching market specifications (Hicks et al 1990) as a result of leaner carcasses produced (Hironaka and Kozub 1973 ; Hironaka et al 1979 ; Hironaka et al 1984 ; Glimp et al 1989 ; Levy et al 1971 ; Murphy and Loerch 1994 ; Albin and Durham 1967 ; Ledger and Sayers 1977) even though feed efficiency is improved and higher carcass yields are achieved (Levy et al 1971). Restricting feed intake is associated with reduced lipogenesis and activity of lipogenic enzymes (Mills et al 1989). Murphy and Loerch (1994) reported that restricting feed intake decreased both intra muscular and sub cutaneous fat deposition as lipogenesis in bovine tissue is related directly to quantity of feed consumed above maintenance (Mills et al 1989).

2.5.5 Conclusion

The bunk management strategies reviewed, ie. *ad lib* feeding, restricted feeding and clean bunk management, differ in management level required and cost of production. *Ad lib* feeding requires a lower level of management, but costs associated with feed wastage, machinery and labour requirements are higher. Restricted feeding requires a highly skilled level of management but minimises feeding costs and improves feeding efficiency. The clean bunk management, with a midday bunk assessment is the only strategy that utilises indicators provided by the animal to determine feed requirements. These indicators, ie. feed remaining in the bunk and feeding activity level, minimises production costs, as it reduces feed wastage, machinery and labour requirements, and optimises animal performance. A successful bunk management strategy is one that takes account of all variables associated with feeding lot fed cattle, ie. rapid fermentation rate, animal behaviour and environmental influences and, at the same time, meets management requirements and performance objectives. These areas are investigated in more detail in the following sections.

2.6 SUMMARY

The objective of feeding cattle is to optimise feed intake and thereby performance, however a fine line exists between maximising production and maintaining animal health (Nocek 1996). Variation in feed intake has been recognised as the primary cause of digestive disorders, high feeding costs and poor performance (Stock et al 1995). A major factor responsible for feed intake variation includes changes in the environment, ie. incidence of heat stress, falling barometric pressure and rain events. In an attempt to control feed intake variation and thereby reduce costs and improve performance, several bunk management strategies have been developed. These bunk management strategies attempt to control feed availability to match the animals requirement for optimal performance.

There are no previous reports of comparative studies of bunk management strategies conducted under Australian commercial feedlot conditions. The objective of the study reported in this thesis was to compare a range of bunk management strategies, in terms of feeding costs and animal health and performance during the summer period under commercial feedlot conditions. The experimental section was based on the hypothesis that a feeding strategy that provides feed in quantities that match natural feeding activity and encourages animals to clean the bunk of feed at midday will give the best animal production results.