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Analysis of the potential to manipulate the rumen of northern beef cattle to improve performance

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Abstract

This project provides evidence that progress in improving liveweight gains of cattle has been limited since the 1950's. Currently used interventions that provide increased weight gain include minerals, ionophores, non-protein nitrogen, protein meals and Leucaena. There is a lack of knowledge of integrated effects of supplementary feeding strategies on profitability. The most important new developments were methodological rather than products. The capacity to understand rumen function using advanced meta-genomic methods, in which Australia has world-leading skills, will open a new era in ruminant production. Technologies that provide promise, include bacteriocins, anti-microbial proteins, fungi, exogenous enzymes, and protozoal control.

Confirmation that cattle on high fibre, low protein pastures exceed nutritional standards for feed intake and efficiency of production of microbial protein provides strong evidence for the potential to increase efficiency. A ranking tool to evaluate the economic effects of existing or new strategies was developed.

Recommendations include;

- Develop a manual for northern beef production based on report provided to MLA
- The meta-analysis of effects of bambermycin, probiotics and fibrolytic enzymes;
- An evaluation of practical means to use algae at remote sites
- Systems research into responses to supplementation and
- The development of a large project into fermentative systems that will make use of new technologies to understand and manipulate the rumen.

Executive summary

The northern production systems
This work was conducted in order identify ways in which the efficiency of beef cattle production in northern Australia could be improved by use of supplementary feeds or rumen modifiers. The target population is beef producers in northern Australia. It is this group that will benefit from the results and recommendations developed in this project.

Findings
The strengths of the system reside in the seasonal production of large amounts of poor quality pasture. These pastures are converted to marketable beef with a low energetic efficiency, providing the potential for marked improvements in efficiency. The feedlot industry benefits from the presence of the pastoral industry and is energetically efficient at converting feed to beef. There appeared to be little evidence of improvements in weight gain of cattle in the industry over the period from 1959 to 2000 and later (Chapter 5). Weight gains in the wet period are poor compared to those on temperate pasture. During the dry period weight gains are low and often weight is lost.

- Weight gain was approximately 17 to 20% higher on improved pastures in comparison to native pasture. *Leucaena* plantings can provide sufficient enhancements in growth rate to encourage wider adoption of this technology. Weight gains varied markedly with the predominant pasture type, indicating the potential for agronomic approaches to provide benefits that overcome environmental limitations to production e.g. seasonal growth, heat, cold, and humidity.

- Fertiliser expenditure on large northern beef properties was less than 1% of income (ABARE 2010 – Chapter 4). This observation suggests that sustainability aspects of the production system may require consideration.

- The feed base is very poorly defined in terms of modern feed evaluation. While many old studies (studies from 1950 to 1980) could be found, there were very few data available that provide sufficient detail for relatively sophisticated nutritional modelling.

- Supplements are widely used as identified by interviews conducted; review of literature and from evidence of expenses on forage in northern beef properties in ABARE (2010). Despite this there seems to be little consolidated and integrated understanding of the responses to the provision of supplement in the pastoral system. This could be contrasted with the levels of knowledge of production responses in feedlot cattle.

- Compensatory weight gain is a factor that deters some producers from supplementing feed or supplementing more feed. Further understandings of aspects of compensatory growth are needed.

- Survey results (Chapter 9) and literature review were consistent in providing a clear perspective on the limitations to production and industry practices in regard to supplementation.

- Evidence was elucidated from the weight gain responses observed on the pastures low in protein and high in fibre, from modelling in Chapter 10 and from literature review (McLennan 2005) that performance of cattle on these pastures exceeds that anticipated

from current nutritional standards in terms of dry matter intake and efficiency of nitrogen use to produce microbial protein, hence weight gain. This clearly indicates a need for further research to understand these mechanisms and indicates the opportunity to further improve production efficiency.

Existing Rumen Modifiers

In many cases, there was sufficient information available to provide good quantitative evaluations of the merit of these products for production, especially in feedlot diets. Data to support use on tropical pasture production systems was much less abundant, however, there was sufficient evidence to support the use of some products. The following (Table A) provides a summary of the recommendations and estimates of cost to use existing rumen modifiers.

Table A. A summary of currently available products and details of recommendations for use arising from the project; a subjective evaluation of the strength of published evidence of effect from the authors based on the quantity and quality of data reviewed; and recommended costs per head per day.

Product / Product class	Recommendation	Strength of evidence 1 low to 5 high	Use details	Estimated cost $/hd/day (300 kg animal)
Monensin	Use on feedlot and pasture	5 feedlot 2.5 pasture*	Available in water, liquid feeds, dry feed and bolus forms	1.5 to 2.5
Lasalocid	Use on feedlot and pasture	4 feedlot 2 pasture	Available in liquid feeds, dry feed	2 to 2.5
Bambermycin (Flavomycin)	There is a need for further quantitative, meta-analytical evaluation of this product. Data appear positive.	3 feedlot 2 pasture	Available in liquid feeds, dry feed	2 to 2.5
Virginiamycin	Use on feedlot. Possible use to control acidosis in loose mix preparations.	4 feedlot 2.5 pasture	Available in dry feeds	3.6 to 4.5
Tylosin	Use on feedlot. Possible use to control acidosis in loose mix preparations.	4 feedlot 2 pasture	Available in liquid feeds, dry feed	2 to 2.5
Yeasts	Needs more evidence of effect for each product as these are not generic. There is a need for further quantitative, meta-analytical evaluation of this product. Data appear positive, but very mixed.	3.5 feedlot 1.5 pasture	NA	Varies with the specific products
Probiotics/ DFM	Reduce shedding of *E. coli* O157. Production responses	4 Feedlot 3 Feedlot	NA – non generic products NA	Varies with the specific products
Essential Oils/ Plant Botanicals	Need evidence of *in vivo* effects	1 Feedlot 1 Pasture	NA	
Polyethylene Glycol	Increased production when feeds high in condensed tannins are fed	3 Pasture	-	-

*pastures include temperate and tropical (note in all cases studies on tropical pastures are limited)

Novel interventions and new technologies

The most important perspective gained from this part of the review was the explosion of knowledge into the ecology of the rumen and on fermentation technologies that has been provided by new laboratory methods developed over the past 15 years. The insights into the ecology of the rumen will allow the development of a new level of quantitative nutritional knowledge. These new skills will pave the way to new discoveries and production efficiencies.

We drew the following insights from the reviews conducted:

Bacteriocins and AMPs: The rapidly emerging field of study into anti-microbial peptides (AMP) and bacteriocins provides considerable potential to provide effective agents to control sub-populations of ruminal bacteria. However, the AMP and most bacteriocins are peptides and,

therefore, vulnerable to attack by the ruminal microbiota. The limited studies to date with bacteriocins have not identified substantial responses. The substantial investment by the pharmaceutical industry in the AMPs reflects the promise that these and the bacteriocins hold.

Bacteriophages: Studies into the bacteriophages are relatively sparse; however, many of these are from Australian workers who have seminal and important publications on the bacteriophages. The knowledge of this very substantial rumen population is still reasonably rudimentary. The bacteriophages provide opportunities for the targeted removal of bacterial populations; however, resistance to these has been noted to rapidly develop.

Transgenic Bacteria: The achievements of workers to develop transgenic bacteria have been significant and include the insertion of genes to produce bacteria with greater fibrolytic capacity, insertion of genes to detoxify flouroacetate, demonstration of a sustained presence of transgenic bacteria in the rumen and the production of cellulytic enzymes. Recently, improved means of incorporating genetic material into bacteria have been developed. The most substantial inhibition to a programme of continued development of transgenic bacterial interventions is considerations of the safety of these and societal concern about transgenic organisms highlighted in interviews.

Vaccinal Approaches to Controlling Rumen Function: There was considerable scepticism about the value of vaccinal approaches to controlling the ruminal biota expressed in interviews. However, we found strong evidence for the potential for vaccines to effectively influence the microbiota of the rumen. The evidence that ruminal protozoal numbers could be reduced by vaccination and that this resulted in production benefits in sheep indicates an opportunity to control protozoal populations. Given the failure of most other interventions to sustainably reduce numbers of protozoa, this may be worthy of investigation.

Enzymes: Fibre digestion is not maximal under normal dietary conditions. The tropical pastures are high in fibre and interventions that increase fibre digestion will be valuable. The evidence on fibrolytic enzymes was generally positive. The practical limitations of cost and method of application of the enzymes have limited the adoption of these. The potential to reduce the costs of production of enzymes and improve understandings of application may make these a valuable intervention for both the feedlot and pasture based industry.

Fungi: The critical role of fungi in fibre digestion suggests that research in this area may be fruitful. The recent development of new ARISA methods of investigation in which Australian researchers are involved suggests that understandings of the role of fungi will increase markedly as a result of further investigation. The fungi are a useful source of fibrolytic enzymes and may provide *in vivo* and *in vitro* approaches to increasing fibre digestion.

Protozoa: There is evidence that defaunation of ruminal protozoa improves the ADG of ruminants on diets high in fibre, by increasing fibre digestion and nitrogen use efficiency. The increase in microbial protein outflow from the rumen is substantial (about a 20% increase). These findings appear particularly relevant to cattle on tropical pastures. Physiological responses are less for cattle on concentrate diets, suggesting an important role for protozoa in slowing the rate of starch degradation and a potentially valuable role in reducing the risk of acidosis. The potential to increase production performance by manipulating the ruminal protozoa is present; however, considerable funds have already been invested without developing highly effective methods of achieving this.

Algae: The micro-algae are a very good source of nutrients and provide the potential to overcome some of the transport costs in delivering true protein to remote properties. The effectiveness of these as a feed is clear, however, they also have the potential to deliver specific nutrients, including particular lipids. The practical means of growing and delivering the micro-algae in concentrations that are sufficient to have a commercial effect have yet to be developed.

Genetics: The diversity of the rumen microbiota, even among cattle on identical diets, is substantial. However, there is relatively little evidence that this diversity results in marked differences in the efficiency of digestion. At this time, it appears that the focus of genetic selection programmes should be on less specific performance indicators such weight gain, rather than on measures of ruminal efficiency.

Sourcing bacteria from other species: Recent studies provide evidence that strong, mutually beneficial co-evolutionary directions provide a basis from which animals acquire bacteria. The convergence of faecal biomes of very diverse mammalian species on similar diets, indicates a co-diversification for animals and their associated microbial populations (Ley et al 2008) and strongly indicate the potential for animals to acquire beneficial bacteria. These findings and evidence that beneficial bacteria can be successfully obtained and established from other species eg *Synergistes jonesii* provide evidence of the potential for useful bacteria to be identified. The findings of Ley et al (2008) also indicate that the process of acquisition of useful bacteria from other species has been part of the successful spread of the *Bovidae*. The Camelids may be a useful source of material to examine for enhanced fibre digestion because of the similarity in digestive function to ruminants and performance on high fibre diets. There have been substantial studies looking at sources of bacteria that may benefit cattle including transfer studies from kangaroos, African ungulates and buffalo. While, the potential is there to identify useful candidates, the rumen environment is a result of the prolonged acquisition and selection for beneficial bacteria and introduction of new species into a highly competitive environment has challenges including persistence in the rumen. However, there are considerable opportunities with the new molecular identification methods to rapidly advance this field.

There was understandably a considerable diversity of opinion identified in interviews in regards to the most likely technologies to benefit the production system. We ascribe that diversity of opinion to the challenge of maintaining current awareness of developments in such a rapidly expanding area of knowledge.

Given, the potential of many of these areas of investigation to return to producers, the leadership role of Australian researchers and the rapidity of progression of the field, we consider that an integrated programme of research into fermentative technologies with a focus on the rumen would be the most appropriate direction to pursue (see Recommendations below).

Modelling

We identified important variations in the response of cattle fed on feeds high in fibre and low in nitrogen in conducting nutritional modelling. The integrated nutritional and economic model developed provides a ranking tool that can evaluate the potential return from an intervention for a property or region or for the industry. The stochastic model ranking tool allows one to consider the impacts of:

- Production responses by class of cattle (weaners, breeders etc)
- The effects of source of product through costs of transport and bulk density of the product
- Whether the product can be applied for all or part of the year
- Variations in response to treatment, costs of product, returns to producers, costs of delivery etc.
- Impacts on reproduction and mortality rates of supplementation.
- Application to different or all production systems (pasture or feedlot)

The modelling did not extend to a dynamic model to account for impacts on stocking rate, as critical aspects of data were missing to allow such a robust development. However, the model does provide an effective method to rank the value of interventions to the industry.

Recommendations

Table B provides recommendations from this project. The major research programme proposed is ambitious, but builds the foundation for a new era of nutritional research and provides great promise for the ruminant industries and others including bio-fuels and human health.

Table B. Recommendations from this project

Recommendation	Impact	Cost	Success risk	Time frame
Manual of feeding and management of northern pasture systems	High	Low	High	Short
Meta-analysis of promising technologies	Moderate	Low	High	Short
Systems research on impacts of supplementation	Moderate to high	Moderate	High	Medium
Understanding the growth dynamic (compensatory growth)	Moderate to high	Moderate	High	Medium
Algae	Moderate	Moderate	Moderate	Medium
Major research programme on rumen/ fermentation technologies	High	High	Moderate	Medium to long

List of Abbreviations

ADF	acid detergent fibre
ADG	average daily gain
AMPs	antimicrobial peptides
ARISA	automated ribosomal intergenic spacer analysis
ATP	adenosine triphosphate
BCS	body condition score
BHB	beta hydroxybutyrate
BLIS	bacteriocin like inhibitory substance
BSL	Brigalow and Scrublands
Ca	calcium
CCQ	Central coast Queensland
cDNA	complementary deoxynucleic acid
CF	crude fibre
cfu	colony-forming unit
CHQ	Central highland Queensland
Cl	chloride
CNCPS	Cornell net carbohydrate and protein system
CP	crude protein
cPCR	competitive polymerase chain reaction
CSM	cottonseed meal
CWQ	central west Queensland
DCP	dicalcium phosphate
DFM	direct feed microbial
DGGE	denaturing gradient gel electrophoresis
DM	dry matter
DMI	dry matter intake
DNA	deoxynucleic acid
DSP	disodium phosphate
EBW	empty body weight
ECM	energy corrected milk
EE	ether extract
F:G	feed to gain ratio
FCR	feed conversion ratio
FISH	florescence *in situ* hydridization
FPL	falophospholipid
FNIR	faecal analysis
FSCR	first service conception rate
G:F	gain to feed ratio
GM	genetically modified
IAMP	International Animal Health Products
IEO	International Energy Outlook
IgG	immunoglobin G
K	potassium
LAB	lactic acid bacteria
LWG	liveweight gain
ME	metabolisable energy
MICS	minimal inhibitory concentrations
MPN	most probable number
MRSA	methicillin sensitive or resistant *Staphylococcus aureus*
N	nitrogen
Na	sodium
NDF	neutral detergent fibre

NE	net energy
NNT	north of Northern Territory
NPN	non-protein nitrogen
NPV	net present value
NQ	northern Queensland
NWA	north of Western Australia
OM	organic matter
OMD	organic matter digestibility
P	phosphorous
PCR	polymerase chain reaction
PEG	polyethylene glycol
PPM	parts per million
QLD	Queensland
qPCR	Real-time polymerase chain reaction
RDP	rumen degradable crude protein
RFI	residual feed intake
RFLP	restriction fragment length polymorphisms
RNA	ribonucleic acid
S	sulphur
SCM	solid corrected milk
SD	standard deviation
SEM	standard error of the mean
SSH	suppressive subtractive hybridization
SSU	small subunit
SWQ	South west Queensland
TGGE	temperature gradient gel electrophoresis
TMR	total mixed ration
VFAs	volatile fatty acids
VRE	vancomycin resistant *Enteroccus faecalis*
WRF	white rot fungi

Contents

1 Background

1.1 Introduction

About 60% of Australia's beef cattle are in the tropical and sub-tropical regions of Australia. Production systems are designed to take advantage of conditions that allow the low-cost harvest of the rapid growth of largely unimproved pastures during the wet season, and that have declining growth and feed value outside this period. The regions are not homogenous and the challenges that face producers in these regions are consequently similar, but differently constrained. Programs that make beef production in northern Australia more cost-effective will need to reflect the environmental and logistical constraints that apply. Consequently, a focus on improving the nutritional efficiency of cattle in this area may well need to address means of improving rumen function and, particularly, the most effective means of modifying the function of the rumen.

Rumen modifiers and feed supplements are widely used in ruminant production in the more intensive industries, such as beef feedlots. Some of these technologies have been thoroughly reviewed by qualitative (Corah, 1991; Nagaraja and Galyean, 1998) and quantitative (Duffield et al 2008abc; Sargeant et al 2007; Wileman et al 2009) methods. Some of the technologies appear promising, but are not strongly supported by research trials in either intensive or extensive beef enterprises. Part of our goal was to obtain opinion and, where-ever possible data, on the interventions used on cattle and those that may emerge in the coming years.

In this project, we have identified products available in Australia that can alter rumen function; literature, published and unpublished, in the public and private domain, that specifically pertain to beef cattle (or where appropriate dairy stock), but especially studies of cattle raised on tropical or poor quality pastures; experts in the field of ruminant nutrition who would have valuable perspectives on the factors that impede production from cattle in northern Australia studies or had valuable insights in regard to new technologies or other species of herbivore.

We have been particularly interested in identifying factors that are likely to inhibit uptake of technologies in extensive beef industries, including;

i. a lack of familiarity with many of the potential modifiers
ii. uncertainty in regard to magnitude of effect and therefore, potential for cost-effective returns to producers
iii. effective methods of delivery.

As the project developed, we recognized a critical need to evaluate potential changes in transport costs as a vital factor influencing the likelihood of adoption of technologies. Evaluation of this was undertaken in the context of developing a model to value nutritional interventions.

There was a need to broadly evaluate the type of inputs that may influence ruminant production and to put these into a conceptual framework that would allow subsequent quantitative evaluation of economic responses to feed supplements or inputs of any type.

We assessed data obtained on nutritional manipulations and evaluated whether sufficient data existed to develop economic models, and, if so, to which products this could be applied. A general economic model was developed, suitable to test the potential to use products based on quantitative estimates of effect on production provided by meta-analysis and quantitative review of data.

1.2 Study context and definitions

The literature review and discussion with experts in the field led to an understanding that positioning the review appropriately would be critical to the success of the project. Firstly, the system in which interventions operate had to be defined to allow a context in which efficiency gains could be evaluated. Secondly, a definition of the factors that may influence the efficiency of rumen function was required, because there are substantial differences in costs of delivery and expectations of quantum of magnitude of response that may influence adoption of technologies in different regions.

Figure 1 provides a system model for increasing efficiency of beef production in northern Australia by manipulation of rumen function. It should be noted that a number of post-ruminal manipulations that are of value are included in this model including parasite control, growth promotants (hormonal or β-agonists), vaccination against disease and methods of improving reproductive control e.g. prevention of premature pregnancy and resultant death or culling. The inclusion of water in the model is critical as this reflects a means of controlling stock movement, grazing, treatment delivery and harvesting.

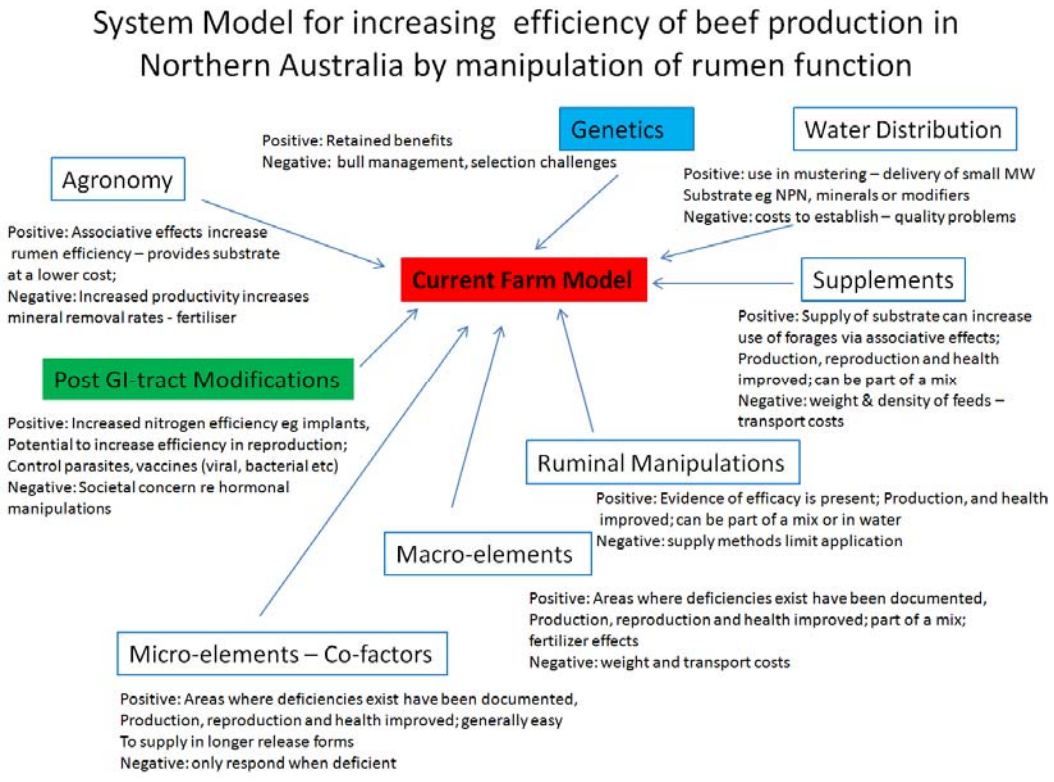


Figure 1. System model for increasing efficiency of production in northern Australia by manipulation of rumen function

The definition of efficiency used in this document is - The value of beef sold per kilogram of internally generated feed after deduction of costs of variable inputs (labour, feed, animal health costs etc). **It is recognised that different properties will have inherently different potential efficiencies that should be reflected in the capital value of the land. The focus of this report, however, is to improve the efficiency of use of the existing or potential pasture bases in northern Australia.**

The definition of nutritional products into three categories may be controversial, but is a critical component in the rationale behind this report. Nutritional manipulations of cattle can be broken down into 3 categories;

- Substrates: These are feed components that supply energy (as carbohydrates or fats) or proteins (that can be used as proteins or as an alternate source of energy). Unavailable fibre in feed has a nutritional function, but no energetic value unless required for rumen stability, when this contributes through associative effects.

- Co-factors: These include the minerals and vitamins that are essential to rumen or post-ruminal function. Most require relatively small rates of inclusion to provide the needs of cattle with the exception of the macro-minerals for which requirements may run toward 100 gm per head per day of intake in economically available forms.

- Rumen modifiers: These fall arguably into two categories – those that suppress populations of rumen microbes (antimicrobial actions) or those that favour or supply other rumen microbes (probiotics). Distinctions blur between these two categories as favouring one population of organisms will inherently not favour some others. A practical differentiation that may have more value in categorizing rumen modifiers is those that are, or have been, used in human medicine and those that have no value in human medicine (beyond that of improving protein supply to the human population).

Typically, substrates are provided in relatively large amounts, whereas the rumen modifiers are supplied in relatively small amounts and the co-factors are intermediate to small. This distinction in amounts required to alter rumen function may greatly influence the regions and methods in which, and by which, technologies are applied.

We recognize that there are threshold amounts of production performance that will provide cost-effective solutions for producers. Hunter et al (1993) calculated that the efficiency of retention of feed metabolisable energy in carcases sold from northern beef cow-calf enterprise may be as low as 2 to 3%, based on a series of assumptions. The assumptions used by Hunter et al (1993) may be conservative, as costs of exercise and weight loss for stock and gain were not explicit. Consequently, the percentage of retained feed energy may be lower than that estimated by Hunter et al (1993). However, particular, technologies or the application of a series of complementary technologies that allow weight grains to be sufficient to reduce time to sale by a season, and that reduce time to first successful weaned pregnancy by a season, or increase weaned pregnancy rates markedly have especial value in improving the efficiency of feed energy retention and potentially economic efficiency from the enterprise. A goal of this project is to identify strategies that may markedly increase the efficiency of production.

2 Project objectives

The objectives of this study were to:

- undertake a literature review and consult with technical experts both nationally and internationally to identify options to manipulate the rumen function of beef cattle in northern Australia to improve productivity
- review the role of currently used and novel nutritional additives such as Protexin®, polyethylene glycol (PEG), yeasts, ionophores, antibiotics, etc, and evaluate their potential to improve digestive efficiencies in grazing situations

- provide a summary of the current additives used in grazing and feedlot animals, including dose rates, potential liveweight gains, cost benefits and situations in which these can be used cost effectively
- investigate other species of herbivore such as the water buffalo, banteng cattle, camel and native animals that have successfully adapted to the nutritional environments of rangelands of northern Australia and outline the reasons for their successful adaptation and opportunities for rumen manipulation in beef cattle
- evaluate and document the complexity, feasibility, delivery horizon, production benefits, indicative costs and probability of success of potential technical solutions
- create a model to assess the priorities for future scientific investigations, if indeed sufficient evidence is available to support further research
- document and justify high priority areas for future research.

3 Methodology

3.1 Literature review

In order to address the objectives of this study, comprehensive literature searches were conducted to obtain the necessary information and data. The aims of the literature searches were to evaluate qualitative studies and reviews on new technologies, technologies in use, and on aspects of production performance of northern beef cattle and to obtain data that could be used to quantitatively assess the efficiency of current technologies and production practices. Published papers and abstracts mainly in English, but some in other languages, internal (SBS*cibus*) and external reports, from 1959 to 2010, were identified by:

i. computerised literature searches (electronic databases)

- Goggle scholar
- CAB (Commonwealth Agricultural Bureau)
- BA abstracts (Biological Abstracts)
- PubMed (http://www.ncbi.nlm.nih.gov./entrez/query.fcgi)
- Scirus (http://www.scirus.com/srsapp)
- Sciencedirect (www.sciencedirect.com)
- Agricola (http://agricola.nal.usda.gov)
- Life sciences
- VEIN (http://vein.library.usyd.edu.au)

ii. hand searching (library searches of relevant journals for published papers and conference proceedings that were not available online)
iii. checking references (cross-referencing citations in papers obtained)
iv. review of citations from review papers
v. personal communication, especially through the structured and unstructured interviews conducted in association with this project, including:

- communication with the authors of identified papers and scientists who have been working in the relevant field of study
- communication with industry bodies (e.g. MLA, ABARE), scientific institutes (eg CSIRO), manufactures and distributors of the products.

Due to the varied nature of the objectives of this study, the inclusion criteria were broader than might usually be considered for quantitative literature review. Many of the published studies and abstracts lacked rigour of study design, particularly in areas of production responses and

responses to supplement. These studies of the productivity of grazing cattle in northern Australia often lacked sufficient information on the review subject, including on pasture species, breed or class of cattle and season.

It was not feasible to find every relevant study for all the aspects of the production system and technologies investigated in this project. Many studies that we were aware of were not published in peer reviewed journals, or even proceedings, and may not have been indexed in electronic databases such as CAB or Pubmed.

In these reviews, we attempted to:

- be comprehensive,
- minimise bias
- be efficient.

We reviewed more than 3000 papers, abstracts, reports and reviews, and selected or considered studies that had sufficient information and/ or data pertinent to the aims of this project.

There were a considerable number of recent published papers and reports that comprehensively reviewed the new technologies and their implications for the northern production system. In some cases, we relied on good, comprehensive, recently published reviews to provide material on which to base quantitative estimations of effect or from which objective understandings of the potential for benefit could be derived.

3.2 Survey and economic model

The methodologies that were used for the survey and economic modelling are provided in Chapters 9 and 10, respectively.

4 Nutrition and productivity of beef cattle in northern Australia

The intent of this section of the review was to provide a very brief overview of the pastoral beef production system of northern Australia and to focus on studies that provide detailed information on the nutritive value of pastures and on the performance of cattle on the beef enterprises in these regions. The northern beef industry is a major employer in northern Australia and cattle production is the major form of land use in this region (ABARE 2009; Turner 1975). Australia is the world's second largest exporter of beef (ABARE 2009) and live cattle exports from the northern beef industry are also substantial.

4.1.1 Tropical beef production and nutrition

It was not our intention to provide a comprehensive review of the literature relevant to describe beef production in northern Australia. During the process of researching this project we found many documents of value. We include, at the end of this report, a bibliography of further reading of papers that we consider to be important in describing the system. We have concluded that a crucial future research task is an effective synthesis of existing literature through a quantitative review process (see Chapter 5). The methods used in this project were based on the premise that quantitative estimates of response were most critical to determine, whether these were based on a physiological response or a production response.

About 60% of Australia's beef cattle are in the tropics and sub-tropics. Less than 5% of the pastures in these regions have been improved with fertilisers and introduced pasture species. Recent economic data (ABARE 2010) indicates that total expenditure on fertiliser for large and medium beef properties in northern Australia rarely exceeded an average of $10,000 during 2007-2008. The advantages of this system are the low cost of pasture, while the disadvantage is the great variability in pasture production reflected in a marked variation in growth and development of animals.

The major constraints to production are:

- under-nutrition, both in amount and quality of feed
- costs of management inherent to such extensive properties
- heat stress
- parasites and disease.

Poppi and McLennan (1995) reviewed major limitations to the beef production system arising from deficiencies in the energy and protein content within the dominant pastures of the northern beef industry and explored the interactions between these major nutrients. However, the profitability of beef production systems in northern Australia also depends on adequate levels of pasture production. The low availability (at times) and low nutritive value of pastures, especially during the dry season, ensures that without some form of supplementation most animals will lose weight during this period. Deaths occur during extended dry periods, especially in more susceptible groups, such as weaners and breeders. A critical determinant of feed availability is the stocking rate and, inherently, attitudes to the risk of underfeeding cattle. The variability and seasonality for pasture growth is well demonstrated in Figure 2 from the Queensland Government report on the State of the Environment (2007). This risk of overstocking, whether systematically or on a more limited basis when conditions are very adverse, must be viewed as structural. Despite these risks, stocking rates are often extremely low, with many hectares being allocated to a single animal (Tothill and Gillies 1992). The latter observation stresses the importance of grazing management under conditions where the energy loss from exercise during grazing or obtaining water will become significant determinants of performance.

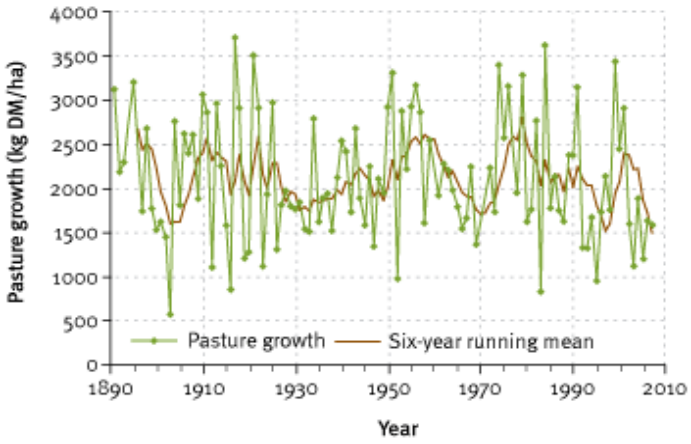


Figure 2. Estimated Pasture Growth in northern Australian from 1890 to 2010 (http://www.derm.qld.gov.au/environmental_management/state_of_the_environment/state_ofthe_environment_queensland_2007/state_of_the_environment_queensland_2007_contents/land_pasture_production_and_condition.html)

Figure 3 provides further insight to the structure of the industry. Figure 3a from Hamlin (2001) displays livestock density in Australia, whereas Figure 3b from ABARE (2009) displays the scale of enterprise. Clearly, while stocking rates are lower in northern Australia, scale of enterprise is far greater.

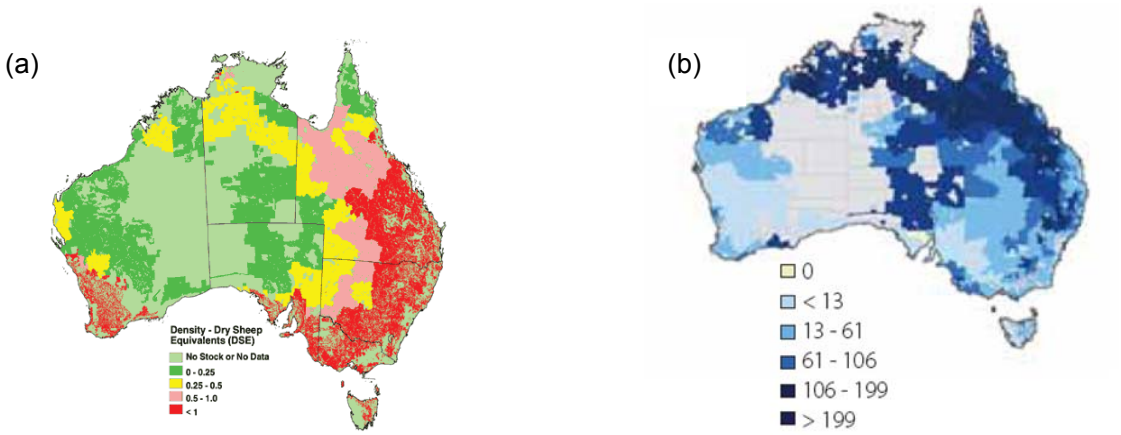


Figure 3a. Australian livestock density (Source: Hamlin 2001) b. Scale of enterprise (Source: ABARE 2009)

In contrast to pasture-based production, feedlot production has a high capital and high variable cost. Of necessity, feedlots are sited closer to the grain producing regions of Australia, because costs of transport greatly increase the costs of feed and reduce the cost efficiency for those further away from grain growing regions. Feedlot systems rely on a markedly different efficiency of feed intake to gain to be cost-effective. The pasture and feedlot systems are complementary; the pasture- based systems generate stock to finish in the feedlots.

There are several areas that we identified as being relatively poorly described in the northern pasture-based beef production system that are the subject of particular review in this document. These were all critical to the development of understandings in regard to the likely response to rumen modification or supplementation. These include quality of forages available to grazing stock, quantitative review of typical weight gain responses for cattle in northern Australia,

quantitative review of reproductive responses to weight gain, and aspects of compensatory weight gain.

4.1.2 Pasture and feed quality: Northern Australia

In extensive systems, pasture quality largely determines production responses to nutrition. In northern Australia the quality of native pastures is usually low. High rainfall and leaching keep essential nutrients, especially nitrogen, low in the soil profile, and plants are, therefore, usually low in protein. The wet, monsoonal zone native pastures have high levels of structural carbohydrates (Minson 1990). The plants have high cellulose and lignin contents, and low digestibility, making it difficult for stock to obtain sufficient energy for rapid growth. Many of the soils are low in phosphorus, and the plants usually have also low phosphorus content. Reviews of the role of phosphorus in the nutrition of northern Australian cattle production system include Jubb et al (1993), McCosker and Winks (1994), and Ternouth (1990) Miller et al (1997).

4.1.2.1 Native pastures

Native pastures will sustain relatively high liveweight gains for only 2–3 months, and subsequently, only maintenance or loss of weight for cattle due to the rapid early growth and associated high cell wall content of the pastures. Poppi and McLennan (1995), however, also note the relatively poor weight gains of cattle on the wet season tropical pastures in comparison to the performance of cattle on temperate pastures.

The species composition and growth of native grass communities in northern Australia is primarily determined by the moisture available to the plants. The seasonality of rainfall, drainage, and propensity of areas to flood, all affect the distribution of native grass species. Native legumes and forbs form only a minor part of the pasture communities, although they may be locally significant during their short growing season. The dominant native pasture types are a mixture of fast-growing perennial medium height grasses and medium and taller species (2–3m), which increase as the rainfall and length of growing season increases from south to north. Local ground cover can vary considerably in dominant species and relative density, generally in response to soil moisture, and to a lesser degree soil fertility. Perennial grasses are more nutritionally valuable for a longer period of the year than the tall growing annuals.

Native pasture species are generally not capable of withstanding heavy grazing pressure because of their:

- low dry matter production
- short growing period
- low nutritive quality, particularly during the dry season
- low to medium palatability
- inability to withstand frequent or intense defoliation.

4.1.2.2 Improved pasture

Improved pastures may consist of an introduced grass, an introduced legume or a mixture of both, sown on cleared land in a well-prepared seedbed. The growth of improved pasture in these regions depends on the availability of adequate soil moisture and fertility, the care taken at planting and appropriate sowing rates at establishment. Improved pastures can provide:

i. greater pasture stability under higher stocking density than native pastures
ii. a full sward of palatable species
iii. greater dry matter production
iv. better nutritive quality, especially during the dry season
v. species adapted to intense and frequent defoliation.

Some of these pastures can be established for special purposes, including:

i. feed for stock that will benefit most from better nutrition
ii. conservation as hay or silage
iii. reclamation of degraded areas
iv. protection of holding paddocks and laneways that are subjected to heavy grazing
v. legumes in rotation
vi. seed production.

There are three main improved pastures types in northern Australia:

i. **legumes**: The main pastures in this category are Stylo (Townsville, Verano), perennial stylo (Graham, Cook, Endeavour, Schofield, Seca, Fitzroy), Calopo, Phasey Bean, Siratro and Centro
ii. **grasses**: The main grasses used are Pangola grass, Signal grass, Guinea grass, Gamba grass, Para grass, Hymenachne, Buffel grass and Sabi grass
iii. **Leucaena**:

Since the decimation of Townsville Stylo in the 1950's, new perennial Stylos have been introduced, including Verano, Amiga and Seca Stylo. Effects of Stylos on animal production can be substantial. Instead of losing liveweight in the dry season, cattle can continue to gain weight for up to 46 weeks, resulting in an extra 20–30 kg weight gain per head.

Leucaena was identified as a key technology that would provide benefit to the northern beef industry if more widely adopted (See Chapter 5). Leucaena represents a special case of an improved species. *Leucaena leucocephala* ssp*. glabrata* cultivars have been established for pasture on more than 200,000 ha in Queensland. Smaller commercial stands have also been established in the Northern Territory and the Kimberley region in Western Australia. In combination with grass pasture, Leucaena is now recognized as one of the most productive and sustainable tropical free-grazing cattle forage systems. Leucaena pastures are also being established in southern Queensland and northern New South Wales in areas previously thought to be too cold (http://www.leucaena.net/leucaena.htm).

The Leucaena grazing system in adapted environments provides a combination of valuable attributes:

i. The material selected has very high nutritive value (digestibility, crude protein and essential nutrients) compared to other tropical forages. This allows much faster weight gains (See Chapter 5) and turn-off rates that lead to greater profitability and flexibility in marketing beef cattle.
ii. It is a long-lived system that, while costly to establish, can remain productive for 30–40 years with minimal maintenance.
iii. It is a deep rooted system, providing green forage longer into the dry season and drought than conventional grass-based grazing systems. Recent drought conditions have highlighted how Leucaena can reduce the cost of drought supplements (http://www.leucaena.net/leucaena.htm).

Environmental benefits also accrue from Leucaena plantings. Nitrogen fixation in the soil improves soil fertility and promotes better grass growth. Growth in association with a vigorous and adapted grass (e.g. Buffel, Rhodes, Green Panic) will prevent soil erosion. The deep rooted habit of Leucaena reduces the potential for deep drainage and the movement of saline soil water that causes dryland salinity. Being a woody-stemmed tree, Leucaena acts as a carbon sink by sequestering significant amounts of carbon from the atmosphere. Methane emissions from cattle grazing Leucaena are substantially lower than from cattle grazing tropical grasses, probably due

to the high digestibility and condensed tannin content of Leucaena forage (Dixon and Coates 2008).

A long and productive life of Leucaena is a key contributor to profitability (Shelton and Dalzell 2007). A long-term study of persistence under grazing of individual trees grown in a grid pattern with companion-sown grass on well drained alluvial soils at Samford, south-east Queensland (1100 mm average annual rainfall) revealed average tree survival rates of 89% at 16–20 years, 82% at 25–29 years, 76% at 31–35 years and 74% at 37–41 years after planting, respectively, (Jones and Harrison 1980; Jones and Bunch 2000). These pastures experienced on average eight frosts each year (many <-3^{o}C), were periodically slashed in winter and received a total of 440 kg phosphorus (P)/ha applied between 1959 and 1996 (Noble et al 1998).

Radrizzani et al (2010) conducted a survey on long-term productivity of Leucaena (102 Queensland graziers identified from the membership list of The Leucaena Network). The survey results showed a decline in Leucaena productivity in 58% of aging pastures, and declines in grass growth (32%) and livestock productivity (42%) associated with declining Leucaena growth. Leucaena decline was greater in soil types of marginal initial fertility, particularly brigalow clay, soft wood scrub, downs and duplex soils. Maintenance fertiliser was not applied to most (98%) Leucaena pastures surveyed despite significant amounts of nutrient removal, particularly phosphorus and sulphur, occurring over prolonged periods of moderate to high grazing pressure. They predicted that large areas of Leucaena pasture will continue to suffer soil nutrient depletion under current management practices. Leucaena contains an amino acid, mimosine. Both mimosine and products of hydrolysis, 3-hydroxy-4 (1H)-pyridone (3,4-DHP) are toxic to cattle.

4.1.3 Definitions of dominant pasture communities in the beef regions of northern Australia

There have been several attempts to consolidate approaches to broadly categorising the production regions of the northern beef industry (Tothill and Gillies 1992; Hamlin 2001; Bortolussi et al 2005). We have used these to provide an efficient examination of the dominant pastures in the regions and a framework to evaluate data available on the nutritional values of these pastures. **Notwithstanding ample evidence of high fibre, low protein, very variable and often low mineral content, having detailed pasture analysis is an essential step towards understanding the likelihood of responses to rumen manipulation or supplementation**.

We adopted the following regional definitions from Hamlin (2001) in preference to the later definition of Bortolussi et al (2005) on the basis that these are more inclusive criteria, including areas outside of the northern zone, and provide subdivisions in the Northern Territory that have value in examining the feed base. Unfortunately, more recent data on stock numbers for these regions were not found.

Table 1 taken from Hamlin (2001) compares some of the features from the Tothill and Gillies (1992) and Wilcox and Cunningham (1994) studies with those undertaken for the National Land and Water Resources Audit (2001) and others. Figure 4 in Chapter 5 also highlights the regionally dominant pastures.

Table 1. Comparison of animal numbers and estimates of rangeland land degradation, early and late 1990s

Regions	Major vegetation types	Estimated stock numbers (1993)
Kimberley Pilbara	Eucalypt woodland, various grasslands, Sorghum australiense, spinifex with bare ground	643,000 cattle, some sheep in central-south, (WA Bushlands)
Darwin-Gulf	Kangaroo-grass, perennial sorghum grass, spinifex, some Mitchell grass patches	232,000 cattle

Victoria River and Barkly Tableland	Mitchell grass and bluebush, soft Spinifex	384,000 cattle (Victoria River) 457,000 cattle (Barkly Tableland)
Alice Springs	Spinifex predominates, some mulga with annual grasses	297,000 cattle
Cape and Gulf	Low eucalypt woodland with various grass types	586,000 cattle
North East Uplands, Queensland	Eucalypt woodland, brigalow, bluegrass treeless plains. Black speargrass, Aristidaspp., Mitchell and soft Spinifex	1.2 million cattle and 2.2 million sheep
Western Plains Queensland	Extensive grasslands, mulga, gidgee, other Acacia woodlands, Spinifex	2 million cattle and 8 million sheep
Western Division NSW (Far Western Plains)	Mulga woodland, box and cypress pine, mallee woodlands, floodplain grasses, saltbush and bluebush	137,000 cattle and 5 million sheep
WA Bushlands (south and east of Pilbara to Nullarbor)	NW-SE tussock grasses and acacias, mulga, mallee eucalypts, chenopod shrubs	2.5 million sheep, few cattle
Northern South Australia	Low shrublands and mulga to north, saltbush, bluebush, grasses and acacias to south	137,000 cattle north of dog fence, 1.3 million sheep south of dog fence

Sources: Wilcox and Cunningham (1994); Tothill and Gillies (1992); Hall et al (2001); NLWRA rangeland grazing pressures project (unpublished); Waters and Rivers Commission (1997); Kerin and Hyder Consulting (2000); State of Queensland (1999); Pople and Grigg (1999); SA Department of Environment, Heritage and Aboriginal Affairs (1998); EPA NSW (2001).

4.1.4 Nutritive values for pastures used in northern beef industry

The search for nutritional information on both native and improved pastures was a key focus of the literature searches conducted during this project. Detailed literature searches found only limited quantitative data on the nutrient composition of the most important forages. The majority of these data were dated. While there are unlikely to be substantial changes in these pastures, the detail required for nutrition models has increased as have methods of nutritional analysis. The only data identified that provided relatively detailed nutritional analyses of pastures or hay were two MLA reviews (McLennan et al 2002; Poppi and Quigley 2009). The analyses obtained from these reviews are used in Chapter 10 to provide a validation for the modelling approaches in this review.

Sources that provided information on the nutritional composition of the northern pastures include Wesley-Smith (1972; 1989; 1993) and Wesley-Smith and Ford (1982), who examined native and improved pastures at the end of the wet and dry seasons in the Northern Territory, specifically the Katherine and Adelaide River regions (Table 2).

Table 2. Pasture quality average at Katherine and Adelaide River (Wesley-Smith 1989)

Pasture quality (% DM)	End of wet		End of dry		Maintenance levels required
	Native	Improved	Native	Improved	
Crude protein (%)	3–6	8–10	1–3	4–10	7.0
Phosphorus (%)	0.03–0.05	0.09–1.4	0.02	0.04	0.12–0.18
Digestibility (%)*	30	45–60	30	40–50	50

* Digestibility data obtained from Adelaide River only

Other older sources of information on northern pastures include Gartner et al (1980), who provided information on the mineral composition of older pastures, and Minson (1990), who

provided a detailed review of the nutritional value of tropical pastures, some basic information on tropical and temperate grasses and legumes and some excellent, but generic, data on the mineral content of tropical pastures and legumes. Similarly, Humphreys (1991) provided information on the protein, carbohydrate and mineral content of tropical pastures that is useful, but basic.

Hamlin (2001) and Bortolussi et al (2005) and information from the tropical forages CD Rom (Cooke et al 2005) were used to identify the major grass species used in the northern beef industry. These are listed in Table 3. In order to evaluate and model the likely responses to supplementation, as much information as possible on the nutritional value of these pastures was sought.

There are reasons for the lack of comprehensive feed analysis of pastures used in the northern beef industry, including awareness that cattle rarely feed solely on a dominant species of pasture and that the extensive nature of the system has limited adoption of nutritional analytical methods in more common use in more intensive production systems, including feedlots. The difficulty of measuring the mix of ingested pastures is reflected in the development of near infrared reflectance spectrometry methods to assess the dietary intake of cattle from faecal analysis (FNIR) (MLA 302/ 320). Despite obvious strengths to the FNIR approach, detailed analyses of dominant pastures provide a basis for provision of supplementary feeding, through providing an understanding of the carbohydrate, protein and lipid structures. Further, there is the potential to understand the exposure to the risk of cattle for mineral and vitamin deficiency.

Forages in Northern Australia are generally low in nutritive value and poorly digestible. Limited quantitative data on nutrient composition of these forages is available and the majority of this is dated; hence, there is a requirement to quantify the current nutritive composition of dominant forages in Northern Australia (Table 3). Nutritive value is often highly variable from the start to the end of the growing season. The majority of the pastures described in Table 3 are tolerant to drought, low soil fertility and heavy grazing.

Table 3. Summary of nutritive value, palatability, strengths and weaknesses of common forages grazed in Northern Australia (Source: Leche et al 1982; Cooke et al 2005)

Common Name	Scientific Name	Nutritive Value (% DM)	Palatability	Strengths	Limitations
Buffel grass	*Cenchrus ciliaris*	CP[1] – 9.8 ± 0.6 CP digestibility 50-60% Ash – 11.8 ± 0.4 EE[2] – 1.3 CF[3] – 30.0 ADF[4] – 40.1 ± 0.3 OM[5] – 88.3 ± 0.4 Ca[6] – 0.3 P[7] – 0.1 Lignin – 8.9 ± 3.0	– Moderate to good palatability	– Persistent – Very drought tolerant – Quick to respond after rain – Widely adapted	– Requires high fertility for production – Intolerant to prolonged water logging – Moderate to high oxalate levels – Fluffy seed difficult to sow – Invasive and competes with native pastures
Speargrass	*Heteropogon contortus*	CP – 3.8 ± 0.5 Ash – 7.1 OM – 9.3 ADF – 22–32 P – 0.09–0.15 Ca – 0.23–0.3	– Palatable in early vegetative stages otherwise only consumed with urea and molasses	– Adapted to low fertility soils – Palatable when young	– Intolerant of water logging and heavy grazing – Quality declines with maturity
Mitchell Grass	*Astrebla* spp.	CP – 5.8 Ash – 10.7 CF – 36.1 OM – 89.3 Ca – 0.3 P – 0.1	– Poor palatability in the wet season – Eaten in the dry season	– Very drought tolerant – Good stand over feed – Grows well in heavy cracking clay soil	– Not very palatable
Callide Rhodes grass	*Chloris gayana*	CP – 17 (young leaves) – 3 (old leaves) P – 0.4–0.1 Na - 300–3100 ppm (variety dependent)	– Young growth very palatable – Tetraploids consumed in preference to diploid varieties	– Widely adapted – Easily established – Early nutritive value – High salt tolerance – Tolerant of heavy grazing – Good seed production	– Short season of nutritive peak in many cultivars – Fluffy seed difficult to sow – Poor adaptation to acid, infertile soils – Need high fertility to persist
Kangaroo grass	*Themeda triandra*	Digestibility 54–75% CP – 5-17	– Becomes coarser with maturity – Highly palatable	– Adapted to a range of soil types , salinity tolerant – High drought tolerance	– Intolerant of heavy grazing
Bluegrass	*Bothriochloa spp.*	CP – 7–14 Ca – 0.325	– Palatable when young	– Adapted to low fertility – Drought tolerant – Tolerates heavy grazing	– Unpalatable at maturity

Common Name	Scientific Name	Nutritive Value (% DM)	Palatability	Strengths	Limitations
Spinifex	*Triodia* spp.	CP – 5.0 ± 1.1 Ash – 7.4 ± 0.5 EE – 5.6 CF – 34.2 ± 1.4 OM – 92.5 ± 0.5 Ca – 0.2 P – 0.1	– Not very palatable		
Mulga	*Acacia aneura*	CP – 14.7 ± 1.4 Ash – 4.9 ± 0.4 EE – 2.5 ± 0.5 CF – 29.8 ± 1.8 OM – 95.1 ± 0.4 Ca – 1.0 ± 0.1 P – 0.1 Lignin – 19.4	– Low	– Drought tolerant – Allows growth of understorey – Long lifespan	
Townsville stylo	*Stylosanthes Humilis*	CP – 11.5 OM – 94.3 P – 0.1	– Palatable	– Tolerates heavy grazing – Adapted to a wide range of soil types	– Unreliable production – Vulnerable to anthracnose damage and diseases in wet conditions
Kazungula	*Setaria sphacelata*	High Na content CP – 6–20 DM digestibility 70% in 3-week old re-growth	– Extremely palatable when young, declines with maturity	– Tolerant of sandy, stony soils – Hardier and more adaptable and more drought resistant than other cultivars	– Prefers soil pH 5.5–6.5 – High oxalate content
Nandi	*Setaria sphacelata*	CP – 6–20 DM digestibility 70% in 3-week-old re-growth	– Extremely palatable when young, declines with maturity	– Tolerates water logging – Heavy spring/summer seeding reduces feed quality. – High oxalate levels – Not very drought tolerant	– Prefers soil pH 5.5-6.5 – Requires medium textured fertile soils – Slow establishment
Narok	*Setaria sphacelata*	Lower Na and oxalate content than other cultivars CP – 6–20 DM digestibility 70% in 3-week-old re-growth	– Extremely palatable when young, declines with maturity	– Heavy spring/summer seeding reduces feed quality – High oxalate levels – Not very drought tolerant	– Prefers soil pH 5.5–6.5
Splemdida	*Setaria sphacelata*	CP – 8.5 P – 0.33 K – 4.94 Ca – 0.20 Na – 0.06 Mg – 0.18 Cl – 1.14	– Palatable	– High quality feed – Good for cut-and-carry – Tolerates poor drainage – Survives in low fertility	– Low sodium content – High oxalate levels – Must be propagated vegetatively

[1]CP, crude protein; [2]EE, ether extract; [3]CF, crude fibre; [4]ADF, acid detergent fibre; [5]OM, organic matter; [6]Ca, calcium; [7]P, phosphorous

5 Liveweight gain of cattle and supplementation in the north

5.1 Liveweight gain of grazing beef cattle

This review of liveweight gain responses of beef cattle in the northern Australia was conducted to provide validation for the modelling undertaken in this report and quantitative information on the effects of pastures (native or improved), breed (cross-bred, *Bos taurus* and *Bos indicus*), class of cattle (breeders, steers, bulls, heifers, calves and weaners) and season (dry and wet) on the productivity of cattle in the northern grazing system. The marked seasonal fluctuations in feed supply and pasture quality, and consequent pattern of wet season liveweight gain and dry season liveweight loss, until animals reach a marketable weight, were important to document.

Many studies have investigated pasture quality, weight gain of cattle and impact of supplementation in northern production systems during the past four decades. We reviewed more than 500 papers, proceedings abstracts and reports from 1959–2010 and extracted data from 160 studies; including peer-reviewed published articles, surveys, proceedings abstracts and research reports by the State Goverments, MLA and CSIRO. Data from individual studies within papers were extracted and compared with similar studies from other sources for presentation in the tables and figures presented in this Chapter. Sources included review papers/reports (Holroyd and Rourke, 1988; Bortolussi et al 2005abcde; Dixon 1998 -Report to MLA; Beef cattle Performace in north Australia 2000; Rickert and Winter 1980; Sullivan and Rourke 1997; Wesley-Smith 1989; Lindsay et al 1989; McCosker and Winks 1994; Radrizzani et al 2010).

5.1.1 Historical data preceding 1980: Regional influences: Dominant pasture types – A review of performance

In order to examine changes in performance over time, data from a review conducted by Rickert and Winter (1980) are summarised in Table 4. Rickert and Winter (1980) reviewed beef cattle production in northern Australia on the basis of evaluating performance in four distinctive environments defined by dominant plant species:

i. Tropical Tall Grass
ii. Northern Spear Grass
iii. Southern Spear Grass
iv. Brigalow and Scrub Lands (BSL) (Figure 4).

Beef cattle production in the first three zones relies largely on native pastures, while in the BSL zone improved and sown grasses are widely used. In all zones, beef cattle demonstrate a seasonal pattern of liveweight gain that reflects changes in pasture quality. These findings highlight the complexity of beef production in northern Australia.

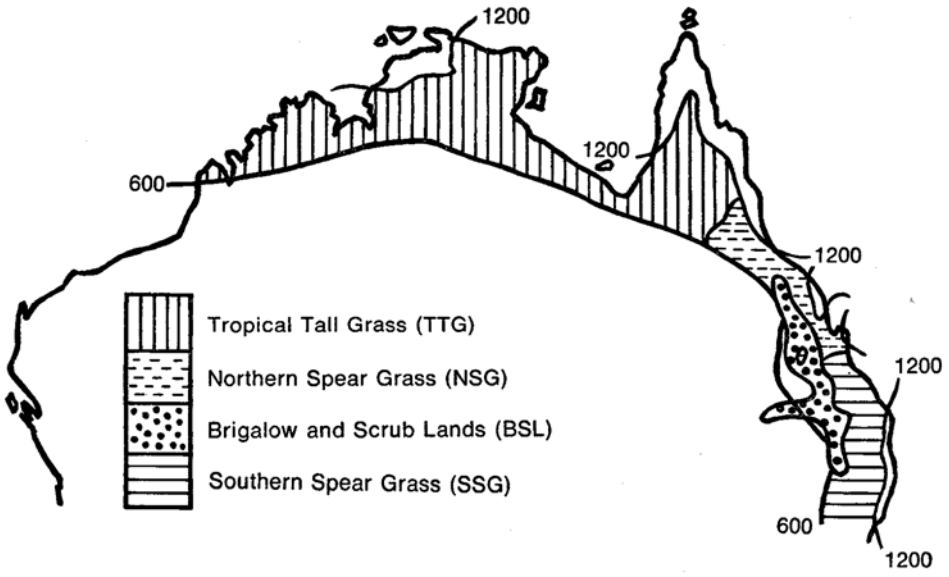


Figure 4. Zones of extensive beef cattle production in northern Australia receiving 166–1200mm rainfall per year (Source: Rickert and Winter 1980)

Table 4. Annual liveweight gain (kg/head or kg/ha) of cattle from four pasture types in four zones of northern Australia (Source: Rickert and Winter, 1980)

Pasture type	Zone											
	Tropical Tall Grass (hot monsoonal)			Northern Spear Grass (warm monsoonal)			Southern Spear Grass (cool sub-humid)			Brigalow and Scrub Lands (cool subhumid)		
	Kg/hd	Kg/ha	Source*	Kg/hd	Kg/ha	Source*	Kg/hd	Kg/ha	Source*	Kg/hd	Kg/ha	Source*
Clear native pasture	49	6	1	33	13	2	83	25	3	190	101	6
				100	35	16	110	33	4			
							120	30	5			
Native pasture oversown with a legume	55	24	12	104	33	7	143	106	8	Generally not applicable		
				40	16	2	121	93	3			
							103	54	9			
Native pasture oversown with legume and superphosphate applied	100	83	12	123	50	2	149	148	3	The relatively fertile soils support sown grasses and few legumes persist under grazing		
				122	58	7	111	61	9			
							92	107	9			
							120	100	5			
							146	136	4			
							154	129	8			
							167	245	8			
Fully sown grass or grass-legume pasture	130	260	13	170	200	15	160	160	5	178	204	10
							17	146	4	161	172	6
							183	150	14	195	195	11
							130	106	14	230	286	11
										220	275	11
										150	186	11

Sources: Norman, 1965; Winks et al 1974; Shaw and ‘t Mannetje 1970; Tohill 1978; ‘t Mannetje 1978; Coaldrake et al 1969; Gillard 1979; Bowen and Rickert 1979; Shaw 1978; Coaldrake and Smith 1967; Silvery 1978; Winter et al 1978; Evans et al 1978; Bisset and Marlow 1974; R.J. Jones (pers. Comm.); Winks (pers. Comm.)

5.2 Performance

Our initial aim was to explore liveweight gain of different breeds (*Bos taurus, Bos indicus*, cross-bred) and classes of cattle, grazing on different pasture types and under various environmental conditions. However, due to a lack of detailed and specific information in many studies, this goal was not achieved. Some studies reported the liveweight of cattle, but because the duration of the trials was not reported, we were unable to use these data. The data obtained from abstracts, proceedings and reports often lacked sufficient information on the class of cattle, season and type of pasture. Seasons were estimated from the dates provided in these studies, without specific knowledge of the onset of the wet (or dry) periods for each region and year. Studies reviewed for this report contained 457 weight gain comparisons, most of which were conducted on cross-bred cattle.

A summary of the studies that investigated liveweight gain of cross-bred cattle is provided in Table 5. There was a very considerable variation in average daily gain (ADG) among different classes of cattle, on different pasture species, and during different seasons. However, the results show that it is very likely that all classes of cattle grazing native pasture will lose weight during the dry season. The weight loss during the dry season reduces the viability of beef production in the north. In contrast, to the weight loss during the dry season, estimated daily liveweight loss or gain during the wet season was more positive and ranged from -0.66 to 0.94kg per day. However, the pattern of weight gain or loss varied by region and with class of cattle.

Table 5. Studies that investigated average daily liveweight gain (kg/hd/day) of grazing cross-bred cattle in northern Australia

Class of cattle	Liveweight gain (kg/hd/d) Number of trials/sub-studies Median (Min - Max)					
	Dry season		Wet season		Annual	
	Native pasture	Improved pasture	Native pasture	Improved pasture	Native pasture	Improved pasture
Steers	N=33 0.004 (-1.12–0.64)	N=4 0.03 (-0.04–0.10)	N=32 0.59 (0.25–1.90)	N=13 0.28 (0.34 - 0.99)	N=52 0.37 (-0.15–0.74)	N=1 -0.38
Breeder cattle	N=6 -0.24 (-1.06–(-0.08)	–	N=15 0.27 (-0.66–1.18)	N=2 0.64 (0.45 - 0.83)	N=1 -0.05	–
Heifers	N=8 -0.23 (-1.33–0.27)	–	N=11 0.32 (-0.63–0.94)	–	N=1 -0.13	N=6 0.27 (0.13–0.43)
Weaners	N=12 0.14 (-0.13–0.82)	N=8 1.29 (1.23–1.32)	N=9 0.46 (0.23–0.64)	–	N=22 0.35 (0.17–0.62)	N=6 0.76 (0.66–0.97)
Calves	–	–	N=14 0.77 (0.27–0.94)	–	N=3 0.16 (0.15–0.55)	–

Sources: Holroyd and Rourke 1988; Bortolussi et al 2005abcde; Dixon 1998 -Report to MLA; Beef cattle Performace in north Australia 2000; Rickert and Winter 1980; Sullivan and Rourke 1997; Wesley-Smith 1989; Lindsay et al 1989; McCosker and Winks 1994.

Figure 5 shows the trend in ADG of all classes of stock from 1959–2000 and Figure 6 shows the liveweight gain of all breeds and classes of stock, as well as cross-bred steers, in studies conducted from 1959–2000. These figures show little or no evidence of improvements in the ADG of cattle in studies conducted over that period.

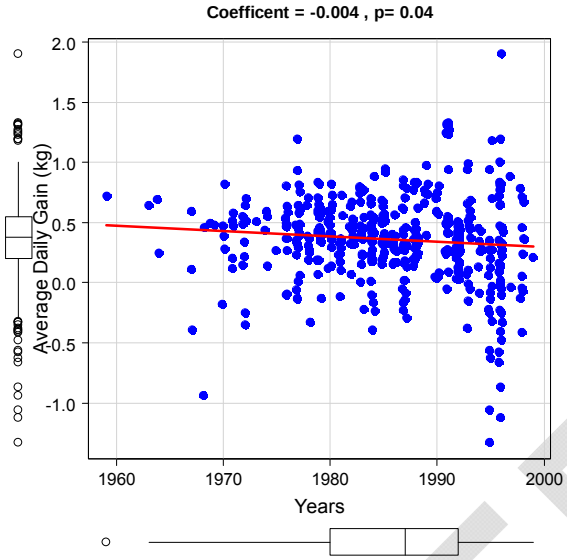


Figure 5. The trend of ADG in all classes of cattle, breeds and during dry and wet seasons from 1959–2000

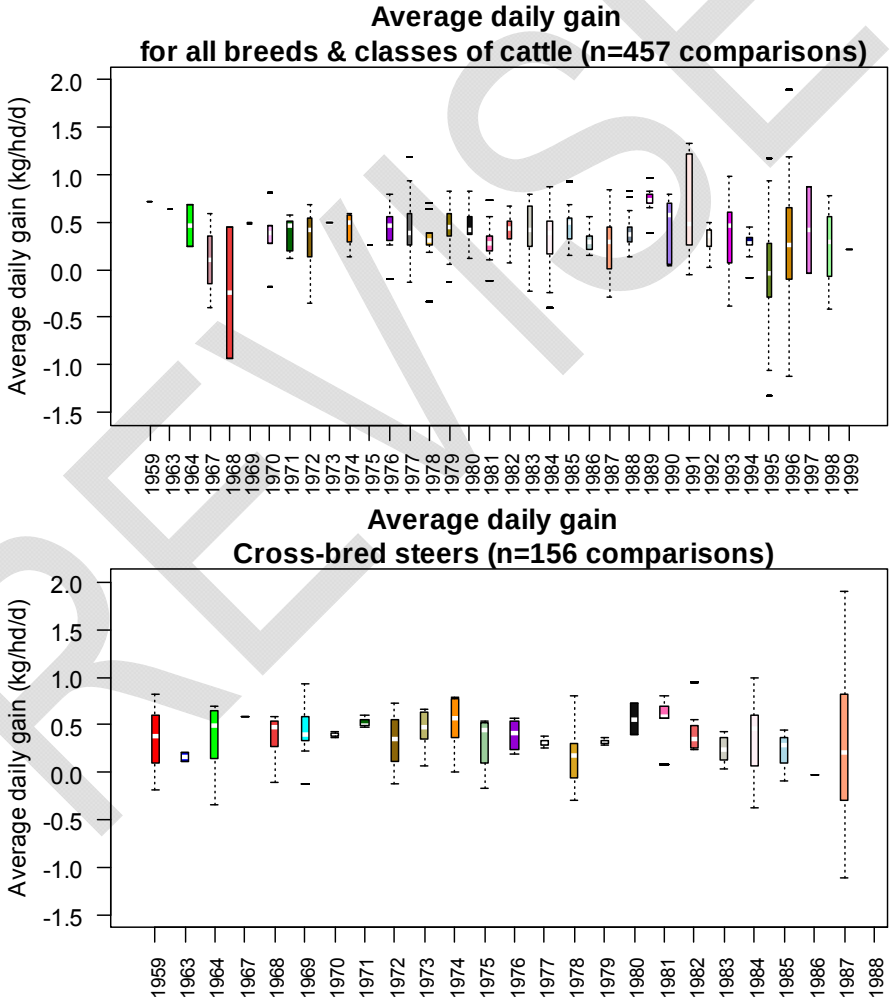
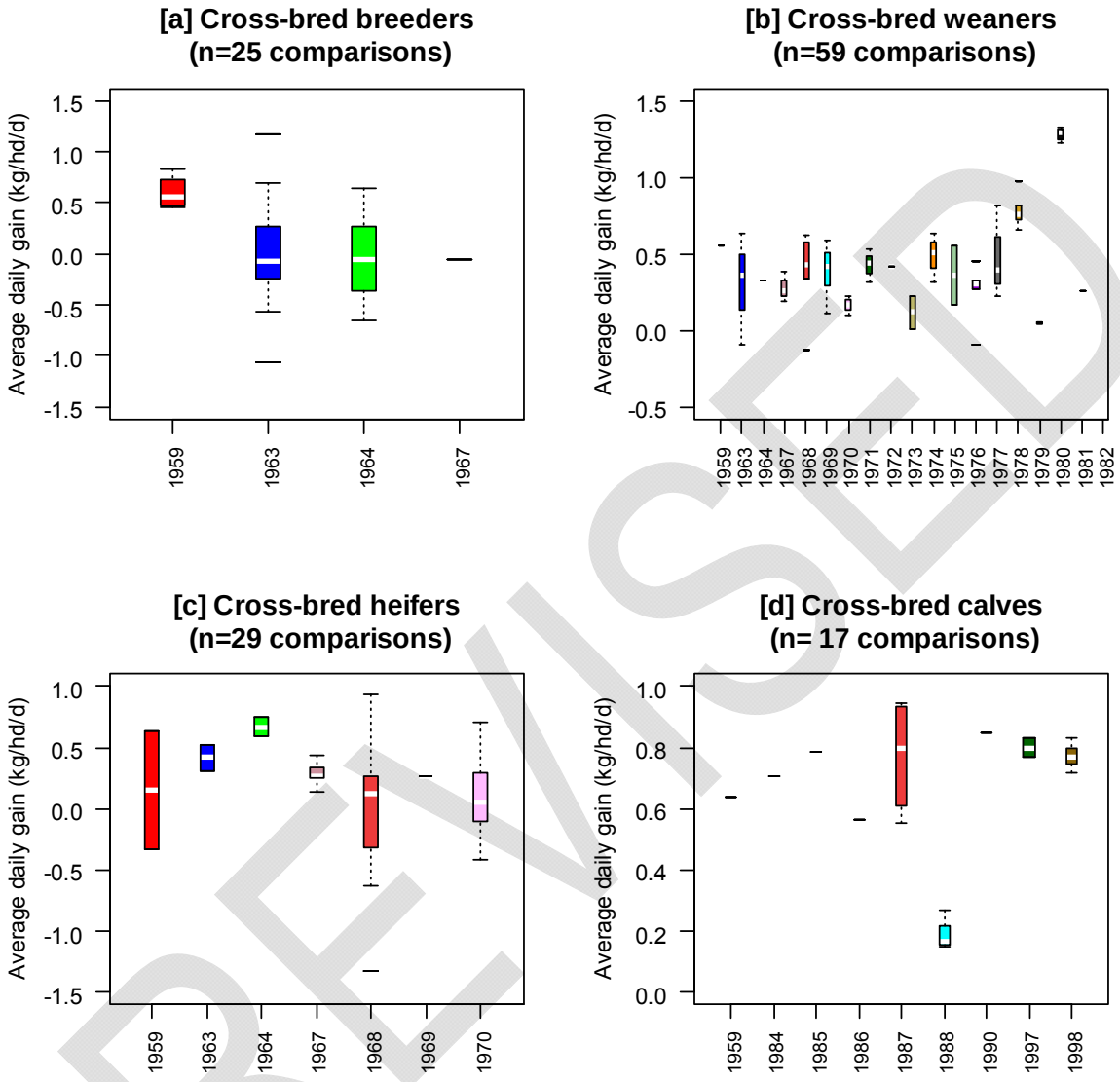


Figure 6. Summary of average daily liveweight gains for all classes of cattle and breeds in studies conducted from (1959–1999) and for cross-bred steers (1959–1988)

Results of the studies that reported ADG for different classes of cattle are presented in Figures 7a-d. Breeder cows and calves had the lowest and highest liveweight gain, respectively. However, all categories showed considerable variation in responses.



Figures 7a-d. Summary of studies that investigated the average daily liveweight gain of cross-bred breeder cows, weaners, heifers and calves

A summary of studies that reported liveweight gain for the different breed categories, different classes of cattle, during the dry and wet seasons is presented in Figure 8. The median and top percentile ADG of *Bos indicus* cattle appears to be greater than for the other categories. The median ADG of cattle grazing on improved pasture was 17 to 20% greater than those grazing on native pasture. The median ADG of cattle during the wet season is 50% more than that of the dry period.

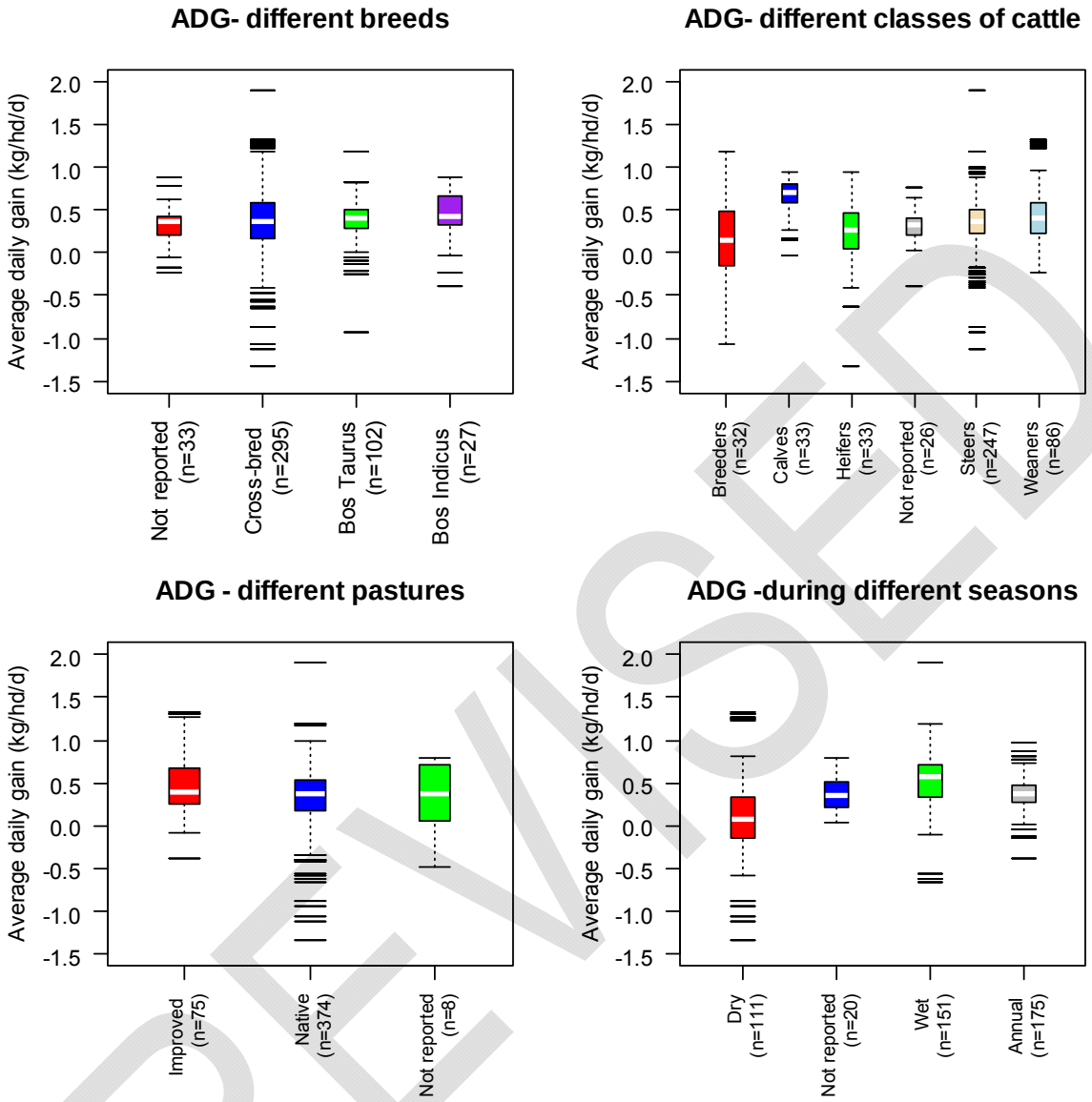
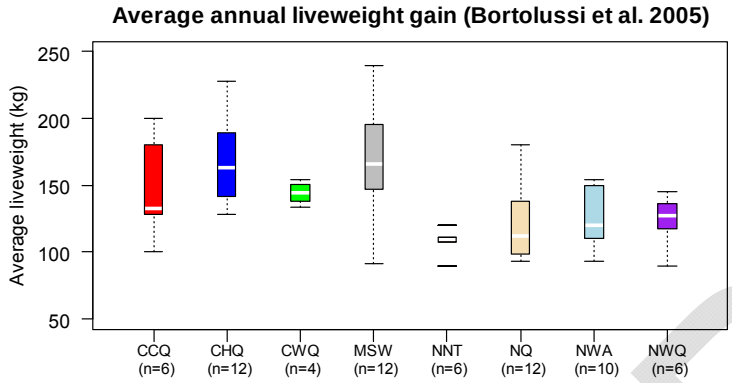
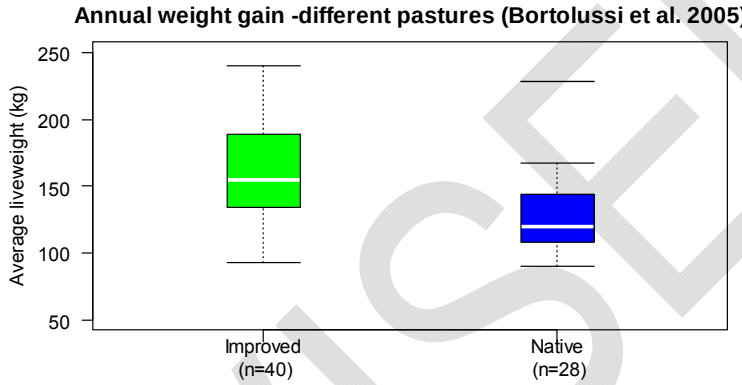


Figure 8. A summary of studies that investigated the average daily liveweight gain of different breeds and classes of cattle during the dry and wet seasons

Bortolussi et al (2005) reported that the annual liveweight gain differed between regions in northern Australia, and was greater in cattle grazing on improved pasture by around 17%, a figure that is very consistent with the studies included in this review. The duration of supplement feeding also varied by region, with the Northern Territory having the longest duration and Central West Queensland the shortest (Figure 9).





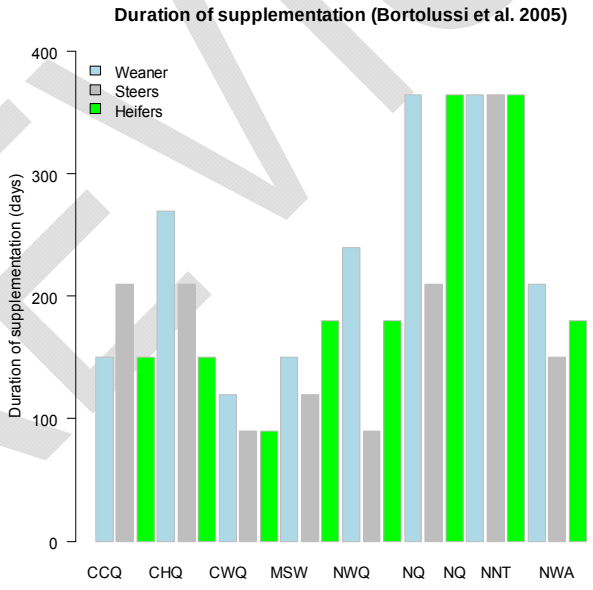


Figure 9. Summary of survey results on average annual liveweight of mixed herds with and without supplementation in different regions, on native or improved pastures and duration of supplementation (Bortolussi et al 2005)

CCQ= Central Coast QLD, CHQ= Central Highland QLD, CWQ= Central West QLG, MSW= Maranoa-South West
NWQ= North West QLD, NQ= North QLD, NNT= North Northern Territory, NWA= North West Australia

The results of our review of the ADG of cattle grazing native or improved pastures are presented in Tables 6, 7 and 8).

Table 6. Average daily liveweight gain (kg/hd/day) of cross-bred cattle in north Australia grazing different native pastures during the dry and wet seasons

Pasture species/ Cross-bred cattle	Season	No of comparisons	Kg/hd/day Median (Min - Max)
Black Speargrass/ Speargrass *(Heteropogon contortus)*	Dry	14	-0.24 (-1.33–0.02)
	Wet	14	0.27 (-0.63–1.18)
	Annual	2	0.01 (-0.05 - 0.07)
Mitchell Grass (*Astrebla spp.*)	Dry	6	-0.16 (-1.12–0.15)
	Wet	4	1 (0.31–1.9)
Callide Rhodes grass *(Chloris gayana)*	Annual	1	-0.05
	Wet	1	0.57
Kangaroo grass *(Themeda triandra)* & blue grass (*Bothriochloa* spp.)	Wet	9	0.47 (-0.10–0.83)
Bluegrass (*Bothriochloa* spp.) & Speargrass *(Heteropogon contortus)*	Annual	3	0.17 (0.03–0.26)
Spinifex (*Trioda* spp.)	Annual	1	0.37

Sources: Holroyd and Rourke 1988; Bortolussi et al 2005a,b,c,d,e; Dixon 1998 -Report to MLA; Beef cattle Performace in north Australia 2000; Rickert and Winter 1980; Sullivan and Rourke 1997; Wesley-Smith 1989; Lindsay et al 1989; McCosker and Winks 1994

Table 7. Average daily liveweight gain (kg/hd/day) of *Bos taurus* cattle in north Australia grazing different native pastures during dry and wet seasons

Pasture species/ Bos Taurus cattle	Season	No of comparisons	kg/hd/day Median (Mix – Max)
Kazungula *(Setaria sphacelata)*	Dry	1	0.25
	Wet	1	0.47
	Annual	1	0.38
Nandi *(Setaria sphacelata)*	Dry	1	0.34
	Wet	1	0.47
	Annual	1	0.41
Narok *(Setaria sphacelata)*	Dry	1	0.42
	Wet	1	0.48
	Annual	1	0.44
Splemdida (*Setaria sphacelata*)	Dry	1	0.34
	Wet	1	0.51
	Annual	1	0.43
Mitchell grass (*Astrebla* spp.)	Annual	2	0.36 (0.33–0.38)
Spinifex (*Triodia* spp.)	Annual	1	0.35

Sources: Holroyd and Rourke 1988; Bortolussi et al 2005abcde; Dixon 1998 -Report to MLA; Beef cattle Performace in north Australia 2000; Rickert and Winter 1980; Sullivan and Rourke 1997; Wesley-Smith 1989; Lindsay et al 1989; McCosker and Winks 1994

Table 8. Average daily liveweight gain (kg/hd/day) of *Bos indicus* cattle in north Australia grazing different native pasture species during dry and wet seasons

Pasture species/ Bos Indicus cattle	Season	No of comparisons	kg/hd/day Median (Mix – Max)
Black Speargrass (*(Heteropogon contortus)*	Wet	1	0.33
Brigalow-eucalypt, ironbark, cypress pine & sandalwood	Wet	2	0.64 (0.46–0.82)
	Annual	1	-0.041

Sources: Holroyd and Rourke 1988; Bortolussi et al 2005abcde; Dixon 1998 -Report to MLA; Beef cattle Performace in north Australia 2000; Rickert and Winter 1980; Sullivan and Rourke 1997; Wesley-Smith 1989; Lindsay et al 1989; McCosker and Winks 1994

The results of Bortulussi et al (2005) who examined annual weight gain of cattle grazing different pasture communities are presented in Table 9.

Table 9. Average annual liveweight gain of cattle grazing native or improved pastures (Bortulossi et al 2005)

Pasture Status	Pasture community	No of observations	Median ± SD (kg/hd)	Range
Native				
	Acacia woodland (infertile soil)	1	93	
	Annual sorghum/annual tallgrass	1	110	
	Aristida-Bothriochloa + box	3	148 ± 0.32.0	103–165
	Aristida-Bothriochloa + narrow leaf ironbark	3	128 ± 14.1	117–145
	Aristida-Bothriochloa + silver leaf ironbark	2	113 ± 28.3	93–133
	Black speargrass	4	124 ± 10.3	117–140
	Blue bush	1	108	
	Bluegrass (all states)	2	120	
	Gidgee	1	108	
	Mitchell grass	2	159.5 ± 96.9	91–228
	Mulga	1	130	
	Perennial tallgrass and other	3	142 ± 16.4	136–167
	Ribbongrass	7	143 ± 24.7	95–164
	Spinifex	2	130 ± 33.9	106–154
	WA short tussock grass	1	90	
Improved	Acacia woodland -fertile soils	1	180	
	Aristida-Bothriochloa + box	2	179 ± 29.7	158–200
	Aristida-Bothriochloa + narrow leaf ironbark	3	100 ± 23.4	97–139
	Aristida-Bothriochloa + silver leaf ironbark	1	237	
	Black speargrass	3	141 ± 30.9	133–190
	Blady grass	1	135	
	Brigalow - softwood scrub	1	188	
	Cypress pine	4	190 ± 38.9	147–240
	Gidgee	1	150	
	Ribbongrass	4	151.5 ± 26.7	125–180
	Saltwater couch (Marine plains)	1	150	
	Softwood scrub	1	151	
	Spinifex	3	191 ± 10.0	180–200
	WA short tussock grass	1	93	

Our review of weight gain performance of cattle on the different native pastures was consistent with that of Bortolussi et al (2005). These findings reinforce understandings of the limitations of performance on tropical, native pastures, but also highlight that some properties and trials achieved weight gains well above the average.

5.3 Liveweight gain of lot-fed cattle

The objective of this part of the study was primarily to review the performance of grazing cattle in north Australia. Therefore, the performance of feedlot cattle was not explored in as much detail as that of grazing cattle. There is a vast database of papers on performance of cattle in feedlots from North America, but Australian data on feedlot performance are limited, with extensive literature searches yielding little useful information on ADG of feedlot cattle in northern Australia. Hasker et al (1996) summarised the results of ADG from three feedlots to demonstrate the variation in performance among feedlots (Table 10). Cusack et al (2007) explored the factors that influenced weight gain in 2468 head of cattle that were enrolled in a commercial feedlot in southern Queensland. Breed of cattle entering was a significant factor influencing performance. *Bos indicus* cross cattle (Santa Gertrudis and Santa Gertrudis cross) cattle had the highest ADG and lowest rates of respiratory disease. Respiratory disease had substantial impacts on ADG and mortality. The ADG in this study was 1.52 (SD 0.61). Differences in the method of determining ADG in feedlots exist and maximal gain is not necessarily the prime determinant of economic performance. Therefore, a detailed compilation of industry data was not attempted.

Table 10. **Estimated average daily gain (kg/hd/day) for steers from different sources in 3 feedlots in southern Queensland (Source: Hasker et al 1996)**

Feedlots	Source of steers	Breed	Number of steers	Lot	Days	ADG (kg) (mean ± SD)
1	Wilton	Droughtmaster	208	1	78	2.46 ± 0.44
		Droughtmaster	113	2	105	2.23 ± 0.35
		Droughtmaster	119	3	103	2.18 ± 0.34
		Droughtmaster	119	4	67	2.06 ± 0.35
		Droughtmaster	111	5	60	1.95 ± 0.43
		Droughtmaster	103	6	53	1.99 ± 0.51
		Droughtmaster	135	7	103	2.01 ± 0.32
		Droughtmaster	136	8	97	2.14 ± 0.36
2	Gatton	Brahman x Hereford	107		84	1.36 ± 0.30
		Brahman-cross	17		77	1.89 ± 0.31
		Hereford	8		77	1.80 ± 0.29
	Jandowae, Killarney, Scone	Hereford	171		163	1.28
	Boggabri, Narrabri	Hereford	129		132	1.79
	Dalby, Tambo, Wandoan	Unknown	250		81	1.60
	Moree	Simmental x Hereford	208		133	1.62
	Julia Creek	Brahman-cross	144		75	2.03

Conclusions- the objective of examining weight gain performance for cattle in the northern industry was achieved. As expected, the variation in performance was large and reflected the variety of conditions under which cattle are grown in the northern industry.

- There was a lack of well documented studies that would allow the development of a multivariable model to account for the effects of season, class, breed and pasture type on weight gain.
- Within the range of studies, there was evidence of the capacity to achieve good weight gains, particularly in weaners on improved pastures; however, weight gains even in the wet season were well below those achievable on temperate pastures and crops.

- The literature available was largely published before 2000, perhaps reflecting a shift in emphasis of studies after that time. However, there was no evidence of an improvement in ADG from 1959-2000 over the time period represented by the literature.
- As expected, weight was almost always lost during the dry period.
- Performance was approximately 17–20% higher on improved pastures, in comparison to native pasture.
- Supplementary feed was supplied for much or all of the year (Bortolussi et al 2005).
- The data gathered, analysed and presented supported reports that the efficiency of weight gain is likely to be low because wet season weight gains are not always sufficiently large to allow cattle to finish by 24 months of age or to be mated at 15 months of age.

5.4 Supplements and liveweight gain

The effectiveness of supplementation with phosphorus, ionophores, cottonseed meal and molasses and urea on growth rate and ADG of grazing cattle has been studied in northern Australia (MLA reports: Miller et al 1997; McLennan 2002). Table 11 provides a summary of effects on liveweight gain of different supplements.

Table 11. Effects of supplementation on liveweight gain of grazing cattle on native or improved pastures during dry and wet seasons in north of Australia

Supplements/ Others	Amount of supplement	No of comparisons*	Vehicle/diet	Daily weight gain (kg/hd/d) Median (Min-Max)		
				Control (no supplement)	Treatment	Difference
Phosphorus (P, DCP, DSP, phosphoric acid)	5–10g/day	23		0.25 (0.06–0.47)	0.36 (0.2–0.58)	0.11
Lasalocid	150mg/day	4	Cotton seed meal (CSM) + Urea	0.08 (-0.14–0.58)	0.30 (0.05–0.43)	0.22
		1	Cotton seed meal (CSM) + Urea	0.24	0.41	0.27
Monensin	100mg/day	4	Cotton seed meal (CSM) + Urea	0.08 (-0.14–0.58)	0.31 (0.02–0.42)	0.23
		2	Molasses	0.29 (0.24–0.30)	0.42 (0.40–0.43)	0.13
		1	Cotton seed meal (CSM) + Urea	0.24	0.37	0.13
		1	M4U		0.36	
Whole cottonseed Meal	0.3–1.0kg	4	Urea	0.08 (-0.14–0.58)	0.30 (0.06–0.41)	0.22
		46	-	0.14 (-0.41–0.68)	0.22 (-0.46–0.68)	0.24
Molasses & Urea						
M10U	Molasses (0.5 - 5.0L/d) made up 32% to 80% of products used	5		0.13 (-0.23–0.62)	0.24 (-0.16–0.62)	0.11
M8U	Urea (25 - 60g/d) made up 8% to 100% of products used	2	Cotton seed meal (0.5 kg/d)	0.15 (-0.02–0.32)	0.25 (0.15–0.35)	0.10
		5	Leucaena	0.02	0.49	0.47

			(-0.23–0.62)	(-0.19–1.0)	
Urea only	11	Salt		0.14 (-0.91–1.96)	-0.01
			0.15 (-1.12–1.9)		
Urea protected protein (Urea)	3		0.24 (-0.40 - 0.32)	0.36 (0.09–0.4)	0.12
Molasses	5			0.02 (-0.44–0.32)	-0.03
			0.05 (-0.41 - 0.36)		
Leucaena	8		0.1 (-0.23 - 0.62)	0.44 (-0.13–0.98)	0.34

DCP: dicalcium phosphate; DSP: disodium phosphate
Sources: Holroyd and Rourke 1988; Bortolussi et al 2005a,b,c,d,e; Dixon 1998 -Report to MLA; Beef cattle Performace in north Australia 2000; Rickert and Winter 1980; Sullivan and Rourke 1997; Wesley-Smith 1989; Lindsay et al 1989; McCosker and Winks 1994; McLennan 2002

McLennan et al (2002) examined a number feed options designed to increase the efficiency of supplementary feeding. In this study (McLennan et al 2002) and subsequently (Poppi and Quigley 2009), a key focus has been on the type of supplements required to increase the flow of protein to the small intestine by increasing the yield and efficiency of yield of microbial protein. These studies explore both the practical implementation and deeper understandings of the interactions between energy and protein explored in the review of Poppi and McLennan (1995). These data and those in Tables 6 to 10 are used to validate the nutritional modelling strategy used in Chapter 10.

Leucaena is considered a supplement in some regions because of its nutrient profile. The results from 13 experiments, primarily from Latin America and Australia, have been summarised in Table 12.

In most cases the objective of the study was to improve liveweight gain during the 'dry' or 'cool' season by using Leucaena pastures as a supplement. This was achieved by having a proportion of the total land area established with Leucaena, or by controlling the number of hours per day that cattle grazed a small area of Leucaena. In some cases, it was not stated whether Leucaena was provided as an additional area to the basal grass pastures; if this was the case, cattle grazing the Leucaena plus grass treatment would have been on a slightly larger area than those grazing the grass only treatment.

Table 12. A summary of studies in Latin America, Fiji and Australia that investigated the effect of Leucaena on average liveweight gain in grazing beef cattle

Grass species	Liveweight gain (kg/hd/d)		Access to Leucaena	Period of year (days)	Source
	Without Leucaena	With Leucaena			
Native pasture	0.59	0.70	25% on area basis	Spring, summer (130)	Quirk et al (1988)
Native pasture	0.22	0.39	4 hours/day	Winter (100)	Gandara et al (1986)
Native pasture	0.18	0.33	25% on area basis	Winter, Spring (160)	Foster and Blight (1983)
Native pasture	-0.15	0.16	25% on area basis	Autumn, Winter (180)	Addison et al (1984)
Native pasture	0.23	0.51	6% on area basis	Spring ,Summer, Autumn (224)	Zoby et al (1989)
Native pasture	0.25	0.35	25% on area basis	Year (365)	Quirk et al (1990)
Native pasture	0.25	0.56	100% on area	Year basis (365)	

Cenchrus ciliaris	0.6	0.6	10 or 20 hours/week	Cool season (200)	Carvalho Filho et al (1984)
Brachiaria decumbens	0.49	0.64	4 hours/day	Dry season (120)	Paterson et al (1982)
Hyparrhenia rufa	0.27	0.35	10% on area basis	Dry season (155)	Paterson et al (1983)
Cynodon plectostachyus	0.29	0.41	4 hours/day	dry season (252)	Palomo et al (1980)
Dicanthium caricosum	0.21	0.50	20% on area basis	year (365)	Partridge and Ranacou (1974)
Pennisetum clandestinum	0.07	0.34	3 hours/day	autumn, winter (90)	Zacharias et al (1991)
Panicum maximum	0.52	0.67	30% on area basis	rainy season	Castillo et al (1989)
Panicum maximum	0.18	0.37	30% on area basis	dry season	

The increases in liveweight gain of cattle given access to Leucaena varied widely. This was expected in view of the differences in the quantity and quality of the base pasture and the amount of Leucaena on offer. Other limiting factors in the experiments could be plant or diet related (e.g. low sodium intakes) or animal related (e.g. parasite infestation restricting ADG). Overall, there was a 70% or higher increase in liveweight gain in 8 of the 15 comparisons listed in Table 12. There was only one experiment in which there was no advantage from the Leucaena supplement (Carvalho Filho et al 1984) and this was attributed to the high protein content of the base pasture and the low availability of Leucaena at the end of the trial. Replacing 20% of *Dicanthium caricosum* pasture with Leucaena in Fiji more than doubled liveweight gain (Partridge and Ranacou 1974). Falvey (1976a) reported an advantage from grazing of Leucaena as a supplement, but this comparison is not listed in Table 12 as the base pasture included a vigorous legume, Townsville stylo (*Stylosanthes humilis*).

Supplementary grazing of Leucaena can substantially improve liveweight gain over that achieved on grass pastures. The percentage increase will be greatest when the pasture base is low in quality and when the intake of Leucaena is high. Based on findings from these studies, a doubling of liveweight gain can be achieved by effective use of Leucaena.

Conclusions - The responses to supplements will be influenced by the basal diet and by other feeds that are supplied.

5.5 Fertility

Reproductive performance is one of the most important factors influencing the profitability of a beef breeding herd (Entwistle 1983). Poor nutrition delays the onset of puberty and the resumption of ovarian activity after calving (Galina and Arthur 1989). The challenge of achieving reproductive efficiency in northern cattle has been recognised for a very long time. Under-nutrition reduces pregnancy rates, increases the duration of anoestrus, and reduces calf growth and weaning weights.

The impact of under-nutrition is usually expressed via body condition and weight of breeder cows (O'Rourke et al 1991a). Body condition score (BCS) of cows has been used for supplementation decisions (Derouen et al 1994). Maintaining a minimum BCS of 5 (using a 9-point Australian scale) will minimise the duration of post-partum anoestrus in *Bos taurus* cattle (Osoro and Wright 1992). Nutritional management and pregnancy rates of beef herds in the Barkly Tableland region have improved in the last 20 years (Bortolussi et al 1999). Burns et al (2010) conducted a comprehensive qualitative review exploring the factors that may influence reproductive performance of cattle in

northern Australia. They reported that overall reproductive efficiency of cattle was influenced by pregnancy rate, weight by number of calves per breeding female retained for mating and overall lifetime of calf weight weaned per mating. However, this review lacked quantitative data on reproductive performance or estimated financial benefits of improving fertility of grazing cattle in north Australia.

A total of more than 300 papers (published papers, reports, proceedings, reviews, and abstracts) were reviewed and reproductive data extracted from 172 studies for analysis. The data obtained from the literature review often lacked detailed information on the class of cattle, season and type of pasture. Studies reviewed for this report contained 502 comparisons (Figures 10 to 12) which were mainly conducted on cross-bred and *Bos taurus* cattle. A summary of pregnancy rate for different breeds of breeder cattle (heifers and cows) grazing native pasture during different seasons in northern Australia is presented in Table 13. The reported pregnancy data were defined and presented differently; most studies presented these data as pregnancy or conception rate, percentage pregnant (in tables) and some as number of pregnant and non-pregnant cows or heifers. The pregnancy rate differed among breeds, with parity (heifers vs. cows) and between seasons (dry vs. wet seasons). Due to the lack of data on the mating dates in most studies, it is likely that the classification of season for pregnancy rates of the studies reviewed has been based on the time (season) that pregnancy diagnosis or calving occurred and, consequently, the higher pregnancy rate results during the dry season reflects this association. The pregnancy rates were higher for cattle mated during the wet season and the resultant pregnancy was confirmed and reported during the dry period.

Table 13. Summary of studies that investigated pregnancy rate or calving rates for cattle grazing native pastures in northern Australia

Class of cattle	Class of cattle	Number of comparisons Median (Min - Max)		
		Percent Pregnant (%)		Calving rate (%)
		Season		
		Dry	Wet	
Cross-bred	Heifers	N= 37 75.0 (4.0–96)	N = 31 42.5 (10.0–84.5)	N=6 47.0 (39.0–55.0)
	Cows	N= 30 89.3 (43.5–100)	N= 50 62.0 (7.0–92.0)	N=27 71.5 (38.0–84.0)
Bos taurus	Heifers	N= 16 79.5 (56.0–98.0)	N= 13 61.5 (27.5–91.5)	N=9 51.0 (50.0–79.0)
	Cows	N=10 78.0 (50.0–98.0)	N=11 62.0 (34.0–93.5)	N=36 74.0 (46.0–94.0)
Bos indicus	Heifers	N=2 68.5 (50.0–87.0)	N=1 43.0	–
	Cows	N=3 87.0 (87.0–00.0)	N=2 45.5 (29.0–62.0)	N=9 78.0 (53.5–82.0)

Sources: Holroyd and Rourke 1988; Bortolussi et al 2005abcde; Dixon 1998 -Report to MLA; Beef cattle Performace in north Australia 2000; Rickert and Winter 1980; Sullivan and Rourke 1997; Wesley-Smith 1989; Lindsay et al 1989; McCosker and Winks 1994

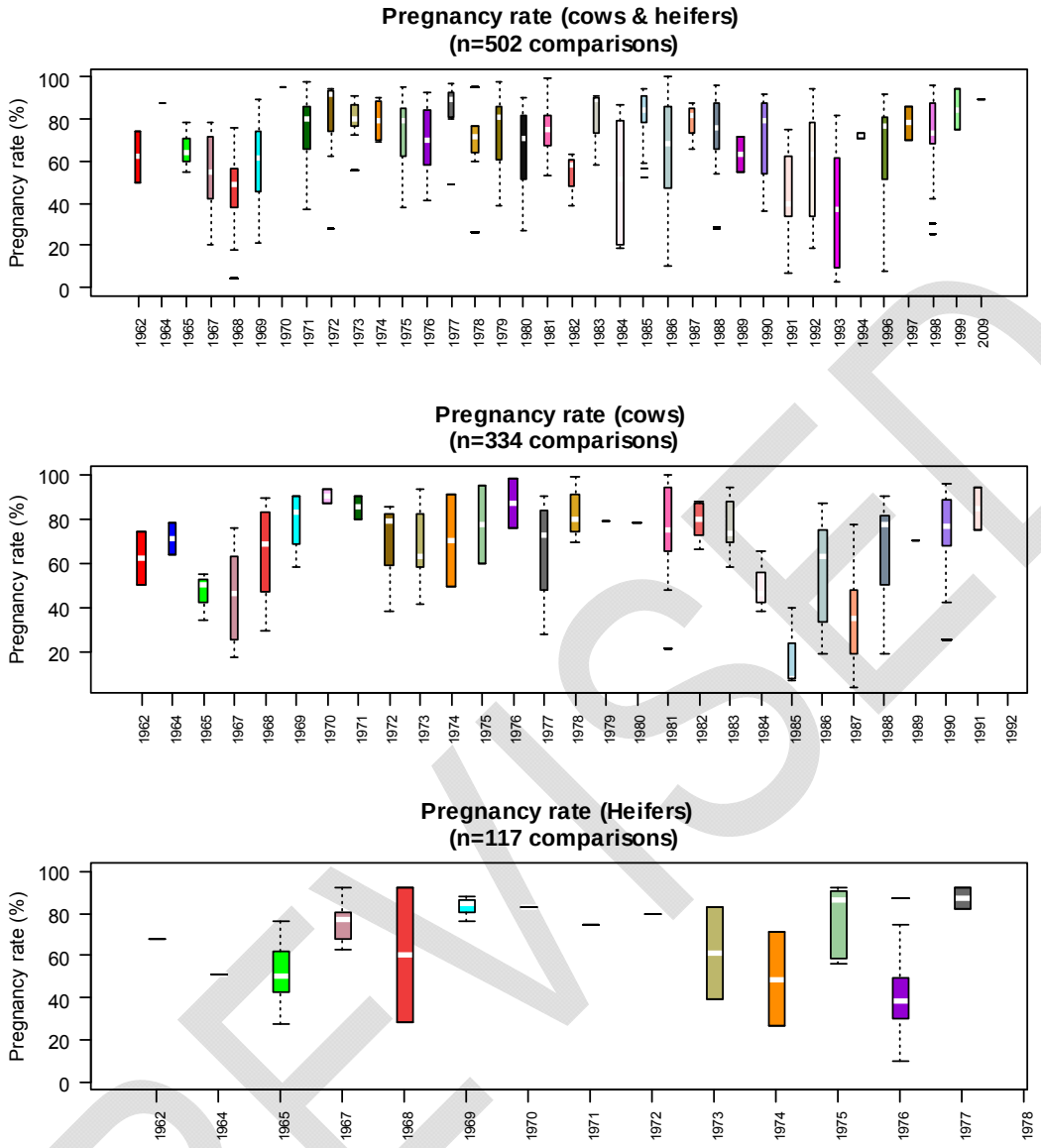


Figure 10. Summary of results of pregnancy data in breeder cows from 1962–2009, and a subset of data for cows and heifers

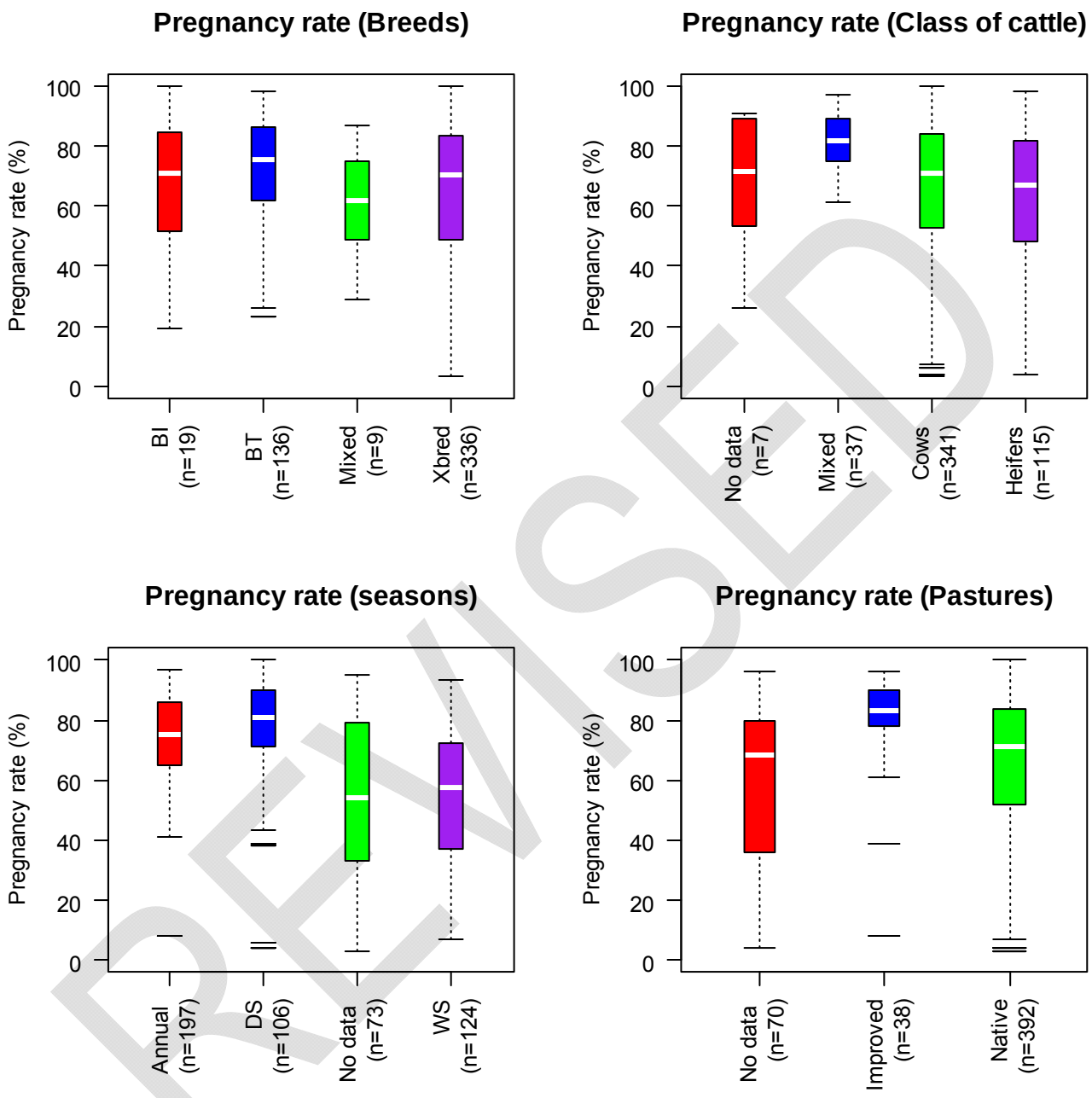


Figure 11. Summary of results of studies on percentage rate pregnant for different breeds, and different classes of cattle grazing on different pasture types during the dry (DS) and wet seasons (WS)

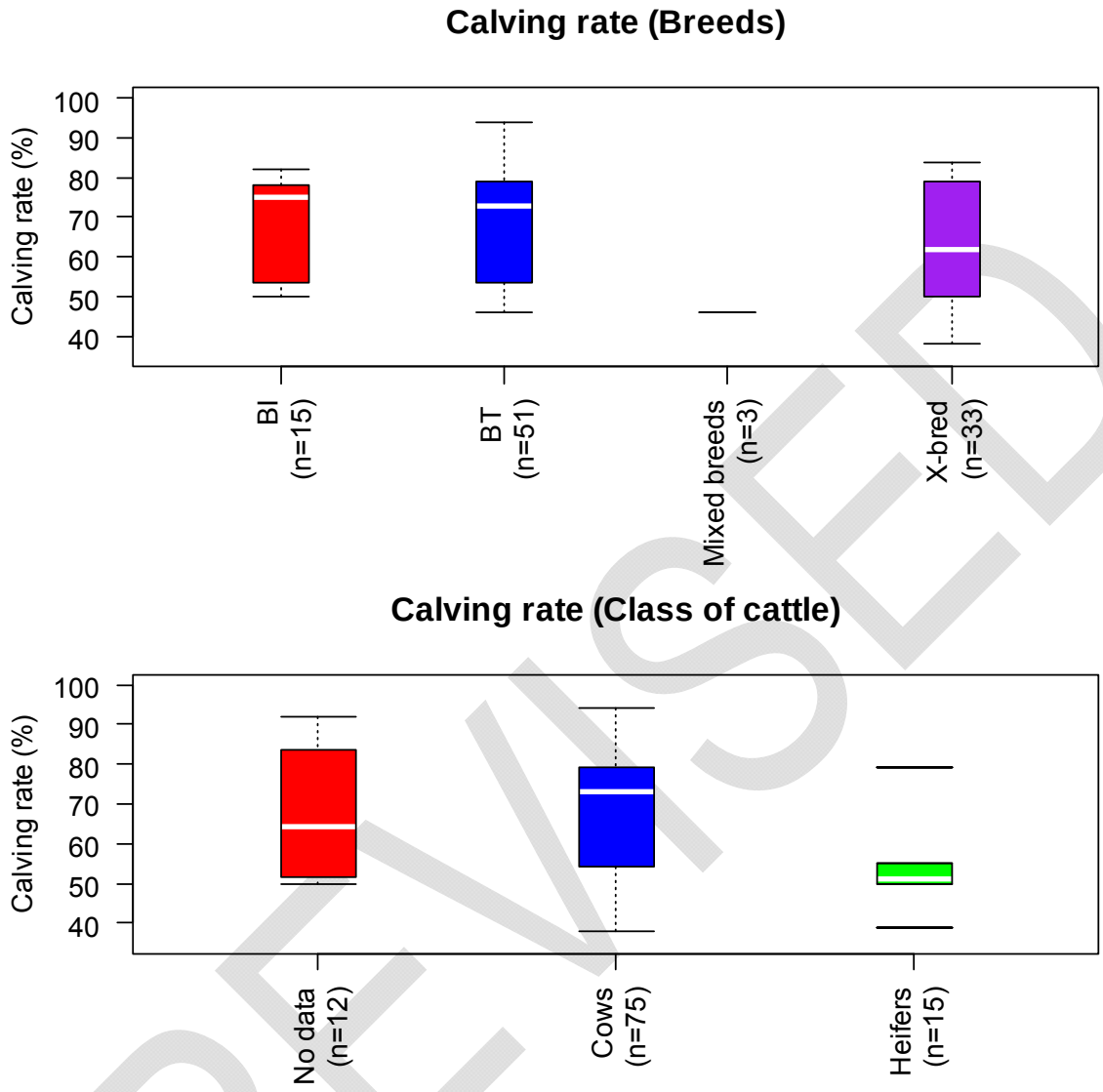


Figure 12. Summary of results of studies on calving rate for different breeds, and different classes of cattle

5.5.1 Relationships between liveweight gain and fertility in north Australia

The results of 31 trials that reported body weight and pregnancy percentage of grazing cattle were used to quantify the association between the weight gain and pregnancy rate. Results of the analysis show that for an increase of 1kg in body weight of grazing cattle, there is a 0.12% improvement in the pregnancy rate for the cattle ($P < 0.0001$; Table 14 and Figure 13). The magnitude of this association is influenced by the season ($P < 0.0001$).

Table 14. Association between pregnancy rate and body weight of cattle grazing native pasture in north Australia (Adjusted R^2 = 0.47)

	Reference group	Coefficient ± SE (N= 31)	Significance
Body weight		0.12 ± 0.02	P <0.001
Season	Dry		
	Annual	-9.01 ± 1.99	P <0.0001

Source: Holroyd and Rourke 1988

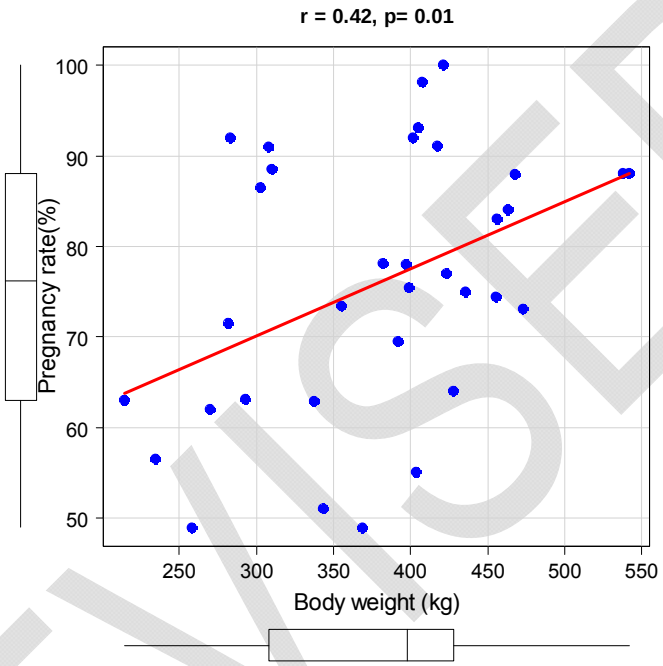


Figure 13. Summary of studies (n=31) investigated relationship between liveweight gain and pregnancy rate in cattle grazing native pasture in north Australia

Dixon et al (1998) also reported that with *Bos indicus* cross-bred cows in less than 'store condition', pregnancy rate was increased by approximately 5% for each 10kg increase in breeder liveweight at mating (Figure 14, obtained from Dixon et al 1998).

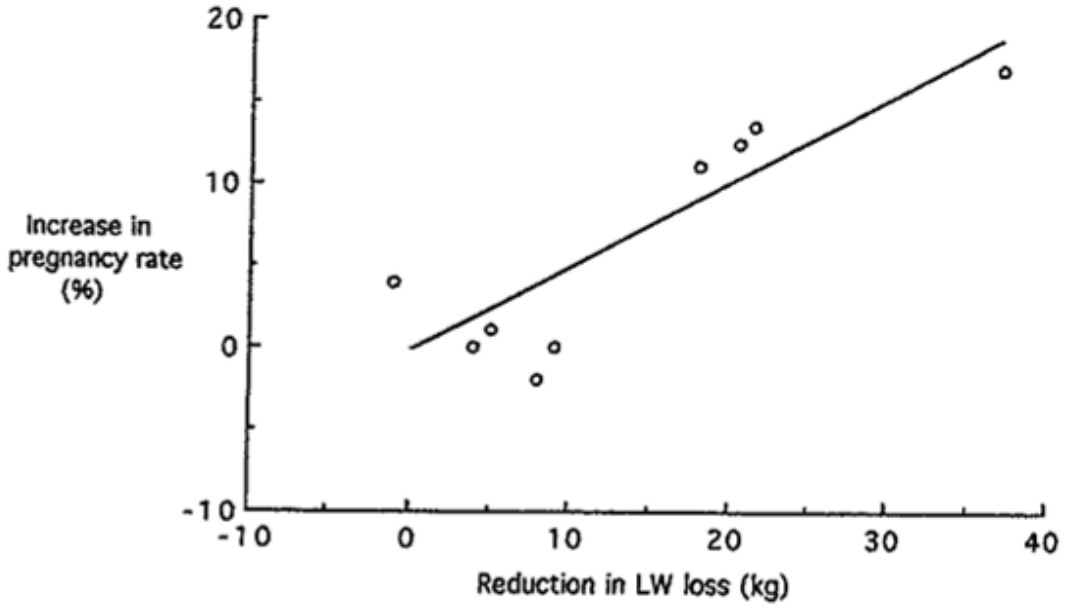


Figure 14. Relationship between liveweight loss and pregnancy in breeder cows (Source of data: Holroyd et al 1983; Source of figure: Dixon et al 1998)

The association between liveweight and reproductive performance has also been examined in other studies (Lamond 1970; Holroyd 1985). Goddard et al (1980) developed a model to represent this relationship in Droughtmaster cows (Figure 15; Goddard et al 1980). This figure suggests that the association between liveweight gain and pregnancy rate is curvelinear, and the effect of liveweight on fertility was more substantial with lighter, rather than the heavy cows. However, data from other studies (Anderson 1990) shows that this association could also be linear (Table 15).

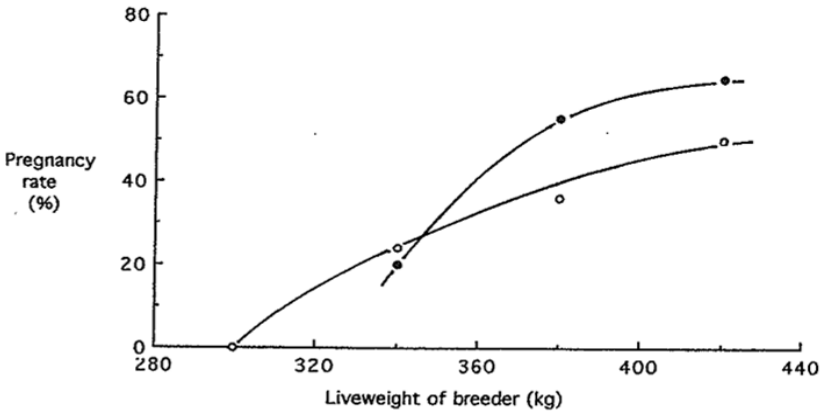


Figure 15. Relationship between start of mating liveweight of lactating first-calf cattle (O) or mature breeders and subsequent pregnancy rate (Source: Goddard et al 1980)

Table 15. Approximate increases in pregnancy rate or calving rates (%) of lactating *Bos indicus* crossbred cows due to an increase in liveweight. Where the liveweight-fertility response was curvilinear, the response has been expressed as two approximately linear relationships for a lower and a higher liveweight range. Liveweights are for the start of mating except where otherwise indicated (Source: Dixon, 1998)

Source of data and age of cows	Type of response	Liveweight range (kg)	Increase in pregnancy rate per 10kg increase in LW (%)
Goddard et al 1980			
First calf cows	Curvilinear	300–340	6
		340–380	3
Mature cows	Curvilinear	340–380	9
		380–460	3
Anderson 1990			
Swan's Lagoon (Data set 1)	Linear	290–350	4
First calf cows	Linear	390–450	4
Mature cows			
Swan's Lagoon (Data set 2)			
First calf cows	Linear	260–390	3
Mature cows	Curvilinear	310–350	5
		350–450	0
Fletcherview			
First calf cows	Linear	290–360	8
Mature cows	Linear	340–410	3
O'Rourke et al 1991 (Mt Bundy)			
Mature cows	Curvilinear	260–360	3
(Liveweight in the mid-dry season)		360–430	0
O'Rourke et al 1991 (Kidman Springs)			
All ages	Curvilinear	240–290	4
		290–390	0
Meaker 1975 (South Africa)			
Mature	Linear	310–440	7
Buck et al 1976 (Botswana)			
All ages (mostly mature cows)	Curvilinear	290–330	7
		330–430	1
Summary		**Median (min–max)**	**3.50 (0.0–9.0)**

Dixon (1998) suggested that where the response was linear over a range of liveweights, the responses were between 3% to 8% increase in pregnancy per 10kg extra liveweight. Where the response was curvilinear:

- for low liveweight cows, the pregnancy rate response to increased liveweight was approximately 4–9% per 10kg additional weight
- for heavier cows, the pregnancy rate response to increased liveweight was lower, approximately 0–3% per 10kg of additional weight.

Dixon (1998) concluded that in cows weighing less 340kg, a 5% increase in pregnancy rate could be achieved per 10kg additional liveweight during mating. In contrast, in cows weighing more than 340kg, the expected increase in pregnancy rate was estimated to be between 0–3%. The latter estimate is very similar to that identified in the multivariable study conducted for this study (Table 15).

Conclusions- This large database of studies demonstrated that fertility, either pregnancy rate or percentage calved varied markedly. Within these studies, a consistent database was available that allowed a multivariable examination of the effects of body weight on percentage of cattle pregnant. Unfortunately, this database did not contain many studies with cattle of low bodyweight. However,

cattle mated in the wet season (calved or pregnant in the dry season) had a significantly higher pregnancy rate. The pregnancy rate increased by 0.12% per kg of additional liveweight. Given the similarity to the estimate of Dixon (1998) for cattle >340kg of liveweight, we consider that percentage pregnancy will increase by approximately 0.12% per kg of liveweight. For lower liveweights of less than 340kg, an estimate of 0.6% increase in pregnancy rate per kg of liveweight should be used based on the data from Dixon (1998).

5.5.2 Supplements and fertility

Of the studies that were reviewed for the ADG and pregnancy rates, a subset of the data were re-analysed to estimate the impact of supplementation on reproductive performance of grazing cattle. These studies investigated the effect of supplement feeding on pregnancy rates at different stages of the breeding cycle, during different seasons, using different breeds and grazing different species of pasture. Due to limited amounts of data on all these parameters, it was not possible to estimate the effect of supplementation for each sub-category. Consequently, all data were summarised based on the class of supplementation (e.g. phosphorus). A summary of the effect of supplement feeding on liveweight gain is presented in Table 16.

Table 16. Effects of supplementation on pregnancy of grazing cattle on native or improved pastures during the dry and wet seasons in northern Australia

Supplements/others	No of comparisons	Vehicle/diet	Pregnancy rate (%) Median (Min & max)		
			Control (no supplement)	Treatment (supplemented)	Difference (%) (T- C)
Phosphorus - Kynofos (Dicalcium Phosphate dihydrate, Monocalcium Phosphate) - Ultraphos (Monocalcium Phosphate)	22	NPN (Uramol)	46.5 (0.0–92.0)	47.5 (1.5–91.0)	1.0
Protein	7-Years data from one farm	Ultrapro	40 (7.0–65.0)	57 (24.0–77.0)	17.0
Cottonseed Meal (CSM)					
CSM	2		53.0 (25.0–92.0)	61.5 (39.0–84.0)	8.5
CSM + Urea	2		53.0 (25.0–92.0)	64.5 (54.0–75.0)	11.5
CSM + Urea + DCP + S + Salt	2		53.0 (25.0–92.0)	89.0 (86.0–92.0)	36.0
N, S, P & salt	11		80.0 (25.0–81.0)	82.0 (46.0–95.0)	2.0
Molasses & Urea (different combinations)	3		54.0 (52.0–92.0)	48.0 (35.0–91.0)	-6.0

Source: Holroyd and Rourke 1988; Bortolussi et al 2005abcde; Dixon 1998 -Report to MLA; Beef cattle Performace in north Australia 2000; Rickert and Winter, 1980; Sullivan and Rourke 1997; Wesley-Smith 1989; Lindsay et al 1989; McCosker and Winks 1994

The pregnancy results in Table 16 represent findings on interventions conducted under a wide range of conditions. The responses to phosphorus alone or in the presence of non-protein nitrogen, or with molasses, do not suggest a considerable benefit, whereas the studies conducted using a true protein source suggest quite positive responses.

5.6 Aspects of compensatory growth

A number of interviewees considered that the cyclical weight loss evident in the northern production system and subsequent compensatory growth were major factors deterring producers from using interventions. Wesley-Smith (1991) indicated that compensatory gain may reduce the weight advantage and economic advantage of supplementary feeding. Consequently, we considered that a focussed review of this area was essential to the goals of this project. Compensatory gain has been investigated by studies in Australia including, but certainly not limited to Greenwood and Cafe (2007); Greenwood et al (2009); Hunter et al (1993); Lindsay et al (1993); Ryan et al (1993a,b), Tudor (1972); Tudor and O'Rourke (1980); Tudor et al (1980) and is the subject of extension documents from MLA (e.g. Growth Path to Profit). *Compensatory growth* is the term that Bohman (1955) used to describe the accelerated and /or more efficient growth that commonly follows a period of growth restriction (Droulliard and Kuhl 1999). There seemed to be differences in the way the interviewees for this project (see Chapter 9) broadly defined compensatory growth, that were contextual, real or semantic or combinations of these. Given, the critical importance of weight loss and regain to the northern beef production system and the impact on the efficiency of production, as defined in this report, a review of compensatory growth was undertaken. Owens et al (1995) note that change in live weight is imprecise as an indicator of growth (accretion of protein and fat tissue) and this is a critical perspective to maintain while evaluating the information on compensatory growth.

Compensatory growth is a well recognised aspect of cattle production, although the detailed physiology of the process is still poorly defined. Cattlemen have made use of the increased efficiency of growth that occurs in cattle after a period of feed deprivation for at least the last 100 years (Fox et al 1972). The beef feedlot industry is well aware of the potential to increase efficiency of gain in cattle that have been previously underfed and uses this knowledge to achieve more efficient weight gains.

Hornick et al (2000) define the extent of compensatory gain through the use of a compensatory index calculated as displayed in Figure 16.

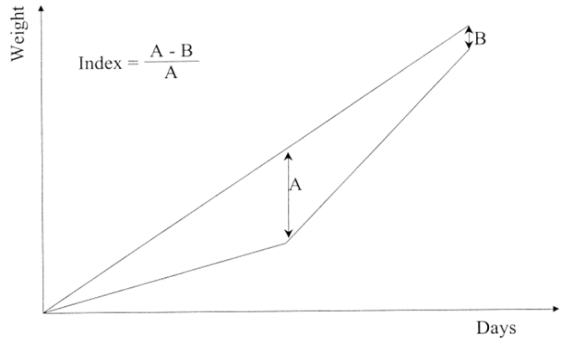


Figure 16. A compensatory index, a method to measure the catch-up growth

Hornick et al (2000) note that compensatory growth responses to additional nutrients vary largely. Factors that influence the response include length and severity of deprivation, the nature of dietary restrictions (energy, protein or both) and age of the animals. For the pasture-based industry of northern Australia, the concern of producers and researchers is that incremental gains achieved by supplementation may be lost and not effectively regained compared to unsupplemented cattle

following periods of weight loss and compensatory gain. Impacts of cyclic growth and weight loss have been considered in regard to beef quality and there is some evidence that cyclic loss may be associated with less connective tissue strength in meat (Oddy et al 2001).

The questions that arise in discussing the role of compensatory gain in the northern beef production system include the following:

i. What is the composition of the weight lost during periods of inanition, disease and/or adverse environmental impact that cause weight loss?
ii. Are the body tissue component losses the same in underfed adult and younger cattle?
iii. What is the composition of weight regained in the compensatory phase and on average what percentage of loss is regained and is that mass, gained as profitable cuts, or offal or as gut fill?
iv. How might weight loss be mitigated?

Many of these questions will be addressed, in part, through a consideration of the physiology and energetics of growth. In particular, given the lack of protein in pastures used in the northern beef production system and widespread deficiency of macro and micro-minerals in the tropical grazing systems, an understanding of the efficiencies of protein accretion and skeletal development are also pertinent. These understandings are integrated in the following discussions.

5.6.1 What is the composition of the weight lost during periods of inanition, disease and/or adverse environmental impact that cause weight loss?

Owens et al (1995) highlight the impact of rumen fill and water intake on the precision with which weight measurements occur. A more precise determinant of growth, predominantly the accretion of protein, fat and bone, is achieved by determining empty body weight (EBW), a process in which the digesta are removed from the gastrointestinal tract after animals are slaughtered and all remaining tissues are weighed (Owens et al 1995). The determination of EBW is a process only suited to detailed experimental protocols and determination of compensatory gain in the field will be subject to a lack of definition of the type of gain.

The composition of weight loss will be influenced by the availability of forages in the dry season. The extent of rumen-fill increases with increasing fibre content of the diet and with increased moisture content (Droulliard and Kuhl 1999). It can be speculated that initial loss of tissue mass in the dry season may be masked by increased rumen fill with more fibrous, less palatable species that will increase digesta mass and consequently body weight. McCown and McLean (1983) found that the dry matter of the late dry season buffel grass *(Cenchrus ciliaris)* was very high, approximately 40%, but underwent a rapid decline to approximately 18% dry matter following new growth and rain. On tropical grass pastures, when nitrogen content is very low during the dry season, abrupt loss of fasted live weight following first rain can be largely attributed to decreased gut contents (McLean et al 1983). McLean et al (1983) concluded that live weight was a very misleading index of cattle well-being when cows were losing weight in the early wet period. Further, that the long dry season was probably the more important period of nutritional stress, owing to the magnitude of depletion of tissue reserves. In that study (McLean et al 1983), approximately 72 % of body fat reserves and *ca.* 10 % of body protein were mobilized from June to late October.

From a teleological perspective, it can be argued that long term survival will be best favoured by a synchronised mobilisation of lipid and rapidly mobilised protein stores; structural protein and that

important for metabolic functions will be preserved. This pattern of mobilisation is observed in lactating cattle. Sainz and Bentley (1997) found that liver weights and protein content were markedly reduced in limit fed steers. Webster et al (1995) found even more dramatic, but very rapidly reversible losses, of approximately 40% and 30% in liver mass for lambs underfed energy and protein, respectively, for 7 weeks. The rapidly labile protein reserves that may be first mobilised in underfeeding have been estimated at 5.6% of total body nitrogen (N) in growing *Bos taurus* steers (Biddle et al 1975). Hogg (1991) in a review of compensatory growth noted that the weight is lost in liver, gut, and intestines, which are all metabolically active tissues. Evidence of elevated mRNA levels of carnitine palmitoyltransferase 1 (4.6-fold), fatty acid binding protein 3 (2.0-fold), and acyl-coenzyme A oxidase 1 (2.8-fold), all of which are indicators of beta-oxidation, shows that a lipid mobilisation arises in underfed Angus cattle (Brennan et al 2009). Beta-oxidation is incomplete when insufficient carbon chains from propionate or glucogenic amino acids are available to match acetate flux arising from catabolised fats, resulting in increased ketogenesis (Lean et al 1992). Propionate precursors will be limited from diets based on dry season pastures, as will protein, and therefore, amino acids will be used inefficiently to support maintenance.

Muscle fibre diameter is decreased during periods of weight loss. Greenwood et al (2009) found that Belmont Red cattle fed to lose weight after weaning had significantly more loss of area of the type 2X (fast glycolytic) myofibrils and least loss of type 1 (slow oxidative) myofibrils from the longissimus lumborum muscle after 115 days of underfeeding. It appeared that these changes were reversible as myofibril areas in these muscles returned to nearly comparable to groups fed to gain weight by 721 days. Hornick et al (2000) note that the metabolically active tissues or organs, such as liver and intestine, show the greatest weight loss. Droulliard et al (1991) found that severe protein restriction was particularly harmful to performance following re-feeding and that severity of nutrient restriction had a more profound impact on compensatory growth than the duration of restriction. The field data support the teleological contentions outlined above. Baldwin (1995) addressed the energy requirements for maintenance and production and the contributions of different tissue masses and physiological states to the energy requirements. The review of Baldwin (1995) provides observations that are valuable in identifying organs, such as liver, that contribute most to the energetic costs of maintenance. The incremental costs for the animal to maintain non-essential protein stores are high, because protein, particularly viscera, has a high maintenance cost.

5.6.2 Are the body tissue component losses the same in underfed adult and younger cattle?

There is evidence that prenatal and pre-weaning growth, if restricted severely enough, can influence performance in the future. Greenwood and Cafe (2007) found that severe, chronic growth retardation of cattle early in life reduces growth potential, resulting in smaller animals at any given age. Underfeeding earlier in life reduces the capacity for long term compensatory growth (Coleman and Evans 1986; Berge 1991; Greenwood and Cafe 2007). Biddle et al (1975) found that there was a 44% difference in the amount of labile body protein N between steers weighing 280kg compared to those weighing 144kg, suggesting that labile reserves may be relatively greater in the young animal.

It appears, however, from literature search and review of older texts that there is little directly comparable data on the nature of body weight loss of older and younger cattle in northern Australia or on tropical pastures. The study data available support observations from the field, comments from interviewees (see Chapter 9) and review literature (Berge 1991; Hornick et al 2000; Greenwood and Cafe 2007) that the impact of under-nutrition is particularly severe in younger, especially unweaned cattle. The potential for compensatory growth appears to be greatest when cattle are about 25–30 percent of mature size (Hogg 1991).

Hogg (1991) noted that skeletal size and ultimately mature size, but not weight, are fixed when the epiphyses of the long bones fuse. In interviews conducted as part of our project, it was indicated that the frame that could be achieved prior to the closure of epiphyses was an important determinant of whether subsequent growth lead to a leaner or fatter animal. Specific support for this contention appears to be limited, but the proposition appears to be logical that smaller framed animals with a lower mature body size will be fatter than the cattle with a larger mature body size exposed to the same feeds.

5.6.3 What is the composition of weight regained in the compensatory phase and, on average what percentage of loss is regathered. Is that mass regained, gained as profitable cuts, or offal or as gut fill?

One of the risks in assessing the impact of compensatory growth by using live-weight as the determinant in the northern beef system will be the increase in gut fill following the onset of the wet season. It is likely that increased appetite observed in compensatory growth phases (Berge 1991), coupled with a greater feed availability, better water access, and higher moisture content in the feed, will confound the measurement of tissue accretion if the sole measure of tissue accretion used is body weight. Caution, therefore, needs to be exercised in regard to the extent that changes in weight reflect marketable product.

Many workers have identified a change in the composition of body mass for cattle that are severely feed-restricted in early life and that are subsequently re-fed. During the early re-accretion phase, protein is the dominant deposit. Muscle contains approximately 17% protein; therefore, weight gains are apparently efficient. In many cases, the time taken for liver weights to be regained is considerable (Hogg 1991).

Cattle reach a mature body size (maximum body protein mass) when the body fat content is approximately 36% of empty body weight regardless of sex and background (Owens et al 1995). Mature body size is a function of genetics, nutrition and hormonal status. Greenwood and Cafe (2007) propose that within pasture-based production systems for beef cattle, the plasticity of the carcass tissues, particularly of muscle, allows animals that are growth retarded early in life to attain normal or slightly leaner carcass composition at equivalent weights in the long term, albeit at older ages. If high energy concentrates are provided following severe growth restriction from birth to weaning, then at equivalent weights post-weaning the slowly-grown, small weaners may be fatter than their well-grown counterparts (Greenwood and Cafe 2007). Hornick et al (2000) also conclude, based mostly on northern hemisphere studies, that animals that achieve compensatory growth are fatter. It is feasible to hypothesise that the impact of re-feeding on body composition may depend on the most limiting nutrients in the diet, and perhaps on the stature of the cattle being fed, such that cattle fed on diets in which protein is not the most limiting nutrient may develop a leaner mass than those fed a relative excess of energetic precursors. If frame size is not optimal it is possible that the mature body size will be smaller and the process of partitioning towards adipose deposition commence at a lower body weight. Greenwood and Cafe (2007) conclude that retail yield from cattle severely restricted in growth during pregnancy or from birth to weaning is reduced compared with cattle well grown early in life when compared at the same age later in life. However, retail yield and carcass composition of low- and high-birth-weight calves are similar at the same carcass weight. Similarly, Belmont Red cattle that were significantly growth impaired, and did not achieve full compensation, i.e. equivalent weight, after re-alimentation on grass, had similar carcase characteristics and beef quality to those fed to achieve ‘rapid growth’ (Tomkins et al 2006).

In terms of modelling or predicting the nature of weight gain, considerable progress has been made (Ferrell and Oltjen 2008). These workers (Ferrell and Oltjen 2008) note the value of a number of models including models developed by Di Marco and Baldwin (1989), the CNCPS model, and a mechanistic, dynamic model developed in sheep, but adapted for cattle (Soboleva et al 1999). Ideally, models should be able to accommodate the effects on maintenance that result from underfeeding and the variability in maintenance associated with changes in energy expenditure associated with the changes in visceral protein mass identified by Sainz and Bentley (1997).

It appears that extreme caution is required in interpretation of weight gain data over both the feed restriction (dry) and the re-feeding period (wet) in the northern beef system due to the very probable changes in ingesta and water contents of the tract, that controlling the amount of weight lost may allow the negative impacts on subsequent performance of cattle to be limited; and that the theoretical efficiencies of weight gain and loss are relatively high, however, these will be influenced by the nature of the tissue regained. Both Lindsay et al (1993) and Owens et al (1995) explore the efficiencies of gain of protein and fat noting the similar efficiencies estimated in a number of species and the markedly lower efficiency achieved in protein gain compared to that theoretically achievable. It is not clear from the literature whether adequate prediction of the end value of tissues deposited before the dry season can be made.

5.6.4 How might weight loss be mitigated?

The potential to mitigate the amount of weight loss, or more critically body tissue that has marketable value is significant. In Chapters 6 and 8, we investigated the responses achieved in feeding trials with various nutritional interventions. These form the basis of the model validation, but also provide evidence of the extent of mitigation that can be achieved by feeding strategies already enacted.

Other manipulations that may control weight loss were considered. The most obvious of these is the decision to remove cattle to end use, e.g. live export or backgrounding facilities, feedlots or other properties with viable feed. Another is to manipulate the amount of weight loss using post-ruminal interventions. Considerable work was conducted through the period from 1970 to the mid 1990's in exploring methods by which growth could be manipulated using anabolic or oestrogenic implants, β-adrenergic agonists, such as ractopamine and α_2-adrenergic agonists and other agents including somatotropin and corticosteroids (Lindsay et al 1993; Hunter et al 1993).

The current position is that only the anabolic and oestrogenic implants are available for managers to use and these are widely used in the Northern beef industry (Hunter 2010). Hunter (2010) reviewed the literature in regard to the efficiency of use of these agents and concluded that only high doses of trenbolone acetate (>300mg per day) were successful in mitigating weight loss during periods of liveweight loss (Houston et al 1992; Hunter and Magner 1990; Hunter et al 1993; Rumsey et al 1980). The product capable of delivering this dose is no longer available on the Australian market. It is worth noting that the nutritional conditions under which those response trials were conducted were not carefully defined. We, therefore, need to be careful in regard to ascertaining why responses were achieved and consider that such pathways may be able to better manipulated by combinations of approaches. Of the other manipulations considered, the β-agonists are available in other countries. These are delivered in feed and zilpaterol hydrochloride, cimeterol and ractopamine are used in beef feedlot production in other countries. Trials using the β-agonists with either monensin and tylosin (Winterholler et al 2008) or anabolic implants (Montgomery et al 2009) have shown additive effects in improving weight gains under lot-fed conditions. The potential to use several

manipulations in combination to increase performance on poor quality pastures does not appear to have been explored in great detail.

A combined strategy to manipulate the system, using combinations of rumen modifiers with co-factors, substrates and/ or anabolic agents (dietary or otherwise) may well be economically effective provided that such a strategy results in the capacity to allow cattle to be sold before the next period of poor growth or weight loss, thereby saving a year to turnoff and profoundly altering the economics of production.

Deeper understandings of the limitations to growth, and even more critically for northern Australia methods of controlling economically valuable tissue loss and efficient regain of those tissues, are needed at a metabolic and meta-genomic levels to evaluate what impairs maintenance of the different tissue pools during weight loss and which pathways are up-regulated in compensatory gain.

6 Rumen modifiers and supplements

Rumen modifiers are not buffers or neutralising agents. Instead, they act by directly altering the balance between the different populations of microbes in the rumen and can modify the proportion of volatile fatty acids (VFAs) produced. Rumen modifiers play an important role in cattle production, with the positive effects of supplementation on production animal well being and the environment increasingly being recognised.

Rumen modifier premixes have usually been designed for the feedlot market. The commercial formulations include a relatively inert carrier, such as ground rice husk. This means that rumen modifiers are usually given to the animal in a dry form, although liquid supplements and blocks can also be used. In addition, monensin is available in a controlled release capsule for individual long term dosing and can also be delivered through the drinking water. Several dispensers currently available make water medication commercially practicable in some situations. Rumen modifiers that are used in cattle are list in Table 17.

Table 17. In-feed rumen modifier products currently registered for beef cattle and commercially available in Australia

Rumen modifiers	Generic name	Trade name	Manufacturer/distributor*
Glycolipid (Bambermycin)	Flavophospholipol	Flaveco® Gainpro®	International Animal Health Products (IAHP) Intervet
Ionophores	Lasalocid	Bovatec® various® Lasalocid®	Alpharma
	Monensin	Rumensin® Moneco® Promensin®	Elanco IAHP Virbac
	Salinomycin	Bio-Cox® Saleco® Salindox®	Alpharma IAHP Dox-al
Antibiotics	Virginiamycin	Eskalin®	Pfizer Animal Health
	Tylan	Tylosin®	Elanco Animal Health
	Avilamycin		
	Oleandomycin		
	Kitasamycin		
	Fermenten	Fermenten®	Church & Dwight Co

Fermenten	Lactobacillus acidophilus	Protexin®	International Animal Health Products (IAHP)
Probiotic	Live yeasts	See Appendix I	
Yeasts	Yeast extract	See Appendix I	
	Yeast culture	See Appendix I	

* These were obtained from Avcare publication on enteric antibiotics (2003) and checked against the APVMA site http://services.apvma.gov.au/PubcrisWebClient accessed October 25th 2010

6.1 Flavophospholipol

Flavophospholipol (FPL) is a glycophospholipid antibiotic that has marked antibacterial effect on gram-positive micro-organisms found in the digestive tract. There is limited efficacy against gram-negative organisms, particularly *Salmonella* spp. and *E. coli*. The mode of action for FPL is inhibition of bacterial reproduction by intervening in the biosynthesis of murein, the structural substance of bacterial cell walls. Since animal cells have no comparable structure in the cell wall, FPL is extremely well tolerated by mammals.

Flavophospholipol improves protein supply (Hamann 1983; Kraszwski et al 1991; Behrens et al., 1993), possibly by increasing protein outflow from the rumen (Behrens et al 1993) as a result of decreased bacterial catabolism of protein and amino acids within the rumen (Poppe et al 1993 and Corpet et al 2000). There also appears to be improved amino acid absorption in the small intestine (Behrens et al., 1993). Inclusion of FPL in the diet can improve dry matter intake and feed conversion efficiency. Flavophospholipol increased the proportion of propionic acid produced in rumen fluid (Fallon et al 1986). It has also been suggested that FPL can be used as a therapeutic against acidosis in dairy cattle (Van Nevel, 1991) and its effect on rumen fermentation has been described by in detail Van Nevel and Demeyer (1988).

An interesting attribute is the capacity for FPL to reduce the prevalence of organisms with transmissible plasmid resistance to other antibiotics. There is no evidence of cross-resistance to other antibiotics such as penicillin, tetracycline or the macrolides (Wasielewski et al 1965). One of the major areas of public concern regarding the use of in feed antibiotics in animals is the potential for the development of drug resistant bacteria that pose a risk to human health. Flavophospholipol is from a class of antibiotics that are not used in human medicine. In addition, its “plasmid curing” effect (Bogaard et al 2002) and reduction in shedding of multi resistant *Salmonella* spp and *E. coli* (Dealy and Moller 1977ab) suggests that FPL may have a unique role in the food animal industries. A quantitative assessment conducted by SBS*cibus* (2003) showed that the ADG of beef calves and cattle supplemented with FPL was 0.084kg per day (9.1%) and 0.063kg (7.7%) per day greater than negative control group cattle, respectively (Table 18).

Table 18. Estimated differences in average daily gain of calves and adult beef cattle supplemented with Flavophospholipol (SBS*cibus* 2003)

	No of studies (No of trials)	Difference in ADG (kg per day) Mean ± SE (%)	Difference in weighted mean difference (kg per day)
Beef calves	11 (17)	0.084 ± 0.02 (9.1%)	0.080
Beef cattle	19 (24)	0.063 ± 0.01 (7.7%)	0.054

The diets used in the FPL studies (Table 18) were generally more applicable to beef feedlots, however, some of the studies were conducted with cross-bred cattle in northern Australia on tropical pastures. The weight responses from these studies were similar in percentage increase in ADG to those conducted on more digestible diets. Three feeding trials were undertaken in Australia where FPL (Gainpro®) was fed to beef cattle managed under different conditions. In two of the three trials, the performance of Gainpro® was compared to that of alternative rumen modifiers.

The first study compared the efficacy of the rumen modifiers, Salinomycin (Salocin 120®) and FPL (Gainpro®) when added to a molasses based production ration. The rations were fed to steers in pens at the QDPI Swans Lagoon Research Station at Millaroo near Townsville, North Queensland. The addition of both FPL (Gainpro®) and monensin to a molasses based production supplement increased liveweight gain by 83% compared with controls over 62 days.

The second study was a feeding grazing trial in southern Australia (Victoria). FPL (Gainpro®) was fed to British Breed beef cattle grazing spring pastures. A non-significant weight gain advantage of 5.2 kg (4.5%), based on empty weights, favoured the inclusion of 30 mg of the FPL/head/day in the diet.

The third study was conducted in northern Australian trial and included cattle grazing dry season pastures and supplemented with a molasses/urea based survival ration including FPL (Gainpro®). Cattle that received the supplement that included FPL realised a 68% improvement in liveweight gain over 71 days compared to cattle receiving the supplement without FPL.

Smith et al (1995), in the USA, compared the effects of FPL (Bambermycin) and monensin on ADG of steers grazing Bermuda grass, fescue and native pasture. The ADG of steers supplemented with Bambermycin was 14% less than the control, whereas the ADG of steers fed monensin was 10% greater than control group.

Unfortunately, not all of the studies using FPL were published in full and there needs to be more detailed investigation and publication of results to support what appear to be positive initial findings.

6.2 Ionophores

Ionophores are the most widely adopted of the rumen modifiers used in cattle. The benefits of ionophores include:

i. enhanced energy efficiency of rumen bacteria and consequently cattle
ii. improved nitrogen metabolism in rumen bacteria and in cattle
iii. a reduction in incidence of digestive disorders resulting from instability in rumen fermentation
iv. control of protozoa in the rumen and in the lower tract, specifically anti-coccidial actions.

Monensin was the first of the ionophores identified. The mode of action of the ionophores against coccidia and bacteria appears to be similar. Ionophores form complexes with extracellular sodium and dissolve into the lipid bilayer membrane of either bacteria or coccidia. The complexes in the membrane allow total intracellular sodium concentrations to increase and potassium concentration to decrease. The bacteria or protozoa attempts to re-establish the sodium-potassium gradient, resulting in increased activity of ATP dependent Na^+-K^+ pumps. The intracellular sodium concentration increase is so large and so rapid that the pumping capacity is soon overwhelmed and

the cell dies. Ionophores have greatest activity against gram-positive bacteria, and sensitive ruminal organisms are listed in Table 19.

Table 19. Sensitivity of rumen bacteria to monensin (Source: Chen and Wolin 1979; Dennis et al 1981)

Micro-organism	Strain	Sensitivity
Ruminococcus albus	7	Highly sensitive
Ruminococcus flavefaciens	C94	Highly sensitive
Bacteroides succinogenes	S85	Sensitive
Bacteroides ruminocola	GA	Sensitive
Butyrivibrio fibrisolvens	D1,49 and A38	Highly sensitive
Selenomonas ruminantium	GA192,HD4,D, GA31 and PC18	Unaffected
Methanobacterium ruminantium	PS	Slightly inhibited
Methanobacterium formicicum	MF	Moderately inhibited
Methanosarcina barkeri	MS	Moderately inhibited
Eubacterium cellulosolvens	5494	Extensively inhibited
Eubacterium ruminantium	GA195	Slightly inhibited
Lachnospira multiparus	D32	Moderately inhibited
Lactobacillus ruminus	RF1, RF2, RF3	Slightly inhibited
Lactobacillus vitulinus	CL1, RL1, RL2	Moderately inhibited
Streptococcus bovis	124	Slightly inhibited
Succinomonas amylolytica	$B_2$4	Slightly inhibited
Succinovibrio dextrinosolvens	0554	Slightly inhibited

Ionophores prevent or aid in the prevention of digestive and metabolic disturbances caused by erratic feed intake or specific disorders, including bloat and acidosis. Ionophores have the potential to aid in the control of acidosis by two distinct mechanisms:

i. reducing numbers of lactic acid-producing bacteria including *Streptococcus bovis* and *Lactobacillus* spp
ii. reducing the variation in feed intake.

Ionophore use produces consistent eating behaviour in beef cattle, which contributes to a reduction in acidosis, feedlot bloat and death. However, the magnitude of these effects on the outcomes identified remains largely unquantified.

There is relatively little evidence of bacterial or protozoal resistance to ionophores. Genes responsible for ionophore resistance in ruminal bacteria have not been identified and there is little evidence that ionophore resistance can be spread from one bacterium to another. This reflects the non-specific anti-porter action of ionophores on cell membranes function. Use of ionophores in animal feed is not likely to have a significant impact on the transfer of antibiotic resistance from animals to man (Russell and Houlihan 2003).

Ionophores available in Australia include monensin (Rumensin^{TM}), lasalocid (Bovatec^{TM}) and salinomycin. The effect of ionophore supplementation in beef cattle is summarised in Table 20. There is evidence of variability in response among ionophores on feed intake, weight gain and efficacy in both feedlot and grazing beef cattle.

Table 20. The response of beef cattle to ionophores

Ionophore	Grain-fed			Pasture-fed	Dose per head per day	
	Intake	Weight gain	Efficiency	Gain	Feedlot (mg/kg of feed)	Pasture-fed (mg/ day)
Monensin	Decrease	No change	Increase	Increase	5.5–33	50–300
Lasalocid	No change, increase	Increase	Increase	Increase	11–33	60–300
Laidomycin propionate	No change, increase	Increase	Increase	No data	6–12	25–50
Lysocellin	Decrease	No change, increase	Increase	Increase	11–33	80–100
Narasin	Decrease	No change	Increase	No data	8–6	-
Salinomycin	No change, increase	No change, increase	Increase	Increase	5.5–16.5	50–100

6.2.1 Monensin

Monensin is produced by the bacterium *Streptomyces cinnamonensis*. Monensin modifies rumen function to increase total VFA production and to increase propionate percentage (Burrin and Britton 1986), reduce variability in feed intake (Thonney et al 1981; Fox et al 1988; Abe et al 1994) and reduce methane output (Stanier and Davies 1981).

A recent meta-analysis by Duffield et al (2010, pers comm) that included 57 studies (151 trials) showed that monensin improves feed efficiency in growing and finishing cattle, both in studies reporting feed to gain ratio (F:G) and in studies reporting gain to feed ratio (G:F). Monensin reduces kg of feed per kg of gain by about 0.55kg of feed. Monensin reduced DMI by 0.28kg and improved ADG by 0.032kg/d. The pooled estimated feed efficiency of the included studies was 6.6% (Table 21). While diets with corn silage present provided a lower DMI, effects were similar for growing as opposed to feedlot cattle. The point effects for production in the beef cattle were similar to those in dairy cattle (Duffield et al 2010), suggesting a consistent response to the intervention in different environments.

Table 21. Summary of effect size estimates of monensin on performance outcomes in growing and finishing cattle derived from meta-analysis (Source: Duffield et al 2010)

Outcomes measured	Trials	Effect size[1] (95% CI)	Effect Size *P* value	Weighted mean difference[2] for monensin-control (95% CI)	(%) Change
Feed efficiency (kg feed/kg gain)	124	-0.951 (-1.12, -0.78)	<0.001	-0.55 (-0.64, -0.46)	-6.6%
DMI (kg)	133	-0.748 (-0.92, -0.57)	<0.001	-0.285 (-0.35, -0.23)	- 3.2%
ADG (kg/d)	138	+0.283 (0.14, 0.42)	<0.001	+0.032 (0.019, 0.044)	+2.8%
Feed efficiency (kg gain/kg feed)	20	+ 0.285 (-0.011, 0.58)	0.06	+ 0.0036 (-0.00047, 0.0078)	+2.5%

[1] Effect size = a standardized z-value to statistically compare treatment versus control differences between studies.
[2] Weighted mean difference is estimate of actual effect of treatment in units measures, CI = Confidence Interval.

Wilkinson et al (1980) conducted twelve pasture trials, involving a total of 434 beef cattle to assess the efficacy of monensin in grazing cattle under European conditions. The ADG of the control and monensin-supplemented cattle averaged 0.786 and 0.893kg/head per day respectively, an advantage of 107g/head per day or 13.7% in favour of the monensin treatment (P<0.001). The growth-promoting effect of monensin showed no tendency to diminish with time.

The effects of supplemental grain and monensin on forage digestibility and intake were evaluated by Dahl et al (2007) in beef cows grazing native range pastures in mid-summer and early autumn on a US farm over a 2-year period. The digestibility of organic matter (OM) and neutral detergent fibre NDF was similar between monensin and corn supplemented cattle, but monensin supplemented cattle had higher digestible organic matter intake than control groups.

There are limited data on the effect of monensin in grazing beef cattle in northern Australia. Lindsay et al (1989) compared the effects of three rumen modifiers added to cottonseed meal (CSM) fed to *Bos indicus* steers grazing native pasture (predominantly *Heteropogon contorus*) during the dry season. Their results demonstrated that CSM supplementation during successive dry seasons increased ADG, however, the addition of monensin did not significantly improve weight gain of steers.

Lindsay et al (1990) found that the addition of monensin or avoparcin to molasses-based rations enhanced propionate production and improved performance. With high intakes of molasses based diets (3.7kg/day) the addition of either monensin (with intake of 3.2kg/day molasses) or avoparcin (with intake 3.8kg/day molasses) significantly increased liveweight gain and improved feed conversion ratio. Incorporating monensin into molasses-based diets made the diet less palatable, reducing intake, leading to reduced bloating and reduced risk of molasses toxicity. Feeding monensin in this way improved liveweight gain of northern beef cattle by up to 0.17kg/d (Lindsay et al 1990). The economic importance of these improvements in liveweight gain was estimated by assuming appropriate values for costs and returns. Lindsay et al (1990) estimated net returns, assuming that liveweight gain was valued at $1.10/kg and commercial prices for each rumen modifier from $3.50 per head when lasalocid was added to molasses and urea, to $14.20 with the addition of monensin to a high energy molasses diets (Table 22)

Table 22. Estimated benefits of inclusion of rumen modifiers to dry season supplements offered to young cattle for 100 days (Source: Lindsay et al 1989)

Supplement	Rumen modifier	Liveweight gain (kg/hd)	Cost of rumen modifier ($/100 days)	Margin ($/hd)
High energy (molasses diet)	Monensin	15	2.34	14.2
	Avoparcin	15	6.39	9.60
Protected protein in dry season	Monensin	12	3.30	9.90
	Avoparcin	8	0.90	7.90
Molasses + urea in dry season	Monensin	12	3.30	9.90
	Avoparcin	8	0.90	7.80
	Lasalocid	4	0.90	3.50

Reproductive performance of monensin supplemented cattle. Sixteen studies or experiments within studies were used in an evaluation the effect of monensin on reproductive performance in beef and dairy heifers (Lean et al 1994). Reproductive performance outcomes were not consistently measured across studies, hence different outcomes were assessed using subsets of studies according to the measurement of the following outcomes: puberty rate, first service conception rate (FSCR), pregnancy rate, interval to oestrus and days to conception. Puberty rate, FSCR, and pregnancy rate were analysed using a fixed effects meta-analysis model for dichotomous variables.

Puberty rate, that is the rate at which prepubertal heifers reached puberty while on either monensin or control diets, was significantly higher in heifers fed monensin by a weighted difference of 32% (95%CI 16% to 47%) which was a weighted 61% improvement over controls. There was no significant difference in FSCR and pregnancy rate in heifers fed monensin (improvements of 2% and 1% respectively). There was heterogeneity in the dataset; some studies showed a 5% to 38% increase in %FSCR due to monensin treatment, while the rest reported a 4% to 7% reduction in %FSCR. Similarly for pregnancy rate, 6 studies reported an 8% to 18% increase, one reported no effect and the remaining studies reported a 4% to 26% reduction. Days to oestrus and days to conception were evaluated by summary measures analysis, using the results from each study measuring this outcome as the experimental units. Heifers fed monensin had a significant reduction (P=0.01, based on 11 studies) in days to first oestrus, with a weighted mean decrease of 27 days (Median decrease of 22 days).

6.2.2 Lasalocid

Lasalocid (Bovatec®) is an ionophore with similar activity to monensin. Lasalocid is not used as commonly as monensin as a feed additive in the Australian cattle industries. It appears possible that this product will have efficacy in modifying the risk of acidosis. There is less information available on responses to lasalocid in pasture-fed cattle than on monensin. However, one study found that lasalocid-treated cattle had higher dry matter intakes and greater weight gains than monensin-treated cattle (Thonne et al 1981). Lasalocid can be recommended under similar circumstances to monensin. A summary of studies on the effects of lasalocid on ADG and G:F is presented in Table 23. This shows that estimated ADG of cattle fed lasalocid was greater (1.25kg/hd/d) than those in the control group (1.20kg/hd/d). Similarly, estimated G:F was greater in lasalocid-fed cattle (0.05 *vs.* 0.01).

Table 23. Summary of studies on the effects of lasalocid on ADG and G:F

Authors	Comparisons/ Herds	Class of cattle	Breed	Feeding system	ADG (kg/hd/d)		G:F	
					Control	Lasalocid	Control	Lasalocid
Andersen and Horn 1987	1	Heifers	Hereford & Hereford x Angus	Grazing (Wheat pasture)	1.03	1.03		
	2				1.03	1.14		
Worrell et al 1990		Yearling Steers	Crossbred x Angus	Grazing (Rye pasture)	1.28	1.58		
Strauch et al 2003		Cows	Brahman	Grazing (Bermuda grass pasture over-sown with ryegrass)	0.06	0.11		
Morris et al 1990	1	Yearling steers	British x Brahman	Feedlot TMR	1.64	1.69	0.155	0.158
	2				1.64	1.63	0.155	0.255
Duff et al 1994		Steers	Crossbred	90% concentrate	1.7	1.6	0.17	0.19

6.3 Antibioitics

6.3.1 Virginiamycin

Virginiamycin (Eskalin®) is an antibiotic with primarily gram-positive activity. It is effective in reducing lactic acid production *in vitro* (Nagaraja et al 1987) by removing *S. bovis* (Hedde et al 1980), the organism primarily responsible for lactic acid production on starch-based diets. Virginiamycin may not be as effective in controlling the risk of acidosis on predominantly pasture diets or diets where *S. ruminantium* can be well established in the rumen. This contention is supported by several studies (Courtney and Seirer 1996; Clayton et al 1999). Other effects of supplementing with virginiamycin include increased average daily weight gain and/or feed conversion efficiency, and a reduction in the incidence and severity of liver abscesses (Rogers et al 1995). A reduction in *in vitro* digestibility of the diet with virginiamycin treatment may have depressed feed intake in some trials (Thorniley et al 1996).

There are limited data on the effect of virginiamycin on grazing beef cattle. Fiems et al (1992) conducted three experiments on the effect of virginiamycin on the ADG of grazing bulls and heifers. Virginiamycin increased liveweight gain per hectare in bulls by 12% and in heifers by an average 10% (7 to 13%). Similarly, the ADG increased in virginiamycin supplemented bulls by 22% and in heifers by an average 10%.

Effects of virginiamycin supplementation on the performance of feedlot cattle have also been investigated. Rogers et al (1995) showed that steers and heifers fed finishing diets with virginiamycin had an improvement in ADG and feed conversion, but with no substantial effect on dry matter intake. A summary of 9 comparisons (Table 24) of virginiamycin shows that ADG was greater in virginiamycin (1.25kg/hd/d) that the control group (1.20kg/hd/d).

Table 24. **Summary of studies on the effects of virginiamycin on ADG and G:F in steers and heifers**

Authors	Comparisons/ Herds/Doses	Class of Cattle	Breed	Feeding System	ADG (kg/hd/d)		G:F or F:G	
					Control	Treatment	Control	Treatment
Salinas-Chavira et al 2009	1	Steer calves	Holstein	Feedlot	1.37	1.38	G:F= 0.176	G:F= 0.180
	2			Feedlot	1.37	1.41	G:F= 0.176	G:F= 0.183
Boucque et al 1990		Bulls	Belgian white-red		1.28	1.38		
Fiems et al 1992	1	Bulls	Belgian white-red	Pasture	0.59	0.72		
	2	Heifers	Belgian white red and Holstein	Pasture	0.51	0.55		
	3	Heifers	Belgian white red and Holstein	Pasture	0.73	0.81		
Van Koevering et al 1991	1	Steers		Feedlot	1.66	1.67		
	2				1.66	1.63		
	3				1.66	1.72		
Rogers et al 1995	10 trials	Steers & heifers		Feedlot	1.31	1.37	F:G= 6.58	F:G= 6.36
Van Koevering et al 1991 (carcass basis)	10 g /tonne	Steers		Feedlot	1.68	1.69	F:G=5.72	F:G=5.65
	17.5 g/tonne				1.68	1.70	F:G=5.72	F:G= 5.61
	25g/ tonne				1.68	1.73	F:G=5.72	F:G=5.62
Preston et al		Steers	Cross-		1.68	1.69		

1989		bred			
McDowall et al 1996 (40 PPM for first week, and 20 PPM thereafter with 5 different amounts of barley & oats	West Lort River	Weaner steers	Paster + Barley + Oats	0.13	0.14 - 0.57
	Mt Howick Station			0.26	0.14 - 0.71
	Young River Station			0.16	0.30 - 0.66

The more recent studies of Salinas-Chavira et al (2009) on the effects of virginiamycin and monensin on the performance of Holstein steers showed that virginiamycin did not affect ADG but increased G:F and dietary net energy (NE). Virginiamycin also did not affect ruminal or post-ruminal digestion of OM, NDF, starch and N, and microbial efficiency, but tended to increase N efficiency. Monensin supplementation did not affect growth performance or dietary NE or digestion of OM, NDF, starch and N. These results suggest that virginiamycin can enhance feedlot growth-performance and dietary energetic efficiency of lot-fed steers.

Erasmus et al (2008) demonstrated that combined supplementation of virginiamycin and monensin increased energy corrected milk production of dairy cattle compared to supplementation with either additive alone. Similar studies analysed by SBS*cibus* demonstrated a marked increase in milk production compared to cattle fed a probiotic (Rosher and Lean unpublished). Both virginiamycin and monensin control gram positive bacteria, have effects on acidosis and can decrease plasma β-hydroxybutyrate (BHB) concentrations. The combined effects on acidosis and energy balance suggest a complimentary effect between virginiamycin and monensin. It is feasible that the combined positive effects of the two additives on improving acidosis, energy balance, potentially decreasing subclinical ketosis, stabilizing feed intake and rumen fermentation, could contribute to increased performance. Virginiamycin is used in conjunction with monensin in feedlot cattle to control acidosis, especially in introductory diets. Virginiamycin is highly effective in controlling rumen fermentation to reduce lactic acid production is a useful means of reducing health risks from acidosis.

6.3.2 Tylosin

Tylosin a macrolide antibiotic that, like virginiamycin, is effective in reducing lactic acid production *in vitro* (Nagaraja et al 1987). Combined supplementation of cattle with tylosin and monensin resulted in significantly lower rumen pH, higher volatile fatty acid and blood urea nitrogen concentrations and lower mean glucose concentrations than supplementation with either with virginiamycin or tylosin alone (Lean et al 2000).

A meta-analysis by Wileman et al (2009) showed that feedlot beef cattle fed a ration without tylosin had an estimated 30% (95% CI= 18.62 to 44.77%) risk of liver abscesses compared with 8.0% (95% CI= 4.43 to 14.07%) in cattle fed a diet that contained tylosin ($P < 0.01$). However, these studies did not show a consistent advantage in treated cattle relative to control cattle with respect to ADG, G:F, and DMI. The meta-analysis (Wileman et al 2009) did not examine at the severity of liver abscesses and relate this to subsequent performance. This may explain the lack of significant difference in ADG between tylosin treated cattle and the control group. Nagaraja and Lechtenburg (2007), in their review of liver abscesses, reported significant variation in the performance effects of cattle with abscessed livers and stated that the variation was probably a function of severity of hepatic involvement.

Potter et al (1985) conducted a study in 14 herds to investigate the effect of tylosin or tylosin plus monensin on ADG and G:F in Hereford, Hereford cross and mixed breeds steers. The estimated effects of tylosin on ADG (1.36 *vs.* 1.36kg/hd/d) and G:F (0.14 *vs.* 0.15) were similar between the treated and control groups. Similarly, this study and others showed that there was little difference between tylosin plus monensin and control groups for ADG (1.39 *vs.* 1.41kg/hd/d) and G:F (0.15 *vs.* 0.16) in (Table 25). These results indicate that the use of tylosin is most appropriate to prevent of liver abscesses in feedlot cattle, rather than supplementation of cattle fed on pasture.

Table 25. Summary of studies on the effects of Tylosin + Monensin on ADG and G:F in steers

Authors	Comparisons/ herds	Class of Cattle	Breed	Feeding System	ADG (kg/hd/d)		G:F	
					Control	Treatment	Control	Treatment
Stock et al 1995	1	Steers	Cross-bred	Feedlot	1.42	1.46	0.161	0.168
	2				1.42	1.46	0.161	0.168
Duff et al 1994				Feedlot	1.7	1.5	0.17	0.17
Meyer et al 2009				Feedlot	1.76	1.78	0.145	0.156
Potter et al 1985	1	Steers and heifers	Hereford x Angus		1.52	1.37	0.163	0.180
	2	Steers	Mixed		1.62	1.53	0.153	0.156
	3	Steers	Hereford & Hereford cross		1.08	1.03	0.114	0.121
	4	Steers	Mixed		1.37	1.38	0.137	0.160
	5	Steers	Mixed		1.30	1.35	0.140	0.159
	6	Steers	Hereford x Angus		1.42	1.41	0.139	0.152
	7	Steers	Hereford & Hereford x Angus			1.16		0.126
	8	Steers	Hereford cross		1.47	1.45	0.147	0.167
	9	Steers	Hereford		0.95	1.12	0.134	0.170
	10	Steers	Hereford & Hereford x Angus		1.33	1.34	0.153	0.161
	11	Steers	Holstein		1.17	1.35	0.127	0.148
	12	Steers	Hereford & Hereford x Angus		1.50	1.54	0.181	0.186
	13	Steers	Hereford		1.33	1.40	0.149	0.171
	14	Steers	Mixed		1.60	1.62	0.137	0.151
Depenbusch et al 2008		Yearling heifers	Crossbred	Feedlot	1.32	1.31	0.165	0.169
					1.21	1.19	0.154	0.155

6.4 Fermenten

Fermenten is produced using a patented nitrogen source (amino acids, peptides and ammonium salts). It increases microbial protein yield and efficiencies of microbial production in the rumen by approximately 19% (Chalupa et al 1997). Fermenten is fed to cattle as a source of ruminally degradable amino acids, peptides and non-protein N (NPN).

Supplementation of rumen degradable crude protein (RDP) to cattle fed low-quality forages often increases forage intake and animal performance (Köster et al 1996; Kunkle et al 2000). *S*tudies with dairy cattle showed that addition of Fermenten to diets for growing heifers hastened body

development due to enhanced ruminal protein metabolism (Chalupa et al 1997; Murphy 2004). However, Cooke et al (2009) found that forage-fed Brahman-crossbred heifers fed supplements containing Fermenten had similar growth and development, but inferior reproductive performance compared to heifers fed supplements containing urea.

6.5 Live yeasts and yeast cultures

The three main types of yeast most commonly used to produce feed and food grade yeast-based products are *Phaffia rhodozyma*, *Candida utilis*, and *Saccharomyces cerevisiae*. Yeasts are fed as a live yeast preparation (e.g. Levucell (Lallemand), Yea Sacc (Alltech) or CJ Hansen), as killed baker's yeast or as a yeast culture (Diamond V). There are three forms in which yeast is fed to cattle and most of these relate to the use of *S.cerevisiae*. Yeast culture is defined as a mixture containing yeast cells (usually *S. cerevisiae)* and the culture medium in which they are grown. This mixture is dried in order to prevent the destruction of its nutrient content (Lynch and Martin 2002) and has been derived from specific yeast cell components such as the cell wall, the cell membrane, and the cell extract. A large number of yeast products are available for use in cattle in the USA and Appendix I provides details of these.

Yeasts and yeast culture products modify ruminal fermentation (Wiedmeier et al 1987; Harrison et al 1988), increase numbers of ruminal bacteria (Harrison et al 1988) and stimulate their growth (Dawson et al 1990; Erasmus et al 1992). Yeast culture products also increase the initial rate of forage digestion in the rumen and increase milk production in early-lactation dairy cows (Sanchez et al 1997; Dann et al 2000; Rabiee et al 2008). Yeasts stimulate both growth of cellulolytic and lactate-utilizing bacteria in the rumen, increase fibre digestion and increase the flow of microbial protein from the rumen (Martin and Nisbet 1992; Newbold et al 1996).

Desnoyers et al (2009) conducted a meta-analysis on the impact of yeast products on rumen function and found that yeast supplementation increased rumen pH (+0.03 on average) and rumen volatile fatty acid concentrations (+2.17m*M* on average), tended to decrease rumen lactic acid concentration (−0.9m*M* on average), but had no influence on acetate-to-propionate ratio. Total-tract organic matter digestibility was also increased by feeding yeast (+0.8% on average). While these positive findings are relatively modest in importance to rumen function, the methods used in this meta-analysis are of concern. There was no attempt to differentiate the various yeast products used and it is possible that particular preparations may perform better than the average.

Both Desnoyers et al (2009) and Rabiee et al (2008) evaluated the effect of yeast supplementation on milk production in lactating dairy cows and found positive milk production responses of a similar magnitude, not withstanding methodological differences. These milk production responses were larger than those reported following the use of monensin. The milk production increases, however, were not associated with an increase in efficiency of production similar to that found for monensin (Desnoyers et al 2009; Rabiee et al 2008). These findings in lactating cows suggest that there is a potential for benefit of feeding yeasts on concentrate or energy dense diets, such as those fed in feedlots.

Results of trials with yeasts under feedlot conditions have not all been significantly positive in regard to weight gain (Beauchemin et al 2003; Fiems et al 1995; Keyser et al 2007). Support for the potential for yeasts to produce benefits in feedlot nutrition is provided in a commercial presentation of results. The Diamond V® company provided data from 25 studies in feedlot cattle that show an average, modest improvement in ADG (1.42 vs. 1.49kg/hd/d) and F:G ratio (5.89 vs. 5.65) in supplemented feedlot cattle (Anon 2010). These results are unweighted and require a full meta-

analytical evaluation to determine the weighted mean, the effect size of the estimate and further evaluation of factors that may have influenced the results, including duration of feeding, type of diet and environmental conditions.

The positive effects of yeast supplementation on rumen pH (Williams 1991) and capacity to reduce ruminal lactate concentrations (Lynch and Martin 2002) indicate a potential to use yeast in control of acidosis (Chaucheyras-Durand et al 2008). These results, however, have not always been reflected in substantial alterations in measures of rumen function associated with acidosis (Beauchemin et al 2003) or on pH (Desnoyers et al 2009). It is not possible at this time to conclude that yeast feeding has a positive effect in controlling acidosis in feedlot cattle.

We could not identify studies conducted using yeasts in cattle grazing tropical pastures and there were limited studies available on weaned calves or heifers published in peer-reviewed journals. The form of delivery of live yeast is a matter of some concern in the extensive field situation. Products based on live yeast are vulnerable to the effects of heat and the environment of northern Australia will be inhospitable to yeasts. The impacts of this may be less in feedlots where conditions can be controlled and feed is often consumed within a matter of hours. Extensive rangeland supplementation will probably be unsuited to live yeast cultures. It should be noted that some live yeast preparations have micro-encapsulation to protect against environmental effects, e.g. some Lallemand preparations.

There may be sufficient information available to conduct a meta-analysis of the effects of yeast on weight gain in feedlot cattle. Such an analysis should address responses to yeast product, examine the consistency of responses to yeasts, examine differences in responses for different yeast products, seek evidence of publication bias and examine sources of variability of responses to yeasts.

6.6 Probiotics and direct fed microbial (DFM) products

Probiotics have been defined by Fuller (1989) as “a live microbial feed supplement, which beneficially affects the host animal by improving its intestinal microbial balance”. The European Union has acknowledged this category of products by categorising these as ’feed additives’. Other workers, especially in the USA, have preferred the term ‘direct fed microbial’ (DFM), which has a broader definition as “a source of live, naturally occurring microorganisms” (Yoon and Stern, 1995). Throughout this report, we will refer to DFM, because probiotics are a subcategory of DFM.

The concept of DFM use is attractive; that one or several bacteria or other microorganisms that are beneficial may be used to provide a more favourable rumen environment, allowing increased efficiency of production or better health. One of the most important advantages of such additives is the avoidance residues in meat and milk of regulated antibiotics.

We were able to identify a large number of products that broadly fit the criteria of DFM. The products available in Australia are listed in Appendix I. This product list is provided to indicate the significant marketing and development effort that is associated with the DFM, despite a relative paucity of data in peer reviewed journals on the effects of these products.

Given that the focus of this review is on either extensive pasture production or feedlot performance, the effect of bacterial DFM on neonatal calves is not considered in detail. There are some data to suggest a potential for probiotics to deliver a benefit in health to calves. However, the results have been variable (Timmerman et al 2005; Kung 2001; Chaucheyras-Durand and Durand 2010).

Krehbiel et al (2003) reviewed DFM and included a history of the development of these products in man and animals. Conceptually, the potential to produce DFM that are effective is inherent to many of the manipulations discussed within this report, including sourcing bacteria from other species, enhancing fibre digestion using transgenic or selected bacteria such as in the case of *Synergistes jonesii*, antibiotic and yeast treatments, and bacteriocin treatments. The DFM should act on rumen microorganisms to increase concentrations of useful microorganisms by exogenous supply, and at the same time provide substances that may favour competition against less desirable microorganisms. Interestingly, while the focus of research has been on ruminal activity, the commonly used bacteria include species of *Lactobacillus, Propionibacterium, Bifidobacterium, Enterococcus,* and *Bacillus.* Kung (2001) suggests that most bacterial-based DFM are probably directed towards effects in the lower gut and not in the rumen. *Lactobacillus acidophilus,* for example, produces lactic acid, which may lower the pH in small intestines to levels that inhibit the growth of pathogenic microbes.

There are four major areas of proposed use of microbial DFM:

i. to improve the adaptation of cattle under stress to feedlot diets
ii. to increase ADG or other indicators of performance of cattle in feedlots
iii. to reduce the shedding of *E. coli* O157 and *Salmonella* spp. from cattle fed in feedlots
iv. to reduce the risk of lactic acidosis.

A summary of studies using DFM in weaned cattle from 1980–2005 is provided in Sargeant et al (2008). Table 26 summarises the results for published studies on the use of DFM in cattle not included in this review. All were conducted in feedlot cattle, and we were unable to identify any studies on production responses of cattle on temperate or tropical pastures.

Sargeant et al (2008) provides a quantitative review of the effect of microbial DFM on shedding of *E. coli* O157. It concluded there was evidence of efficacy for the probiotic combination *Lactobacillus acidophilus* NP51 (NPC 747) and *Propionibacterium freudenreichii* at reducing numbers of *E. coli* O157 shed by feedlot cattle.

Table 26. Responses of cattle in studies conducted to examine bacterial DFM

Objective of study/ Study	**DFM and Conc** (cfu/hd/d)	**Outcome**	**Comments**
Adaptation of cattle to new environmental challenges			
Fox 1988	*L. acidophilus*, *L. plantarum*, *L. casei*, and *S. faecium*	13.2% increase in ADG 2.5% increase in feed consumption, 6.3% improved feed:gain	Mean from abstracts by Crawford et al 1980; Hutcheson et al 1980; Kiesling and Lofgreen 1981; Davis, 1982; Hicks et al 1986 (report only)
Dew and Thomas 1981		No performance response	Newly weaned calves (Abstract only)
Kercher et al 1985 & Kercher et al 1986		No performance response	Newly weaned calves (Abstract and report)
Krehbiel et al 2001	5 x10^9 *E. faecium*, *L. acidophilus*, *B. thermophilum*, and *B. longum*	No performance response	466 newly received feedlot calves (Report only)
Orr et al 1988	0, 2.2 x 10^6, 2.2 x 10^8, or 2.2 x 10^{10} *L. acidophilus*	Quadratic relationship between ADG and DFM concentration ADG greater for calves fed 2.2 x 10^6 or 2.2 x 10^8 No difference in feed intake and efficiency	Abstract

Lee and Botts 1988	2.2 x 10^8, 2.2 x 10^9, or 2.2 x 10^{10} cfu of *S. faecium*	Improved performance	Abstract only
Gill et al 1987	0.7 x 10^9	Increase in ADG by 9.3% and Gain:Feed by 9.5%	Report only
Cerna et al 1991	*L. plantarum, S.faecium, S. lactis, P. Freundereuchii*	7.8 – 12.5% increase in weight gain	Full paper
Cruywagen et al 1996	1ml (5 × l0^7) *L. Acidophilus*	Improved ADG during first 2 weeks of age	Full paper
Bechman et al 1977	2.5 x 10^{11} *L. acidophilus* sp.	17% improvement in ADG	Neonatal calves (Abstract only)
Jenny et al 1991		No improvement in feed efficiency	Neonatal calves (Full paper)
Abu-Tarboush et al 1996	*L. acidophilus* + *L. plantarum* or culture containing *L. acidophilus* 27SC (added to milk)	No improvement in feed efficiency	24 Holstein bull neonatal calves (Full paper)
Increase Feedlot performance			
Huck et al 1999	(1) *L. Acidophilus* BG2FO4 for the entire period, (2) *P. freudenreichii* P-63 for the entire period; (3) *L. acidophilus* BG2FO4 for 28 d, followed by *P. freudenreichii* P-63 for the remainder of the period; and (4) *P. freudenreichii* P-63 for 28 d, followed by *L. acidophilus* BG2FO4 for the remainder of the period.	Possible improvement in carcase grade when *P. freudenreichii* P63 was fed for the entire feeding period	Abstract only
Swinney-Floyd et al 1999	*Propionibacteria* P-63, 1x10^9 and *L. acidophilus* 5345, 1x10^8	Increased ADG and improved Gain:Feed No change in carcass characteristics	Abstract only
Beauchemin et al 2003	*E. faecium* EF 212 6 x 10^9	No change in ADG or other efficiency measures	Low numbers n = 16, detailed evaluation of rumen function – little effect on this (Full paper)
Brashears et al 2003	*L. acidophilus* NPC 747 and NPC 750	Body weight gains (on a live or carcass basis) and feed intakes did not differ among treatments Carcass-based gain/feed ratios tended (P < 0.06) to be better for the two DFM treatments groups than for control animals	Full paper
Greenquist et al 2004	1 × 10^9 *P. freudenreichii* NP 24, 1 × 10^6 *L. acidophilus* NP 45, and 1 × 10^9 *L. acidophilus* NP 51	No change in ADG or other efficiency measures	Large study 3569 head with heifers and steers (Extension publication only)
Vasconcelos et al 2008	*P. freudenreichii* NP 24) with 1 x 10^7,1 x 10^8, or 1 x 10^9 of *L. acidophilus* NP 51	A 2-3% improvement in gain:feed, but a quadratic response dependent on the *L. acidophilus* dose. No differences for final BW, carcass-adjusted final BW, period, DMI, or total DMI	2 trials with 480 head (Full paper)
Ware et al 1988	*L. acidophilus 1* x10^8 BT1386	Increase in ADG approx 4% and improved Gain:Feed approx 3%	Combined data from 8 feedlot trials at 6 different locations (Abstract only)
Galyean et al 2000	1 x 10^6 *L. acidophilus* NP 45; 1 x 10^4 *L. acidophilus* NP 45 + 1 x10^4 *L. acidophilus* NP 51; and 1 x10^6 *L. acidophilus* NP 45 +1 x10^6 *L. acidophilus* NP 51	Improved ADG, final BW and carcass daily gain and weight Gain:Feed improved for the first 56 days only No change in carcass characteristics except improved HCW	Progress report
Rust et al 2000ab	1 x10^9 *P. freudenreichii* NP 24	Increased final BW and carcass adjusted final BW, increased ADG and feed efficiency. No difference in DMI or carcass characteristics	Reports only
Kiesling et al 1982		No differences in final BW or Gain:feed in the DFM receiving	Abstract only

		period	
Brown et al 2006	5 x10^8 for 28 d followed by *P. freudenreichii* 1 x10^9 from d 29 to slaughter	No difference in DMI, carcass adjusted ADG or Gain:Feed Increased 12th rib fat	Report
Beeman 1985	*Lactobacillus* culture	BW gain 47.3 DFM vs. 37.8 kg control	Holstein steer calves (Short paper)
McPeake et al 2002	Varying concentrations of *L. acidophilus* LA45 and LA51 and *P. freudenreichii* PF24	Positive linear effect of *L. acidophilus* Increase in growth rate 2.6% and carcass weight 6 kg	Combination of 6 US trials (Abstract)
Huck et al 2000	*L. acidophilus* BG2FO4 (MicroCell) and *P. freudenreichii* P-63 (MicroCell PB)	Heifers fed *L. acidophilus* for 28 d followed by *P. freudenreichii* had greater gain (5.0%) and improved feed efficiency (5.1%) compared with controls	450 heifers (Extension publication)
Elam et al 2003	*L. acidophilus* NP51 and NP45 and *P. freudenreichii* NP24, varying concentrations and combinations	Overall no significant effect on performance and carcass characteristics	Two experiments with 240 and 660 steers (Full paper)
Shedding of pathogenic bacteria			
Peterson et al 2007	*L. acidophilus* NP51 1 x10^9	NP51-treated steers were 35% less likely to shed *E. coli* O157: H7 than were steers in untreated pens (odds ratio = 0.58, P = 0.008).	448 animals (Full paper)
Stephens et al 2007	*L. acidophilus* NP 51	At a low or high dose rate 69 and 74%, respectively, cattle were less likely to have detectable faecal *E. coli* levels	Full paper
Ohya et al 2000	*S. bovis* LCB6 and *L. gallinarum* LCB 12	An increase in VFA, especially acetate, correlated with the diminution of *E. coli* O157:H7 numbers	Full paper
Brashears et al 2003	*L. acidophilus* NPC 747 and NPC 750	Decreased incidence of *E. coli* O157:H7 in the faeces	Full paper
Elam et al 2003	*L. acidophilus* NP51 and NP45 and *P. freudenreichii* NP24, varying concentrations and combinations	1 x 10^9 *L. acidophilus* NP51,1 x 10^9 *P. freudenreichii* NP24 decreased faecal *E. coli* shedding	Full paper
Tabe et al 2008	1 x 10^9 *L. acidophilus* LA 51 and 1 x 10^9 *P. freudenreichii* PF 24	A 32% decrease in *E. coli* O157:H7 in the faeces	144 steers (Full paper)
Reduced risk of acidosis			
Kung and Hession 1995	*M. elsdenii* B159 8.7 x 10^6 cfu/ mL of culture fluid	Decreased L-lactic acid concentrations by > 90% and increased valerate concentrations	*In vitro* study (Full paper)
Klieve et al 2003	*M. elsdenii* YE34 and *B. fibrisolvens* YE44	Earlier establishment of lactic acid utilising bacteria during adaptation to grain	10 cannulated steers (Full paper)
Robinson et al 1992	*M. elsdenii* 407A	Improved feed intake	Abstract only
Greening et al 1991	*M. elsdenii* 407A(UC-12497)	Prevented lactic acid accumulation Innoculated steers ate 24% more DM	Abstract only
Kim et al 2000	*P. acidipropionici*	Decreased acetate and butyrate conc and increased propionate with increased dosage	Abstract only
Ghorbani et al 2002	*Propionibacterium* P15 or a combination of *Propionibacterium* P15 and *E. faecium* EF212 1 x 10^9	No effect on ruminal fermentation products or ruminal or blood pH	Full paper
Aviles 1999	*P. acidipropionici* DH42	Lowered ruminal and blood pH Lactate and VFA conc not affected	PhD thesis
Henning et al 2009	*M. elsdenii* NCIMB 41125	Eliminated the need for a series of adaptation 'step up' diets	Book chapter
Van Koevering et al 1994	*L. acidophilus*	Lowered ruminal lactate conc	Abstract only

Disturbingly, most of the production studies on the effects of bacterial DFM on beef cattle were not reported in full or were reported in non-peer reviewed sources. The lack of fully published

information, despite evidence of active research programmes, suggests that either the review process did not favour publication of the reports, or that reports were not submitted in full or were flawed. We consider that it may be possible to undertake meta-analytical evaluation of the data in these studies to examine it in more detail.

The potential of DFM products to reduce the risk of acidosis in feedlot cattle has been demonstrated. An increase in the use of lactate by *S. ruminantium* has been observed for products based on *Aspergillus oryzae.* The addition of *M. elsdenii* as a probiotic to rumen fluid *in vitro* and *in vivo* has also resulted in a decrease in lactic acid concentration and an increase in pH (Klieve et al 2003; Kung and Hession 1995). Hagg et al (2010) did not find any production advantages in lactating Holstein dairy cattle treated with *Megasphaera elsdenii* in a study with reasonable statistical power. Notwithstanding this finding, we consider that the data on interventions using *M. elsdenii* show some promise as an intervention to reduce the risk of acidosis in feedlot cattle. In the nine studies identified and presented in Table 26 associated with acidosis, there was evidence of increased ruminal valerate, decreased lactic acid production and reduced need to provide step up diets.

This project was asked to examine the product Protexin (International Animal Health), which is available in the market for use by beef producers. Protexin is a blend of live viable bacteria (e.g. *180 x 10^6 CFU/g as Lactobacillus acidophilus, L. delbrueckii* subsp. *bulgaricus, L. plantarum, L. rhamnosus, Bifidobacterium bifidum, Enterococcus faecium, Streptococcus salivarius* subsp. *thermophilus*) that may benefit cattle by improving the balance of intestinal microorganisms. Extensive literature review and interview with International Animal Health management did not provide data on which an evaluation of Protexin could be made. We note that a number of products outlined in Appendix I have similar characteristics to Protexin, but also note that these products are unique due to differences in the source of bacteria.

There are many more probiotic products available on the US market than available in Australia. Overwhelmingly, these lack evidence of specific action or efficacy, with the exception of reducing shedding of *E. coli* O157.

It is likely that DFM products are produced on the premise that these provide 'natural' antimicrobial actions mediated through putative bacteriocins. It is our view that these pose a potential risk to industry by:

- being ineffective, thereby wasting investment
- the potential to create bacterial resistance that may only be slowly recognized
- inappropriately, as well as appropriately, displacing current use of rumen modifiers
- preventing other products with more specific action that incur a regulatory cost barrier entering the market.

We believe that all products entering the food chain with putative promicrobial and antimicrobial actions should meet the same critical tests of efficacy and safety, for animals and humans, before market entry.

The lack of strong evidence of efficacy in regard to weight gain or other production responses for the DFM products suggests that the organisms identified and tested to date are not highly effective at increasing ADG or other measures of performance in the feedlot. It remains to be determined if other bacteria identified through current or future research will be more effective. The potential for benefits is suggested by the effects of DFM on shedding of *E. coli* O157 and *Salmonella* spp. from cattle fed in feedlots and the promising, but inconclusive, responses to *Megasphaera elsdenii.*

6.7 Polyethylene glycol

Polyethylene glycol (PEG) is a petroleum derivative that acts as a solvent, surfactant, and wetting agent. It can easily penetrate the skin, and can weaken protein and cellular structures.

Several studies conducted in beef cattle in northern Australia demonstrate that the inclusion of PEG as a supplement for cattle consuming high tannin diets (e.g. mulga) can improve dry matter intake and protein utilization. Moderate concentrations of condensed tannins in the diet can reduce the degradation of dietary protein in the rumen (McNabb et al 1996) and can increase the apparent absorption of essential amino acids, especially branched-chained amino acids such as valine, from the small intestine (Waghorn et al 1987; Bermingham et al 2001). In cattle, tannins bind to substrates, usually proteins, carbohydrate or lipids, and inhibit digestive enzymes, or exert anti-microbial effects (Scalbert 1991). PEG forms a stable complex with tannins, thereby preventing the binding between tannins and proteins (Bandran and Jones 1965). Therefore, PEG has been used to reduce the detrimental effect of condensed tannin in ruminant diets (Pritchard et al 1998; Barry 1989; Silanikova et al 1994; Jones et al 2000).

Strachan (1989) demonstrated that the inclusion of PEG in a diet of beef cattle in northern Australia that contained mugla improved DMI, and nitrogen retention and digestibility. Similarly, Canbolat et al (2005) studied the effect of PEG on *in vitro* gas production, metobolizable energy and organic matter digestibility of *Quercus cerris* leaves and found that PEG supplementation significantly increased gas production, organic matter digestibility (OMD) and the estimated metabolisable energy (ME) content. Similarly, positive responses were found in gas, digestibility and short chain fatty acid production *in vitro* by Getachew et al (2000) who examined responses to PEG in a range of forages including *Acacia* spp. A recent study by Nahand et al (2010) demonstrated that PEG supplementation had a significant effect on gas production, OMD and ME content of apple tree leaves. They suggested that PEG supplementation can be used to improve the nutritive value of tannin-containing tree leaves.

Getachew et al (2001) found an increase in microbial protein production from the use of PEG. The improvement in gas production, OMD and ME increased as a dose dependent response to the level of PEG. There has been successful inclusion of PEG in lick block formulations. Despite the very positive *in vitro* and *in vivo* findings and increased DMI (Strachan 1989), we were unable to find controlled studies providing evidence of increased weight gains in treated cattle. Interviewees considered that PEG was an effective tool to assist with increasing performance of cattle browsing *Acacia* spp.

6.8 Summary of all products

A summary of all currently available products and recommendations for their use in the northern beef production system in provided in Table 27 based on published evidence and costs of products.

Table 27. A summary of currently available products and details of recommendations for use arising from the project; a subjective evaluation of the strength of published evidence of effect from the authors based on the quantity and quality of data reviewed; and recommended costs per head per day

Product / Product class	Recommendation	Strength of evidence 1 low to 5 high	Use details	Estimated cost c/hd/day (300 kg animal)
Monensin	Use on feedlot and pasture	5 feedlot 2.5 pasture	Available in water, liquid feeds, dry feed and bolus forms	1.5 to 2.5

Lasalocid	Use on feedlot and pasture	4 feedlot 2 pasture	Available in liquid feeds, dry feed	2 to 2.5
Bambermycin (Flavomycin)	There is a need for further quantitative, meta-analytical evaluation of this product. Data appear positive.	3 feedlot 2 pasture	Available in liquid feeds, dry feed	2 to 2.5
Virginiamycin	Use on feedlot. Possible use to control acidosis in loose mix preparations.	4 feedlot 2.5 pasture	Available in dry feeds	3.6 to 4.5
Tylosin	Use on feedlot. Possible use to control acidosis in loose mix preparations.	4 feedlot 2 pasture	Available in liquid feeds, dry feed	2 to 2.5
Yeasts	Needs more evidence of effect for each product as these are not generic. There is a need for further quantitative, meta-analytical evaluation of this product. Data appear positive, but very mixed.	3.5 feedlot 1.5 pasture	NA	Varies with the specific products
Probiotics/ DFM	Reduce shedding of *E. coli* O157. Production responses	4 Feedlot 3 Feedlot	NA – non generic products NA	Varies with the specific products
Essential Oils/ Plant Botanicals	Need evidence of *in vivo* effects	1 Feedlot 1 Pasture	NA	
Polyethylene Glycol	Increased production when feeds high in condensed tannins are fed	3 Pasture	-	-

7 Delivery methods of supplements for grazing cattle in northern Australia

After review of available information on the northern beef industry we have formed the view that modification of production is an all-year around proposition for the industry. This view has been developed from the review of materials in Chapters 5 to 7, from interviews and from observation of the production system.

Simply, cattle in Northern Australian production systems experience such profound deficiencies of energy, protein, macrominerals, microminerals and cofactors through the pasture system that production is substantially less viable unless supplement is provided. This evaluation is supported by the usage rates of supplementary feeds in the Northern Australia documented in our survey, by Bortolussi et al (2005) and by ABARE (2010).

The form of supplementary feeding and the impact of supplementary feeding or rumen modification are determined by the:

i. distance from and availability of different feeds for a property
ii. education level and the knowledge of the efficacy of supplementary feeds and products
iii. bulk density of feeds
iv. efficiency with which these products can be delivered to cattle
v. rate limiting factors on a property such as topography, size of paddocks, fencing and facilities for feeding
vi. class of stock
vii. availability and quality of basal forages
viii. availability of water
ix. willingness to employ labour
x. seasonal conditions.

Problems with controlling intake and achieving good distribution of supplement throughout the herd have been encountered during dry season supplementation of urea-molasses fed in aqueous solution through a roller drum system (Winks et al 1970, 1979) and with dry licks of salt-urea-sulphur

(McLennan et al 1981). McLennan et al (1993) compared various delivery methods, including drinking water, roller drum feeders and open troughs, for feeding urea sulphur and molasses supplements to weaner heifers during the dry season in northern Queensland. While cattle supplemented via open troughs performed better than the other two methods, the results of this experiment highlighted the potential for feeding urea in the drinking water to cattle.

Feed rejection rates recorded in studies reflect an aversion of cattle to new products and feeding systems, but also dominance structures within a herd and the access provided to a product (Bowman and Sowell 1997). Non-feeder rates of cattle are highest when allowances of feed are low and when the quality of pastures is high. Given that a large numbers of factors influence decision-making on supplements, it is unsurprising that there are a wide range of methods used to deliver supplements and rumen modifiers. The following table (Table 28) provides a concise review of supplement delivery systems including the costs and efficacy of these.

Table 28. Associated costs (capital and variable), products, recommended access, variations in intake and associated risks

Delivery Systems	Costs		Pasture control	Potential to deliver products	Recommended access	Reported coefficient of variation in intake (%) and non-feeder rates (%)[1]	Risks
	Capital	Variable (Labour)					
Water	Very High	Moderate	Low	NPN, Mod Micro, Co	Daily Volume	NA	Water quality will influence availability of microminerals. NPN sources can be toxic and great care needs to be taken with supply in water. Less useful in the wet season.
Loose Mix	Moderate	Moderate	High	All	66 cm per adult head	41%;15%	Grain based loose mixes may provide a risk of acidosis. Less useful in the wet season.
Blocks	Low	Moderate	High	All*		79%;14.3%	Urea toxicity can occur with rain on blocks. Less useful in the wet season.
Molasses Licks (fluid)	Low	Moderate	High	E, NPN, Mac, Micro, Mod, Co		60%;23.6%	Low bulk density. Less useful in the wet season.
Boluses	Low	Low	Nil	Micro, Co, Mod	Individual dose or treatment	< 1%	Rare insertion injury
Vaccines	Low	Low	Nil	Mod	Individual dose or treatment	< 1%	
Oral drench, Inoculation	Low	Low	Nil	Mod	Individual dose or treatment	< 1%	Rare drench injury

Legends: E= energy supplies, TP= true protein, NPN= non protein nitrogen, Co= cofactors e.g. vitamins, Mod= modifiers of rumen function e.g. ionophores, Mac= Macro-minerals, Mic= Micro-minerals.
* while blocks can deliver all nutrients the capacity of these to supply large amounts of energy or true protein is low.
[1] Data are taken from Bowman and Sowell (1997) and include sheep and cattle studies.

The potential to integrate feed and watering systems into the agronomic management system is substantial. Figures 17a,b show the pattern of grazing around feed and water supplies and Figure 18

shows the stock density close to a molasses lick feeder. The placement of feed and water can influence grazing patterns of cattle. Pickup and Chewings (1994) demonstrated that the variance in pasture cover was strongly related to the presence of water and that effect was greatest within 2km of water; however, that effects of grazing on pasture cover extended to 4km and even 6km during wet periods. In modelling of the effects of water on grazing distribution patterns in large herbivores, estimates based on cattle data indicated strong effects within a 2km zone, and a markedly linearly diminishing effect to 4km (Bailey et al 1996). Roath et al (1982) found marked declines in utilization of pasture with increased distance from water and salt; by 2km utilization of pasture had declined to 1% of that available. This distance is consistent with modelling done for this project showing that the energy gained from ingestion of a moderate quality tropical pasture will only modestly exceed maintenance and that exercise incurred in the harvest of this needs to be minimised, in order not to exceed the energetic benefit gained from the pasture. The use of watering and feed points, and possibly shade, need to be considered in regard to the capacity to increase pasture utilization.

Figure 17a. Pattern of grazing around water

Figure 17b. Pattern of grazing around feed

Figure 18. Stock density around molasses lick feeder

The capital and variable costs of providing water can be high, depending on the energy sources required to pump water. The supply of urea in drinking water has been trialed. Provided there is no alternative water supply, this system has the advantage of compulsory supplementation in amounts proportional to water intake and, therefore, approximately to liveweight. The method has proved successful for sheep in north-western Queensland (Stephenson et al 1981), but problems with depressed water intakes were encountered when used for cattle in northern Western Australia (Holm et al 1981). Further testing under varying conditions of season, pasture, and property management and development is required before the widespread implementation of water medication for cattle can be recommended. One interviewee was particularly concerned that water supplementation systems were not effective delivery systems, noting that water quality problems lead to high costs and ineffective supplementation. Comprehensive reviews of the use of water in northern production systems have been conducted (Hill et al 2003; Entwistle et al 2005).

There are other considerations of grazing patterns on pastures, including impacts on the soils through erosion and damage to riparian zones (Pickup and Chewings 1994), increased fertility of areas close to water and feed through nutrient transfer, and increased risk of parasitism with greater stock density. Supplements and water need to be considered, therefore, not merely on the basis of nutritional supply, but as system management tools. Unfortunately, information on the latter was not available to allow these concepts to be included in modelling for this study. Measurement and modelling of the integrated effects of water and feed is needed.

8 New technologies

The currently available methods for manipulating ruminal fermentation involve microbial biotechnology such as ionophores, antibiotics and microbial feed additives. The uptake of these technologies has been restricted to a few antimicrobial compounds and some organisms that can be added to feed. The concept of improving animal performance by going beyond simply meeting requirements of ruminal protein and energy has been investigated for several decades. New developments in other fields, such as recombinant DNA technology, bacteriophages, bactriocins, indicate that the future methods may have a much wider scope.

8.1 Bacteriophages

Lytic bacteriophages are viruses that bind to specific bacterial cell surface receptors, inject their DNA, and take over the biosynthetic machinery of the bacterium to produce daughter phages, which are released by lysis of the host cell to repeat the process in other target bacteria (Guttman et al 2004; Kutter and Sulakvelidze 2005). Because bacteriophages exhibit a high degree of specificity for their host, it has been suggested that they could be used as a 'designer antimicrobial' to eliminate specific pathogens from the gastrointestinal microbial population (Greer 2005). Table 29 provides details of lytic bacteriophages that have been identified to date.

Table 29. Bacteria for which lytic bacteriophages have been identified

Bacteria	Reference
E. coli	Stanford et al (2010)
Prevotella spp.	Ambrosic et al (2001)
Propionibacterium spp.	Cheong and Brooker (1999)
Ruminococcus albus	Klieve et al (2004)
S. bovis	Klieve and Bauchop (1991)
S ruminantium	Cheong and Brooker (1998)

Lytic bacteriophages were first isolated from the bovine rumen by Adam et al (1966). These are usually present in large numbers, 10^7 to 16^9/ml of ruminal fluid (Klieve and Swain 1993). Such a high concentration suggests that these could cause sufficient bacterial lysis to reduce the efficiency of feed utilization (Firkins et al 1992). The development of a procedure for measuring phages in rumen fluid based on DNA analysis (Klieve and Swain 1993) has made it possible to investigate the diversity of rumen phages and the factors that influence their population size (Swain et al 1996; Klieve et al 1996). The new procedures have also made it possible to study the factors responsible for the occasional spontaneous lysis of a large proportion of rumen bacteria (Nolan and Leng 1972).

Lytic bacteriophages promote immediate bacterial lysis, but lysogenic phages can be retained in the bacterial DNA until a later time. Klieve et al (1996) concluded that lytic ruminal phages were of little importance, but that 25% of the ruminal bacteria contained chromosomally stable lysogenic prophages. Large numbers of phages have been observed in the period shortly after feeding, but phage numbers alone are not indicative of bacterial turnover. No two individuals had similar DNA banding patterns, even when similarly fed and penned together, indicating that there is considerable individual diversity in phage populations among animals (Swain et al 1996).

Phages that infect the cellulolytic bacteria may impact more heavily upon ruminal fermentation than other types of phages in general, due to the importance of cellulose degradation to ruminal fermentation and the limited number of species that ferment cellulose. Klieve et al (2004) isolated and characterised four new phages in the rumen fluid that can infect *Ruminococcus albus*, a cellulolytic ruminal bacterium. This suggests that the cellulolytic populations of the rumen could be subject to lytic events that would reduce fibre degradation.

Gregg et al (1994) demonstrated that phage DNA could be incorporated into *Prevotella ruminicola,* a fibrolytic rumen bacterium that is capable of degrading hemicelluloses. The long-term ambition of the project was to improve the efficiency of hemicellulose fermentation. Genetic modification of rumen bacteria is possible through use of phages as vectors for gene transfer by transduction (Morrison 1996).

The potential for bacteriophages to be used to treat, control or eliminate bacterial populations has been explored and there are an increasing number of scientific papers being published on use of these agents in a number of species. Callaway et al (2008) demonstrated that bacteriophages can

be used to reduce *E. coli* O157:H7 in cattle before slaughter. Stanford et al (2010) administered polymer encapsulated bacteriophages by top-dressing feed or via capsule to feedlot cattle artificially infected with naladixic acid-resistant *E. coli* O157:H7 with some evidence of reduced shedding of *E. coli* in treated cattle.

There are several strategies already available to producers for controlling acute lactic acidosis (RAGFAR 2007) and bloat. The use of antimicrobial agents and ionophores to control acidosis and especially bloat is one of the more effective approaches available to feedlot production systems (see Chapter 6). New methods of controlling lactic acid bacteria in the ruminal environment that have been recently proposed include dietary supplementation of long-chain fatty acids, induction of passive and active immune responses to the bacteria, and the use of lytic bacteriophages. McAllister et al (2006) state that Tarakanov (1994) was able to reduce the numbers of *S. bovis* using a bacteriophage.

While no examples of ruminal manipulation with bacteriophages were identified, there is sufficient evidence of efficacy to suggest that manipulation of bacterial populations using bacteriophages will be possible. However, several workers including Joerger (2003) note that resistance to bacteriophages arises rapidly. It may be necessary to view these as a single strategic treatment, e.g. to remove or reduce *E. coli* in the rumen prior to slaughter, or to use these in conjunction with other therapies to allow the introduction of new bacteria or other organisms.

8.2 Bacteriocins and antibacterial peptides

8.2.1 Bacteriocins

Since the 1920s' studies (Gratia 1925; Rogers 1928) have reported that some strains of *E. coli* could inhibit other strains of *E. coli* and that lactococci could also produce antibacterial substances. Whitehead (1933) demonstrated that the lactococcal factor was proteinaceous. Mattick and Hirsh (1944) examined a concentrated lactococcal factor against pathogenic streptococci and Taylor et al (1949) attempted to use the same inhibitory substance to treat bovine mastitis. The bacteriocins are small, heat stable, bacterially produced antimicrobial peptides. There are now several thousand antibiotic agents of microbial origin identified (Ross et al 2001). Most of the bacteria and archae produce one or more bacteriocins (Klaenhammer 1988; Riley 1998). The aim of this Chapter is to review the bacteriocins that have most immediate relevance to cattle production.

Lactococcal bacterial strains produce a variety of antibacterial substances (Hirsch and Grinsted 1951), and these compounds were initially called 'antibiotics'. However, the term 'bacteriocin' was introduced in the 1950's to differentiate these ribosomally synthesized peptides from classical antibiotics (Jacob et al 1953). The classical definition of bacteriocins was largely based on colicins (Tagg et al 1976), and bacteriocins have recently been re-defined (Montville and Kaiser 1993). The bacteriocins are heterogenous in chemical structure, source, spectrum of activity and function and are closely related to the antimicrobial peptides reviewed in this Chapter. The Lantibiotics are small peptides < 5 kDa, the non-lanthionine peptides are larger, up to 10 kDa, heat labile proteins are larger still and complex bacteriocins contain carbohydrate and lipid moieties.

Many genera of lactic acid bacteria (LAB) including *Lactobacillus, Lactococcus*, *Leuconostoc, Streptococcus* and *Carnobacterium* are capable of producing small peptides that can inhibit a broad range of Gram positive bacteria (Cleveland et al 2001). Most LAB bacteriocins inhibit bacteria by forming pores in the cell membrane and dissipating the proton motive force. Gram negative bacteria are protected from the lethal effect of LAB bacteriocins by the outer membrane. Many different types

of LAB bacteriocins have been studied and characterized, and the most widely known are nisin, lacticin, enterocin, pediocin, and plantaricin (Ray 2003). These have been extensively studied for their application in foods (Cotter et al 2005), but just a few of them have been used in livestock.

Lantibiotics are bacteriocins produced by LAB. Lantibioitics contain lanthionine rings and are typically classified as Class I bacteriocins. There are several LAB species capable of producing lantibiotics (McAuliffe et al 2001). The lantibiotics that have been more frequently identified and characterized are nisin and lacticin. A number of researchers have suggested that bacteriocin producing bacteria or their bacteriocins could be used to modify rumen fermentation.

Nisin is a group N inhibitory substance produced by *Lactococcus lactis*. Nisin is the most studied and best understood bacteriocin (Jack et al 1995). Nisin molecules assemble in the cell membrane, which leads to the loss of intracellular solutes. Nisin also appears to inhibit the peptidoglycan synthesis of Gram-positive bacteria (Wiedemann et al 2001), but the independence of this from the dissipation of proton motive force has not been clearly established. The activity of nisin is mediated through binding of lipid II, which is a target for antibiotics including vancomycin (Cotter et al 2005). The possibility exists of bioengineering derivatives or analogues of nisin to provide effective antimicrobials.

The effect of Nisin on rumen fermentation has been studied. Callaway et al (1997) found that when mixed ruminal bacteria were incubated *in vitro* with ground hay, even low concentrations of purified nisin inhibited methane production, decreased the acetate to propionate ratios and reduced ammonia production from a mixture of peptides and amino acids. Monensin can reduce the concentration of ammonia in cattle by more than 50%, and this decline may be due a decrease in the specific activity of the mixed population to deaminate amino acids *in vitro* (Yang and Russell 1993). Jalc and Laukova (2002) compared the effect of nisin on rumen fermentation to monensin using an artificial rumen system. Nisin increased the degradation of hemicellulose and the production of acetate and butyrate, but had no effect on cellulose degradation, methane production and microbial synthesis efficiency. The limited effect of nisin on rumen microorganisms may be due to its degradation in the rumen (Russell and Mantovani 2002). When cattle were fed nisin, changes in ammonia concentration, the specific activity of deamination, or acetate to propionate ratio could not be detected (Russell and Mantovani 2002). These results suggest that nisin is not a satisfactory replacement for monensin.

At least three different bacteriocins have been identified in *Streptococcus bovis*, but only one of these was characterized as a lantibiotic (Lee et al 2002; Whitford et al 2001; Xiao et al 2004). *S. bovis* is an important ruminal LAB that is predominant when cattle are fed starch-based diets and is largely responsible for rumen acidosis (Hungate 1966). Bovicin HJ50 was identified in a *S. bovis* strain isolated from milk, and this lantibiotic was capable of inhibiting a wide spectrum of Gram-positive bacteria. The potential application of this particular bovicin on rumen fermentation, however, remains to be explored. Joachimsthal et al (2010) identified a bacteriocin like inhibitory substance (BLIS), Sb 15, from *S. bovis* and found that this had a wide spectrum of inhibitory actions on organisms including normal rumen flora and Clostridia that are potential pathogens.

Lantibiotics can also be produced by *Butyrivibrio fibrisolvens* (Kalmokoff et al 1999). *B. fibrisolvens* is one of the dominant rumen bacteria capable of degrading fibre compounds and one of many species producing bacteriocins (Kalmokoff et al 1996). Butyrivibriocin OR79A has been the only lantibiotic characterized from *B. fibrisolvens* and has broad inhibitory activity against rumen Gram-positive bacteria. Despite the promising characteristics of this lantibiotic, no application has been reported.

Other bacteriocins- Two of the bacteriocins isolated from *Streptococcus bovis* strains have been proposed as a potential feed additive to inhibit indigenous ruminal *S. bovis* and prevent rumen acidosis (Mantovani et al 2002; Whitford et al 2001). Bovicin HC5 was identified in a rumen isolate and is capable of inhibiting most Gram positive ruminal organisms tested. This bacteriocin was characterized as a novel type of bacteriocin because it had 4 amino acid residues. Bovicin HC5 reduced methane production by approximately 50% when added to mixed ruminal cultures as semi-purified preparations (Lee et al 2002). The methanogenic bacteria did not appear to develop resistance to bovicin HC5. The inhibitory activity of the same bacteriocin has been tested against *Listeria monocytogenes* strains as a potential method to prevent the proliferation of this pathogen in silages (Mantovani and Russell 2003). Further work needs to be conducted to confirm the feasibility of bovicins to enhance animal productivity.

In addition to the lantibiotic described above, two other bacteriocins have been isolated from *Streptococcus bovis* strains and proposed as a potential feed additives to inhibit indigenous ruminal *S. bovis* and prevent rumen acidosis (Mantovani et al 2002; Whitford et al 2001). Bovicin HC5 was identified in a rumen isolate and was found that was capable of inhibiting most Gram positive ruminal organisms tested. This bacteriocin was characterized as a novel type of bacteriocin because it had 4 amino acid residues not previously reported. Bovicin HC5 reduced methane production by approximately 50% when added to mixed ruminal cultures as semi-purified preparations (Lee et al 2002). The methanogenic bacteria did not appear to develop resistance to bovicin HC5. The inhibitory activity of the same bacteriocin has been tested against *Listeria monocytogenes* strains as a potential method to prevent the proliferation of this pathogen in silages (Mantovani and Russell 2003). Further work needs to be conducted to confirm the feasibility of bovicins to enhance animal productivity.

B. fibrisolvens is also reported to produce non-lantibiotic bacteriocins (Kalmokoff and Teather 1997; Rychlik and Russell 2002b). Kalmokoff and Teather (1997) characterized butyrivibriocin AR10, the first bacteriocin identified in an anaerobic rumen bacterium. More recently a bacteriocin was detected in *B. fibrisolvens* strain JL5 and this compound could inhibit several Gram-positive rumen bacteria (Rychlik and Russell 2002b). It was hypothesized that treatment with this bacteriocin might reduce ammonia production in the rumen and eventually improve feed efficiency because it was capable of inhibiting *Clostridium aminophilum*, an amino acid fermenting rumen bacterium. The potential for this bacteriocin was, however, not supported by additional studies that showed *C. aminophilum* was capable of developing resistance against it (Rychlik and Russell 2002a). These results suggest that novel bacteriocins may be identified that would have a significant effect on modifying rumen fermentation. However, given that ruminal populations are rapidly adaptive and that these are co-adapted, the potential for ruminal bacteria to counter bacteriocins is unsurprising.

There have been at least two attempts to use bacteriocins in preventive, therapeutic products for cattle. Nisin was licensed by Immunocell Corporation in 2004 for use by Pfizer Animal Health in a product called Mast Out that was designed to prevent mastitis in cattle. However, the agreement was terminated in 2007 according to a news release (http://www.reuters.com/article/idUSBNG13445620070719), which indicated that the termination was not due to any unexpected efficacy, technical or regulatory problems. Ryan et al (1999) found that lacticin 3147, another bacteriocin, impregnated teat sealant acted to reduce risk of mastitis in the artificially challenged quarters.

In conclusion, the utilization of bacteriocins or bacteriocin-producing bacteria in cattle is a field with enormous possibilities for both research and commercialization. There are very active investigations

into the use of these as antibacterial agents. Klieve and Hegarty (1999) suggested that bacteriocins could be used to decrease ruminal methane production *in vivo*. A need for the development of alternative antimicrobial agents will probably be a driving force to continue identifying novel bacteriocins and testing existing ones. It appears likely that new antimicrobial approaches may utilize combinations of bacteriocins to obtain a broader spectrum for target organisms. Joachimsthal et al (2010) suggest that bacteriocins, colicins or BLIS may be used to replace ionophores or to act in conjunction with these to remove ionophore resistant organisms.

While there are limitations to the use of these agents that appear inherent, specifically the rapid development of resistance to bacteriocins identified to date, the potential to develop new and carefully targeted therapeutics is substantial. The potential to use these commercially is supported by the long standing use of nisin in the food industry. A substantial review of bacteriocins and the use of these in the food industry is provided by Cotter et al (2005).

8.2.2 Antimicrobial peptides

An emerging area of interest related to the bacteriocins is that of the antimicrobial peptides. Antimicrobial peptides (AMPs) are small cationic peptides that protect their hosts against a vast array of microorganisms. The AMPs are an essential part of the innate immune system. The peptides confer a substantial advantage to their hosts, which include bacteria, plants, insects and higher animals. A vast number of the peptides have been identified and are recorded on the following web site http://aps.unmc.edu/AP/main.html.

The antimicrobial peptides are a subcategory of the broader group of peptide therapeutics and can be classified on the basis of whether these are produced in the ribosome or not (Koczulla and Bals 2003). The non-ribosomal peptides are produced enzymatically by non-ribosomal peptide synthetases. The AMPs have emerged particularly as products of interest because there is the capacity to synthesise these according to design specifications. Hartman (2010 unpublished) notes that peptides are attractive alternatives to antibiotics because of a specificity advantage over protein therapeutics and an increased potency when compared to the small molecule drugs (Marx 2005; Vlieghe et al 2010). While the mechanism of action of the AMPs has not been fully elucidated, there is evidence that these act to disrupt the integrity of bacterial cellular membranes to result in a 'leakage' of cell content and changes in ion regulation. These peptides can be part of the granules involved in bacterial killing systems of immunocytes.

There are three notable classes of AMPs that have action against bacteria or viruses;

i. cathelicidins
ii. defencins
iii. histatins (Bals 2000).

However, there are a large number of other active agents identified, in particular from the intestine (Rossi et al 2008). Cathelicidin acts *in vivo* against Group A *Streptococcus* and has *in vitro* efficacy against *E. coli*, Group B *Streptococcus* and *Staphylococcus aureus* (Guani-Guerra et al 2010). Some of the defencins have potent antiviral actions (Guani-Guerra et al 2010), a trait that may potentially have value against bacteriophage populations. Table 30 derived from the review of Rossi et al (2008) lists AMP products that have been developed for therapeutic use and indicates the potential for the AMPs to be used to control bacterial populations.

Table 30. Antimicrobial peptide products and their affect on bacterial populations (Rossi et al 2008)

Antimicrobial Peptide	Target organism	*In vivo* or *in vitro* testing	Results
Pheromonicin	Methicillin sensitive or resistant *Staphylococcus aureus* (MRSA)	In vitro	No activity
Pheromonicin-AgrD1	Penicillin resistant *Staphylococcus aureus*	In vitro	Active – inhibited growth by 60%
Pheromonicin-PA	*Pseudomonas aeruginosa*	In vitro	inhibition
Pheromonicin	MRSA	V - mice	Increased longevity * no observable toxicity
Pheromonicin-PA	*Pseudomonas aeruginosa*	V - mice	90% survival to day 10 v 100% mortality by day 2 in controls * no observable toxicity
Pheromonicin-PMCEF	Vancomycin resistant *E. faecalis* (VRE) and MRSA	In vitro	Inhibition of growth of VRE
Pheromonicin-PMCEF	VRE	In vivo - mice	100% survival *vs.* 100% mortality in 3 days
Cathelicidin BMAP28	*Staphylococcus aureus*	In vivo- rats	Increased efficacy of other antibiotics in co-treatment
G10KHc	*Pseudomonas aeruginosa*	In vitro	Increased killing in presence of tobramycin (several studies with different approaches)
STAMP (C16G2)	*Streptococcus mutans*	In vitro	Reduced minimal inhibitory concentrations (MICs)
CAMs	*Acenebacter baumannii*	In vitro	Active against 4 of 13 strains that were colicin resistant
Acylated dermaseptin derivatives	*Streptococcus mutans, Actinomyces viscosus, Streptococcus salivarius, Actinnobacillus actinomycetemcomitans*	In vitro	Bacteriocidal against all and fungicidal against *C. albicans*
AMP LL37	*Pseudomonas aeruginosa, Escherichia Coli, Salmonella typhimurium, Staphylococcus aureus, Staphylococcus epidermidis, Listeria moncytogenes and* VRE	In vitro	Inhibits growth of these

Hartman (2010 unpublished) notes that there are approximately 60 peptide drugs on the market today, yet this is set to grow rapidly with over 200 peptides in clinical trials and over 400 in pre-clinical phases (Albericio 2004; Danho et al 2009; Loffet 2002; Marx 2005). Many of these are not used or investigated as antimicrobials, indicating the diversity of function of this class of agent. It is clear that these are an important emerging class of antimicrobial agents with substantial potential to be used in rumen modification.

8.3 Transgenic insertions into ruminal bacterial populations

Enhancing the efficiency of ruminal bacteria has been a goal of conventional approaches to improving the productivity of cattle. The major focus of investigations to enhance the efficiency of ruminal bacteria have been directed towards improving the efficiency of digestion of fibre (Gregg et al 1987; Krause et al 2003). Two major approaches of manipulation have been used to improve plant-fibre digestion:

i. addition of new fibrolytic genes to bacteria with relatively weak fibre degrading characteristics (Smith and Hespell 1983; Teather 1985; Gregg et al 1987)
ii. increasing the expression of fibre degrading enzymes in microorganisms that ordinarily have strong fibrolytic capabilities (White et al 1990; Rogers 1990).

The development of improved ligno-cellular digestion is also pivotal to second generation ethanol production technologies and is, consequently, a significant area of parallel research (Lynd et al 2002). The limitations to achieving greater rates of digestion of fibre (hemicelluloses, cellulose and lignin) and lignocellulose, in particular, are discussed in later in this Chapter.

Other potential applications for transgenic bacteria include production of essential amino acids, improved efficiency of microbial protein production (Teather 1985; Brooker et al 1989), and production of bacteria that detoxify or control specific toxins or anti-nutrients (Mackie and White 1990; Gregg and Sharpe 1991). Optimism has been expressed about the potential for transgenic technologies to provide diverse benefits in animal production (Smith and Hespell 1983; Teather 1985; Gregg et al 1987).

There were a number of challenges encountered during the development of transgenic bacteria. Of the complications that were encountered during early attempts to manipulate rumen bacterial genetics, one vital aspect was largely unforeseen. The genetic diversity within single phenotypic species of bacteria is very substantial. As early as 1987, it was found that individual isolates of the same rumen bacterial species may show very substantial genetic variation (Gregg et al 1987). This diversity is now well recognised, but the full diversity of the rumen micobiota has been far from characterised. Gregg (2010 pers comm) noted that individual strains of bacteria are often present only in concentrations of 100,000 cells/ml, which is at the point of detection of many previous assays. He considered that the genetic diversity is much greater than even understood now, and that the complexity is underestimated. Gregg (2010) noted that *Butyrivibrio fibrisolvens* is a good example; in one sample of rumen fluid 5 species and 10 different genera of apparently identical organisms were found (Hudman and Gregg 1989) that reflect the evolutionary direction and the convergent evolution of organisms in the rumen. The majority of techniques previously used to investigate rumen microbiology were based on bacterial culture, isolation, enumeration and nutritional characterization and could probably account for only 10 to 20% of the rumen microbial population. There is a burgeoning list of bacteria that have been characterised using DNA analysis, but only a small percentage of these have been cultured. It is widely acknowledged that our understanding of rumen populations of bacteria is very limited (Krause et al 2003). Newly developed methods for understanding ruminal populations outlined in Appendix II are providing a means to expand knowledge of the rumen. It is possible that this increase in knowledge will provide better approaches for the development and insertion of transgenic bacteria.

The very considerable program developed in Australia during the 1980 to 1990's to produce transgenic bacteria has not been summarised in peer reviewed journals. It would not be appropriate to review that program for this project, but some important insights and achievements from that program have been identified in review of the literature and in the interviews conducted for this project and are incorporated in this review.

These achievements include, but are not limited to;

- improved methods to characterise microbiota in the rumen
- insertion of genes to produce bacteria with greater fibrolytic capacity
- insertion of genes to detoxify flouroacetate
- sustained presence of these transgenic bacteria in the rumen

- improved means of incorporating genetic material into bacteria
- production of celluloytic enzymes.

Some of the challenges encountered in developing transgenic rumen bacteria are outlined by Brooker et al (1989). Of these, the challenge of providing efficient means of gene transfer of selected material has been overcome (Beard et al 1995; Gregg pers comm. 2010). Transgenic insertion has been made relatively easy using plasmids as a vehicle for selected gene sequences and using electroporation (Neuman et al 1982) as a means of insertion. By using approximately 20 kv/ cm to open bacterial pores, the DNA drifts in and is incorporated (Beard et al 1995). While many cells die in this process, those remaining can express the gene and can retain expression of the desired characteristics for at least 200 generations.

Krause et al (2003) suggest that the assumption underlying programs to develop genetically modified bacteria is that the rumen microbiota do not produce the correct mixture of enzymes that will maximise plant cell wall degradation. A number of interviewees used a similar analogy for the ruminal ecological niche likening the rumen environment to a 'jungle' or 'untamed forest'. These interviewees considered that it was likely that effective means of positively manipulating the ruminal degradation of fibre would be developed. A number of interviewees, notably Van Soest and Hans Jung, had an alternate perspective, perhaps best stated by Weimer (1998) "The implicit principle driving such work is that cellulose digestion is limited by the cellulolytic capabilities of the resident microflora. Yet this principle does not stand up to close scrutiny. There is abundant evidence that the kinetics of cellulose digestion is first-order with respect to cellulose concentration or available surface area (Waldo et al 1972; Van Soest and McQueen 1973; Fisher et al 1989; Weimer et al 1990; Maglione et al 1997)." In other words, cellulose digestion is limited not by the population or activity of the cellulolytic microbes, but rather by the amount of cellulose available for microbial attack. Weimer (1998) considered that the most productive research direction would be one in which effort was expended on altering the availability of fibre in plants through agronomic research. This view was supported in the interviews with Professors Van Soest and Jung.

Notwithstanding the validity of conducting research and developing means to implement agronomic use of plants with better digestibility, there is support for the position taken that the rumen environment is relatively inefficient compared to an optimal position. The first evidence comes from repeated observations of adaptive processes to change in dietary substrate, perhaps best exemplified by adaptations of cattle to feedlot induction diets, or dairy cows in transition feeding, or for cattle introduced to lush pasture. An adaptation period of approximately 14 days results during which ruminal efficiency is reduced. However, the end result of this adaptation process is not consistently expressed. Brulc et al (2009) used comparative metagenomics (phylotype analysis and SEED subsystems-based annotations) to examine randomly sampled pyrosequence data from three fibre-adherent microbiomes and one pooled liquid sample. Even though the three animals were fed the same diet, the community structure, predicted phylotype, and metabolic potentials in the rumen were markedly different with respect to nutrient utilization. This observation supports a contention raised in discussion with R. L. Baldwin and J. MacNamara that modelling of rumen requires, in part, a stochastic approach rather than a strictly deterministic approach such as that used in the deterministic and dynamic model of rumen function MOLLY. Further, such observations (Brulc et al 2009) suggest that there may be room for genetic selection of better adapted meta-genomic structures with selection of the host mammal (see Chapter 8, Section 10).

Krause et al (2003) note that the most active fibrolytic bacteria (*Ruminococcus* and *Fibrobacter*) do not produce exocellulases against crystalline cellulose and that providing this attribute would make these more potent fibre digesters. Some success has been achieved in the insertion of genetic

material into fibrolytic bacteria. Glycosyl hydrolases have been inserted and expressed in *B. fibrisolvens*, however, despite improved fibre digestion *in vitro* (Gobius et al 2002; Krause et al 2001; Xue et al 1997) these bacteria did not effectively compete with highly fibrolytic bacteria found in the rumen (Krause et al 2001). Gregg (pers comm. 2010) noted that small plasmids and their associated cellulase actions did not impair viability of bacteria in the rumen. The transformed organisms, at least in the case of the four strains of *Butyrivibrio fibrisolvens*, transformed with a gene encoding fluoroacetate dehalogenase used in sheep were maintained. Similar results were found in cattle in which every transgenic bacteria inserted in the rumen survived. The genetically modified (GM) bacteria were present at $>10^5$ cells/ml of rumen contents (4 animals), $>10^6$/ml (5) and $>10^7$ cells/ml. These strains OR85, 149/33, OB291 and S2/10 successfully colonised the cattle rumen to have similar concentrations to the 'native organism' inserted in the rumen in parallel (McSweeney 2004; Gregg pers comm. 2010). Despite these successful studies, studies have often not achieved success in expressing outcomes when incorporating modified strains to an ecosystem as complex as the rumen (Sprenger et al 1999; Krumholz et al 1999; Lynd et al 2002). Further, attempts to insert very active fibrolytic bacteria from kangaroos into cattle failed, because the bacteria failed to survive, a result supported by a similar difficulty in maintaining the bacteria in an *in vitro* rumen-based fermenter (Klieve 2008).

Russell's group at Cornell investigated the use of *Prevotella* to produce bacteria that could maintain fibre digestion at a low pH. This adaptation could have great value for feedlot and dairy cattle (Gardner et al 1995ab). Mutagenesis has been suggested as another technique to increase cellulolytic activity of the rumen. The frequency of appearance of induced mutants, mainly of cellulolytic types, resistant to low nutritional inputs or with a higher capacity to degrade substrates of interest such as cellulose, may be increased by selection and insertion of these.

Gregg et al (1996) suggested that as with all manipulation of genetic materials, there is a need to characterize the modified organisms in great detail and determine their possible effects, before release into the environment. In addition to consideration of the primary intended function of the modified microbes, other factors to be evaluated including:

i. whether altered organisms could impart their new capability to non-target species, such as feral ruminants, or monogastric pest species
ii. how the altered microbes and favourable adaptations provided might alter the behaviour of the host, in grazing or browsing patterns
iii. whether the novel genes can be transferred to other bacteria, with potentially more harmful properties
iv. how the characteristics of the altered bacteria might alter their competitiveness and therefore influence the microbial balance of the rumen.

The potential applications of genetic manipulation to bacteria involved in ruminant nutrition and metabolism are diverse. Intervention in complex processes, including fibre digestion, is technically feasible and has been demonstrated to a point. However, achievement of significant nutritional gains appears likely to depend upon modification of a range of bacterial strains. The problems of *in vivo* stability, plasmid retention and extended impact on the ecosystem must be addressed specifically for each newly modified bacterial strain. Notwithstanding the failures to provide impact to date, it appears likely that there will be successful modification of fibre digestion achieved through genetic modification of bacteria, because of the importance of this achievement to ethanol production (Lynd et al 2002). Only further detailed evaluation and understanding of the ruminal ecosystem will provide a framework in which opportunities for successful manipulation of the system, including those involving transgenic enhancement of the microbiota, will markedly increase.

8.4 Manipulations of fungal populations

The microbial population of the rumen is characterized by a wide diversity in the types of anaerobic micro-organisms present. The major groups of ruminal micro-organisms include bacteria, fungi, protozoa, yeasts and bacteriophages. The bacteria number 10^{10}-10^{11} cells/ml of rumen fluid from more than 50 genera, the ciliate protozoa 10^4-10^6/ml from at least 25 genera, anaerobic fungi 10^3-10^5 zoospores/ml from 5 or more genera and there are $l0^8$-10^9 bacteriophages per ml of ruminal fluid (Hobson 1988). The fungi comprise about 8% and the protozoa approximately 40 to 50% of the total microbial mass. A substantial proceedings on the role of protozoa and fungi in ruminant digestion was produced in Australia in 1989 (Nolan et al 1989) and provides excellent background information on research on rumen micro-organisms.

The main genera of fungi in the rumen are the *Neocallimastix*, *Piromyces Caecomyces* (all monocentric), *Orpinomyces* and *Anaeromyces* (both polycentric). These fungi are obligate anaerobes that play a vital role in the digestion of fibre in the rumen. The fungi are sensitive to the type of diet being consumed and are relatively slow growing. Fungi are markedly lower in numbers when lush diets that provide rapid digesta flow rates are fed, such as feedlot or dairy diets. Conversely, fungal numbers are higher for when high-fibre diets, such as those usually available in the grazed northern beef industry, are being consumed.

There has also been interest in aerobic fungi, including white-rot basidiomycetes, for their potential to improve the ruminal degradation of wheat straw previously infected with these fungi.

Two very substantive reviews of fibre digestion (Krause et al 2003; Lynd et al 2002) provide a framework in which to consider fungal activity and the potential to manipulate this. These references (Krause et al 2003; Lynd et al 2002) provide substantial detail on the chemistry of fibre digestion by fungi and bacteria. Lynd et al (2002) note that cellulases from aerobic fungi have received more study than have those of any other physiological group of fungi, and that fungal cellulases currently dominate the industrial applications of cellulases. It is important to note, however, that fungi do not solely digest fibre. While the ruminal anaerobic fungi colonize plant tissue and degrade lignified plant cell wall that is not degraded by other microorganisms (Krause et al 2003), the anaerobic fungi also assist with hemi-cellulose and starch degradation and utilise simple sugars (Mountfort and Roberton 1988). *Neocallimastix* spp., whether obtained from sheep or cattle, fermented cellulose, glycogen, inulin, maltose, raffinose, starch, sucrose, xylan and xylose (Phillips and Gordon, 1988). *Neocallimastix frontalis* (Wallace and Joblin 1985) and *Neocallimastix* spp. strain N1 and *Piromyces* spp. strain P1 are proteolytic (Asao et al 2008). The apparent degradation of ligninified plant cell wall is not an action mediated through a direct effect on lignin, rather an effect whereby the fungus solubilises the cell wall through dissolution of xylan in the lignin-xylan matrix rather than by lignin depolymerisation (McSweeney et al 1994). Through this action, up to 34% of the lignin in plant cell wall can be apparently degraded (McSweeney et al 1994).

The energetics of fibre digestion for bacteria is explored in detail by Lynd et al (2002) and provides a framework for understanding the challenges of improving energy yields in the rumen from cellulose and lignin. Lynd et al (2002) propose a series of important considerations in assessing the bioenergetics fibre digestion by bacteria. The steps, modified for fungi, that need to be assessed include the:

i. costs of the filamentous invasion of the cell wall
ii. metabolic burden of cellulase synthesis

iii. potential net ATP gain as a result of phosphorolytic rather than hydrolytic cleavage of cellodextrins
iv. bioenergetic demands for transport of cellulose hydrolysis products
v. metabolic cost of interactions with glycocalyx or bacterial biofilms.

The ATP required to produce cellulase in bacterial cells is relatively substantial (Lynd et al 2002), raising two questions:

i. What is the relative contribution of fungi and bacteria to fibre digestion?
ii. What is the potential to improve this by manipulation of the rumen?

Studies of the relative contribution of bacteria and fungi to ruminal degradation of fibre have provided differing conclusions. A series of studies investigated the relative contribution of fungi, bacteria and protozoa to fibre digestion using antimicrobial approaches (Dehority and Tirabasso 2000; Windham and Aiken 1984; Lee et al 2000). All workers noted the complexity of interactions among rumen micro-organisms involved in fibre digestion (Journay 1989) and note synergistic relationships between fungi and rumen bacteria, particularly the Archae (Fonty et al 1998; Joblin et al 1990), but also antagonistic relationships (Bernalier et al 1993; Dehority and Tirabasso 2000). The *in vitro* studies of Windham and Aiken (1984) and Lee et al (2000) differ in their conclusions. Windham and Aiken (1984) concluded that the most active fibre digesting community in the rumen was the bacteria, whereas Lee et al (2000) concluded that fungal activity was responsible for most plant cell wall degradation. Lee et al (2000) ranked the order of contribution to cell wall degradation as highest for fungi, intermediate for bacteria and lowest for protozoa and noted both positive and negative interactions among these. Unfortunately, the study designs used limit the extent to which these results should be extrapolated to the animal. It appears reasonable, at this time, to conclude that robust quantitative evaluations of the relative contributions of fungi, protozoa and bacteria to fibre digestion are not available. It is also clear that interactions among these have the capacity to both increase and decrease the efficiency of fibre digestion.

On face value, the use of the white rot fungi (WRF) or basidiomycetes for their potential to improve the ruminal degradation of lignin is attractive. The enzymatic breakdown of lignin requires the use of oxygen to break the lignin bonds. Therefore, the use of these fungi is necessarily pre-ruminal. Shrivastava et al (2010) found marked improvements in the feed value of straws previously treated with WRF. Jalc et al (1996), found significantly higher IVDMD values, NDF, ADF and cellulose digestibility (%) with straws treated with WRF. However, the production of propionic acid decreased, n-butyric, n-valeric and isovaleric acids increased and the volatile fatty acid (VFA) production expressed in mol VFAs.kg-1 digested dry matter decreased in diets treated with WRF. The total microbial production also decreased at fermentation in the WRF treated diets. These results (Jalc et al 1996) represent in vitro fermentation responses and at least one feeding trial found increased growth in sheep fed on WRF treated feed.

However, the challenges of practically controlling an aerobic degradation of fibre masses and not incurring growth of tricothene fungi or accumulating associated toxins produced by these will be substantial. In extensive management systems, such as the northern grazing system, the practical constraints to using the WRF appear considerable. Perhaps use of forage crop residues may provide an alternative fibre source for feedlot cattle, but these cattle are sensitive to feed inputs that reduce appetite, both in terms of growth and risk of acidosis. Because of this, the opportunites to use the WRF also appear limited for feedlot cattle.

Fibre digestion in the rumen is not maximal, with 20-70% of cellulose not digested (Varga and Kolver 1997). It is unclear whether, in the majority of cattle adapted to diets, fibre digestion, while not being maximal, is in fact optimal, reflecting the views of Weimer (1998) discussed above. Krause et al (2003) suggest that the fermentation is not optimal, because the fibre in cattle faeces is fermentable.

However, the energy balance estimates of the benefit of fermenting this fibre for the ruminal micro-organisms are not clear. An increased understanding of the energetics of fibre digestion by fungi should allow an estimate of the potential to harvest more energy through an increase in fibre digestion. The use of automated ribosomal intergenic spacer analysis (ARISA) methods (see Appendix II) provides increased understanding of the genetic diversity of ruminal fungi (Denman et al 2008, Edwards et al 2008). This increase in ability to characterise the fungi should allow a clearer understanding of the means of manipulating fibre digestion by ruminants, and an estimate of the extent to which this can be improved.

8.5 Manipulations of protozoal populations the rumen

The protozoa represent perhaps the largest mass of organisms in the rumen and are consequently of importance. Early studies in sheep found marked increases in wool growth and growth rates of sheep after defaunation leading to intense interest in defaunation (Leng 1988). These studies arose from observations that the rumen entodiniomorphid protozoa engulf bacteria and often kill and digest these resulting in futile cycles that may reduce the efficiency of protein and energy production. Not all bacteria are killed and some are endosymbiotic and live within the protozoa. There is a close association between protozoa and methanogens. Finlay et al (1994) estimated that 37% of rumen methane emissions may be generated by endosymbiotic methanogens.

The protozoa may play an important protective role in the rumen by engulfing starch granules and slowly releasing these. The large holotrichs are drawn chemotactically to glucose (Abe and Iriki 1989). The slow release reflects the fate of the protozoa that largely lyse in the rumen (40 to 60%), rather than escape to undergo small intestinal digestion. The holotrich and polyplastron protozoa have longer turnover times that the smaller entodiniomorphs (Leng 1998) and have a residence time in the rumen that is four times longer than that of bacteria. The effects of protozoa on fibre degradation have been examined *in vitro* (Lee et al 2000) and through modelling (Dijkstra and Tamminga 1995). While Lee et al (2000) found that the contribution of protozoa to fibre digestion was ranked low, modelling suggested that the contribution of the protozoa was about 17–21% of NDF under conditions similar to those of grazing cattle in the north of Australia and much lower for very high concentrate diets, at 3- 5% of NDF degradation at the highest intake level. On low nitrogen diets the protozoal deamination of amino acids (Jouany et al 1988) may provide ruminal ammonia for bacteria and provide a benefit on diets with low nitrogen intake (Hegarty et al 1994).

Many methods of defaunation have been successfully used including physical and chemical treatments of rumen content, isolation of calves or lambs and dietary manipulations by inducing a drop in pH, particularly by rapidly introducing concentrates. Other dietary manipulations include increasing the lipid content of diets, and saponins. The effects of defaunation have been quite variable and have been studied using meta-analytical methods (Eugene et al 2004). This study considered more than 90 publications and 169 comparisons of the effects of defaunation of the protozoa. Results of models developed examining the effects of defaunation on ADG were positive, but more sowith diets that had high levels of forage or that were low in nitrogen and higher in NDF, as measured by the ratio of N:% NDF. The percentage of concentrate in the diet also influenced ADG responses to defaunation which decreased with increased concentrate in the diet. Defaunation did not significantly alter feed intake, but lowered feed conversion efficiency (Eugene et al 2004). A

decrease in the percentage of organic matter or apparent cell wall digested in the rumen by 7.3% and 4.6%, respectively, with defaunation supports the role of protozoa in fibre digestion. Duodenal outflow of non ammonia nitrogen was 17.5% greater in defaunated animals, as a percentage of liveweight, probably reflecting the significant increase in microbial nitrogen outflow from the rumen of 22%. Responses to defaunation in regard to VFA and pH identified by (Eugene et al 2004) support the hypothesis that the protozoa provide a protective role on high concentrate diets as defaunated animals had lower pH and higher VFA on high concentrate diets. Unsurprisingly, the molar concentrations of acetate fell and those of propionate increased. Ammonia concentrations in ruminal increased for defaunated animals on diets that were less than 10% crude protein.

The findings of the meta-analysis (Eugene et al 2004) support and build on the qualitative review of the effects of defaunation of Demeyer (1988). The practical implications of the impacts of defaunation are worthy of investigation in animals on poor quality feed, such as pastures in northern Australia, but there may be relatively little benefit for feedlot cattle, given the potentially protective role of protozoa in the risk of acidosis. The ionophores have the potential to partially defaunate the protozoa (see Chapter 6), suggesting that more studies on the role of these in cattle on poor quality pastures may be of benefit. Given, that defaunation with ionophores is only partial; other agents or methods that may be considered should include detergents, plant saponins and oils.

8.6 Vaccinal control of rumen populations

Not all the micro-organisms present in the rumen are essential or necessarily beneficial. The benefits proposed for vaccinal approaches to modifying ruminal populations are the ease of integration with management and a relatively low cost of treatment, if effective. There is a considerable potential benefit for extensively managed systems, because of the potential for a single treatment (even if repeated injections are needed) to have longevity of action. For feedlots, vaccines could be integrated into existing backgrounding programs. However, considerable scepticism to a vaccinal approach was present in the interviews conducted. The negative views were based on the consideration that antibodies raised to rumen organisms would be short lived in the rumen, act as a source of protein and be digested.

Immunological approaches to manipulating rumen microbial populations, specifically ciliated protozoa, have been investigated. Serum antibodies raised to ciliates have an immobilizing effect on a mixed rumen ciliate populations *in vitro*. This effect decreased predation on bacteria. Williams et al (2008) examined changes in rumen protozoal numbers in Merino sheep that were vaccinated with two protozoal formulations. They found that a vaccine with whole fixed Entodinium or mixed rumen protozoal cells as antigens decreased numbers of protozoa in the rumen and that this change reduced rumen ammonia-N concentrations and increased wool growth. Similar improvements in wool growth were identified by Baker et al (2002) who also noted liveweight gain and efficiency of liveweight gain.

Vaccination with a multivalent polyclonal antibody preparation against *Streptococcus bovis* maintained a higher rumen pH and decreased ruminal L-lactate concentrations (Gill et al 2000; Shu et al 2000). Similarly, preparations of polyclonal antibodies against *S. bovis* or *Fusobacterium necrophorum* were successful in reducing rumen concentrations of target bacteria and increasing pH in steers fed high-grain diets (DiLorenzo et al 2006).

There are many approaches being investigated for reducing the methane production of ruminant livestock. These have relevance to the evaluation of vaccination to increase ruminal efficiency in the feedlot or on pasture because such studies can indicate whether vaccinal interventions against

ruminal microbiota can be effective. There has been a novel immunization approach to decrease the numbers and/or activity of methanogenic archaea in the rumen. Wright et al (2008) vaccinated sheep with an anti-methanogen vaccine that was based on three strains belonging to the genus *Methanobrevibacter* and produced a 7.7% decrease in methane production per kg of dry matter intake. Wright et al (2008) also found that less than 20% of the different species of methanogens detected in those sheep were closely related to the methanogens in the vaccine. On the basis of these findings, it was suggested that greater methane abatement might be possible if a greater proportion of the methanogen species/strains were targeted by the vaccine. The significance of this study is to highlight the potential for vaccinal approaches to have a benefit. Similarly, vaccination with virulence factor proteins from *E. coli* HO157 resulted in strong specific antibody titres and significantly less shedding of *E. coli* HO157 from calves challenged with the organism (Potter et al 2004). It has been speculated that production of antibodies that are expressed in oro-pharyngeal secretions and saliva may have effect in the rumen. These contentions are supported by information contained within two patents (Baker 2000; Baker et al 2002). In both these patents results are provided to demonstrate increase concentrations of immunoglobin G (IgG) in saliva after vaccination of sheep with antigens from a mixture of Archae (Baker 2000) or protozoa (Baker et al 2002).

While proof of concept has been achieved, vaccinal approaches to controlling disorders such as acidosis have not progressed greatly. The challenge in managing acidosis or reducing methane production is that effective control of the challenge relies on disposal of hydrogen into safe, efficient sinks in the rumen. In the case of acidosis, the removal of lactic acid is critical due to the very low pKa of lactic acid. However, organisms other than *S. bovis* have the potential to form lactic acid and the condition may reflect the generation of vaso-active substances including histamine and lipo-polysaccharides derived from the death of coliforms rather than the increased growth of *S. bovis* populations. Therefore, vaccination to control one population of bacteria, may not change the risk of the disorder as the problem is much more related to an abundance of one or several substrates eg starch and sugars, rather than one particular bacterial population. Such observations reinforce the importance of understanding the ruminal ecosystem to a greater extent, to ensure that new intervention strategies are appropriately directed and are effective.

8.7 Enzymes

The optimum fermentation of structural carbohydrates in forages is vital to improving energy intake, energy yield, protein nutrition, cofactor production and ruminant performance. Fibre digestion in ruminants is not maximal because between 20-70% of cellulose alone remains undigested (Varga and Kolver 1997). The application of exogenous fibrolytic enzymes to forages has been investigated since the 1960's as a method of enhancing fibre digestion and thus animal performance. Commercially available exogenous enzymes are commonly used in the pig and poultry industries; however, adoption in the beef industry has been significantly slower.

Fibre fermentation depends on production of fibrolytic enzymes produced by some rumen bacteria, anaerobic fungi and protozoa. The main fibrolytic bacteria are the Gram-positive *Fibrobacter succinogenes* and *Butyrivibrio fibrisolvens* and the Gram-negative bacteria *Ruminococcus albus* and *Ruminococcus flavefaciens* (Cheng et al 1991; Krause et al 2003). The majority of enzymes involved in fibre degradation are glycosyl hydrolases, most commonly cellulases, hemicellulases and xylanases. These enzymes hydrolyse the glycosidic bond between carbohydrates or carbohydrates and non-carbohydrates (Henrissat and Bairot, 1993). The degradation of cellulose, in particular, requires several enzymes that are joined together in a molecular structure known as a cellulosome. The cellulosome adheres to the surface of plant cell walls, providing the initial step in fibre breakdown (Krause et al 2003).

Numerous studies have examined the effects of exogenous enzymes on performance in beef cattle (Table 31). However, results have been highly variable when applied to forages and Australian studies are scarce. The application of exogenous enzymes to high grain diets has been more consistent (Beauchemin et al 2003). The following are a summary of key performance observations from exogenous enzyme studies in Table 31. The responses to the enzymes appear to be variable over diets.

- Improvements in ADG between 6.8-24% were achieved when Agrozyme was applied to forage and improved feed efficiency was improved between 6.0-21.2% (Burroughs 1960).
- Pro-Mote® use increased ADG by 9% in feedlot finishing steers and improved feed:gain ratio by 10% (Beauchemin et al 1999).
- Beauchemin et al (1995) found increased weight gain when a cellulose and xylanase mixture was applied to timothy hay, but no production response was observed for any enzyme concentration tested when applied to barley hay. Similarly, with another enzyme mixture, Spezyme CP and Xylanase B, improved feed efficiency was observed when this was applied to a barley diet but not a corn diet (Beauchemin et al 1997).
- Treatment of a TMR diet with a commercial mixture of cellulose and xylanase increased ADG in feedlot steers to a greater extent than treating silage alone (McAllister et al 1999).
- ZoBell et al (2000) fed an endogluconase and xylanase mixture, but found no significant effects on DMI, ADG or feed efficiency in crossbred steers, whereas Perry et al (1960) found that ADG was decreased.

The quantification of dry matter and fibre digestibility effects of the exogenous enzymes fed to ruminants have also been the subject of studies, both *in vitro* and *in vivo*, producing mixed results (Table 32). Yang and Xie (2010) reviewed the fibrolytic activity of 18 commercially based in *in vitro* ruminal batch cultures.

The milk production responses to use of fibrolytic enzymes are more consistent as shown in Table 33 (Granzin 2004). An Australian study with Pro-Mote® conducted in lactating dairy cattle fed on kikuyu and supplemented with a grain: protein meal mixture showed a non-significant response of 0.8 litres of fat corrected milk in heifers and a 0.9 litre response (P = 0.06) in adult cattle (Granzin 2004).

The variable responses in *in vitro* and *in vivo* to exogenous feed enzymes could suggest that enzyme additives are not effective at enhancing fibre digestion. However, it is more likely that the exogenous fibrolytic enzymes are effective and the high level of variability can be accounted for by differences in enzyme type, enzyme-substrate specificity, level of supplementation, method of application and the energy balance of the animal (Beauchemin et al 2003). These suggestions are supported by the consistent milk production responses observed.

The mode of action of exogenous enzymes is not entirely understood. McAllister et al (2000) proposed that it is unlikely exogenous enzymes improve fibre degradation by direct hydrolysis. It is probable that enhanced fermentation results from synergistic interactions between the native and exogenous enzymes. Exogenous enzymes would need to be unique in comparison to native enzymes in order for improved fibre digestion to occur (McAllister et al 2000).

Exogenous enzymes are most effective when energy is the limiting nutrient in growing animals. The most effective means of applying these is subject to further investigation. Enzymes have been applied to hay or ensiled forages in a liquid form, as a supplement in feed or as a premix infusion,

although the latter method has not been successful (Lewis et al 1996; McAllister et al 1999; Sutton et al 2001). It has been proposed that enzymes are more effective when applied to high moisture feeds such as silages; however, some enzymes have been more effective when applied to dry forages. Applying enzymes to feed before consumption enhances the binding of the enzyme to the feed, and reduces proteolysis. To be effective an enzyme-based product must be capable of resisting proteolytic attack, other enzymes and acidic conditions, and should not affect the synthesis of endogenous enzymes.

Table 31. Summary of the effects of exogenous enzymes on dry matter intake (DMI), average daily gain (ADG) and feed efficiency in beef

Reference	Cattle Type	Enzymes	Source	Application	Group	DMI[1]			ADG[2]			FCR[3]		
						Cont[4]	Treat[5]	SEM[6]	Cont	Treat	SEM	Cont	Treat	SEM
Beauchemin et al 1999)	Feedlot finishing heifers (370kg)	Xylanase cellulose	Pro-Mote® (Biovance Technology, Ohama, NE)	Rolled grain		10.73	10.62	0.25	1.40	1.53	0.03	7.72	6.95	0.42
Beauchemin et al 1997	Crossbred steers (408kg)	High in xylanase, low in cellulose	Spezyme CP (Genencor, Rocester, NY)	Water	Barley – Spezyme	9.99	9.53	0.25	1.43	1.52	0.07	7.11	6.33	0.26
					Barley – Xylanase		9.86	0.25		1.40	0.07		7.13	0.26
		High in cellulose, low in xylanase	Xylanase B (Biovance Technologies)		Corn – Spezyme	9.55	9.29	0.25	1.33	1.19	0.07	7.26	7.83	0.26
					Corn – Xylanase		9.10	0.25		1.33	0.07		6.95	0.26
McAllister et al 1999	Feedlot steers	Cellulase xylanase	(Finnfeeds International Ltd., Marlborough, UK)	TMR Silage	TMR - Conc	10.13	9.54	0.29	1.13	1.25	0.03	8.90	8.56	0.49
					1.25 L/T	7.74	7.49	0.19	1.32	1.28	0.05	5.93	6.10	0.16
					DM		7.74	0.19		1.36	0.05		5.77	0.16
					- Conc 3.5		8.16	0.19		1.40	0.05		5.99	0.16
					- Conc 5									
ZoBell et al 2000	British crossbred steers	Endoglucanase, xylanase	(Finnfeeds International Ltd.)	TMR		10.1	9.55	0.29	1.22	1.16	0.08	8.72	8.68	0.23
Burroughs et al 1960	Feedlot heifers and steers		Agrozyme	Ration		No effect			1.86	1.98		Feed/100lb gain 1201	Feed/100lb gain 1129	
Perry et al 1966 – Trial 1	Yearling steers	Cellulase, amylase, hemicellulase, dextrinase, proteinase	Agrozyme (Merck and Co., Rahway, NJ)	Ration		13.9	14.2		1.04	1.08		9.4	9.4	
Perry et al 1966 – Trial 2		As above	Agrozyme	Ration		7.2	7.7		0.77	0.81		9.5	9.6	
		Amylase protease	Takamine (Miles Chemical Company, Clifton, NJ)				8.0			0.80			10.1	
		Protease amylase gumase	Zymo-Plast (Pabst-Brewing Co., Milwaukee, Wisconsin				7.5			0.77			9.9	

Reference	Cattle Type	Enzymes	Source	Application	Group	DMI[1] Cont[4]	DMI[1] Treat[5]	DMI[1] SEM[6]	ADG[2] Cont	ADG[2] Treat	ADG[2] SEM	FCR[3] Cont	FCR[3] Treat	FCR[3] SEM
Perry et al 1966 – Trial 3	Yearling steers	As above	Agrozyme	Ration		13.8	14.0		0.89	0.94		10.2	9.9	
		As above	Agrozyme				14.2			0.93			10.1	
		Amyloglucosidase	Diazyme (Miles Chemical Company)				13.7			0.88			10.2	
		As above	Takamine				13.8			0.90			10.1	
		As above	Zymo-Plast				14.2			0.94			10.0	
Beauchemin et al 1995	Weaned crossbred calves	Xylanase cellulose	Xylanase B (Biovance Technology) Spezyme CP (Genencor)	Lucerne hay	-Conc 1	10.2	10.8	0.6	1.03	1.27	0.08	9.9	9.0	0.7
					-Conc 2		10.5	0.6		1.28	0.08		8.7	0.7
					-Conc 3		11.7	0.6		1.34	0.08		8.5	0.7
					-Conc 4		10.9	0.6		1.19	0.08		9.6	0.7
					-Conc 5		10.3	0.6		1.12	0.08		9.5	0.7
				Timothy hay	-Conc 1	8.8	8.3	0.4	1.21	1.32	0.12	7.3	6.5	0.6
					-Conc 2		7.5	0.4		1.13	0.12		7.5	0.6
					-Conc 3		9.2	0.4		1.24	0.12		6.3	0.6
					-Conc 4		8.6	0.4		1.27	0.12		6.8	0.6
					-Conc 5		9.3	0.4		1.64	0.12		5.9	0.6
				Barley silage	-Conc 1	7.5	8.1	0.4	1.12	1.15	0.08	7.1	7.0	0.4
					-Conc 2		6.8	0.4		0.99	0.08		7.2	
					-Conc 3		7.8	0.4		1.02	0.08		7.6	
					-Conc 4		7.3	0.4		1.12	0.08		6.9	
					-Conc 5		7.3	0.4		1.11	0.08		7.0	
Rovics and Ely, 1962	Steers and heifers				Steers				1.06	1.10		6.04	5.91	
					Heifers				1.00	1.05		4.49	4.31	
Perry et al 1960	Steers	As above	Agrozyme (Merck and Co., Rahway, NJ)						0.99	0.81				
		Amyloglucosidase												
		Amylase protease	Diazyme (Miles Chemical Company)							0.93				
			Takamine (Miles Chemical Company, Clifton, NJ)							0.91				
Clark et al 1960	Hereford steers	Proteases amylases	Rhozyme F-3C						1.38	1.56				
		Proteases amylases cellulases	Rhozyme F-4D							1.58				

[1]**DMI**, dry matter intake (kg/day); [2]**ADG**, Average daily gain (kg/day); [3]**FCR**, feed conversion ratio, [4]**Cont**, control; [5]**Treat** treatment; [6]**SEM**, standard error of the mean

Table 32. Summary of effects of exogenous enzymes on dry matter and/or fibre digestibility *in vitro* or *in vivo* in ruminants

Reference	Enzymes	Source	App	Study Type	Finding
Colombatto et al 2003	Protease, cellulases, hemicellulase, α-amylase	(Cargill Inc, St. Loius, MO)	TMR	*In vitro*	- Increased NDF degradability by 43% at high and 25% at low pH - Hemicellulase degradability increased by 79% at high and 51% at low pH
Nakashima et al 1988	Polysaccharidase		Ensiled rice straw	*In vitro*	- NDF content decreased and overall solubility increased
Colombatto 2000				*In vitro*	- Improved rate of fibre digestion
Wang et al 2001		(Biovance Technologies Inc. Omaha, NB)	Steam rolled barley and lucerne hay	*In vitro*	- Decreased NDF content and increased disappearance of DM in barley - No effects on lucerne hay - Increased cellulolytic bacteria numbers
Yang et al 1999	Cellulases xylanases	Pro-Mote® (Biovance Technologies Inc.)	Cubes mixed with concentrates, lucerne hay or silage	*In vitro/ In vivo*	- Digestibility of organic matter and NDF was increased - Milk production increased
Carreon et al 2010		Fibrozyme (Alltech Inc. Nicholasville, KY, USA)	Corn stover and lucerne hay	*In sacco*	- Increased disappearance of DM, starch, NDF and ADF
Rode et al 1999	Cellulases xylanases	Pro-Mote® (Biovance Technologies Inc.)	TMR	*In vivo*	- Increased digestibility of: DM Control 61.7 vs enzyme 69.1% NDF 42.5 vs 51.0 ADF 31.7 vs 41.9 CP 61.7 vs 69.8 - Increased milk yield 35.9 vs. 39.6 kg/d
Lewis et al 1996	Cellulases xylanases	Grasszyme (FinnFeeds International, Marlborough, Wiltshire, UK)	Hay and barley	*In vivo*	- Increased disappearance of DM, NDF and ADF - Digestibility was greater when enzyme was applied 24h prior to feeding vs immediately before feeding
Feng et al 1996	Cellulases xylanases	Alphazyme and Grasszyme (FinnFeeds International)	Grass	*In vitro & in vivo*	- Increased disappearance of DM and NDF both in vivo and in vitro
Krause et al 1998	Cellulases xylanases	Pro-Mote® (Biovance Technologies Inc.)	Barley	*In vivo*	- Increased digestibility of ADF by 28% over control
McAllister et al 1999	Cellulases xylanases	(FinnFeeds International)	Barley silage	*In vivo*	- No effect on digestibility - Digestibility greater when enzyme applied to silage vs intra ruminal dose
Dong et al 1999	Cellulases xylanases	(Novo Nordisk, Denmark)	Grass hay	*In vivo*	- Increased OM, cellulose and hemicellulose digestibility by 9, 15 and 20% respectively
Hristov et al 2000		(GNC Bioferm, Saskatoon, SK)	Intr-ruminal	*In vivo*	- No effect on DM, CP and NDF digestibility
Hristov et al 1998	Cellulases xylanases	(FinnFeeds International)	TMR	*In vivo*	- No effect on DM, CP and NDF digestibility
Gallardo et al 2010	Cellulases xylanases		Range of hays, silage and grasses	*In vitro*	- Increased potentially degradable fraction degradation of NDF (62.0 vs 65.7%) and ADF (52.8 vs 56.9%) of lucerne hay only

Table 33. Effects of fibrolytic enzymes on the productivity and nutrient intake of lactating dairy cows (Granzin 2004)

Reference	Diet	Cow/tr. and stage of lactation	Difference in milk production				Difference in liveweight (kg)	Difference in intake	Difference in digestibility		
			Difference in milk yield (L) (% rel. to control)	Fat %	Protein %	SCM or ECM (L) (% rel. to control)		kg DM/cow.day (% rel. to control)	OM	NDF	Starch
Applied to grain/TMR											
Beauchemin et al 1999	Barley silage/alfalfa/barley grain	4 (LS)	+0.9 (3.0)	+0.12	+0.05	+1.5 (5.2)	.	+ 0.2 (0.9)	40	15	49
Rode et al 1999	Corn silage/alfalfa hay/barley grain	10 early	+ 3.6 (10)	-0.50	-0.21	+1.0 (3.0)	+0.03	+ 0.3 (1.6)	67	85	14
Yang et al 1999[3]	Barley silage/alfalfa/barley grain	4 (LS)	+ 1.6 (6.8)	-0.03	+0.13	+2.0 (9.0)	.	+ 0.4 (2.0)	21	36	9
Yang et al 2000	Corn silage/alfalfa hay/barley grain	14 early	+ 2.1 (5.9)	-0.15	-0.05	+1.0 (3.3)	-0.09	+ 0.4 (2.1)	37	17	15
Average			**+2.1 (6.4)**	**-0.14**	**-0.02**	**+ 1.4 (5.1)**	**.**	**+0.3 (1.7)**	**41**	**38**	**22**
Applied to forage											
Lewis et al 1999	Alfalfa, barley/corn grain	10 early	+ 1.2 (3.0)	-0.16	-0.08	-0.1 (-0.2)	.	+1.8 (7.4)	.	.	.
Schingoethe et al 1999	Corn silage, alfalfa, corn grain	10 early-mid	+ 6.3 (15.9)	+0.01	-0.07	+6.2 (+15.0)	.	+1.8 (7.4)	.	.	.
			+ 1.6 (4.0)	-0.24	-0.10	NC	.	+2.2 (9.0)	.	.	.
			+1.1 (4.4)	+0.13	+0.09	+1.9 (7.1)	.	+0.8 (3.9)	.	.	.
			+0.9 (3.6)	+0.22	+0.15	+2.6 (9.7)	.	-0.3 (1.5)	.	.	.
			+2.7 (10.8)	+0.14	+0.08	+4.3 (16.0)	.	+1.7 (8.3)	.	.	.
Zheng et al 2000	Corn silage/alfalfa, corn grain	12 early	+4.1 (12.5)	+0.08	+0.07	+4.2 (12.7)	.	-0.5 (2.1)	.	.	.
Dhiman et al 2002	Alfalfa hay/corn silage/ corn grain	10 early	-0.8 (2.0)	-0.08	-0.07	+1.1 (3.1)	-0.06	+0.4 (1.5)	.	.	.
Average			**+2.3 (6.5)**	**+0.01**	**0**	**+2.5 (7.9)**	**.**	**+1.0 (5.1)**	.	.	.

SCM Solid corrected milk; **ECM** energy corrected milk;

The slow adoption of exogenous enzymes in the global industry can be explained by the relatively high cost of enzyme products, lack of consistent performance enhancement and the limited number of products available. Currently the only commercially available enzyme product used in the Australian beef industry is Natuzyme (Bioproton Pty. Ltd, QLD). Natuzyme contains cellulase, xylanase, β-glucanase, α-amylase, protease, pectinase, phytase, hemicellulase, amyloglycosidase and pentosanase. Unpublished results have shown Natuzyme applied to lucerne increased the rate of gas production *in vitro*, indicating increased fibre digestion (Naserian and Ghasemi 2008) When administered to Holstein calves up to 60 days of age at a rate of 0.5 and 1% of body weight, Natuzyme decreased dry matter intake and improved feed to gain ratio (Naserian et al 2008). In dairy studies Natzyme decreased dry matter intake with no effect on milk yield and composition (Ghasemi and Naserian 2008) and extended the peak production period (Altilbany 2008).

A greater range of exogenous enzyme mixtures are commercially available in the United States.

There is future potential for the use of exogenous enzymes in the northern Australian beef industry, particularly enzymes active against cellulose or perhaps lignin because the dominant pastures in northern Australia have relatively high lignin content. However, further research into enzyme-substrate specificity, application methods and rate and performance benefits are required.

8.8 Algae

The algae or microalgae are a diverse group of aquatic, photosynthetic organisms. Algae are readily grown and can be manipulated to produce feed for animals, and can produce specific proteins, lipids and even bio-fuels (Spolaore et al 2006; Rosenberg et al 2008). The *Arthrospira* (*Spirulina), Nostoc, Aphanizomenon* and *Chlorella* species have been used as food for animals and humans, during a period extending over 2000 years (Spolaore et al 2006; Michalak and Chojnacka, 2008). Recently Costa et al (2010) conducted basic chemical analyses on a number of microalgae and macroalgae and compared these to cottonseed and soyabean meals. The nutritional composition and response when fermented *in vitro* indicate that these will be appropriate materials for inclusion in ruminant diets. Duckweed (*Lemna* spp.), which grows prolifically, has been used to manage high fertility waste water and has been suggested as a potential source of feed for cattle (Leng et al 1995).

The potential of the algae to produce bio-fuels and to efficiently produce a vast range of products suggests that algae could be presented either as singly or as a waste product of bio-fuel or other chemical manufacture. Algae are also amenable to manipulation to increase the micro-element content (Michalak and Chojnacka, 2008).

The micro-algae were identified as a potentially valuable resource for the cattle industry by two interviewees. Feeding trials with these products include studies to modify milk fat in dairy cattle (Boeckaert et al 2008), to reduce methane production (Fievez et al 2007) and to supplement cattle on tropical pastures (Poppi and Quigley, 2009; Poppi pers comm). The high lipid micro-algae used in some experiments have markedly decreased dry matter intakes (Boeckaert et al 2008; Fievez et al 2007), however, not all algae are high in lipids (Costa et al 2010). Chowdhury et al (1995) reported the chemical composition of algae grown in Bangladesh and the positive responses to algae of cattle fed on straw. Trials conducted on tropical pastures (Poppi and McLennan, 2010; Poppi pers comm.) indicate that a control diet containing tropical grass hay with less than 7% CP was sufficient for maintenance or small liveweight loss. Supplementing with algae (4g/kgBW/d) resulted in a LWG of 0.6kg/d and also stimulated intake of the hay. Cottonseed meal fed at same level as algae (4g/kgBW/d) provided the same result as algae, but provided a better LWG than algae at lower levels of supplementation on the response curve.

The only limitation to use of the algae will be the generic, practical considerations around the suitability of any protein meal for livestock production. Protein meals based on algae are likely to be high protein (of high degradability), variable lipid, low dry matter and low fibre feeds, well suited to use in extensive and feedlot diets. As, and when, these become available, they will most likely be adopted by producers. One potential scenario may be to grow algae for use as a protein supplement in the extensive regions of Australia to reduce the costs of transport of protein and possibly NPN. However, the logistics, costs and feasibility of such strategies need evaluation.

8.9 Plant secondary metabolites

Plant secondary metabolites are chemical compounds that are not involved in plant growth or reproduction (Patra and Saxena 2010). The role of secondary plant metabolites is to protect the host against microbial and insect attack and these compounds are often associated with plant odour and colour (Wallace 2004). Currently over 200,000 plant secondary metabolite structures have been defined (Hartmann 2007) and can be classified into one of the following four groups:

i. essential oils
ii. saponins
iii. tannins
iv. organosulphur compounds.

However, other compounds also exist.

Plant secondary metabolites have a long history of use in food preservation and medicine. Consequently, there is abundant literature available on their use; however, only a small proportion of the research is applicable to ruminants. The majority of the research applicable to ruminants has been conducted using *in vitro* systems over short timeframes (Benchaar et al 2008). These studies, while useful, have limited value for the industry. Despite the limited amount of data, there is evidence that plant secondary metabolites have potential as rumen manipulators through their ability to improve rumen fermentation and nitrogen metabolism, to decrease methane emissions and to reduce bloat.

Pressure from activists to reduce usage of antibiotics in animal production and the desire to reduce methane emissions are driving recent research into plant secondary metabolites. The potential of plant secondary metabolites as rumen modifiers has been recently reviewed (Wallace et al 2002; Wallace et al 2004; Calsamigilia et al 2007; Hart et al 2008; Partra and Saxena 2009b).

8.9.1 Essential Oils

Essential oils, also known as volatile or ethereal oils are volatile, aromatic compounds with an oily appearance (Burt 2004) that are present throughout plants (Hirasa and Takemasa 1998). Essential oils are not true oils (lipids), but are variable blends of several active compounds (Benchaar et al 2008). The most important are included in the chemical groups terpenoids or phenylpropanoids (Calsamiglia et al 2007). Approximately 15,000 different terpenoid compounds have been described (Gershenzon and Croteau 1991). Individual compounds are described in further detail by Dorman and Deans (2000). Concentrations depend on the growth stage and health of the plant (Dudareva et al 2004), along with environmental factors including temperature, light and water stress (Stardt and Bertin 1998; Gershenzn et al 2000). They can be extracted by steam distillation, or solvent or pressure extraction under liquid carbon dioxide (Moyler 1993; Packiyasothy and Kyle 2002). Examples of essential oils and their main components are provided by Benchaar et al (2008).

Essential oils are believed to inhibit bacterial growth largely due to their hydrophobic nature and lipid affinity, which increases the permeability of the bacterial cytoplasmic membrane, causing subsequent leakage of cytoplasmic constituents, thereby disrupting the proton motive force (Hart et al 2008). Bacteria use ionic pumps to counteract the disruption, a process that uses large amounts of energy, hence their growth is reduced and lysis occurs in some cases. Gram-negative bacteria have demonstrated greater resistance to essential oils compared to Gram-positive bacteria (Chao et al 2000). Interaction with the bacterial membrane is considered the primary mode of action, although essential oils have also been shown to coagulate cell constituents and interact with groups of proteins and enzymes (Juven et al 1994).

The effects of a variety of essential oils on rumen fermentation products, including ammonia, propionate and total volatile fatty acids, have been previously investigated (Evans and Martin 2000; Ando et al 2003; Benchaar et al 2003; Cardozo et al 2004, 2005; Newbold et al 2004; Busquet et al 2005ac, 2006; Castillejos et al 2005, 2006, 2007; Fernandez et al 2005; Beauchemin and McGinn 2006; Martinez et al 2006) and results tabulated by Hart et al (2008). The majority of these studies reported no effects on rumen fermentation products at low concentrations; however, fermentation products were typically decreased when essential oils were administered at doses in excess of 3000 mg/l. These effects are considered the result of pressures on rumen microbial populations that subsequently affect their numbers and activities; however, effects vary depending on the chemical composition of essential oils (Hart et al 2008). There are inconsistencies in effective dose rates (Hart et al 2008), a matter which could be further investigated.

Pure, natural mixtures and man-made blends of essential oils are currently commercially available for use as rumen modifiers (Hart et al 2008). The most well known of these products is Crina Ruminants (Akzo Nobel, Gland, Switzerland), which consists of the natural and nature-identical compounds thymol, eugenol, vanillin and limonene (Rossi 1995). A number of fermentation studies involving Crina have been conducted (Table 34). Crina had no effect on ammonia concentrations in any of the studies or on propionate concentrations, with the exception of the decreases observed by Castillejos et al (2007) at 5, 50 and 500mg/l of Crina. Increases in total VFA concentration were observed by Benchaar et al (2003), Castillejos et al (2005) and Castillejos et al (2007).

Table 34. The effects of Crina on rumen fermentation products (Source: Hart et al 2008)[1]

Test system	Dosage	Substrate:Feed	Ammonia	Propionate	Total VFA	DM deg	Methane	Reference
RUSITEC	40mg/d	Alfalfa:grass hay and barley	NE	ND	NE	ND	NE	Fernandez et al 2007
RUSITEC	40mg/d	Forage:concentrate (80:20)	NE	NE	NE	NE	NE	Fernandez et al 2005
In vivo (sheep)	110mg/d	TMR	NE	NE	NE	ND	ND	Castillejos et al 2007
In vivo (sheep)	110mg/d	Forage:concentrate (60:40)	NE	NE	NE	NE	ND	Newbold et al 2004
In vivo (cattle)	750mg/d	TMR	NE	NE	increase	NE	ND	Benchaar et al 2003
In vivo (cattle)	1000mg/d	TMR	NE	NE	NE	decrease	NE	Beauchemin and McGinn 2006
Continuous culture	1.5mg/l	Forage:concentrate (60:40)	NE	NE	increase	NE	ND	Castillejos et al 2005
Continuous culture	5mg/l	Forage:concentrate (60:40)	NE	decrease	increase	NE	ND	Castillejos et al 2007
Continuous culture	50mg/l	Forage:concentrate (60:40)	NE	decrease	decrease	NE	ND	Castillejos et al 2007
Continuous culture	500mg/l	Forage:concentrate (60:40)	NE	decrease	decrease	NE	ND	Castillejos et al 2007

[1]Effects on rumen fermentation are relative to control ($p < 0.05$): **NE**, no effect; **ND**, not determined; **DM deg**, dry matter degradation.

Essential oils and their blends have potential as effective ruminant feed additives in the future; however, more extensive *in vivo* studies need to be carried with an emphasis on gathering performance and fertility data which are currently scarce. Although there are commercial products available overseas, these may not be beneficial to the northern beef industry, because of lack of sufficient evidence of efficacy to date.

8.9.2 Saponins

Saponins are compounds produced predominantly in plant tissue that is the most vulnerable to microbial attack (Hart et al 2008). They are high molecular weight glycosides that form stable foam in aqueous solutions (Hart et al 2008). Their mode of action is primarily based on increasing membrane permeability, which is believed to occur as a result of the formation of a micelle-like aggregation of saponins and cholesterol (Seeman 1974); however, more complex interactions have been hypothesized (Yamasaki et al 1987; Takechi and Tanaka 1995; Choi et al 2001). The potential use of saponins as rumen manipulators is complicated by the ability of rumen micro-organisms to metabolize saponins (Gutierrez et al 1959; Makkar and Becker 1997). Although a number of plants containing saponins are used as livestock feeds, (Wina et al 2005), only a small number of these are used as a source of saponins for feed additives (Cheeke 1996). These include *Yucca schidigera, Quillaja saponaria* (soapbark tree), *Sapindus saponaria, Sapindus rarak and Camilla sinensis* (Wina et al 2005). Products based on *Y. schidegera* and *Q. saponaria* are commercially available overseas.

Studies have investigated the effects of saponins on ruminal fermentation products and protozoa numbers (reviewed by Hart et al 2008; Wina et al 2005). The key findings were variable effects on total ruminal VFA production, which may be explained by the variation in saponin type and concentration (Hart et al 2008). However, a number of studies reported increased propionate concentrations, particularly on concentrate based diets, suggesting that diet composition may influence responses (Hart et al 2008). A reduction in ammonia concentrations occurred in a number of the studies (Lu and Jorgensen 1987; Lu et al 1987; Makkar et al 1998). Wina et al (2005) reported a total of 28 studies that showed saponin reduced protozoal numbers, eight that showed saponin decreased protozoal activity, seven that showed it had no effect and three that reported an increase in protozoal numbers. Protozoal reduction occurs as the result of the presence of sterols in protozoal membranes that can be easily bound to the saponins (Williams and Coleman 1992). The antiprotozoal effect has been demonstrated to be only transient, with protozoal populations reaching comparable counts to controls after 9 or 14 days of saponin supplementation (Newbold et al 1997; Ivan et al 2004). Information on the effect of saponins on bacteria is more limited, and appears to be dependent on saponin and bacterial type as expected.

Literature on the effect of saponins on ruminant performance is scarce. The main source of saponin used in performance studies is *Y. schidegera* extract or powder, available as a commercially product (Wina et al 2005). This product produced variable results in sheep and cattle (Table 35). *Enterolobium cyclocarpum* leaves and sapindus extract from *Sapindus rarak* fruit have improved average daily gains in sheep (Table 35; Leng et al 1992; Navas-Camacho et al 1993; Thalib et al 1996; Wina et al 2006). Studies in cattle are limited and there is no literature on the effect of saponins on reproduction.

Saponins appear to have beneficial effects of defaunation of protozoa in the rumen and manipulation of the ruminal fermentation products towards greater production of propionate. However, many saponin studies have only been conducted *in vitro* and there are few *in vivo* studies. Some saponins are toxic to ruminants.

Saponins are metabolized by rumen micro-organisms, and these treatments appear to have only a transient affect on protozoal populations. There are limited products commercially available

and limited studies have been conducted on their effects in cattle in tropical environments. At present, saponins do not appear to have great potential benefit to the northern Australian beef industry.

8.9.3 Tannins

Tannins are water soluble polyphenolic polymers that have the ability to form complexes with proteins and are found in many forage trees, shrubs, legumes, fruits, cereals and grains (Patra and Saxena 2010). Tannins are commonly classified as either hydrolysable or condensed tannins. Tannin concentrations of greater than 5% of dietary DM have negative effects on feed intake and rumen fermentation (Patra and Saxena 2010). Additionally, hydrolysable tannins are potentially toxic and can result in death.

Table 35. Summary of performance results of saponin supplementation in ruminants

Saponin source	Doseage	Delivery method/diet	Animal	Results	Comments	Reference
Yucca schidigera (sarsaponin)	30 mg/kg DM	Hay:concentrate (1:1)	Sheep	- No increase in body weight		Eliwinski et al 2002
Sevarin (Distributors Processing Inc., Porterville, CA) *Yucca schidigera* (sarsaponin)	150mg/d	1) soybean meal 2)1% urea 3) 1% urea + saponin Basal diet = corn + corn silage	Crossbred feedlot steers	- Daily gain improved (0.74kg) compared to urea group (0.66kg) over first 28 days of feeding - No improvement over soybean meal group (0.84kg) - Feed:gain 9.87 compared to 10.11 (urea), 7.96 (soybean meal)	Average of 4 trials	Mader and Brumm 1987
Deodorase (Alltech Biotechnology, Nicholasville, KY) *Yucca schidigera*	250mg/kg	Mixed diet 45% hay, 50% rolled barley and 5% soybean meal	4 fistulated Hereford steers	- No effect on feed intake or weight gain		Hussain and Cheeke 1995
Enterolobium cyclocarpum leaves		Oaten chaff	Sheep	- Increased ADG, 115g/d compared to control 93 g/d		Leng et al 1992
Sapindus extract from *Sapindus Rarak* fruit		Added to a rice straw every 3 days Basal diet = elephant and native grass (50:50) + 0.5% BW concentrate	18 sheep	- Improved ADG 54.8g/d compared to control 44.8g/d		Thalib et al 1996
Sapindus rarak fruit	0.24, 0.48 and 0.72g/kg BW	Mixed with wheat pollard, fed twice daily Basal diet + sugar cane tops	28 Javanese sheep	- Improved ADG 53.2g/d compared to control 36.9g/d		Wina et al 2006
Enterolobium. cyclocarpum leaves	0, 100 and 300g/d	Pennisetum hay	12 crossbred sheep	- Improved ADG 28.6g/d (100g/d dose), 29.7g/d (300g/d dose) compared to control 19.8		Navas-Camacho et al 1993
Yucca powder	150mg/kg	90% concentrate	Male lambs	- No effect on ADG		Gorgulu et al 2004
Quillaja saponaria	40mg/kg	30% hay	Lambs	- No overall effect on ADG - Greater response in males (315g/d) compard to females (239g/d)	Abstract only	Bosler et al 1997

At low concentrations, tannins have been shown to have the beneficial effect of decreasing the degradability of proteins in the rumen by forming tannin-protein complexes, hence reducing microbial attack, enhancing protein utilization and lowering methane emissions (Mueller-Harvey 2006). Methanogenesis is also decreased by t protozoa populations by tannins.

It has been suggested rumen micro-organisms adapt to tannins. Tannins can also be degraded by rumen micro-organisms, hence these treatments will not be effective at reducing methanogenesis in the long term (Patra and Saxena 2009a). Increases in protein utilization improve the host's immune system increasing tolerance or resistance to parasites. Tannins also exhibit antimicrobial actions lower fibre utilization, and decrease the rate of digestion, an action that may help to synchronize the release of nutrients, increasing microbial efficiency (Makkar 2003). Further, the proportion of propionate produced is often increased (Makkar 2003). Due to their ability to precipitate proteins, condensed tannins reduce the occurrence of bloat, a disorder that occurs in cattle grazing high protein improved pastures (Tanner et al 1995). Actions of tannins from specific plants have been summarized by Rochfort et al (2008).

Despite the well-recognized negative effects of high levels of tannin intake on animal performance, data on the effects of tannins on ruminant performance is scarce. Wang et al (1996) showed that lambs fed *Lotus cornculatus* diet (containing 34g/kg DM of condensed tannins) had an ADG of 203g compared to lambs fed PEG (188g). Lambs on a lucerne (0.3g/kg DM condensed tannins) diet had an ADG of 185g, while those on PEG had an ADG of 178g. Barry (1985) showed bodyweight was decreased in ewes fed condensed tannins at a rate of 76-90g/kg DM. Ewes fed *L. corniculatus* containing 18-29 g/kg DM condensed tannins had an ADG of 66.6g/d compared to that of ewes on pasture alone (-4.6g/d) (Ramirez-Restrepo et al 2005). In a second similar experiment ADG was 55.8g/d in the *L. corniculatus* fed animals and 86.8g/d in the pasture fed ewes (Ramirez-Restrepo et al 2005).

Although beneficial effects of tannins have been demonstrated in temperate forages the effect of tannins in tropical pastures are largely unevaluated. The relatively low protein content of tropical pastures or of feedlot diets may limit the potential for tannins to provide significant performance benefits for the Northern beef industry.

8.9.4 Organosuphur compounds

Organosuphur compounds are sourced from the Alliaceae and Cruciferae (Brassicacae) family, by the action of myrosinase and alliinase enzymes (Table 36; Mithen 2006).

Table 36. Examples of plants that produce organosuphur compounds in the Alliaceae and Cruciferae families (Mithen 2006)

Alliaceae		Cruciferae	
Scientific name	**Common name**	**Scientific name**	**Common name**
Allium sativum	garlic	Brassica juncea	
Allium cepa	onion	Wasabia japonica	Wasabi
Allium porrum	leek	Armoracia rusticana	Horseradish
		Brassica oleracea	Cauliflower

There is limited literature on the effect of organosphur compounds on ruminant performance, but a small amount on the effect on rumen fermentation products (Table 37) and feed intake. Garlic oil or garlic bulb did not increase DMI of sheep and cattle (Nolte and Provenza 1992; Bampidid et al 2005; Yang et al 2007; Patra et al 2008); however, Patra and Saxena (2010) reported initial decreases in intake by sheep and buffaloes over the first 10-15 days on a concentrate mixture containing garlic bulbs. The strong smell is the likely cause of reduced intake.

The commercially available product (not in Australia), *Garlic* (Neem Biotech Ltd., Cardiff, UK) which is an aqueous allicin product has recently been evaluated using the rumen simulation

technique (RUSITEC). No effects of daily total VFA or ammonia production were found at two concentrations evaluated, 2 and 20 mg/l of allicin; however, methane production was decreased by 94% at 20 mg/l of allicin (Hart et al 2006). More research is required into the potential of organosphur compounds before these are considered for use in Australia.

8.9.5 Rumen-Up Project

Rumen-Up was a European Commission-sponsored project that was carried out to develop new plant-based dietary supplements to replace chemical additives and antibiotic growth promoters (Wallace 2004). The objectives were to assemble and screen 500 plants or plant extracts for their ability to prevent lactic acidosis, bloat and methane and nitrogen excretion. Samples were also assessed for detrimental effects on rumen fermentation and feed utilization. A total of 23 plants or plant extracts were identified as potential feed additives and showed no detrimental effects on animals (Wallace, 2004). Of these eight were identified as having potential for commercial production. Due to budget constraints only three, *Bellis perennis* (anti-protozoal effect), *Knautia arvensis* (anti-proteolytic effect) and *Urtica dioica* (anti-acidotic effect) were tested *in vivo* in sheep. Positive responses were demonstrated; however, these were not as large as the *in vitro* responses. Detailed results from the Rumen-Up project are available in the Final Report for RUMEN-UP (URL: http://www.rowett.ac.uk).

The main conclusions of the project were that including:

- The inclusion of *K. arvensis in vitro* at a rate of 18% increased soluble protein by 64% with no negative effects on fermentation. This effect accounted for 38% of the comparable effect of monensin. The inclusion of *K. arvensis in vivo* at a rate of 10% produced a shift in energy retention from fat to protein gain. These findings led to a conclusion that *K. arvensis is a p*otential replacement for monensin
- The inclusion of *B. perennis* at a rate of 5% reduced protozoal counts to 1.76 $x10^6$ compared to control *2.20 $x10^6$ in vivo*
- *U. dioica* increased hydrogen ion concentrations and lowered lactate concentrations; however, there was no correlation between pH and lactate *in vitro*.

Due to regulatory hurdles, none of these products were released commercially, but may become available in the future. Further, more in depth *in vivo* studies are required.

Table 37. Summary of the effects of organosuphur compounds on fermentation products in cattle

Compound	Test system	Concentrations	Results	Reference
Garlic bulb extract	Continuous rumen culture	0.22mg/l of extract containing 0.7% allicin	- No effect on acetate, butyrate, propionate or total VFA concentration - Lowered ammnia nitrogen concentration - Increased concentration of peptide and amino acid nitrogen	Cardozo et al 2004
Garlic extract dissolved in ethanol	Batch culture at pH 5.5 and 7	0.3, 3, 30 and 300mg/l extract	- Lowered VFA concentration at 3, 30 and 300mg/l at pH 7 - Increased VFA concentration at at 3 and 30mg/l at pH 5.5 - Decreased VFA concentration at 300mg/l at pH 5.5 - Ammonia concentrations decreased at both pH levels - Propionate concentration increased at pH 5.5	Cardozo et al 2005
Garlic oil	Continuous culture	31 and 312mg/l	- No effect on ammonia or total VFA concentrations - Proportions of propionate and butyrate increased at 312mg.l	Busquet et al 2005a
Garlic oil and its components diallyl sulphide, diallyl disulphide, allyl mercaptan and allicin	Batch culture	0.3, 3, 30, 300 and 3000mg/l	- 300 and 3000mg/l reduced VFA concentration - Allicin had no effect on VFA concentration -Garlic oil, diallyl disulphide and allyl mercaptan increased concentrations of propionate and butyrate at 300 and 3000mg/l	Busquet et al 2005b
Garlic oil and its components diallyl sulphide, diallyl disulphide, allyl mercaptan and allicin	Continuous culture	300mg/l	-Garlic oil and allyl mercaptan increased concentrations of propionate and butyrate	Busquet et al 2005b

A total of 91 Australian plants were screened by Durmic et al (2008) for their potential to inhibit certain ruminal bacteria and biohydrogenation of fatty acids by obtaining ethanolic extracts and essential oils. Two plants (unidentified) showed potential; however, *in vivo* studies are required to investigate these plants further.

8.9.6 Conclusion

In summary, plant secondary metabolites have demonstrated potential for use in ruminal manipulion; however, the majority of studies have been *in vitro* and performance data is scarce. *In vivo* studies with a focus on gathering performance data are required. A limited number of products containing plant secondary metabolites are commercially available, largely overseas, There is little evidence that these will be of economic benefit to the northern beef industry at present. Essential oils appear to offer the most potential because the effects of these do not appear to be transient and, unlike saponins and tannins, these are neither metabolized nor degraded. Tannins offer advantages when feeding high protein diets, thus would be more beneficial for Southern Australia. Organosuphur compounds require further research before these could be evaluated for potnetial benefits..

8.10 Opportunities for genetic manipulation of rumen function

Given that we now consider animals to be meta-genomic structures consisting of a mammalian component and the associated microbiota, the potential for genetic selection of superior lines of cattle based on these new understandings seems feasible. There is compelling evidence, albeit limited, that cattle vary markedly in the micobiota of the rumen, even when fed on identical diets. Brulc et al (2009) used comparative metagenomics (phylotype analysis and SEED subsystems-based annotations) to examine randomly sampled pyrosequence data from three fibre-adherent microbiomes and one pooled liquid sample. Even though the three animals were fed the same diet, the community structure, predicted phylotype, and metabolic potentials in the rumen were markedly different with respect to nutrient utilization. If these different ecosystems vary in efficiency, there may be opportunity to select for more favourable ruminal ecosystems.

The older information on breed, genetics and efficiency of digestion has been reviewed by Warwick and Cobb (1975). Table 38 provides detail of quantitative estimates of differences in digestibility of dry matter among cattle breeds.

Table 38. Quantitative estimates of differences in digestibility of dry matter among cattle breeds

Study	Reference breed	Test Breed	Difference % (Digestibility of DM or CP)	Comments
Phillips et al 1960	Zebu	*Bos taurus*	+2.7% DM	
Ashton 1962	Brahman	*Bos taurus*	+2.7% DM	Native pasture hay diets; no difference for Brahman v cross bred
Howes et al 1963	Brahman	Hereford	-2.0% DM -4.0% CP	Statistically significant for only CP
Vercoe 1967	Brahman x Hereford	Hereford		Inc DM digestibility for cross breeds on high quality feed, no difference on low quality feed
Colditz and Kellaway 1972	Brahman x Friesian	Friesian	+4% at 17^{o}C +4.2% at 38^{o}C	Inc in DM digestibility in Friesians but not significant. Confounded with differences in intake
Moore 1974	Brahman	*Bos taurus*		36 bulls – 6 breeds Herefords inc DM digestibility vs. Brahmans on high energy diet No difference on low energy diet
French 1940	*Bos indicus*	*Bos taurus*	No difference	
Vercoe 1966	*Bos indicus*	*Bos taurus*	No difference	

Herd and Arthur (2009) reviewed the physiological basis for residual feed intake (RFI). Residual feed intake is a concept developed by Koch et al (1963), based on the consideration that feed intake of an animal can be categorised as either feed intake that meets an expected level of production or feed that is a residual, either greater or less, than that used to meet the level of production.

Channon et al (2004) identified significant differences in the steer progeny from sires selected to be high or low efficiency of RFI in faecal pH and faecal starch digestion when the cattle were fed on feedlot diets. It is likely that these differences reflect both ruminal and post-ruminal digestion, but suggest some potential for benefits from genetic selection, at least for feedlot performance. Differences in feed efficiency and RFI on feedlot diets were studied for a number of breeds including Brahman, Brahman cross and continental breeds (Shutt et al 2009). Brahmans did not differ from all other sire breeds for RFI, their lower appetite relative to crossbred contemporaries resulted in the lowest DMI and ADG. Charolais, Hereford, Limousin and Santa Gertrudis sire breeds had the lowest RFI without significant loss of ADG, when these breeds were crossed with Brahman cattle (Shutt et al 2009). Estimates of the sources of variation in RFI provided by Herd and Arthur (2009) are 37% for protein turnover, tissue metabolism and stress, 10% for digestibility, 9% for heat increment and fermentation, 9% for physical activity, 5% for body composition, and 2% for feeding patterns.

Warwick and Cobb (1975) concluded that any differences that existed in the efficiency of digestion were sufficiently small to be of no practical significance. This conclusion needs to be tempered by the consideration that the accuracy of measurement of digestibility of dry matter is relatively imprecise (Herd and Arthur 2009). Differences in digestibility may be greater but hard to detect with significance because of substantial variance. However, the evidence in Table 38 does not support any great magnitude of difference in digestibility between breeds. The within breed variance would need to be much greater than between breeds to warrant further examination. Veerkamp and Emmans (1995) reviewed the evidence for between animal variation in the efficiency of digestion of feed and concluded that most studies in dairy cattle showed little evidence of differences in production that could be attributed to digestion efficiency. Exceptions to that finding were Freeman (1975) and Trigg and Parr (1981), who observed differences in digestive efficiency among cattle. Estimates of the heritability of RFI range from 0.16 to 0.39 (Herd and Bishop 2000; Arthur et al 2001; Robinson and Oddy 2004) and for net feed efficiency Pitchford (2004) estimated an heritability of 0.25 across 7 species and 35 estimates. If the variance attributable to digestion is only 10% of the RFI variance (Herd and Arthur 2009), there appears to be little merit in attempting to improve the efficiency of digestion in the rumen by genetic selection of cattle. While providing estimates of RFI or digestibility is relatively practical for feedlot cattle, the ability to select for the same characteristics on tropical pastures is more difficult. Tropical grass hays have been used for this purpose in many of the early Australian studies eg (Ashton 1962). Unless genetic markers for digestion can be found, it appears that the critical studies required to select cattle for increased capacity to digest tropical pastures would have little chance of success, given the lack of evidence of substantial differences in digestibility between breeds.

The more practical consideration for the northern, pasture-based, beef industry may be to select on weight gain, an outcome that includes the capacity of cattle to harvest and digest pasture, efficiencies of maintenance, exercise and growth, and the capacity to meet environmental challenges. The heritability of weight gain was reviewed by Davis (1993) and studied by many others in active Australian programme (Arthur et al (1994); Prayaga and Henshall 2005; Barwick et al 2009ab; Prayaga et al 2009). The latter studies show that there is potential to improve weight gain in the northern grazing industry by selection of cattle on a number of production performance characteristics.

8.11 Reductive acetogenesis

While the briefing for this project specifically excludes an investigation of methanogenesis, the concept and reality of reductive acetogenic pathways represent an example of alternate modes of rumen function that may be more efficient than those currently based on methanogenic hydrogen sinks.

Reductive acetogenesis is a pathway by which carbon dioxide is reduced to acetate by oxidation of hydrogen, as follows;

$2CO_2 + 4H_2 \rightarrow CH_3COOH + 2\ H_2O$

This provides an alternate route for the disposal of hydrogen from the rumen to the methanogenic route;

$CO_2 + 4H_2 \rightarrow CH_4 + 2\ H_2O$

Weimer (1998) notes that the free energy change ($\Delta G^{o'}$, kJ), is lower for methanogenesis than for reductive acetogenesis, indicating that the former is the more thermodynamically favourable reaction. This observation is supported by the primary role that methanogenesis plays in ruminant production. This mechanism also allows the regeneration of Nicotinamide adenine dinucleotide from the reduced form, thereby ensuring ruminal efficiency. However, the ruminal efficiency comes at a cost as eructation of methane results in a 3 to 12% loss of gross energy (Blaxter and Clapperton 1965; Le Van 1998; Weimer 1998). Strategies used to reduce this loss include more digestible diets, antibiotics, ionophores, yeasts or halogenated methane analogues. There are also alternate pathways that can capture hydrogen into alternate sinks including hydrogen sulphite (from sulphate reduction) and ammonia from nitrate reduction (Weimer 1998; Leng pers comm). While the latter have considerable advantages in some respects and are energetically favoured, both have the potential for toxicity.

The barriers to reductive acetogenesis in the rumen are formidable (Weimer 1998). Foremost is the lower affinity of the acetogens for hydrogen than the methanogens (Mackie and Bryant 1994) resulting in the methanogens outcompeting the acetogens for the resource (hydrogen). These findings are supported by a need to control methanogens in order to achieve acetogenic fermentations in intervention studies (Nollet et al 1997; Le Van 1998; Lopez et al 1999; Fonty 2007), particularly through the use of 2-bromoethanesulfonic acid. Nonetheless, Weimer (1998) notes the potential for successful acetogenic fermentations, including the human colon and certain termites. Acetogenic organisms exist in the hindgut of ruminants, however, there appears to be little work in this area. We are aware of an impending publication from the CSIRO group in St Lucia on this area.

Shifting fermentations towards those in which reductive acetogenesis can play a greater role may have the dual benefit of increased gross energy capture and reduced methanogenesis. Innovative approaches to this opportunity may be a valuable part of research programs that investigate means to improve ruminal fermentation.

8.12 Other animal species

When investigating the potential of other animal species to contribute to the development of more efficient production systems in northern Australia, it is worth evaluating the relative efficiencies of ruminants compared to other herbivores. Perhaps the most comprehensive and coherent reviews of the comparative performance of cattle as an herbivore are provided by Van Soest (1994) and Van Soest et al (1995). We conducted an extensive literature search on nutrition of water buffalo, camelids, banteng cattle and marsupials and this did not provide a body of literature suited to a more incisive perspective than that provided by Van Soest (1994). There was a relatively sparse literature with very few studies that could be considered trials with sufficient numbers of animals to provide strong observations. Consequently, there is a paucity of quantitative data that can be used to make direct comparisons among species. A considerable amount of data on comparative efficiencies among herbivores is presented in Van Soest (1994), however, many of the studies reported in the figures and tables are derived using different forages and different methodologies. Consequently, the strength of evidence is modest for many of the conclusions in Van Soest (1994). We were fortunate to also interview Professor Van Soest in regard to his views on the potentials to improve ruminant efficiency on poor forages and in regard to opportunities to use observations or rumen microbes from other ruminants or herbivores.

An important perspective can be obtained from a paper on the evolution of mammals and their gut microbes (Ley et al 2008). This paper examined similarities and differences in the faecal biota of a very diverse selection of mammals in the context of co-evolution of meta-genomic communities. A key finding was that bacteria appear to be fairly promiscuous between hosts, a factor the authors speculated could account for the spectacular success of herbivores. From the perspective of investigating the potential for other organisms to contribute to the efficiency of production, the findings of this paper and speculation resulting from those findings suggest a limited potential for cross species transfer because advantageous transfers have already been part of successful evolutionary selection.

8.12.1 Marsupials

A critical part of this evaluation was to seek the opinion of one of the leading researchers in marsupial nutritional, Professor Ian Hume, to provide insights on the potential to increase the efficiency of cattle production in the extensive northern grazing system. Professor Hume had a number of valuable perspectives; he noted that in terms of grazing animals, cattle were very efficient fibre digesters. On a comparative basis, the alternate means of processing high fibre diets are reflected in kangaroos, equids and elephants. All of these use relatively rapid rates of transport through the gut and extract the more soluble carbohydrates from the feed and excrete the more fibrous components. The kangaroo is a foregut fermenter, whereas the equids and elephants are hindgut fermenters. The elephant, through size of the tract, has a sufficiently long rate of passage to ensure a relatively greater fibre digestion than equids or kangaroos.

Professor Hume's view was that transfer of organisms from kangaroos to cattle was unlikely to yield positive results because of the very different adaptive approaches to high fibre, lower protein diets. He stressed the extent of the adaptation and the success of the ruminants in grassland systems. This point is also made by Van Soest et al (1995) who note that the bovidae have become the most successful (in terms of genera) and diverse of the ruminant groups. The modern bovid forest browsers represent an evolutionary radiation since the Miocene (Van Soest 1994). Clauss et al (2010) note that foregut fermentation is usually considered to be superior to hindgut fermentation based on observations on digestive efficiency in domestic herbivores, on species diversity today and in the recent fossil records, or prediction from gut models.

A number of others surveyed had come to similar conclusions to Professor Hume regarding the likely success of movement of bacteria from the kangaroo to cattle. All interviewees (with

expertise in this area) particularly noted the extent of adaptation of ruminants to the ecological niche that they inhabit and the success of the ruminant system. Associate Professor Klieve, however, has published on the methanogenesis in kangaroos (Ouwerkerk et al 2009), detailing the quite low emissions in some species, notably the Eastern grey (*Macropus giganteus*). The kangaroos appear to utilise pathways that allow the production of acetate from hydrogen and carbon dioxide; a reductive acetogenesis. However, the extent to which kangaroos rely on, or utilise, reductive acetogenesis is unknown. The potential for reductive acetogenesis to be used to reduce methanogenesis and to potentially improve efficiency of production is estimated to be between 4 to 10% (Joblin 1999, Nollet et al 1997). Reductive acetogenesis is discussed in more detail in Chapter 8, Section 11. Further evidence of the value of investigations in other species was the cloning of cellulases extracted from an anaerobic fungus isolated from a red kangaroo in studies conducted during MLA project TR.043.

8.12.2 Camelids

The camelids are another very successful group of (pseudo) ruminants. The tylopoda consist of the old world camels including the dromedary and Bactrian camel and the South American camelids. Camels have a three compartment stomach, and inhabit the arid and semi-arid zones of northern Australia (Hume 1987) where they represent the only wild populations of the species. Dr Rafat Aljassim at the Gatton Campus of the University of Queensland is researching nutrition of camelids. He provided anecdotal observations that there may be symbiotic performance when camels and cattle are co-grazed, possibly through complementary plant selection, but possibly also through interchange of microbiota. Professor Hume suggested that these may provide a more fruitful group to study than marsupials given the capacity of these to perform on very poor quality feeds and the greater similarity to ruminants.

Clauss et al (2010) speculate that the combination of particle sorting and chewing efficiency differentiates the true ruminants and camelids, and specifically that the particle sorting mechanisms may prevent camelids from achieving the higher feed intakes, metabolic rates, species diversity and geographical spread of the ruminants. For camelids, post gastro-intestinal adaptations are also important. For example, urea recycling is very efficient and camels can decrease water intake and increase the efficiency of urea recycling to reduce losses of water in urine. Further adaptations include a capacity to reduce the dependence of ketogenesis observed in cattle or sheep when underfed (Wensvoort et al 2004).

Professor Van Soest commented that the capacity of camels to succeed in the arid zone reflected their mobility, capacity to selectively graze and the adaptations of plants that are water stressed. Interestingly, plants that are adapted to arid zones have lower lignin content. Camels, that are more selective feeders than cattle, can take advantage of those plants.
Dr Aljassim is studying the bacterial ecosystem of the camel and recently completed a study on lactic acid producing and lactic acid utilising bacteria in the camel. There is a relative paucity of studies on the nutrition of camels.

Camels are a source of racing stock and meat in Australia; the South American camelids provide fibre. Camelids represent a group of animals that are extremely well adapted to arid conditions and poor quality forages. The similarity of camelids to the bovidae, the impressive performance of these on low quality forages, and evidence (albeit weak) of co-grazing benefits suggest reasons to investigate digestive function in these in more detail as part of an integrated program of research into factors that can influence rumen function.

8.12.3 Other bovidae

8.12.3.1 Banteng Cattle (*Bos javanicus*)

Banteng cattle (*Bos javanicus*) or Bali cattle have adapted to the Northern Australian environment and were present as feral populations. The cattle are smaller in body weight than commercial cattle breeds used in the north of Australia.

Personal observation of one of the authors and of others who have worked with banteng cattle in Indonesia, suggests that the animals maintain extremely good body condition despite an adverse nutritional environment. The ability of the banteng to maintain body condition and perform better on poor quality pastures has also been reported by Andrews (1972) and Kirby (1972). The observation may reflect a lower requirement for maintenance associated with a lower mature body weight or may reflect other adaptive mechanisms, such as species differences in voluntary feed intake and utilization of low quality dry season roughages. Field observations of weight change or body condition are insufficiently precise and subject to considerable error in determining the change in empty body mass.

A study of comparative efficiencies of use of poor quality forage concluded that there are few differences between cattle species (Brahman cross, buffalo Banteng and Shorthorn Steers) in their ability to digest and utilize a low quality roughage when comparisons are made between animals of similar liveweight and feed intake (Moran et al 1979). A study of comparative nitrogen metabolism in the same breeds found little evidence of differences in nitrogen conservation in any one species (Norton et al 1979).

We conclude that there are, at present, insufficient data to suggest that there are differences of sufficient magnitude between Banteng cattle and other cattle in metabolism or rumen function to support substantial research in this area.

8.12.3.2 Water Buffalo (*Bubalus bubalis*)

Ford (1977) and Schottler et al (1977) reported that *Bubalus bubalis* cows had higher calving percentages and better overall productivity than *Bos indicus* crossbred cows on tropical native pastures. Moran (1973) also found that buffaloes and Brahman crosses grew equally well over 15 months on improved tropical pastures and at twice the rate of bantengs and Shorthorns. However, during the dry season, liveweight losses were less in the Bantengs and Buffaloes than in the Shorthorns or Brahmans. The buffalo are well adapted to high fibre, relatively unselected diets such as those present in parts of northern Australia. These have large body mass and a large rumen. Siebert and Macfarlane (1969) found that in the wet tropics, buffalo used more water than Shorthorns, while the *B. indicus* types turned over significantly less water on the same pasture. The range inhabited by the feral water buffalo in Australia reflected the strong affinity of the species to wet tropical areas.

Again, quantitative data on buffalo are sparse. Kawashima et al (2006) comment that fibre digestion is more efficient in water buffalo than cattle (Devendar 1992), but this should be regarded as tentative since it was based on relatively few studies. The text 'The Water Buffalo' (Anon 1984) provides the following unreferenced commentary "Many have reported that buffaloes digest feeds more efficiently than do cattle, particularly when feeds are of poor quality and are high in cellulose. One trial revealed that the digestibility of wheat straw cellulose was 24.3 percent for cattle and 30.7 percent for buffalo. The figures for berseem (*Trifolium alexandrinum*) cellulose were 34.6 percent for cattle and 52.2 percent for buffalo. In another trial the digestion of straw fiber was 64.7 percent in cattle, 79.8 percent in buffalo."

However, neither Kawashima et al (2006) nor studies from the Armidale group cited above (Moran et al 1979; Norton et al 1979) determined substantial differences in digestion of fibre or

nitrogen metabolism of the water or swamp buffalo compared to cattle. Moran (1983) later found that there was no difference between buffaloes and Brahmans in their ability to digest dietary nitrogen. However, the buffaloes had lower rates of excretion of urinary nitrogen per unit increase in apparently digested nitrogen, and at the same intake of apparently digested nitrogen had a higher nitrogen balance. Dietary metabolisable energy content did not affect the utilization of digested nitrogen (Moran 1983).

We conclude that there are, at present, insufficient data to suggest that there are differences of sufficient magnitude to other cattle in metabolism or rumen function of the swamp buffalo to support substantial research into these.

8.12.3.3 African ruminants

A series of studies has investigated the microbiology and biology of African ruminants (Odenyo et al 1999; Odenyo et al 2001; Ephraim et al 2005; Dehority and Odenyo 2003). In these studies, there was a focus on the capacity of African ruminants to hydrolyse tannins. Species investigated included the dikdik (*Madoqua guentheri*), camel (*Camelus dromedaries*), Grant's gazelle (*Gazella granti*), zebra (*Equus quagga*) and hartebeest (*Alcelaphus buselaphus*), as well as sheep and goats. Bacteria isolated could completely degrade tannic acid, gallic acid and chestnut tannin, confirming the potential for bacterial detoxification of plant toxins similar to the action of *Synergistes jonesii* on mimosine in Leucaena. Previously, studies had been conducted to characterise the tannin tolerant bacterial isolate from a range of East African (Odenyo et al 2001) and European, North and South American ruminants (Nelson et al 1998). Tannin tolerant species identified in the studies included *Selenomonas*, *Butyrivibrio fibrisolvens* and *Streptococcus* species, including some closely related to *S. bovis*. Subsequently, bacterial isolates identified from different species were tested in regard to the potential to degrade non protein amino acids found in *Acacia angustissima*. Of the two major non-protein amino acids, 4-N-acetyl,-2,4-diaminobutyric acid was substantially degraded by a number of species including adapted sheep, whereas diaminobutyric acid was only substantially degraded by isolates from an adapted sheep, a Kenyan goat and Thompson's gazelle.

McSweeney et al (2005) and Ephraim et al (2007) further explored sources and effectiveness of organisms suitable to detoxify these compounds in wild and domestic animals. Saarisalo et al (1999) demonstrated the efficacy of inoculation with ruminal contents from an adapted sheep in maintaining health of sheep fed on *Acacia angustissima* and the benefits of polyethylene glycol feeding for the sheep fed *Acacia angustissima* in increasing feed intake.

Dehority and Odenyo (2003) found in a comparative study of protozoa in African ruminants that the concentrate selectors had the highest concentrations of protozoa among the species studied and that, at times, the Thompson's and Grant's gazelle provided samples that were free of protozoa. These findings suggest that the protozoa may play an important role in moderating the rate at which more rapidly degradable carbohydrates become available to the ruminal bacteria.

8.12.4 Conclusions

Interestingly, Van Soest (1994) notes that in regard to the claims about 'amazing efficiencies' of overlooked species including water buffalo and bison, many of the claims cannot be supported by rational biochemistry and kinetics. He states "There are no magic enzymes and no magic bacteria that can exceed physicochemical limitations". The constraints of substrate composition on the rate and extent of biodegradation are universal for all anaerobic systems. Van Soest (1994) further notes that the microbial population is determined first by the substrate and secondarily by the turnover capacity of the fermentative compartment. He reinforced these opinions in the discussion of these areas in our interview. These comments were echoed in independent discussions with Dr Hans Jung of the USDA Forage Laboratory, who noted the same physicochemical limitations when interviewed. These are powerful perspectives that

determine limitations to the use of other species, bacterial transfer or gene insertion based on the chemistry of forages and the biochemistry of fermentation.

Notwithstanding the strength of argument presented by Van Soest (1994), there are examples of successful use of bacteria and gene insertion to indicate the potential merit of these directions (Chapter 8, Section 3). Simply, however, the perspectives from Van Soest (1994) helped to frame a realistic context for assessing new developments and provide realistic constraints to the potential benefits of new technologies.

Overall, the potential to identify organisms from a number of fermentative ecosystems, including other species, which may be beneficial will increase. The examples of successful transfer to date are limited to situations where a relatively discreet substrate has become available or is present eg *Synergistes jonesii* and mimosine. The potential to manipulate pathways that are inherently more important will be more challenging, because these are central to the success of the bovidae.

9 Survey of researchers, professionals and suppliers to the northern cattle industry

Two surveys were conducted to evaluate the methods and products currently available to influence rumen function and those that may be developed in the future to increase the production efficiency of cattle in northern Australia. The outcomes of these assessments were used to evaluate research directions and serve the broader purpose of assisting beef producers, nutritionists, consultants and farm advisers in evaluating methodologies available for improving production in Northern Australia.

Two questionnaires were prepared by **SBS*cibus*** and **Joan Lloyd Consulting** to:

i. obtain the expert opinions on beef cattle nutrition, modifying cattle performance, role of supplements and new technologies to improve cattle performance, and
ii. collect information on supplement and modifier use, efficacy, delivery systems and transport.

Draft questionnaires were initially developed and evaluated by the investigators to limit ambiguity of questions. The survey questionnaires are included in Appendix III.

In May 2010, a questionnaire was sent to 27 research and extension personnel working in the fields of rumen microbiology, ruminant nutrition, gene technology and agronomy. The questionnaire was completed during a subsequent interview with the participant or prior to it. Agreement was also sought for a second interview, the aim of which was to discuss innovations proposed by others and to obtain an opinion on these. Interviewees were asked to describe the current conditions and management of cattle in north of Australia and provide information and opinions on the production system. The questionnaire was organised in several sections including:

i. current supplements
ii. delivery methods
iii. estimates on the costs implementation, benefits, efficacy and adoption rate
iv. new technologies.

Part of the intent of each interview was to allow interviewees to explore areas of rumen modification and aspects of the production system that they believed would be important to improving production efficiency.

In July 2010, the industry group (Appendix III) were initially contacted to determine their willingness to participate in the survey. Subsequent to their agreement, a questionnaire was sent to 22 industry experts, including wholesalers, resellers, manufacturers, State Government officers, University extension officers and rural stores. After receiving the completed questionnaires from 10 interviewees, a reminder email was sent to the remaining 12 people/organisations who had indicated a willingness to participate. No further responses were received. Nine of the participants provided the completed questionnaires by email and one was interviewed by phone and the questionnaire was completed during the interview. The participants were given the opportunity for follow-up interviews following review of their initial responses.

9.1 Survey I- Expert opinions on rumen modifiers

A total of 15 research and advisory personnel responded to the questionnaire (15 out of 27: 56%). The information, comments and opinions are summarised in Tables 3 to 6 (Appendix III). The participants were asked to rank their opinions on the overall success of each product, and the reason for giving that ranking. As part of this survey, the participants were asked to rank the availability, cost, efficacy, benefits and adoption rate of different supplements. They were asked to comment on the potential application of new technologies. The ranking of different product categories is list in Table 39.

The rankings were transformed using a formula that assigned a value of "1" to rankings of 1, a value of "2" to rankings of 2, and so on. The values were tallied and the ranks compared in terms of the overall ranking of benefits and adaptation rate. The highest rankings were for macro-minerals, protein/NPN and micro-minerals, respectively and lowest ranking was given for probiotics, yeasts and antibiotics.

Table 39. Ranking of availability cost of implementation, efficacy, benefits, adoption rates and the overall ranking of benefits and adoption rates of the modifiers or supplements. The overall ranking was provided, considering the level of current knowledge, technology required for implementation, fit with current nutrition management practices, level of investment required, return on that investment in benefits to the industry (one is low and nine is high)

Supplements	Ranks					Overall ranking of benefits and adoption rate
	Availability	Cost of implementation	Efficacy	Benefits	Adoption rate	
Ionophores	7	4	4	7	6	6
Antibiotics	2	1	1	4	2	2
Bambermycin	5	2	3	5	5	3
Yeasts	1	7	2	3	3	4
Probiotics	4	8	1	2	4	1
Micro-minerals	3	3	4	6	7	7
Macro-minerals	9	6	6	9	8	9
Protein & NPN	6	5	5	8	9	8
Others	-	3	2	1	1	5

9.2 Survey II- Industry information

Results of the completed questionnaires from 10 participants (10 out of 22; 45%) were compiled and are presented. A similar scoring system, as outlined for survey 1, was also applied for this survey. Briefly, the rankings were transformed using a formula that assigned a value of "1" to rankings of 1, a value of "2" to rankings of 2, and so on. The participants in this survey were industry experts, wholesalers, resellers, manufacturers and State Government officers who covered most of the north Australian regions (Table 40). The survey participants provided

services to 16.2% of farms in north of Northern Territory, 10.8% to 16.2% of regions in QLD and only 5.4% of Northern Western Australia.

Table 40. **Regions of the Northern Beef Industry where the participants represent or service**

Regions	SWQ	CCQ	CHQ	CWQ	NQ	NWQ	NNT	NWA	Others
Percentage covered	10.8%	10.8%	10.8%	13.5%	16.2%	13.5%	16.2%	5.4%	2.7%

The estimated percentages of grazing properties using supplements and the class of supplemented cattle are presented in Table 41. According to the participants of this survey, micro- and macro-minerals, NPN and protein meals are used by more than 90% of grazing properties in north Australia. These are followed in prevalence of use by ionophores and energy sources. These results indicate that ionophores are mainly used for calves and weaners. A view was held by some industry experts that there has been a very large increase in monensin use in loose licks over the last 5 years. In the past, monensin was fed to the cattle with molasses, grain/pellets in weaner loose licks, however, today the use of monensin in loose licks has increased by more than 500% over 5 years. Due to the regulatory obstacles, monensin has not been used in blocks. Because to small number of participants in this survey, some of these results should be interpreted with caution.

Table 41. **Estimated percentage of grazing beef producers in northern Australia who are currently using supplements and rumen modifiers**

Supplements/ modifiers	Percent of properties (%)	Class of stock where products used (%) Median (min and max)				
		Bulls	Breeders	Heifers	Steers & bullocks	Calves & weaners
Protein meal	90.0 (10.0 - 100.0)	8.80 (2.5 - 15.0)	50.0 (5.0–50.0)	25.0 (10.0–30.0)	10.0 (2.50–20.0)	42.5 (10.0–90.0)
Non-protein nitrogen	95.0 (30.0 - 98.0)	20 (3.0 - 30.0)	50.0 (20.0–80.0)	17.5 (2.0–25.0)	10.0 (3.0–20.0)	12.5 (8.0–20.0)
Energy source	20.0 (10.0 - 90.0)	12.5 (5.0 - 20.0)	35.0 (5.0–80.0)	25.0 (20.0–25.0)	25.0 (10.0–25.0)	25.0 (15.0–30.0)
Ionophores	40.0 (3.0 - 90.0)	12.5 (5.0 - 20.0)	10.0 (5.0–20.0)	15.0 (5.0–20.0)	20.0 (5.0–25.0)	75.0 (25.0–00.0)
Antibiotics	5.0 (1.0 - 10.0)	5.0	-	20.0	70.0	5.0
Bambermycin	2.0 (1.0 - 3.0)	-	-	25.0	-	62.5 (25.0–00.0)
Macrominerals	96.5 (15.0 - 100.0)	5.0 (5.0 - 2.0)	40.0 (20.0–50.0)	20.0 (15.0–25.0)	5.0 (5.0–20.0)	20.0 (5.0–30.0)
Microminerals	90.0 (5.0 - 100.0)	5.0 (1.0 - 20.0)	35.0 (1.0–60.0)	20.0	5.0 (5.0–20.0)	20.0 (20.0–30.0)
Probiotic	1	-	-	-	-	95.0
Yeast	1	-	-	-	-	-
Others	1	-	-	-	-	-

Estimated percentages of feedlot properties using supplements, and the age of cattle are presented in Table 42. The majority of feedlot properties use protein, energy, minerals and ionophores supplements in the diet of weaners and finishers diets. These results suggest that the use of antibiotics, probiotics and yeasts is not common in feedlot properties in northern Australia.

Table 42. Estimated percentage of feedlot beef producers in northern Australia who are currently using supplements and rumen modifiers

Supplements/modifiers	Percent of properties (%)	Class of stock where products used- estimated percentage used Median (min and max)	
		Weaners < 12m	Weaners > 12m
Protein meal	80.0 (50.0 - 100.0)	65.0 (50.0–80.0)	50.0 (35.0–100.0)
Non-protein nitrogen	90.0 (50.0 - 100.0)	65.0 (50.0–80.0)	50.0 (3.0–80.0)

Energy source	90.0 (80.0 -100.0)	55.0 (30.0–80.0)	80.0 (70.0–80.0)
Ionophores	90.0 (80.0 -100.0)	55.0 (30.0–80.0)	80.0 (70.0–100.0)
Antibiotics	20.0 (5.0 - 50.0)	20.0	50.0 (20.0–80.0)
Bambermycin	10.0	50.0	50.0
Macrominerals	95.0 (75.0 - 100.0)	75.0	87.5 (75.0–100.0)
Microminerals	92.5 (75.0 - 100.0)	75.0	87.5 (75.0–00.0)
Probiotic	5.0	50.0	50.0
Yeast	7.5 (5.0 - 10.0)	30.0 (10.0–50.0)	30.0 (10.0–50.0)

According to those surveyed, cattle producers predominantly seek nutritional advice from feed manufacturers (sale representatives) and DPI field officers, followed by animal health advisors, nutritionists and fellow farmers (Figure 19).

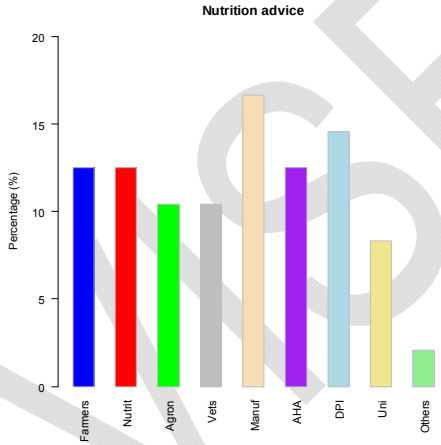


Figure 19. Advice provided to cattle producers in north of Australia on the use of rumen modifiers/feed supplements
(Nutrit= Nutritionists; Agron= Agronomists; Vets= Veterinarians; Manuf= Manufacturers; AHA= Animal Health Advisors; DIP= Department of Primary Officers; Uni= Universities)

When the participants of this survey were asked which class of cattle will most likely to benefit from supplementation, bulls, calves and weaners had the highest ranking, followed by breeders, and then heifers and steers (Figure 20).

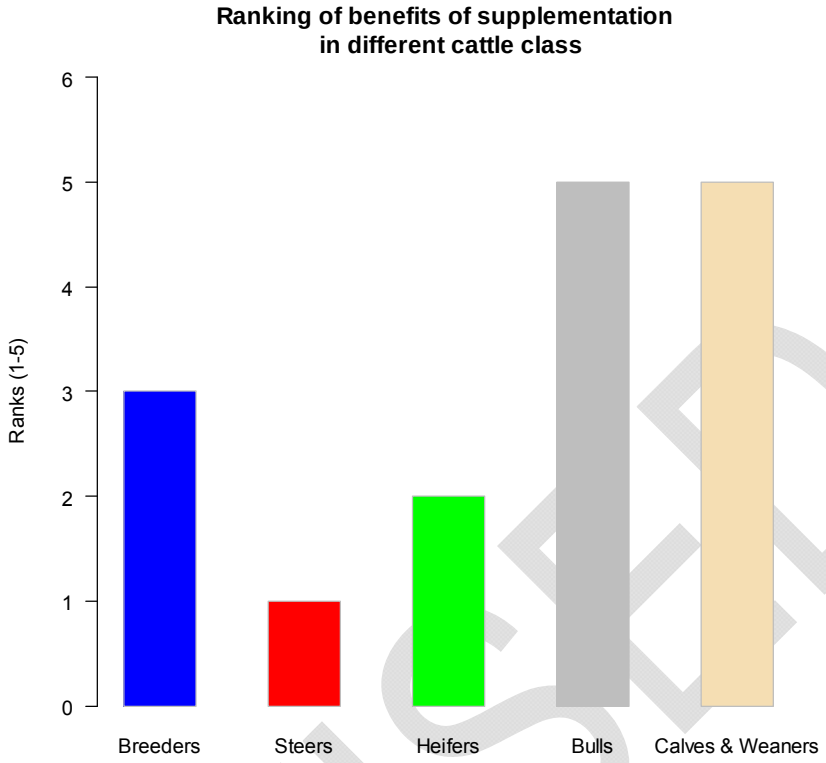


Figure 20. Ranking of classes of cattle which benefit more from supplementation based on information and opinions of participants in this survey (1 is low and 5 is high)

The main reason for supplementation of grazing cattle was to improve the weight gain or reduce the amount of weight loss during the dry season (Figure 21). These were followed by improving the survival and fertility rates of cattle, respectively.

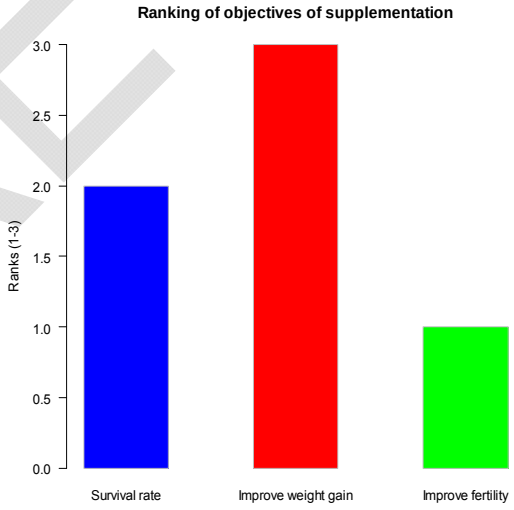
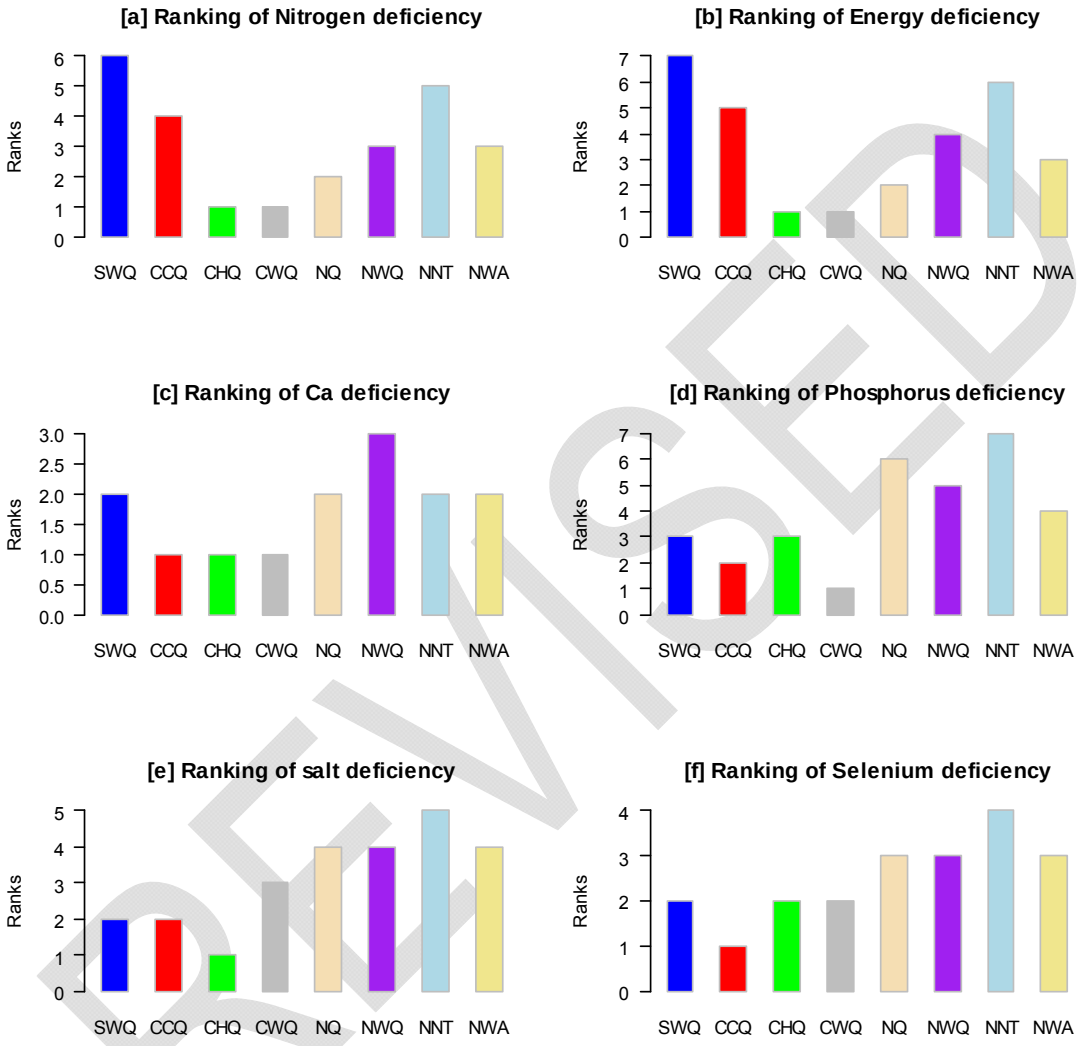


Figure 21. Reasons for the use of feed additives and supplements by producers in northern Australian regions (one is 1 and 3 is high)

The participants in this survey believed that most common deficiencies in nutrients were found in northern QLD, north-west QLD, the north of the Northern Territory and north of Western Australian (Figures 22a-k). Deficiencies of some nutrients are also suggested in other regions such as south-west QLD and central coast of QLD. It appears that the opinions were based on the nature of purchased supplements by cattle producers in each region. The results of nutrient deficiencies that are provided by the industry group need to be validated.



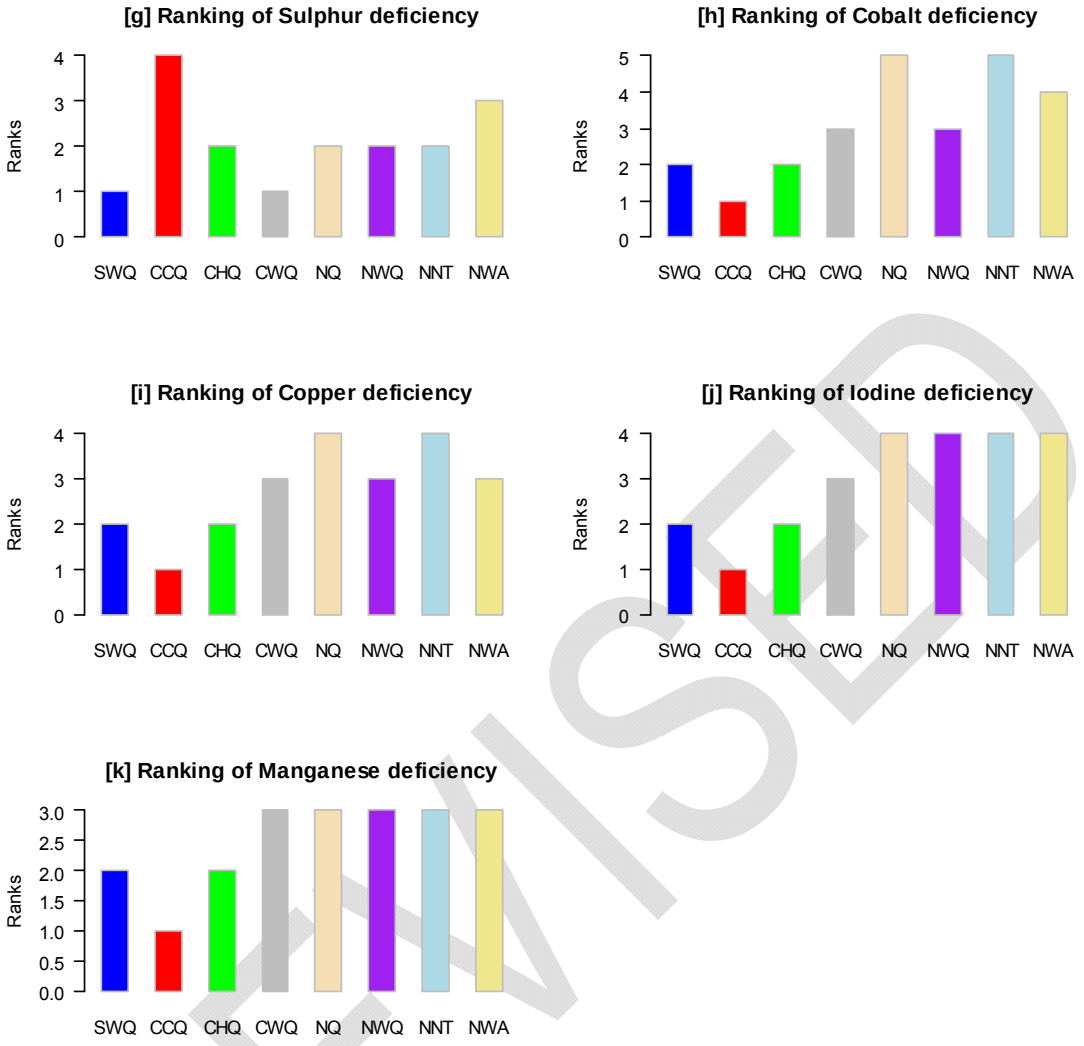


Figure 22a-k. Nutrient deficiencies affecting cattle performance in different regions of north Australia (1 being no deficiency and 7 very deficient)
(SWQ= South West QLD; CCQ= Central Coast QLD; CHQ= Central Highland QLD; CWQ= Central West QLD; NQ= Northern QLD; North West QLD; NNT= North of Northern Territory; NWA= North of Western Australia)

A list of commercial supplements that are currently available in the market and purchased by cattle producers is provided in Appendix IV.

The results of this survey suggest that loose mixes have the highest adoption rate and cost-effectiveness, followed by blocks which had the highest feasibility rating and second highest adoption rate and cost-effectiveness (Figure 23).

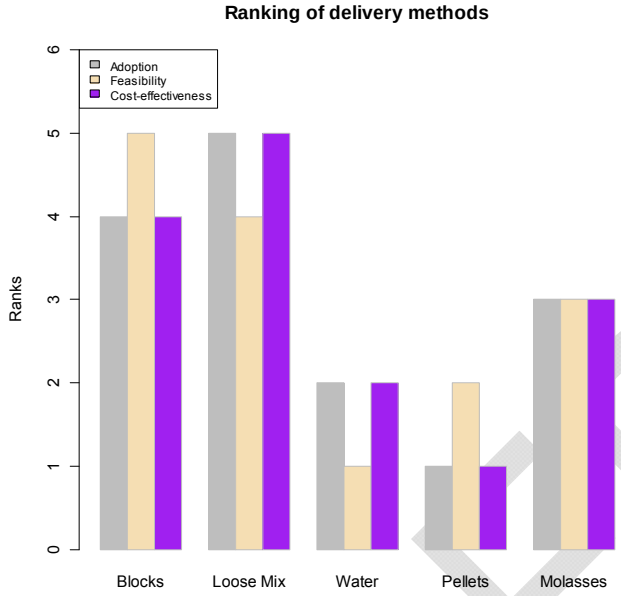


Figure 23. Adoption rate, feasibility and cost-effectiveness of delivery methods used by cattle producers in north Australia (1 is low and 5 is high)

This survey indicates that cattle producers in the north mainly use their own vehicles for the transportation of supplements (Figure 24). Delivery by manufacturers and wholesalers was also common.

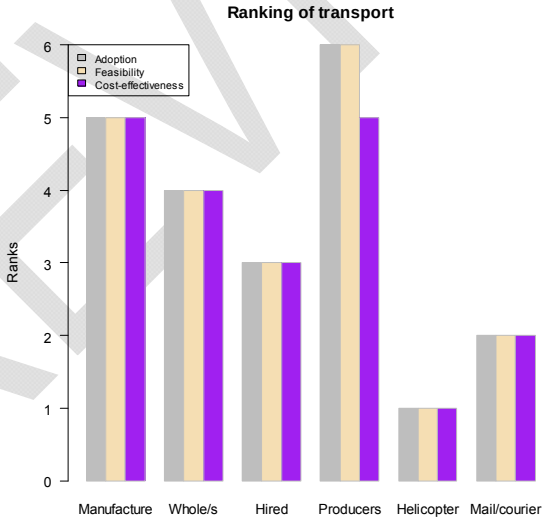


Figure 24. Adoption rate, feasibility and cost-effectiveness of transport methods for delivery of supplements to the producers (1 is low and 6 is high)

Those surveyed consider that supplementation of NPN is more beneficial to productivity of cattle in North Australia than the use of other supplements (Figure 25). Micro-minerals and protein meals also ranked highly. These results are consistent with the rankings provided by the research and advisory community in Survey 1.

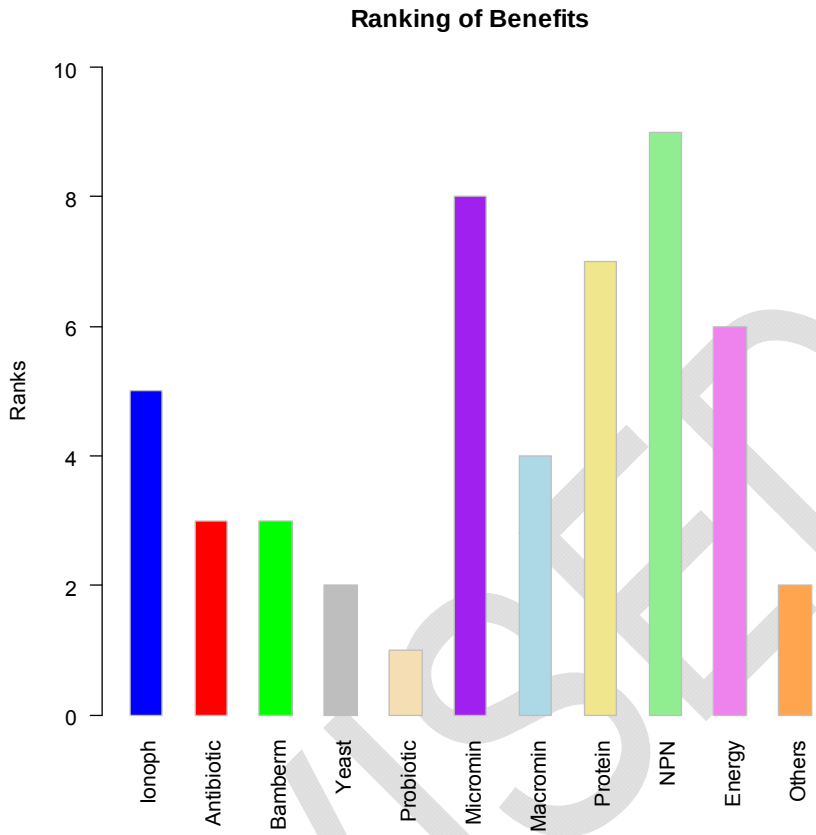


Figure 25. Potential benefits of supplements and rumen modifiers purchased by cattle producers in north Australia (1 is low and 10 is high)
(Ionoph= Ionophores; Bamberm= Bambermycin; Micromin= Micro-minerals; Macromin= Macro-minerals)

The ranking of the obstacles, including costs, transport, labour, knowledge of effects and availability, on the uptake of supplements and rumen modifications by cattle producers in north Australia are presented in Figures 26a-e. The results of this survey suggest that cost of supplements, transport and labour are most likely to be the main obstacles to use of NPN, energy and protein sources. The lack of knowledge of the effect is the main obstacle for the uptake of ionophores, macro- and micro-minerals and probiotics. Availability of antibiotic and energy sources was the major obstacle to the uptake of these.

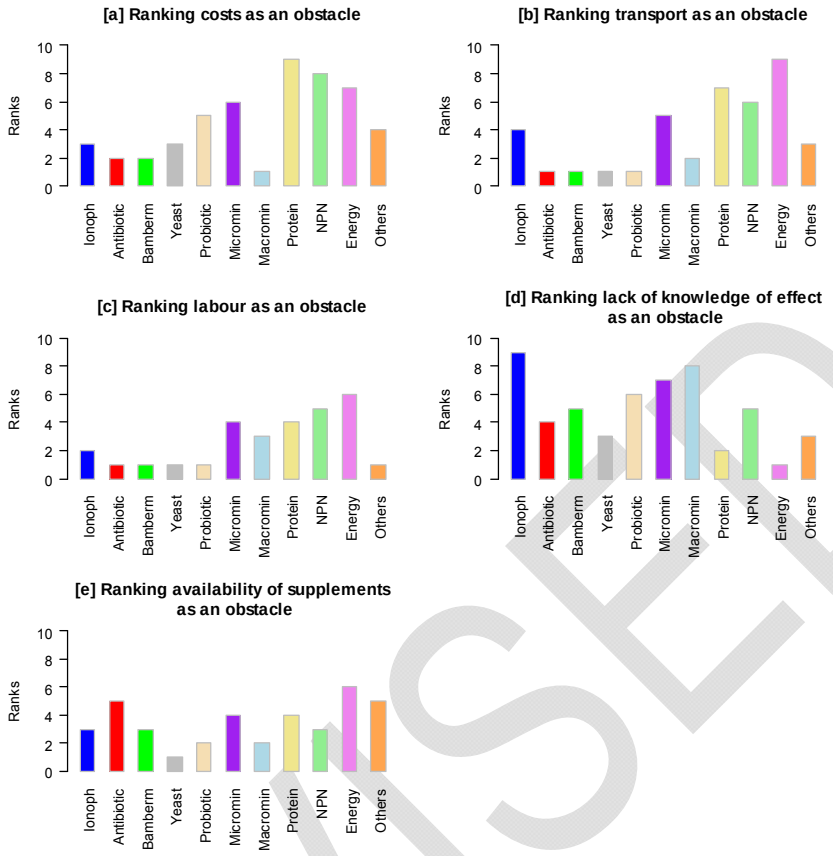


Figure 26a-e. **Obstacles of uptake of feed supplements and rumen modifications by cattle producers in north Australia (1is low and 10 is high).**
(Ionoph= Ionophores; Bamberm= Bambermycin; Micromin= Micro-minerals; Macromin= Macro-minerals)

9.2.1 Improvements suggested by survey participants to enhance the sale/purchase of the supplements in northern Australia

The industry survey also included space for participants to provide suggestions to enhance the sale and/or purchase of supplements in northern Australia. The suggestions received are summarised below:

i. Adoption of wet season feeding is a problem however this is being addressed hopefully via MLA funded research.
ii. A product to improve digestibility of Mulga.
iii. Increase farmer awareness of the value of supplements as strategic management tools.
iv. Improve the ability of farmers to accurately record and assess the cost effectiveness and appropriateness of alternative supplements and strategies in a particular situation.
v. Increase the awareness of farmer's of the value their own labour and expertise in order to accept that time he spends mixing feed or driving a truck is not time spent managing his business and managing his stock to best advantage.
vi. Producers should be made aware that ionophores in loose mixes will give better growth rates.

10 Economic modelling of supplements in northern Australia

It was critical to explore the productivity of grazing and feedlot cattle in northern Australia at different stages of growth in order to develop an economic model that reflects liveweight gain or losses in different classes of cattle under various environmental conditions. We constructed a stochastic model to predict the liveweight gain of a selected number of supplements that are currently used in northern Australia, to predict the associated economic benefits of these products for each stage and different classes of cattle, separately.

This economic model has the potential to estimate the NPV of the following:

- Grazing and lot-fed cattle
- Native and improve pastures
- Dry and wet seasons
- Different classes of cattle (breeders, steers, weaners)
- Mortality rate (%)
- Pregnancy rate (%)
- A number of supplements
- Transport of supplements (distance)

The results of this modelling provide a ranking tool to estimate the benefits of supplements in northern Australia. This tool is suitable to use to rank new interventions against existing technologies.

Ultimately a dynamic model will be required to more fully value interventions, in order to handle the complexity of production systems in northern Australia and account for the changes in herd dynamics that result from increases in growth rates of cattle. Figure 27 provides a conceptual model of the herd structures. A dynamic model would be developed and refined to capture the impacts of additional growth on stocking rate in subsequent years of breeders, replacements and grower cattle. It was not feasible to construct a dynamic economic model to predict all the financial benefit of supplements or interventions, because

- There was a lack of sufficient quantitative data on liveweight gain responses for each stage of production to validate the model,
- challenges exist with modelling compensatory gain as critical understandings of some aspects of this are lacking,
- Capturing the effects of an intervention on time to turn-off and herd structure would be valuable, however, there would still be many uncaptured benefits including interactions with stocking rates and interactive effects of intervention strategies on nutrient transfer, pasture growth and utilisation.
- The complex nature of the dynamic model suggested that it would be premature to develop such a model.

Therefore, outcomes are limited to a benefit ranking rather than a true cost-benefit analysis.

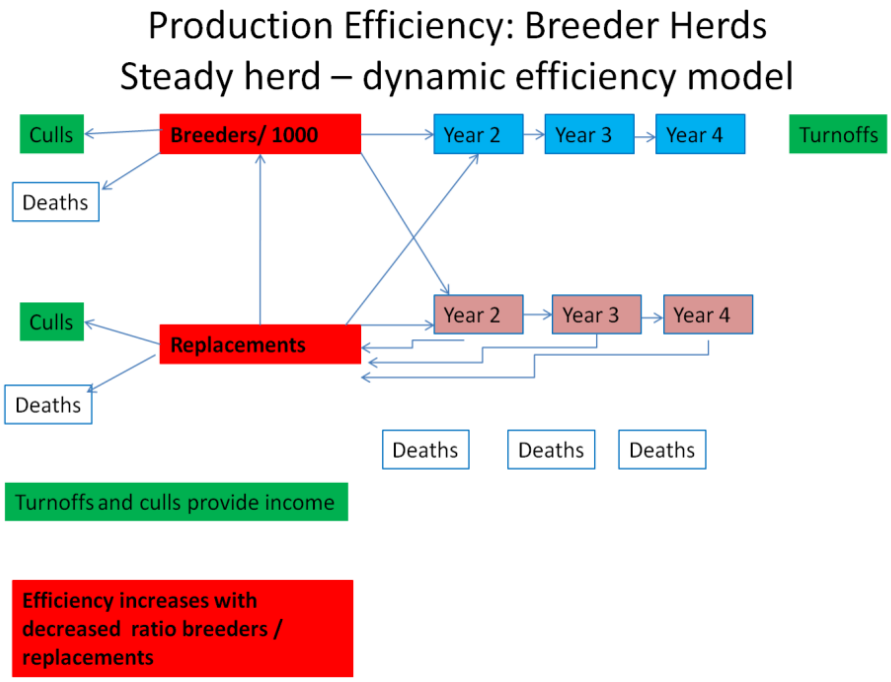


Figure 27. Dynamic efficiency model to predict the productivity of cattle in northern Australia

The objective, therefore, of the economic model developed was to quantify the liveweight gain and ranges (95% confidence intervals) of grazing cattle in northern Australia and rank the economic benefits of different supplementation or intervention strategies. The spreadsheet model that was created captures components of liveweight gains and losses in classes of cattle during dry and wet season of cattle.

A probability distribution of the costs accounts for the stochastic nature of beef production in the north. Further, sensitivity analysis was conducted to assess the relative importance of various cost components on total estimates of growing costs. This tool will be valuable in identifying the most likely interventions to provide benefits to producers based on a combination of the physical characteristics of products and the responses of cattle to the interventions. Our estimates of costs associated with grazing and feedlot beef cattle were derived from the available data on various classes of cattle and under very different conditions (Chapter 5) and should lead to relatively robust ranks. The liveweight gains/losses of growing beef cattle were assessed in a partial budget spreadsheet developed by SBScibus using the data on production and productivity losses.

Testing the model- The model was used to estimate the effect of three supplements and rumen modifiers, NPN, CSM and monensin on liveweight gain during dry and wet seasons, annual mortality rate and annual pregnancy rate of breeder cattle. These three interventions were used to test the model on the basis that these were commonly used and represented three very different classes of product. All have considerable data available to allow an estimation of effect on the growth of cattle.

- The NPN is very well adopted, is of low molecular weight and is readily transportable
- The CSM is of higher weight, lower bulk density, less geographically available and provides greater weight gains. There are well documented responses in fertility to the supply of this.
- Monensin is also widely adopted, especially in feedlots and may have increased adoption if made more available in lick blocks, hence an increased adoption rate profile in the model that may mimic that of novel interventions.

10.1 CPM model

Modelling Approach

The intention of using a modelling approach was to develop a means of evaluating the potential for new technologies to change the efficiency of production, as reflected by effects on cattle grazing northern pastures. We considered that new technologies would provide

- Substrates for production – responses to these should be predictable with a suitable model
- Changes in fibre digestion or rates of passage and these effects should be predictable with a suitable model
- Or changes to the efficiency of use of nitrogen fractions and these should be predictable with a suitable model.

The chosen nutrition model would provide estimates of effect on weight gain of the different classes of cattle of new interventions. The weight gain estimates would be used as input to the economic model.

After discussions with John Black and Professor Bill Chalupa, it was considered that the model CPM nutritional model would provide satisfactory basis for the modelling involved. The CPM model is a derivation of the Cornell Net Carbohydrate and Protein System (CNCPS) nutritional model. This model was chosen from the basis of:-

- Extensive validation of the model across a wide range of nutritional systems.
- The extensive program of development and validation under gone with the model.
- Familiarity to the user (IJL)

The following principles were applied in conducting model;

- The modelling was undertaken on an assumed basis that micro-nutrients, specifically minerals and vitamin co-factors were not limiting to performance of given intervention.
- We tested assumptions in regard to the efficiency of microbial nitrogen production and found that the model predicted this reasonably well. Corrections were not made to the predictions of weight gained by the model, on this basis.
- We found a systematic underestimation of dry matter intake potential based on the use of the eNDF cap and allowed that animals would eat a higher percentage of eNDF than predicted by the model.

The concepts of supplementation strategies or modification strategies must be considered in terms of rate limiting nutrients and availability of co-factor required to provide for efficient rumen function. Simply, the efficiency with which any manipulation or substrate is used will be governed by the most limiting factor that controls metabolism.

In the modelling conducted, we ignored the effects of micronutrients. We considered that the critical area to test was that of energy and protein metabolism and the interactions of these. The modelling was conducted on this basis, and ruminal modifications were considered in terms of

- the amount that they might increase the efficiency of microbial protein production
- the impact modifications of fibre digestion might have.

The goal of the modelling process was to use studies examining ruminal manipulations, specifically inclusions of protein meals or non-protein nitrogen and existing rumen modifiers for which there is good data against a manipulation that may be able to improve the efficiency of production on microbial protein from the existing sources of nitrogen in the rumen.

10.1.1 Methods

Data from two experiments (Poppi and Quigley 2009; experiment 4 and experiment 5) were used to provide a validation for modelling methods that may be used to evaluate ruminal manipulations in cattle. Data from experiment 4 (Poppi and Quigley 2009) were used to examine responses of the CPM model in comparison to data obtained from the experiment in which dry matter intakes and efficiencies and amounts of microbial protein produced were reported for diets based on Speargrass, Mitchell grass, Pangola grass and ryegrass. The data from experiment 5 (Poppi and Quigley 2009) provided liveweight gain responses to cottonseed meal and to a urea and ammonium sulphate mixture. These were also tested against estimates provided by the model.

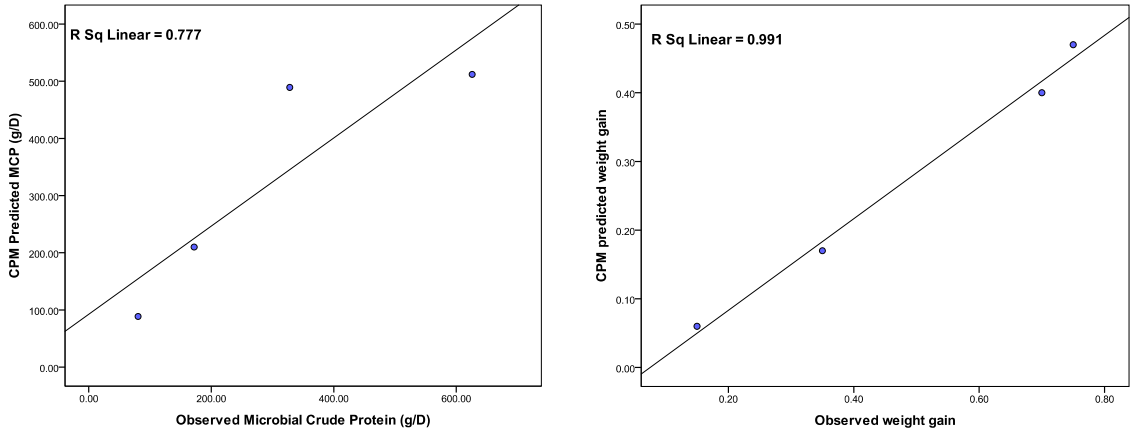
Data on the liveweight of the cattle, environmental conditions as reported or estimated, target weight gains (based on the upper responses observed in the studies of Poppi and Quigley 2009) and feed analysis details were entered. There were adequate data provided on the nutrient composition of the feeds, however, these lacked some detail needed for the model and estimates for these data were provided using detailed data obtained from field samples of these or similar grasses, especially ones obtained from northern Australia that included samples of Buffel grass, Mitchell grass, Flinders grass and Mitchell grass hay and mixed grass containing Kangaroo grass. These samples were obtained in the late dry period (September 2010).

10.1.2 Findings

There was a systematic underestimation of dry matter intake from the model that was evident in both studies. While feed intake was putatively capped by the effective NDF content of the hays used, cattle ate well above the caps. The increase in fibre intake observed in the studies was substantially higher (by approximately 50%) than limits to fibre intake predicted from CPM.

The CPM model was corrected to allow for additional dry matter intake that was observed in study 4 for cattle on Mitchell grass hay fed cottonseed meal. Once this correction was made, CPM predicted and observed microbial crude protein production were similar (R^2 = 0.77, P = 0.1; Figure 28 left). However, the amount of microbial crude protein produced per kg of organic matter estimated from the model did not match the observed results well. The few data available for which these comparisons are made suggest these results should be treated with some caution. The predictions of liveweight gain made with CPM using the cottonseed meal or urea and ammonium sulphate data from experiment 5 were very accurate (R^2 = 0.99, P = 0.04; Figure

28 right; R^2 = 0.91, P = 0.06; Figure xx) once differences in the observed vs. the predicted intake were accounted for and matched to the weight gain of the control group.



Figures 28. Results of CPM modelling of microbial crude protein production and weight gain predicted from the model versus observed results from Poppi and Quigley (2009)

10.1.3 Conclusions and discussion

These data, although limited, suggest that the CPM model acted effectively to model responses on an incremental basis. However, the modelling also showed marked differences in responses of cattle fed on these hays compared to feeding standards. The latter responses are important to understand. These findings were made completely independently of the findings of McLennan (2005), that were subsequently identified and sourced, and who similarly concluded that the CNCPS model (of which CPM is a derivation) acted satisfactorily once DMI was known, but did not accurately predict DMI. It is notable that McLennan (2005) used a different and more extensive database for the validation process, but the conclusions are similar to this study.

The ability of cattle on poor quality pastures to utilize protein with a remarkable efficiency has been noted for some time (van Es 1980: MacRae and Reeds, 1980; ARC 1980; Poppi and McLennan 1995) and were the subject of considerable research from the Armidale group (Leng, Nolan and others) in the 1970-1980's. However, the modelling exercise conducted also indicates a very substantial adaptation also in dry matter intake, probably driven largely by differences in rates of passage or fibre degradation for cattle. This increase in dry matter intake over feeding standards is strongly supported by the weight gain and response to supplement data on industry performance presented in Chapters 4 and 5 and by studies in which the dry matter intake of the dried tropical forages was reported (McLennan 2002; Poppi and Quigley 2009) and in the study of McLennan (2005). We consider that understanding the capacity of animals grazing or ingesting very high fibre, low energy and protein diets to increase appetite is critical to identifying the optimal means of increasing performance in the northern beef grazing industry.

This finding is an important aspect of the rationale for the major project proposed in this review.

10.2 Cost of transportation of supplements and live cattle

In order to develop a model to evaluate the likely impact of improved rumen function on returns to the northern beef industry, it was recognised that a key vulnerability of the industry is the cost of transport. This factor affects both input costs and costs of transport of cattle to point of sale. For large properties and northern beef enterprises it can be calculated that the costs of fuel, oils and grease are approximately 8 to 10% of income (ABARE 2010) and that handling and marketing cost a further 3 to 5% of income. It is unclear how much of the 5 to 10% of income

expended on forage costs could be attributed to fuel and transport as individual properties will vary greatly in this regard. Results from the survey of feed suppliers and industry specialists showed that a wide variety of transport systems were used to deliver feeds. Observation and results of the survey also show that low bulk density products are widely used in northern Australia including molasses products and whole cottonseed.

In terms of attempting to value ruminal inputs, technologies that are early in the development process may be less valuable, if these are supplements rather than small molecular weight modifiers because of higher transport costs. It is possible that transport costs may not vary greatly over the short term and, therefore, may impinge less on the uptake of new technologies that are already available compared to the potential to influence uptake of technologies with similar transport profiles in the future.

Assessments of future costs of transport have been made (Anon, 2008; Graham et al 2008). There are several areas of critical decision making by government that will also influence the cost of transport including the establishment of a carbon tax and the possibility of support for bio-fuels (Quirke et al 2008). Transport costs may increase relatively rapidly under the imposition of a carbon tax (Graham et al 2008), however, the extent to which such taxes would be applied to agricultural inputs remains to be determined.

Graham et al (2008) modelled the impacts of changes in oil availability and pricing using partial equilibrium model of the Australian energy sector (CSIRO's Energy Sector Model). The model included a detailed transport sector representation and was co-developed by CSIRO and the Australian Bureau of Agricultural and Resource Economics (ABARE). The model was developed from 3 assumption positions of how conditions in the international oil market might evolve. The modelling used international projections from Energy Information Administration (EIA; 2007, 2008a,b), that provide a short term oil price outlook (EIA, 2008a) and projections to 2030 (EIA; 2007, 2008b).

- For the first scenario it was assumed that after peaking at US$100/bbl in 2008, oil prices of around US$60 to US$70 will be maintained for the next several decades.
- A second scenario is that the oil price will recover slightly from the high levels of 2008, but steadily increase. These two scenarios rely on new oil resources, technology and processes to access known oil resources at lower cost.
- A third scenario assumed a near term peak in world oil production. The market response to this scenario will depend on how quickly alternative fuels and vehicles become available in that event, and how quickly the availability of oil-based fuel declines (Graham et al 2008).

The latter concepts were the subject of the Australian Senate Enquiry (Anon, 2008) and Quirke et al (2008). Review of the Senate Enquiry Report suggests that there is little alternative for most producers other than road transport (Anon, 2008). A marked increase in costs of transport may trigger increased production of bio-fuels, but the review of Quirke et al (2008) and the Senate Enquiry report (Anon, 2008) suggest that more critical factors may be technology change. In particular, so called 'second generation' that is, production of ethanol from ligno-cellulose appears to be the only realistic way to make ethanol a mainstream fuel in Australia. Quirke et al (2008) explore in detail the potential to produce biodiesel using canola. The latter would provide an interesting potential by-product, canola meal that may have positive benefits for the northern beef industry, both for the grass-fed and feedlot sectors.

Changes in transport costs that were produced through the modelling process of Graham et al (2008) were used for modelling purposes in this study.

10.3 Assumptions and data for the economic model

10.3.1 Assumptions and data

Assumptions include a herd of different classes of cattle grazing native pasture under two different environmental conditions (dry and wet seasons). The estimates required for the partial budget were average liveweight gain/loss per head per day during different seasons and costs associated with mortality and pregnancy rates of cattle, average values of one kg of red meat, average value of cattle (Table 43). These were obtained from the literature, interviewing industry bodies, and animal health and production organisations (Department of Primary Industries) and experts in the field.

Table 43: Assumptions considered in the structure of partial budget

Model structure	Items/costs/sources
1) Class of cattle	
Grazing	
	Breeders
	Steers & Bullocks
	Heifers
	Weaners
Feedlot	
	Young & Adult
2) Season	
Dry	
Wet	
3) Prices	
Price paid per kg liveweight ($/kg)	$1.20 to $2.50; median $1.80
Price Weaner ($/hd) - 6-10 months (260kg)	$460 to $650; median $520
Price of Young cattle ($/hd)- yearling 350-400kg (heifers, steers, bulls)	$580 to $800; $630
Price mature cattle ($/hd)- >12 months 420-650kg (breeders)	$450 to $1400; median $630
Price of calf-weaners ($/hd) - <6 months	$240 to $380; median $290
4) Predicted productivity of cattle grazing native pasture without supplementation	
Average daily gain (kg/hd/d) during dry & wet seasons	Table 5, Chapter 5
Pregnancy rate (%) during dry and wet seasons	Table 13, Chapter 5
Mortality rate (%) during dry and wet seasons	Breeder cows and heifers: 1.5% to 80% Steers and bulls: 7% to 25%
5) Predicted productivity of cattle grazing native pasture with supplementation	
Improved average daily gain (ADG) during dry and wet seasons (kg/hd/d) for different classes of cattle	
Improved pregnancy rate (%)	5% (1% to 9%)
Reduction mortality rate (%)	2.5% (0.5% to 5%)
5) Efficacy of supplements	Table 45
6) Adoption rate of supplements	Table 46
7) Predicted costs associated with supplementations	
Cost of products	Table 46
Cost associated with delivery of supplements	Table 46
	Labour
	Equipment
Costs associated with transport of supplements	
Fuel & oil	($2 to $2.50)
Distance	400 to 3200km
8) Inflation rate	3% to 7%
9) Outcome - Net Present Value (NPV)	$ annualised for 10 years

Due to insufficient studies of high quality, some estimates of the liveweight gains/losses in grazing cattle were subject to adjustment. These adjustments were based on limited published and unpublished data and professional opinions.

10.3.2 Liveweight gain

Average daily liveweight gain (ADG) with known native pastures was estimated using the CPM model, and this was compared with the published results obtained from the literature review and

expert opinions to validate the efficacy of CPM model to predict the productivity of cattle in the north. We considered associations between liveweight gain and compensatory growth in our study on grazing cattle, however, the evidence obtained from other studies on the associations between compensatory gain and productivity of cattle were mostly descriptive and inadequate to quantify the economic impact of compensatory gain on the long term profitability of grazing cattle. There was no reliable information which could predict liveweight gain of cattle during the compensatory growth phases. Therefore, no estimate of this effect was included in this economic cost assessment.

The predicted ADGs were used in the partial budget to estimate the liveweight gain of cattle grazing native pasture with and without supplementation. Estimated liveweight gain/losses without supplementation obtained from the literature and expert opinions were used to compute the liveweight gain/losses of cattle under different environmental condition. The literature review and expert opinions on the most likely weight gain/loss of cattle grazing native pasture was -0.08 and +0.40kg and with a range of -0.91 to 0.41kg, and -0.20 to +1.17kg for the dry and wet periods, respectively. The predicted ADG of feedlot cattle was 1.97kg with a range of +1.28 to +2.46kg.

10.3.3 Mortality rate

The mortality rate of cattle grazing native pasture during dry and wet seasons obtained from the literature review and expert opinions was used to compute a cost associated with increased or reduced survival rate of cattle with and without supplementation.

Literature review and expert opinions on the most likely annual mortality rate of cattle grazing native pasture without supplementation was 10% and 18%; with a range of 1.5% to 80%, and 7% to 25% for breeders (cows and heifers) and steers/bullocks. The predicted mortality rate in feedlot cattle was estimated to be 3.5% with a range of 2.0% to 5.0%. It was assumed that a reduction in mortality rate is the result of supplementation and subsequent liveweight gain and improved body condition. While the association between improved liveweight gain and reduced mortality rate is well established, there are limited quantitative data to assess the magnitude of this association. There is also limited information on the direct effect of supplements on death rates, apart from effects mediated through liveweight. Unless further information is provided on an experimental supplement, the subsequent reduction of mortality rate will be similar among different supplements and will have neutral effect on the cost-benefit analysis of supplementation.

10.3.4 Pregnancy rate

The fertility of cattle is influenced by nutrition, and therefore variations in ADG can lead to change in the risk of pregnancy of breeding cattle. The pregnancy rate of cattle grazing native pasture during dry and wet seasons obtained from the literature review and expert opinions were used to compute the costs associated with increased or reduced risk of pregnancy of cattle with and without supplementation.

The literature review (Chapter 5) estimated that the most likely annual pregnancy rate of cattle grazing native pasture without supplementation was 18% and 55% and with a range of 4.0% to 98%, and 9.0% to 93.0% during dry and wet periods, respectively. An increase in the amount of liveweight gain can lead to improved pregnancy rate in breeder cattle. Findings of Dixon (1998) suggested that the improved pregnancy rate ranged from 1.0% to 9.0% per 10kg extra liveweight. For cattle >340kg of liveweight, the percentage pregnancy increased by approximately 0.12% per kg of liveweight and for lower liveweights of less than 340kg, an estimate of 0.6% increase in pregnancy rate per kg of liveweight should be used based on the data from Dixon (1998). The multivariate analysis of the data obtained from the literature review in this study also showed similar improvement (0.12%) in pregnancy rate. The subsequent

benefit of supplementation on pregnancy rate can also be considered to have neutral effect on cost-benefit analysis, unless information can be obtained to differentiate different supplements.

10.3.5 Delivery of supplement

The costs of delivery of supplements, including labour and equipment, were included in the costs of feeding supplement to grazing and feedlot cattle. This is estimated to be around 2 to 5 cents per animal per day, with 1.0% increase annually.

10.3.6 Transport of supplement

The cost of transportation of various products can be a significant part of supplementation in feed management of grazing and feedlot cattle in northern Australia. A matrix was developed to quantity and predict the cost of transport per kilometre per kg of product fed to animals per day. The data from international Energy Outlook (IEO 2010) were used to predict the cost of fuel for the transportation of supplements for the next 10 years (Figure 29 and Table 44).

Figure 29. World oil prices in three cases, 1980-2035 (2008 dollars per barrel)- Source: International Energy Outlook 2010

Table 44. World oil prices I four cases, 2008-2035 (2008 dollars per barrel)- Source: International Energy Outlook 2010

Years	IEO 2010			IEO 2010
	Reference	Low oil price	High oil price	Reference case
2008	$100	$100	$100	$101
2015	$95	$52	$145	$113
2020	$108	$52	$186	$118
2025	$115	$52	$196	$125
2030	$124	$52	$204	$134
2035	$133	$51	$210	-

10.3.7 Efficacy of products

The effect of the three interventions NPN and CSM (cotton seed meal) and one rumen modifier (monensin) were estimated using the data of Poppi and Quigley (2009) and Duffield (2010). These estimates were then used in the partial budget to compute and rank the benefit of supplementation. The effects of new methodologies can be modelled using CPM. The estimated extra liveweight gain of feedlot and cattle grazing native pasture and supplemented with NPN,

CSM or monensin is provided in Table 45. For the purposes of model testing, responses to the products were used as standard effects and applied regardless of cattle class or season.

Table 45. Estimated ADG associated with supplementation

Feeding systems	Additional liveweight gain associated with supplementation (kg/hd/day)			Sources
Grazing	Minimum	Most likely	Maximum	Chapter 5; Table 16
NPN (urea)	0.1	0.11	0.12	
CSM	0.21	0.23	0.24	
Monensin	0.20	0.22	0.23	
Feedlot		Mean		
NPN (urea) (8% to 10% of DM)	0.064	0.18	0.40	Duff et al 2003; Tedeschi et al 2002; Zinn et al 2003
CSM (8% of DM)	0.128	0.165	0.180	Brown et al 2003
Monensin Weighted mean differences & 95% CI	0.02	0.03	0.04	Duffield et al (2010) Chapter 6, Table 21

The estimated costs of products (NPN, CSM and monensin), transport and delivery of supplements to the cattle at the farm over a period of 10 years are provided in Table 46.

Table 46. Data used to estimate the NPV of supplementation with NPN, CSM or monensin for the current year (2010), and hypothesized/predicted within the next 10 years (2020)

	Median (Min - Max) Current year (2010)		
	NPN	**CSM**	**Monensin**
Estimated amount fed (kg/hd/day)	0.05 (0.02 - 0.09)	1.5 (0.3 - 2.0)	0.0004 (0.0002 - 0.0005)
Estimated cost of products ($/hd/day) (2% increase/year)	0.033 (0.012 - 0.054)	0.825 (0.150, 1,000)	0.022 (0.014, 0.031)
Estimated cost of Delivery ($/hd/day) (1% increase/year)	0.020 (0.003 - 0.005)		
Estimated cost of transport ($/amount fed/day for 800km) The rise over 10 years was based on data provided in Table 44	0.034 (0.013 - 0.060)	0.856 (0.171 - 1.713)	0.0014 (0.0002 - 0.0310)
Assumed/predicted adoption rate (%)			
Year 1 (2010)	Grazing: 73 (60 - 80) Lotfed: 65 (60 - 75)	Grazing: 10 (5 - 15) Lotfed: 17.5 (12.5 – 22.5)	Grazing: 3 (1- 5) Lotfed: 97 (95 - 98)
Year 10 (2020)	Grazing: 88 (76 - 95) Lotfed: 80 (73 - 91)	Grazing: 32 (27 - 37) Lotfed: 32 (25 - 37)	Grazing: 38 (36 - 40) Lotfed: 97 (95 - 98)

10.3.8 Adoption rate of products

The adoption rates of these technologies were predicted or hypothesised using the information and comments obtained from surveys, data on product sales and expert opinion (Table 46). The predicted adoption rates were used to estimate the benefit of using supplements over a period of 10 years.

10.4 Simulation model

A partial budget was developed for each feeding system where cattle are grazing on native pasture to evaluate the financial benefit of supplementation. Partial budgets were developed for an average herd size based on a list of assumptions (Table 43) and the liveweight data for each class of cattle. Some estimates from the previous work in Australia and overseas were also considered in the budget. These assumptions and associated costs and benefits of supplementation were validated by the published information and experts in this field.

The partial budget for this protocol contained the following parts to estimate the cost-effectiveness of supplementation, including:

i. liveweight gain
ii. mortality rate and associated costs
iii. pregnancy rate and associated costs.

The results of literature review, study survey and the expert opinions were used to estimate the average liveweight gain, pregnancy rates during dry and wet seasons. Following the development of partial budgets within each class of cattle, appropriate distributions were created for each variable (e.g. median, min and max for average daily gain) using @RISK v 5.7. (Palisade Corporation, USA). Latin Hypercube sampling was used to recreate the probability distributions for each variable. Latin Hypercube is a recent development in Mont Carlo sampling simulation designed to accurately recreate the input distribution through sampling in fewer iterations. To conduct the sampling procedure, the distribution function was set for 5000 iterations with 1 simulation.

10.4.1 Sensitivity analysis

Following the estimation of NPV, a sensitivity analysis was conducted to determine the effects of model inputs such as fixed costs (e.g. products) and variable costs (e.g. delivery and transport) on the output. This allowed testing of the sensitivity of estimated NPV to the input distributions in the model. When the distribution of an input variable is tested, the input distribution is fixed at a different value across the minimum and maximum range of the distribution. These step values are different percentile values for the input distribution.

10.5 Results and discussion- economic model

10.5.1 Net Present Values of NPN, CSM & monensin

The NPV results of NPN, CSM and monensin for different classes of grazing (native pasture) and feedlot cattle are presented in Table 47 and Figures 30 to 32. The estimated NPVs were computed on an annual basis for a 10-year period, based on 6500 head where 800km transportation is needed to carry the required supplements to the farm. These estimates are provided in Table 47 for the ADG and ADG plus the cost-benefits of supplements on pregnancy and mortality rates. These results can be used as a ranking tool for the assessment of the available products and new technologies. The results indicate that;

- The performance of breeder cows was similar to the heifers.
- The estimated NPVs of ADG of supplemented cattle were small when the subsequent benefits of improved pregnancy rate and reduced mortality rate were not included in the model.
- Increased ADG and body condition improved pregnancy rate and reduction of mortality rate. The economic benefits associated with these improvements were greater than of those associated with ADG alone.
- The NPN supplementation produced a greater NPV, and this followed by monensin and then CSM. However, the 95% confidence intervals of estimated NPVs of monensin were tighter than NPN and CSM. This indicates more certainty about the effectiveness of monensin than the other two products.

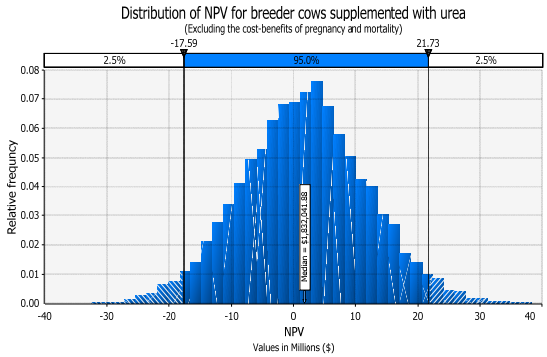
- Supplementation of CSM in grazing cattle produced a smaller margin than NPN and monensin, after excluding or including the benefits of improved pregnancy and mortality in the model.
-
- The lot-fed cattle responses to the tested supplements were similar to the grazing cattle.

Table 47. Estimated NPV of supplementation of grazing and feedlot cattle based on the above assumptions and data obtained from the literature and expert opinions

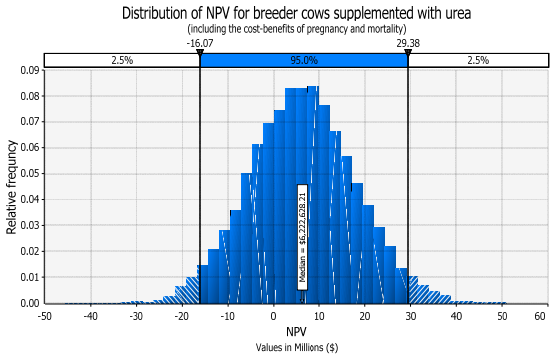
	NPV ($,000)* ADG ± (improved pregnancy & mortality) Median & (95% CI) 10-year period (2010 to 2020)					
Grazing	**ADG of NPN**		**ADG of CSM**		**ADG of Monensin**	
N= 6500	**Cost-benefits of pregnancy & mortality**		**Cost-benefits of pregnancy & mortality**		**Cost-benefits of pregnancy & mortality**	
	Excluded	**Included**	**Excluded**	**Included**	**Excluded**	**Included**
Breeder cows	+1,832	+6,223	+839	+1,944	+1,166	+2,238
	(-17,594, +21,731)	(-16,070, +29,380)	(-4,000, +5,930)	(-3,630, +7,670)	(-3.520, +6,170)	(-3,026, +7,840)
Heifers	+1,944	+6,323	+870	+1,920	+1,146	+2,227
	(-20,150, +24,150)	(-18,760, +30,560)	(-4,300, +6,438)	(-3,980, +8,130)	(-4,050, +6,600)	(-3,630, +8,410)
Feedlot	**NPN**		**CSM**		**Monensin**	
	(excluding the cost-benfits of pregnancy and mortality)		(excluding the cost-benfits of pregnancy and mortality)		(excluding the cost-benfits of pregnancy and mortality)	
Lotfed	+3,016		-455		+240	
(all classes)	(-6,230, +13,930)		(-3,311, +2,618)		(-10,400, +11,640)	

* The NPV results were rounded

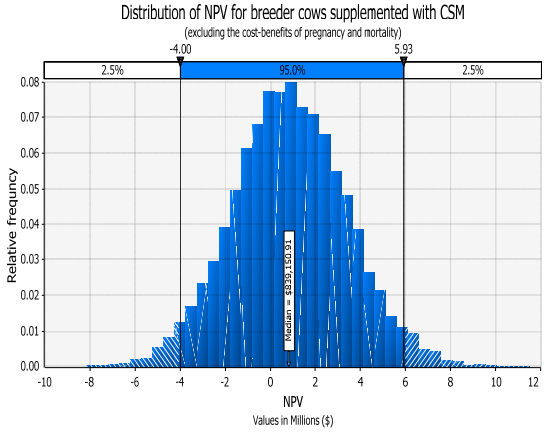
(a)



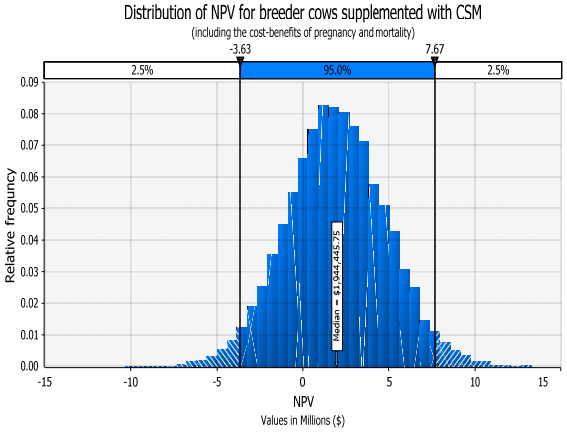
(b)



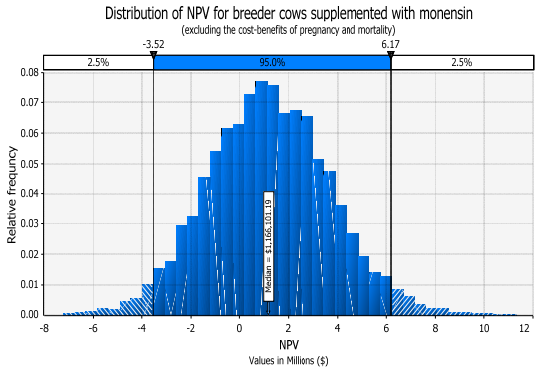
(c)



(d)



(e)



(f)

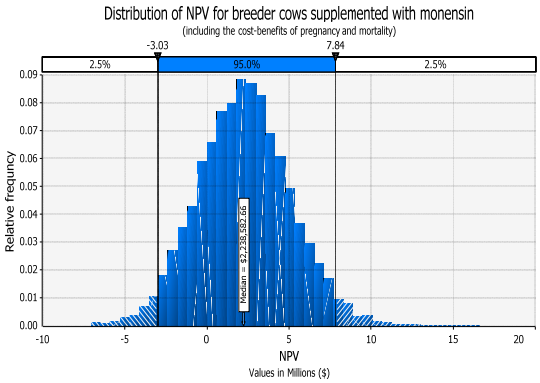


Figure 30a-f. Estimated NPVs of breeder cows supplemented with NPN (urea), CSM and monensin, excluding and including the costs of pregnancy and mortality

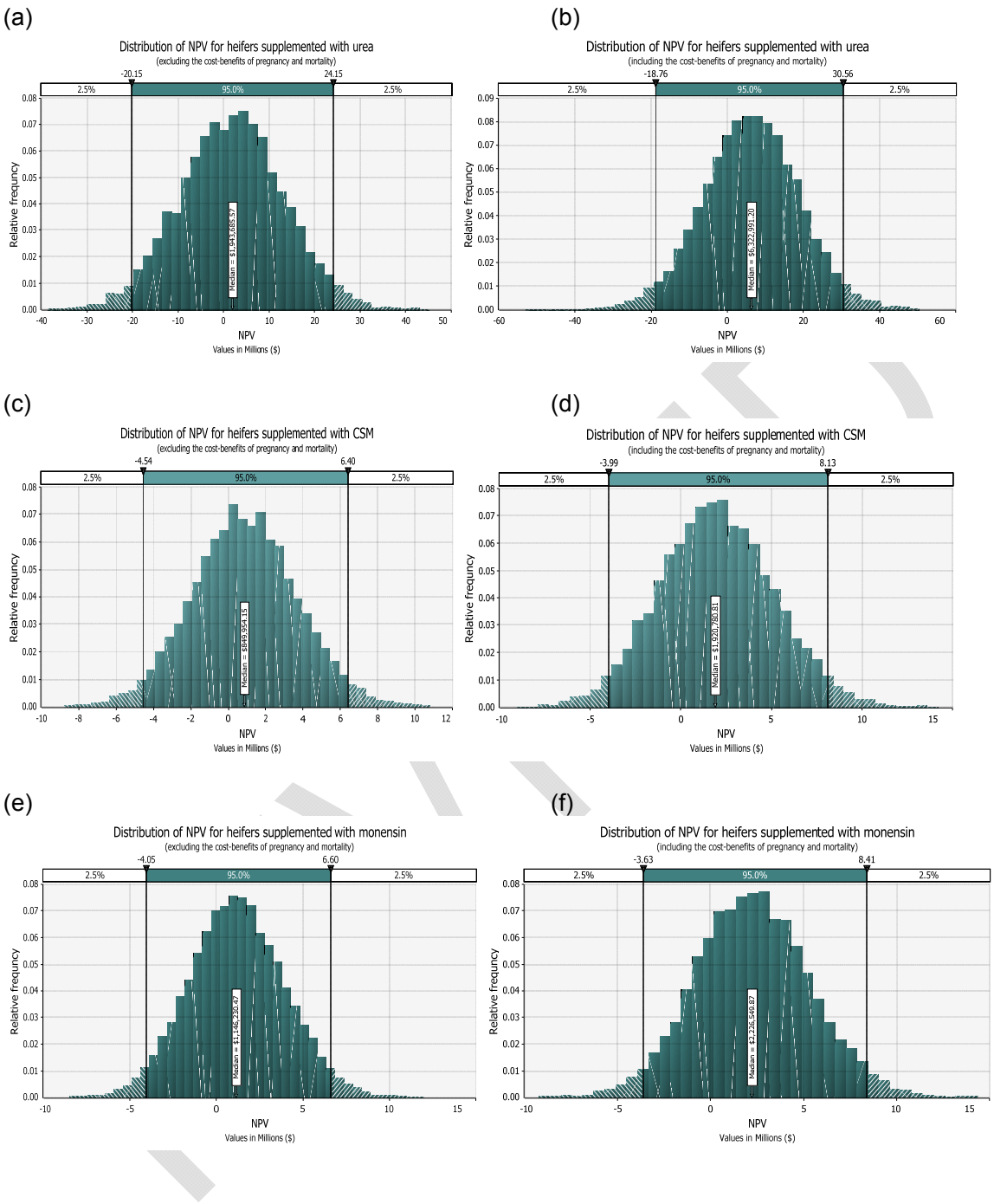
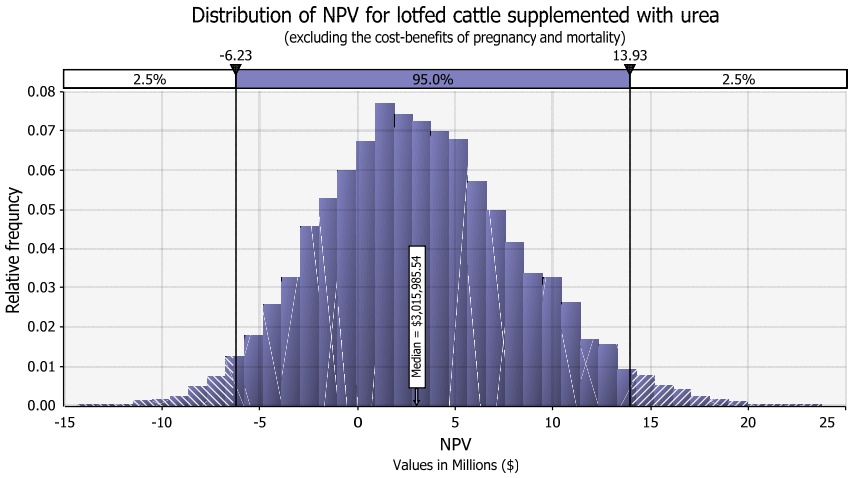
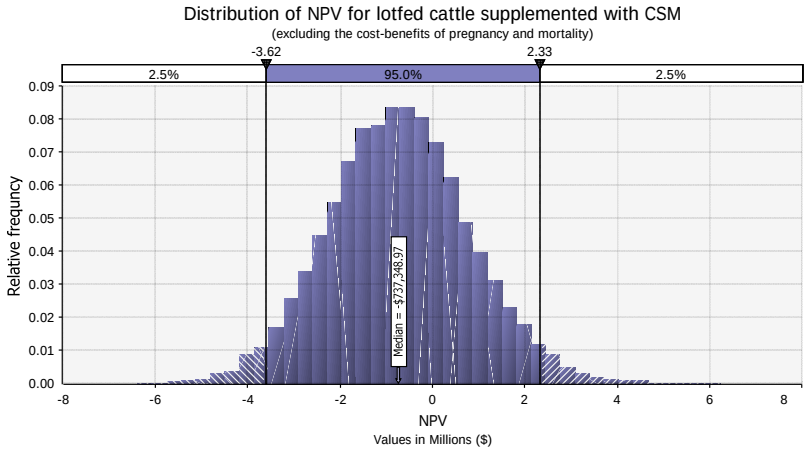


Figure 31a-f. Estimated NPVs of heifers supplemented with NPN (urea), CSM and monensin, excluding and including the costs of pregnancy and mortality

(a)



(b)



(c)

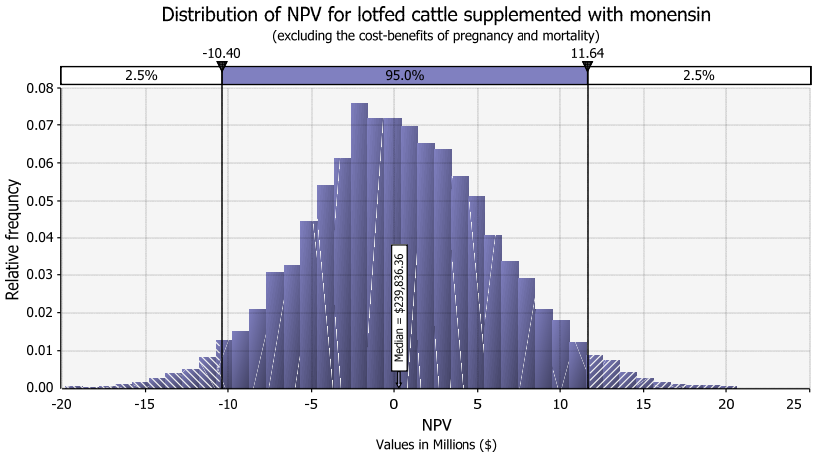


Figure 32abc. Estimated NPVs of lotfed cattle supplemented with NPN (urea), CSM and monensin, excluding the cost-benefits of pregnancy and mortality

10.5.2 Sensitivity analysis

A series of sensitivity analyses were conducted to examine the impact of costs of transportation, products (NPN, CSM and monensin) and delivery of products to the animals at the farm on the estimated NPVs (Figures 34 -36). The results of these sensitivity analyses were only used as a ranking tool to explore the impact of various fixed and variable input costs on the NPV. These showed that the costs of products had the lowest impact on the NPVs for all tested products, whereas the cost of transport had the greatest impact for NPN and CSM products (Figures 34 and 35). The cost of transporation of monensin was lower than NPN and CSM products (Figures 34 and 35).

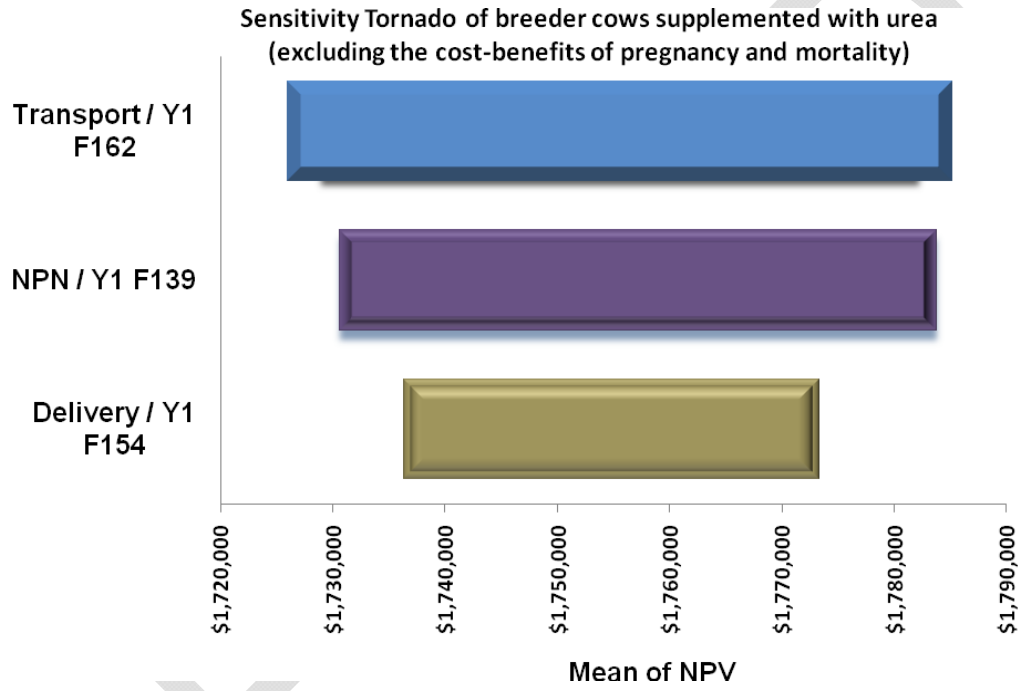


Figure 34. Sensitivity analysis of estimated NPV for breeder cows supplemented with NPN

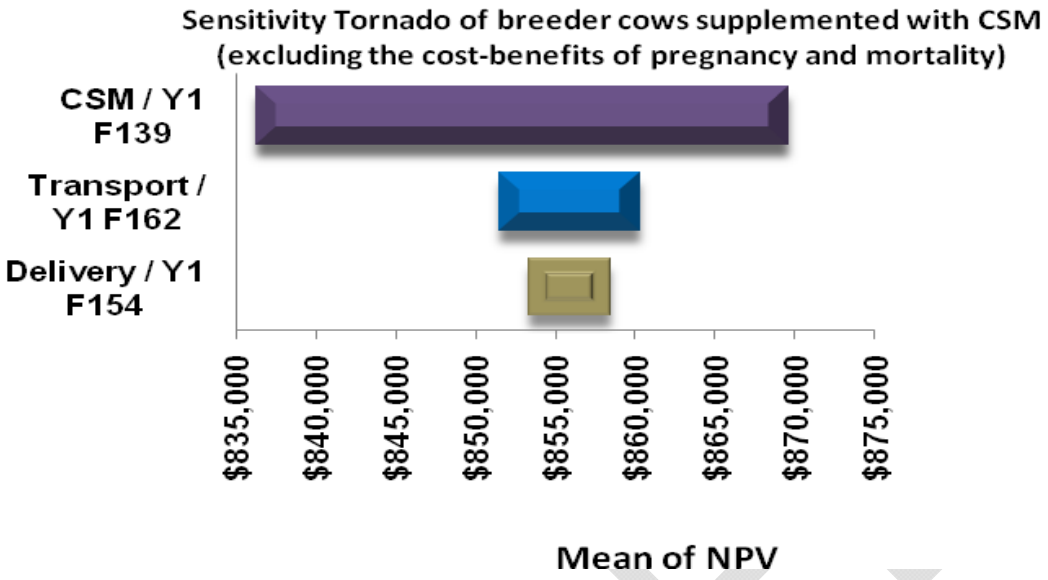


Figure 35. Sensitivity analysis of estimated NPV for breeder cows supplemented with CSM

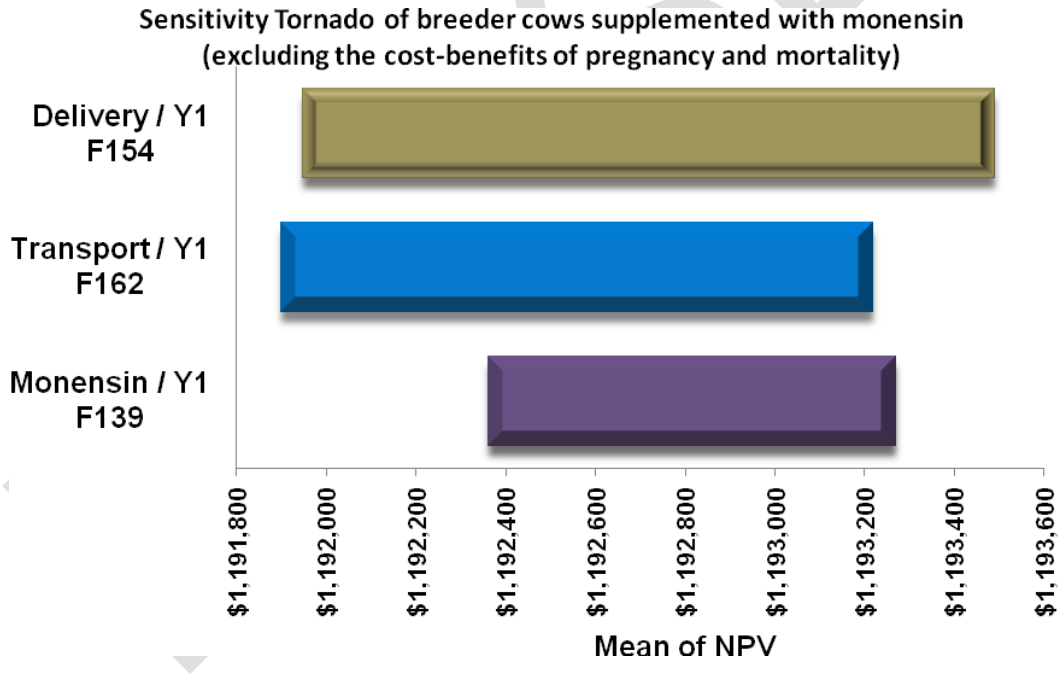


Figure 36. Sensitivity analysis of estimated NPV for breeder cows supplemented with monensin

10.5.3 Conclusions

The development of this economic modelling provided us a valuable tool and opportunity to validate our earlier assumptions and discussions with the industry, about the impact of different components of cattle industry in northern Australia. We provide estimated NPVs of breeder cows, heifers and lot-fed cattle; however, this model has the potential to assess the economic benefits of new technologies under various environmental and grazing conditions, if appropriate data and information become available. We are fully aware that under field conditions, some of these products are fed mixed or combined with other products such as molasses and minerals. The modelling process can accommodate such approaches by allowing for integrated responses developed from nutritional modelling.

11 Success in achieving objectives

Table 48. Success in achieving objectives

Objective	Objectives met	Relevant Sections
Undertake a literature review and to identify options to manipulate the rumen function of beef cattle in northern Australia to improve productivity	Yes – an extensive review is provided of past and present performance	Chapters 4 and 5 on background and compensatory gain
Consult with technical experts both nationally and internationally	Yes – extensive formal and informal discussions	See Chapter 7; Appendix III
Review the role of currently used and novel nutritional additives such as Protexin®, polyethylene glycol (PEG), yeasts, ionophores, antibiotics, etc, and evaluate their potential to improve digestive efficiencies in grazing situations	Yes	Chapter 6; Summary Table 6.8
Provide a summary of the current additives used in grazing and feedlot animals, including dose rates, potential liveweight gains, cost benefits and situations in which these can be used cost effectively	Yes	Chapters 4 and 5; Summary Tables 6.8
Investigate other species of herbivore such as the water buffalo, banteng cattle, camel and native animals that have successfully adapted to the nutritional environments of rangelands of northern Australia and outline the reasons for their successful adaptation and opportunities for rumen manipulation in beef cattle	Yes	Chapter 8
Evaluate and document the complexity, feasibility, delivery horizon, production benefits, indicative costs and probability of success of potential technical solutions	Yes	Chapters 7 and 8; not all technologies are sufficiently developed to apply these criteria to.
Create a model to assess the priorities for future scientific investigations, if indeed sufficient evidence is available to support further research	Yes	Chapter 10
Document and justify high priority areas for future research	Yes	Chapter 13

12 Impact on the red meat industry – Now and in five years time

Given the lack of evidence identified through this review (Chapters 4 and 5) to support marked change in the efficiency of production in the northern pastoral industry over time, one should be cautious in predicting marked changes in practice in that industry. International benchmarking of the Australian feedlot industry has provided evidence of a very efficient industry that is highly competitive. The contrast suggests a proposition; where cost-efficacy of an intervention is evident Australian producers adopt and use technology well.

This study provides a number of quantitative estimates of effects of existing technologies and proposes that these and other reports be refined and consolidated into a producer manual. This manual would include proposed meta-analyses of the effects of interventions including bambermycin, fibrolytic enzymes and DFM to provide more certainty of likely responses. The relative value of interventions can be tested using the economic model developed for the project and rankings included in the manual. Consequently, the pastoral producers should be more aggressive in adopting and better using existing technologies within a 5 year horizon.

It is possible that information derived from proposed studies of the effects on the production system of an integrated supplementary feeding intervention and those on complementary weight gain and algae will be available to influence producers within 5 years.

13 Conclusion and recommendations

13.1 The production system (Chapters 4 and 5)

The strengths of the system reside in the seasonal production of large amounts of poor quality pasture. These pastures are converted to marketable beef with a low energetic efficiency, providing the potential for marked improvements in efficiency.
Our review found the following

- Over 500 studies conducted over the period from 1959 to 2010 were evaluated to extract data on weight gain in the northern, pasture-based system.
- There appeared to be little evidence of improvements in weight gain of cattle in the industry over the period from 1959 to 2000 and later (Chapter 5).
- Weight gains in the wet period are poor compared to those on temperate pasture. During the dry period weight gains are low and often weight is lost.
- Fertiliser expenditures on large northern beef properties were less than 1% of income (ABARE 2010 – Chapter 4). This observation suggests that sustainability aspects of the production system may require consideration.
- Supplements are widely used as identified by interviews conducted, review of literature and from evidence of expenses on forage in northern beef properties in ABARE (2010). Supplements are used from about 100 days to all year round (Bortolussi 2005).
- There is some evidence, albeit limited, that reproductive performance of the northern beef herd has improved over time.

- The response of fertility to body weight gain can be estimated using the data extracted from 170 trials conducted on this (Chapter 5). Pregnancy rate in cattle of greater than 340 kg increased by approximately 0.12% per kg of liveweight gained. For lower liveweights of less than 340 kg, an estimate of 0.6% increase in percentage pregnant should be used, based on the data from Dixon (1998).

- Compensatory weight gain is a factor that deters some producers from supplementing feed or supplementing more feed. The impacts of weight loss or very slow growth may be influencing the potential to grow a larger animal. The observation that skeletal size and ultimately, mature size (but not weight) are fixed when the epiphyses of the long bones fuse (Hogg 1991) supported contentions by interviewees that the impact of weight loss on skeletal growth was an important determinant of final body weight.

- Weight gain was approximately 17 to 20% higher on improved pastures, in comparison to native pasture.

- Weight gains varied markedly with the predominant pasture type, indicating the potential for agronomic approaches to provide benefits that overcome environmental limitations to production e.g. seasonal growth, heat and humidity.

- *Leucaena* plantings can provide sufficient enhancements in growth rate to encourage wider adoption of this technology.

- The feed base is now very poorly defined in terms of modern feed evaluation. While many old studies (studies from 1950 to 1980) could be found, there were very few data available that provide sufficient detail for relatively sophisticated nutritional modelling.

13.2 Key perspectives arising including relevant literature

There is a substantial opportunity to utilise the vast land mass involved in northern beef production to more efficiently deliver beef. The obvious constraints are those of market and costs associated with increased efficiency.

Older feed analyses, especially those of Wesley Smith and Minson and the few recent and more detailed feed and extrusa sample analyses obtained (McLennan, pers comm.) provide evidence that the pasture base in the dry period is characterised by low protein (4 to 6% CP) low P concentrations and NDF of 60 to 70% (see Table 2; Chapter 4). The sugar and starch contents of these pastures are low, as indicated by samples obtained recently (Appendix IV). Older studies and samples of extrusa from cattle grazing wet season pastures indicate that the CP contents may rise to 10 to 12 %, but rarely higher and the NDF contents are in the mid 50 to low 60% range. Notwithstanding the capacity for cattle to select pastures and browse on shrubs and the softer under-storey plants, these feed analyses clearly define the limitations to production, as reflected in the weight gain estimates provided across the large number of years and environments collated in Chapter 5. It is worth noting the variations in performance on different pastures in Table 9 (Bortolussi 2005) and the variation in weight gains displayed in Figures 5 to 9, providing evidence of the potential to improve gains.

However, as Poppi and McLennan (2010) note and as independently confirmed by CPM modelling conducted (Chapter 10), cattle on these pastures use nitrogen with a greater efficiency than is currently incorporated in feeding standards, as evidenced by growth rates achieved in controlled studies. Neither the extrusa data of McLennan (pers comm.) nor hand plucked samples of better feed (Appendix IV) provide evidence that this benefit is obtained solely by selective ingestion of plant material by the cattle. There is a need to understand the ruminal and post-ruminal efficiencies that are achieved by these cattle and to identify the optimal means to

capture the energy and protein contained within the existing feed base. Part of this investigation will need to focus on the nature of weight change both during loss of weight and during the re-accretion of weight. There is a need for further studies on compensatory gain (see Recommendations).

There are innovations in the feed base that provide opportunity for agronomically driven better production, including planting *Leucaena* and improved Stylos. It is very possible that innovations in other areas of agronomy including use of genetic innovations, such as incorporation of brown midrib gene mutation, could improve pasture digestibility (see review Krause et al 2003).

Part of the intervention approach needed must be based on improved agronomic approaches. However, these should be considered in the context of understanding ways to optimise production in a sustainable context. There are some studies, notably MLA (Pigeonhole project MLA NBP.317; 2007), that have examined interventions in a systems context. Increasing the understanding of the interactions among water supply, supplementary feed, the pasture base, new crops and fertiliser use, nutrient transfer from supplementary feeds, and impacts on the environment of different feed and management strategies to increase production is vital (see Recommendations).

13.3 Interventions with currently available rumen modifiers (Chapters 6)

The intent of these reviews was not to provide lengthy qualitative assessments of the potential for these interventions to modify rumen function or the metabolism of cattle, rather to gather as comprehensively as possible evidence of effect of these products or manipulations on production.
Our reviews found the following

- Responses to ionophores, especially monensin, were well characterised by a recent meta-analysis (Duffield 2010) mostly based on feedlot data. The meta-analysis showed a 2.8% increase in ADG that was coupled with a decrease in DMI resulting in a 6.6% increase in feed efficiency. The more limited information available on tropical or temperate pasture-based responses was positive for lasalocid and monensin, but lacked sufficient studies for a meta-analysis. There is evidence that monensin use can reduce time to first oestrus by a median 22 days and increased conception rates, however, few of the studies contributing to the effect were conducted on tropical pasture. Most studies on reproductive performance were conducted on temperate pasture. There was relatively little information available on other ionophores (See Recommendations for use). The latter observation should not be interpreted as a failure to perform of those products, simply an indication that more studies are required.

- Bambermycin (Flavomycin). There were few data available for this modifier on tropical pastures, however, the studies available are very positive. The studies conducted, mostly on confined diets or temperate pastures, showed a 9.1% increase in ADG over controls for calves and a 7.7% increase in ADG for growing cattle. There is a need for further quantitative, meta-analytical evaluation of this product.

- Virginiamycin is registered for use to control acidosis. The product has a well documented efficacy in feedlot cattle and some evidence of benefit for cattle on pastures. The product may be useful to control risk of grain overload for grain-based loose mix supplementation strategies.

- Tylosin is registered for use to control risk of abscesses in feedlot diets. The product has a well documented efficacy for this and reduces the risk of liver abscess by approximately 73%. The product could be useful to control risk of grain overload and liver abscesses for grain-based, loose mix supplementation strategies.

- It is important to recognize that **yeasts** are not generic. There needs to be more evidence of effect for each product to provide an evaluation of these. There is a need for further quantitative, meta-analytical evaluation of some products that may have data available. The responses and underlying physiological data appear moderately positive, e.g. a 0.8% increase in digestibility of dry matter, but very mixed.

- The results available for production responses to probiotics and DFM are very variable. Few of the many studies have been published in peer-review journals, however, there may be sufficient data to conduct a meta-analysis of the responses. These products do appear to be effective at reducing the shedding of *E. coli* O157.

- There was a paucity of *in vivo* data on the essential oils and plant botanicals. The *in vivo* data that are present suggest a relatively low potential for either the pasture systems of the northern beef industry or the feedlot industry to benefit from products identified to date. However, there is the potential to identify new products from plants. There have been extensive programmes to screen plants for effective agents (Eg Rumen-up) that suggest a limited need to investigate this area other than on a case by case basis.

13.4 Key perspectives arising including relevant literature

While there were quite robust data available for feedlot interventions that can be recommended, there were relatively few data available for the existing rumen modifiers on tropical pastures. It may be possible to integrate the dairy and beef data for several of these existing rumen modifiers, particularly the ionophores, bambermycin, yeasts and DFM to provide even more robust estimates of effect that are relevant to cattle on high quality diets i.e. feedlots. The magnitude of effects of these interventions on ADG is relatively modest. However, some of the benefits of some products have not been captured in the reviews including the effects of the ionophores on bloat and coccidiosis control.

The responses to existing interventions provide a broader perspective, specifically, an understanding of the magnitude of response to interventions that are not based on nutritional substrates. These responses may broadly define the likely responses to novel interventions that control bacterial populations that rapidly divide when starch is available (e.g. ionophores, antibiotics), those that reduce protozoal numbers and deamination of proteins (ionophores) or those that provide or stimulate lactate utilisation (yeasts, DFM). None of these interventions have marked effects on fibre digestion, with the possible exception of bambermycin, a product which appears worthy of further investigation. Overall, some of these manipulations provide considerable benefits for beef producers in northern Australia. The modelling of the value of the ionophore intervention confirms the potential impact of the products.

13.5 Support or perspectives from surveys and interviews in regard to current practices

There was strong support, and high adoption rates were estimated, for a number of technologies including non-protein nitrogen, true protein, macro-mineral and micro-minerals. Estimated adoption rates approached or exceeded 90% of producers for many of these. These were considered to be highly effective (with the caveat that micromineral responses depended on deficiency being present and that these deficiencies were distributed geographically). There was also solid support for the ionophores that were used by up to 40% of producers. Antibiotics were estimates to be used on 50% of feedlot properties on the older cattle, but there was little support for other currently used manipulations.

Many of the feeds available in Appendix IV contain mixtures of NPN, protein, macro- and micro-nutrients and some also contain ionophores. One interviewee noted that recent studies with

ionophores showed good responses. Other interviewees noted a lack of understanding among producers of the value of the ionophores. While energy was ranked highly on the basis of need, the costs of delivery, transport and labour were noted as inhibitions to use. Notwithstanding this observation, many of the products listed in Appendix IV are based on molasses to provide a vehicle for delivery of less palatable inclusions and as an energy sources. It appears that energy sources other than molasses, may need further evaluation and may be underutilised in the northern beef industry. Increased uptake of the existing products and Leucaena were seen as being important means of increasing productivity of the northern beef industry.

13.6 Novel interventions and new technologies

Perhaps the most important perspective gained from this part of the review was the explosion of knowledge into the ecology of the rumen and on fermentation technologies that has been provided by new laboratory methods developed over the past 15 years. The insights into the ecology of the rumen will allow the development of a new level of quantitative nutritional knowledge. This part of the review was of necessity more qualitative because many of the technologies are in the very early phase of investigation.
We drew the following insights from the reviews conducted.

- Bacteriocins and AMPs: The rapidly emerging field of study into anti-microbial peptides (AMP) and bacteriocins provides considerable potential to provide effective agents to control sub-populations of ruminal bacteria. However, the AMP and most bacteriocins are peptides and, therefore, vulnerable to attack by the ruminal microbiota. The limited studies to date with bacteriocins have not identified substantial responses.

- The substantial investment by the pharmaceutical industry in the AMPs reflects the promise that these and the bacteriocins hold (see Recommendations)

- Bacteriophages: Studies into the bacteriophages are relatively sparse, however, many of these are from Australian workers who have seminal and important publications on the bacteriophages. The knowledge of this very substantial rumen population is still reasonably rudimentary. The bacteriophages provide opportunities for the targeted removal of bacterial populations, however, resistance to these has been noted to rapidly develop.

- Transgenic Bacteria: The achievements of workers to develop transgenic bacteria have been significant and include the insertion of genes to produce bacteria with greater fibrolytic capacity, insertion of genes to detoxify flouroacetate, demonstration of a sustained presence of transgenic bacteria in the rumen and the production of celluloytic enzymes. Recently, improved means of incorporating genetic material into bacteria have been developed. The most substantial inhibition to a programme of continued development of transgenic bacterial interventions are considerations of the safety of these and societal concern about transgenic organisms highlighted in interviews (Chapter 9).
- Vaccinal Approaches to Controlling Rumen Function: There was considerable scepticism about the value of vaccinal approaches to controlling the ruminal biota expressed in interviews. However, we found strong evidence for the potential for vaccines to effectively influence the microbiota of the rumen. The evidence that ruminal protozoal numbers could be reduced by vaccination and that this resulted in production benefits in sheep indicates an opportunity to control protozoal populations. Given the failure of most other interventions to sustainably reduce numbers of protozoa, this may be worthy of investigation.

- Enzymes: Fibre digestion is not maximal under normal dietary conditions. The tropical pastures are high in fibre and interventions that increase fibre digestion will be valuable. The evidence on fibrolytic enzymes was generally positive. There are sufficient data to

allow a meta-analysis of the effect of fibrolytic enzymes on production. However, there are relatively limited data on any single enzyme product, and very few studies exist that are based on tropical pastures. The practical limitations of cost and method of application of the enzymes have limited the adoption of these. The potential to reduce the costs of production of enzymes and improve understandings of application may make these a valuable intervention for both the feedlot and pasture based industry.

- Fungi: The critical role of fungi in fibre digestion suggests that research in this area may be fruitful. The recent development of new ARISA methods of investigation in which Australian researchers are highly involved (Denman et al 2008) suggests that understandings of the role of fungi will increase markedly as a result of further investigation. The fungi are a useful source of fibrolytic enzymes and may provide *in vivo* and *in vitro* approaches to increasing fibre digestion.

- Protozoa: There is evidence that defaunation of ruminal protozoa improves the ADG of ruminants on diets high in fibre, by increasing fibre digestion and nitrogen use efficiency. The increase in microbial protein outflow from the rumen is substantial (about a 20% increase). These findings appear particularly relevant to cattle on tropical pastures. Physiological responses are less for cattle on concentrate diets, suggesting an important role for protozoa in slowing the rate of starch degradation and a potentially valuable role in reducing the risk of acidosis. The potential to increase production performance by manipulating the ruminal protozoa is present, however, considerable funds have already been invested without developing highly effective methods of achieving this.

- Algae: The micro-algae are a very good source of nutrients and provide the potential to overcome some of the transport costs in delivering true protein to remote properties. The effectiveness of these as a feed is clear, however, they also have the potential to deliver specific nutrients including particular lipids. The practical means of growing and delivering the micro-algae in concentrations that are sufficient to have a commercial effect have yet to be developed.

- Genetics: The diversity of the rumen microbiota, even among cattle on identical diets is substantial. However, there is relatively little evidence that this diversity results in marked differences in the efficiency of digestion. Practical challenges in determining genetic differences in digestion are significant for cattle on tropical pastures. At this time, it appears that the focus of genetic selection programmes should be on less specific performance indicators such weight gain, rather than on measures of ruminal efficiency.

- Sourcing Bacteria from Other Species: Recent studies provide evidence that strong, mutually beneficial co-evolutionary directions provide a basis from which animals acquire bacteria. The convergence of faecal biomes of very diverse mammalian species on similar diets, indicates a co-diversification for animals and their associated microbial populations (Ley et al 2008) and strongly indicate the potential for animals to acquire beneficial bacteria. These findings and evidence that beneficial bacteria can be successfully obtained and established from other species e.g. *Synergistes jonesii* provide evidence of the potential for useful bacteria to be identified. The findings of Ley et al (2008) also indicate that the process of acquisition of useful bacteria from other species has been part of the successful spread of the *Bovidae* as noted by Professors van Soest and Hume. The Camelids may be a useful source of material to examine for enhanced fibre digestion.

13.7 Support or perspectives from surveys and interviews

Each of the technologies were rated, except bacteriocins and AMPs for the potential to provide value to the northern beef industry by the researchers interviewed (Table 39). The opinions on all technologies were diverse.

- Bacteriocins: The societal acceptance of the bacteriocin nisin in the food chain was noted by one interviewee. Discussions with a number of researchers (Gregg, Morrison, Jung, Firkins, McSweeney) outside of the structured survey process highlighted the potential of the bacteriocins and AMPs to provide useful means of controlling bacterial populations.

- Bacteriophage research received quite strong support. Comments were generally positive.

- Transgenic interventions did not receive consistent support, partly on the basis of societal inhibitions to use, however, some researchers were strong proponents for this approach.

- There was only modest support for research into fungal manipulations. However, a number of researchers were candid about a lack of detailed knowledge of this area.

- Modification of protozoal populations was well supported by the researchers.

- Post ruminal manipulations were evaluated and various options were raised including improved control over tissue accretion, use of agents to allow tighter control over oestrus expression, and insertion of BT genes into bacteria to influence insect numbers (Gregg interview).

- Vaccinal approaches to control of rumen populations were poorly rated by the interviewees.

- Use and development of probiotics had strong support from 3 interviewees and little support from others.

- A similar pattern of support was noted for plant botanicals and essential oils with some interviewees expressing enthusiasm, particularly for refined products, while others were unsupportive.

- Enzyme and co-factor interventions were generally well supported, but again a lack of detailed knowledge of the area was expressed by some.

- The genetic interventions received some support, but others were sceptical and alluded to the recent studies providing evolutionary perspectives that suggest the ruminal biome is highly selected for by evolutionary processes. This perspective and the very limited evidence of substantial variance in digestibility of feeds, suggests that there may be little room for additional improvement using traditional genetic selection methods.

Conclusions- Review of the new technologies identified the very substantial potential of some of these to modify the efficiency of production. The results of trials on the fibrolytic enzymes appear very encouraging, but require critical meta-analytical evaluation, particularly in regard to immediate potential for use in feedlots. The practical limitations to the use of these in extensive production systems need examination. Several other observations suggest that there is potential to improve performance. Those observations include;

- the vast increase in knowledge of the ruminal eco-system that is developing and

- the relatively low efficiency with which fibre is degraded.

These observations should be tempered with an awareness of the physico-chemical limitations to fibre degradation discussed in Chapter 8 and concepts of “Quorum sensing” that reflect the ability of a bacterial population to sense when a threshold population is reached (Rossi et al 2008). Responses of bacteria that control populations include production of bacteriocins and AMPs, both of which have considerable potential to provide valuable antibacterial agents. There appeared to be some differences in fundamental approach to the new technologies, with some interviewees seeing these as being a lower priority because of the delay or uncertainty in achieving benefits, while others were very positive about the potential for these to provide benefits.

13.8 Modelling

The CPM model, while validated in some aspects, did not fulfil a critical criterion for successful application, specifically to model DMI. This result was obtained independently of a similar finding (McLennan 2005). However, once adjustments to DMI were made, the model predicted responses with a high level of accuracy on a limited data set. The model was used to provide estimates of growth for subsequent economic modelling.

This process highlighted an important finding implicit in the liveweight and feed evaluation data presented in Chapter 5. It is very clear that the performance of the cattle recorded in the more than 500 studies of liveweight change exceeds that that could be expected from pastures of the quality reported in studies that provided pasture information or in the older and more recent studies of pasture composition (see Chapter 5). These field studies were not sufficiently well described to provide a clear perspective on whether the better than expected responses could be attributed to efficient feed selection (e.g. browse or softer understorey plants), or more efficient ruminal or post ruminal metabolism.

Two studies were identified that provided adequate descriptions of pasture and careful measures of DMI. These provided compelling evidence that the dry matter intake of cattle exceeded the feed standards inherent in CPM, both in terms of total DMI and eNDF. This finding is critical as it means that either i) the passage rate of fibre is greater than predicted by feeding standards or ii) the digestion of the fibre is greater than predicted by feeding standards or iii) both passage and digestion are increased. These observations open new perspectives for researchers.

13.9 Perspectives and priorities identified from both surveys and unstructured interviews

13.9.1 Short term solutions that can be implemented within 5 years to improving production

The need for integration of approaches to improving productivity was noted by several interviewed. While their approaches differed, there was a consistency in the conclusions of these workers that integrated approaches incorporating agronomic and supplementary feeding strategies are needed to cost-effectively achieve the increases in production that allow earlier turnoff, greater longevity or higher fertility. The need to utilise existing and well-understood supplements and modifiers better was stressed and phosphorus, NPN, protein, energy and ionophores were all identified as critical inclusions. A number of interviewees from the research area and from the nutritional and advisory professionals highlighted a need to achieve better rates of adoption for ionophores and to overcome regulatory constraints to the use of these in lick blocks.

Increased use of *Leucaena* was mentioned by a number of those surveyed. The need to improve the means of cost-effectively delivering these, especially in the wet season was noted as a priority. The use of algae and water systems to provide nutrients was mentioned by two interviewees. Subsequent, observations of the extensive northern grazing production system and potential to manipulate the system using watering points reinforced the potential value of extension and innovation in regard to this area of nutritional management.

13.9.2 Medium term solutions that can be developed to implementation within 15 years

Newer technologies were considered as potentially valuable by the interviewees. Probiotic solutions to acidosis by the inclusion of *Megasphera elsdenii* were mentioned as a specific example of a probiotic manipulation, however, bacteriocins and AMPs were identified by other interviewees. Delivery systems for manipulations were considered critical and there was an emphasis on methods that provide benefits with limited intervention e.g. bolus technologies and vaccines. It is important to note that these methods do not deliver additional substrate, however, providing additional substrate was identified as important in the solutions proposed within the 5 year time frame.

13.9.3 Longer term solutions

Most interviewed either declined to speculate over a period beyond 15 years, or identified the potential for investigations into the ecology of the rumen to provide new perspectives. All the technologies suggested have been reviewed in Chapter 8. Interestingly, a number of currently available technologies were suggested including improved grazing management and early weaning and improved quantitative nutritional management approaches. One interviewee suggested that understandings obtained from studies into methods to better utilise straw in livestock diets would provide benefit.

13.10 Recommendations

The following recommendations are provided after considering the production system in the north and understanding that resources will be limited and must be targeted to outcomes that provide both immediate return, but also provide a pathway for continued growth and improved efficiency of use of resources.

Table 49. Summary of recommendations and their potential impact, cost, success of risk and required time frame

Recommendations	Impact	Cost	Success risk	Time frame
Manual	High	Low	High	Short
Meta-analysis of promising technologies	Moderate	Low	High	Short
Systems research	Moderate to high	Moderate	High	Medium
Understanding the growth dynamic	Moderate to high	Moderate	High	Medium
Algae	Moderate	Moderate	Moderate	Medium
Major research programme on rumen/ fermentation technologies	High	High	Moderate	Medium to long

13.10.1 Existing Technology

13.10.1.1 A Manual to Consolidate Existing Information (A Manual)

Assessment: Impact – High; Costs – Low; Success Risk – High; Time Frame – short

There is an extraordinary archive of reports to MLA that are relevant to the northern Production System. During the course of this review, we were slowly able to identify many reports that

provided an excellent resource to define and investigate many of the challenges facing northern beef producers.

These resources should be consolidated by quantitative review into a producer manual that would provide confidence to adopt well described existing interventions. Critically, consolidated pooled estimates of effects of interventions and practical methods to deliver these are needed to allow producers confidently to implement these. Our report identified a lack of evidence for improved efficiency of production over time (Chapter 5). Provision of a manual to address the key areas that influence farm production in a single document should assist in making producers more able to sources the resources required to support decision making. The manual should be available as a hard copy and as a web-based resource. The manual should be incorporated into existing extension programs and have extension programs developed around particular modules.

13.10.1.2 Meta-analyses for promising technologies:

Assessment: Impact – Moderate; Costs – Low; Success Risk – High; Time Frame – short

For the following interventions, there were sufficient studies to suggest that quantitative reviews, i.e. meta-analyses may be possible. Meta-analyses provide quantitative estimates of the effects that can be expected from a treatment and from which economic evaluations of the value of that treatment can be made.

In terms of evaluating whether there is merit in a particular technology or in a group of related technologies, this approach provides an evaluation of both point effects and sources of variation in responses. Three technologies appeared to have sufficient data and, either potential for benefit (bambermycin and fibrolytic enzymes) or magnitude of study programme to merit meta-analysis.

i) Bambermycin see Chapter 6

ii) Fibrolytic enzymes see Chapter 8

iii) Probiotics see Chapter 6

For the first two products, results were sufficiently positive and consistent to suggest the potential for use.

13.10.1.3 Systems Research: Integrated effects of supplement and water on grazing management, profit and sustainability:

Assessment: Impact – Moderate to High ; Costs – Moderate; Success Risk – High; Time Frame – medium

The ‘pigeonhole’ project (MLA NBP.317; 2007), discussed briefly in Chapter 13, Section 2, represents an example of systems research. There is evidence of a lack of sustainable practices i.e. low expenditure on fertilizer (Chapter 4); in the Leucaena project (Radrizzani et al. 2010) and a concern about the lack of evidence of sustainable practices was raised in several interviews (Chapter 9). Others interviewed expressed concern about the lack of adoption of existing practices that are effective and profitable (Chapter 9).

Establish program of ‘case and control’ intervention sites to examine the impact on profit and environment of ‘best practice’ interventions. Each site selected for an intervention should have a comparable control site to ensure that over time, statistically valid comparisons can be made. Sites can be staged and strategies can be refined over time using the inputs from previous

studies to identify areas to be investigated and technologies that should be adopted. These sites can act as a regional focus for extension and discussion groups. Any site selected should not be used for more than a short period, e.g. 3 years to ensure that relevance and interest (novelty) for local producers is maintained.

The aims of the project will be to examine

- the systemic effects of supplementary feeding and water supply strategies by internal and external analysis of the results of combined approaches to improve water/feed allocation, and
- to use outputs from the studies to build modelling approaches to understanding the production system.

In particular the use of supplementary feeds to

- provide practical interventions to increase performance of cattle in wet season, with aim to cost effectively achieve growth rates exceeding 1kg per head per day in yearling cattle.
- increase pasture utilization,
- transfer nutrients,
- establish pastures and
- reduce pressure on riparian and fragile zones

should be examined in conjunction with changes in weight, rumen microbiota and profit.

These and other data generated should be incorporated into decision support models to increase the confidence of producers and advisors in implementing change. In particular, changes in the modelling of dry matter production of pastures are required to effectively model responses to use of pastures. There needs to be either fully integrated or modular approaches to understanding the impacts of fertilizer use or nutrient transfer associated with supplementation on plant communities and sustainability of pasture production.

A critical part of modelling is to have adequate inputs to the predictive models. Pasture analysis and faecal NIR should be utilized to provide cross- validating inputs to nutritional models. The available data on feeds is mostly very dated (see Chapter 4). In most modern production systems there is a strong emphasis on understanding the feed base thoroughly, simply because in all ruminant production systems the greatest single input cost is feed, whether this be pasture or other feeds. In most systems, predictive computer models exist to provide estimates of likely responses to nutritional inputs. The results of the modelling (Chapter 10) show a need to refine existing models or develop new ones.

Therefore, creating a pasture/feed data base is an important part of this above project. However, interest, and great value would be derived from extending the local data and accommodating other similarly collected data in an open access, rigorously constructed database.

While greatest value on feed values is obtained for a particular property, the larger industry would benefit from pastures/feed analyses and faecal NIR determinations. These determinations contributed to an open access database would allow producers and researchers to more rapidly obtain worthwhile estimates of feeds on a seasonal basis.

13.10.1.4 Understanding the growth dynamic:

Assessment: Impact – Moderate to High ; Costs – Moderate; Success Risk – High; Time Frame – medium

Understanding the growth dynamic - A major inhibition to supplement use is concern about compensatory gain (Chapter 5). Despite a very substantial body of research, there are still substantial questions aspects of compensatory gain that are not understood (Chapter 5). Interactions between changes in ruminal conditions and body tissue pools are not well described, nor is the nature of weight lost, nor regained well characterised. Studies that combine meta-genomics characterisation of the changes that occur in the rumen, metabolomic evaluations of changes in metabolic pathways and detailed serial slaughter studies will provide an integrated picture of the responses of cattle to dry period feeding and subsequent responses to changes in the feed base.

Aims: To obtain data that will allow the optimal (cost effective) responses to the nutritional challenges of the late dry period and through the wet period. This period has the largest impact on determining animal weight gains and represents the greatest opportunity to change production efficiency either by increasing gain during the wet period, or reducing weight loss (or increasing gain) during the dry period. Notwithstanding those observations, characterizing the physiological responses to this period is critical to demonstrating that the most cost effective strategies can be implemented.

13.10.1.5 Algae

Assessment: Impact – Moderate; Costs – Moderate; Success Risk – moderate; Time Frame - medium

Algae: Responses to algae feeding were very positive (Chapter 8). For regions in which protein meals cannot be cost effectively delivered the potential to use algae to increase production has been demonstrated (Poppi and Quigley 2009). The algae represent a means to grow true protein on remote farms that may not obtain this protein by other cost-effective means. The feasibility of growing algae on remote farms should be explored.

Aim: Develop practical means to use wet season conditions to grow and harvest algae for future feeding.

There is a need to

- model responses for the feasibility of algae feeding, using data on the number and classes of cattle that these strategies would pertain to and, if use is feasible and potentially profitable for sufficient farms,
- develop engineering designs to achieve cost-efficiency of supply.

13.10.1.6 Major Programme: Understanding the rumen/ fermentation technologies

Assessment: Impact – High; Costs – High; Success Risk – moderate; Time Frame – medium to long

The changes in methods of evaluation the ruminal microbiota discussed in Chapter 8 open a new chapter in nutritional science. However, the implications of these new technologies also will

provide great benefit to a number of other areas including and human health, industrial fermentation technologies and the environmental sciences.

The most important program required is one that will have impact across the northern beef, temperate production and feedlot environments.

The changes in methods of evaluation microbial organisms and the application of these methods to the ruminal microbiota opens a new chapter in nutritional science. An understanding of how the gut microbiota contributes to the aetiology, progression and management of gastrointestinal diseases will lead to nutritional or dietary interventions (eg new generation cereal grains) that modulate gut function, to promote gut health in cattle, ruminants and potentially people. In order to give the project sufficient support, it should be expected that these other areas of investigation should be highlighted and the programme be one of exploration of anaerobic fermentation technologies. Furthermore, there are opportunities to extend this expertise beyond traditional industry partners to include a range of bionutrition companies; as well as the fossil and renewable fuel industries, which are all keenly interested in developing “cleaner and greener” technologies relevant to their commodities.

CSIRO (Queensland Biosciences Precinct) the Univeristy of Queensland, St Lucia (Australian Centre for Ecogenomics) and the *Queensland Alliance for Agriculture and Food Innovation* (UQ, Gatton Campus) have invested heavily in establishing microbial ecology groups in south-east Queensland where there is now a critical mass of more than twenty scientists with interests in anaerobic fermentation in gut ecosystems.

At present less than 20% of organisms in the rumen are characterized. The ecosystem is poorly understood and findings such as those of McLennan (2005) indicate

- less than complete understandings at present of rumen function and
- the potential to improve rumen function.

Australia has world-leading scientists, in critical mass, in southern Queensland, many of whom were interviewed for the project or had their work reviewed. These workers have links to the major research groups throughout the world. A failure of the ruminant industries to provide sufficient resources to engage these workers may lead to a loss of critical mass and loss of the resource to competing industries.

Aim: To provide the impetus and core funding for a major program of research into fermentative systems with a ruminal focus and to encourage other rural funding bodies to recognise and utilise the resources of the group. Support should be sought from Dairy Australia, RIRDC and AWI to encourage sufficient underpinning to allow potential for the group to achieve CRC or similar funding levels. In order to give the project sufficient scale and support, it should be expected that these and other areas of investigation, including environmental and fermentation sciences, should be highlighted and the programme developed be one to explore fermentation technologies.

Study areas should include the

- induction and control of acidosis (Feedlot, dairy, sheep backgrounders)
- adaptation of feedlot diets (feedlot, sheep)
- changes in ruminal conditions in the dry period and during the wet (see compensatory growth)
- impacts of supplements on ruminal efficiency

Production projects (e.g. Poppi and Quigley 2009) have already integrated aspects of ruminal microbiological characterisation. All studies that provide sufficient details of diet will be greatly enhanced by meta-genomic descriptions of the dynamics of change in the rumen. The more sophisticated understanding of ruminal conditions will allow more critical assessments of the aspects of nutrition that have most effect and profit including examination of the ruminal aspect of optimising energy and protein supplementation.

The study of the ruminal ecosystem under standard production challenges will allow a better framework in which novel interventions can be tested whether these are based on bacteriocins, AMP's, bacteriophages, vaccines, novel bacteria from other species, enzymes or any other novel modification.

Further candidate organisms for probiotic product development should be more readily identified once more detail and dynamic models of the rumen are developed from interaction studies. The role of fungi in the rumen needs re-evaluation using the new methods available and given the important role of these in high fibre diets, this research will be particularly pertinent to the northern industry. These approaches will lead to a program of new agent discovery.

Our economic modelling demonstrates that technologies that increase growth rate by 0.2kg per head for cattle in Northern Australia have a positive 10 year payback, if these have similar cost structures to ionophores and are adopted by 40% of the industry over the 10 year period. We consider that the development of at least one new intervention is a reasonable target for the program. This program can and should integrate with those that target methane production.

This program will likely integrate with studies being conducted at other sites internationally, however, there was no evidence identified in this project of a study program anywhere else in the world with a focus on tropical pastures. The evidence provided in the modelling here (Chapter 10) and by McLennan (2005) shows that aspects of rumen function are sufficiently different to other systems to require independent investigation. There is strong evidence throughout this document to support a programme of new discovery in the rumen without need to develop a specific focus. At this point in time, the looming explosion of knowledge of the ruminal ecosystem is a strong basis for the argument that we should not limit the approach to discovery based on current understandings, rather encourage a robust programme of more basic research. That programme of basic research can be framed by the applied context of understanding ruminal responses to supplementation and during challenge with existing and novel technologies to address immediate questions for the production system and to evaluate novel solutions to the limitations.

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15 Appendices

15.1 Appendix I

Table 1. Description of biofeed products registered with the Australian Pesticides and Veterinary Medicine Authority (APVMA) in 2010

Product	Company	Type	Active Ingredients	Claim	Date Registered	Form
Levucell SC 20	Lallemand Inc, Animal Nutrition	Yeast	*Saccharomyces cerevisiae*	Improves fibre digestibility Maintain performance Establishment of GI microflora	Mar 2010	Powder
Levucell SC 10ME Titan	Lallemand Inc, Animal Nutrition	Yeast	*S. cerevisiae*	Improves fibre digestibility Maintain performance Establishment of GI microflora	Mar 2010	Powder
Nutrition Physiology Corporation Npc Beef Culture	Nutrition Physiology Corporation	Probiotics	*Lactobacillus acidophilus* - Strain 45 *L. acidophilus* - Strain 51 *Propionibacterium freudenreichii*	Microbial feed additive for beef cattle for the maintenance of healthy animals during normal husbandry practice.	Jun 2007	
Priority Start Up Gel	Priority IAC Inc.	Probiotics and yeast	*L. acidophilus, Enterococcus faecium, Lactobacillus casei, Lactobacillus brevis, Lactobacillus plantarum, S. cerevisiae*	Establishment of gastrointestinal microflora Reduces weaning and feedlot stress	Mar 2003	Oral Gel
Priority Start Up Capsule	Priority IAC Inc.	Probiotics and yeast	Lactic acid bacteria Vitamin A, choline Vitamin B12, niacin supplement, pantothenic acid as calcium pantothenate, Vitamin D, Vitamin E, *S. cerevisiae*	Maintenance and performance	Mar 2003	Capsule
Priority Dcp	Priority IAC Inc.	Enzymes, Yeast and Probiotics	Amylase, Beta Glucanase, Hemicellulase, *S.cerevisiae, L. acidophilus, P. freudenreichii*	Maintenance and performance	Mar 2003	Powder
Performance Bovine Direct Fed Microbial Gel (Dairy)	Performance Products Inc	Probiotics and yeast	*Bifidobacterium longum, Bifidobacterium thermophilum, Enterococcus faecium, L. acidophilus, S. cerevisiae*	Promotes healthy bacteria, increases feed utilization and maintains a balanced ph	Jan 1999	Oral Gel
Performance Bovine Direct Fed Microbial Powder (Dairy)	Performance Products Inc	Enzymes, Yeast and Probiotics	Alpha Amylase (From *B. subtilis*), Beta Glucanase, Hemicellulase (*B. subtilus*), Poly Glycanohydrolase, *B. longum, B.thermophilum, B.Subtilis, L. acidophilus, S. cerevisiae, Streptococcus faecium*	Promotes healthy bacteria, increases feed utilization and maintains a balanced ph	Jan 1999	Powder
Acid-Pak 4-Way W.S.	Alltech Biotechnology Pty Limited	Enzymes, Minerals and Probiotics	Amylase, Protease, potassium, sodium, *E. faecium, L.acidophilus*	Aids normal gut function and establishment of bacteria	Nov 1996	Powder

Lacto-Sacc	Alltech Biotechnology Pty Limited	Probiotics and Yeast	Lactic acid bacteria, Beta- glucan (Encapsulating Agent), dried *Aspergillus niger* fermentation extract, dried Aspergillus oryzae fermentation extract, dried Bacillus subtilis fermentation extract, fermentation solubles, dried *L. acidophilus* fermentation product, dried *S. faecium* fermentation product, silicon dioxide, *S. cerevisiae*		Nov 1996	Powder
D-Scour Paste	International Animal Health Products Pty Ltd	Plant Extract and Probiotics	*Garlic extract, B. bifidum, E. faecium, Lactobacillus delbrueckii Subspecies bulgaricus, L. acidophilus, L. plantarum, L. rhamnosus, S. salivarius Subspecies thermophilus*	Controls scouring	Dec 2005	Oral Paste
Protexin Paste	International Animal Health Products Pty Ltd	Probiotics	*B. bifidum, E. faecium, Lactobacillus delbrueckii Subspecies bulgaricus, L. acidophilus, L. plantarum, L. rhamnosus, S.salivarius Subspecies thermophilus*	Improves growth, feed utilization, intestinal function and establishment of microflora	Dec 2004	Oral Paste
Protexin Professional Concentrated Multi-Strain Probiotic For Animals And Birds	International Animal Health Products Pty Ltd	Probiotics	*B. bifidum, E. baecium, L. delbrueckii Subspecies bulgaricus, L. acidophilus, L. plantarum, L. rhamnosus, S. salivarius subspecies Thermophilus*, Protexin	Improves growth, feed utilization, intestinal function and establishment of microflora	May 1999	Powder
Protexin Powder Multi-Strain Probiotic For Animals And Birds	International Animal Health Products Pty Ltd	Probiotics	*B. bifidum, E. baecium, L. delbrueckii Subspecies bulgaricus, L. acidophilus, L.plantarum, L. rhamnosus, S. salivarius subspecies Thermophilus*, Protexin	Improves growth, feed utilization, intestinal function and establishment of microflora	Nov 1996	Powder
Protexin Soluble Concentrated Multi-Strain Probiotic For Animals And Birds	International Animal Health Products Pty Ltd	Probiotics	*B. bifidum, E. baecium, L. delbrueckii Subspecies bulgaricus, L. acidophilus, L.plantarum, L. rhamnosus, S. salivarius subspecies Thermophilus*	Improves growth, feed utilization, intestinal function and establishment of microflora	Nov 1996	Powder
Farmer Peck's Yeast Concentrate	Animal Performance Enhancing Products Pty Ltd	Yeast	*S. cerevisiae*	Optimum rumen function on high forage diets	Oct 2000	Powder
Diamond V "Xp" Yeast Culture	Diamond V Mills Inc	Yeast, Enzymes And Probiotics	*P. freudenreichii, Lactobacillus acidophilus, L. casei, L.lactis, Pediococcus cerevisiae, E. faecium, B. subtilis, B. licheniformis, A. oryzae, A. niger, Trichoderma viride* and dried culture media from yeast fermentation of *Saccharom*.	Improves the symbiotic relationship between enzymes and microbes and the rumen	Jan 2001	Powder
Digest 'M' Feed Mate Grain Sorghum Specific Enzymes Carbozyme	Pro Beef Australia Pty Limited	Enzyme	Carbohydrase and cellulase		Not stated	Oral Solution

15.2 Appendix II

Modern molecular techniques in rumen microbiology

Recent advances in molecular technologies have facilitated dramatic increases in our current knowledge of rumen microbiology and ecology. Despite the constant evolution of molecular techniques, only a minute proportion of the estimated rumen microbiological population has been identified. This section briefly describes the new developments in molecular techniques used in rumen microbiological studies including:

- metagenomic analysis
- gene expression analysis
- microarrays
- a new RNA extraction protocol
- automated ribosomal intergeric spacer region (ARISA) method
- new primer sets
- next-generation sequencing.

Recent reviews are available on the complete range of traditional and molecular techniques used in the study of microbial ecology in animals (Deng et al 2008; Makkar and McSweeney 2005; McSweeney et al 2006; Zoetendal et al 2004).

Scientists in Northern Australia that are utilizing and developing molecular techniques in beef rumen microbiology include Assoc. Prof. A. Klieve and Dr D. Ouwerkerk from the Department of Primary Industries in Queensland and Prof. M. Morrison, Dr. C. McSweeney and Dr. S. Denman from CSIRO Livestock Industries (Klieve et al 2003; Morrison and Mackie 1996; Ouwerkerk et al 2002).

The introduction of molecular based methodologies has improved our knowledge of rumen microbial communities and the identification, function and enumeration of individual populations. The next step is to link structural analysis to functional gene activity (McSweeney et al 2009). The newer molecular technologies are more effective and efficient than culture-based, hydrization or fingerprinting techniques, which are summarized in Table xx, owing to their high sensitivity, reproducibility and dynamic ranges.

The choice of molecular technique used in a rumen ecological study is determined by the question being addressed (Zoetendal et al 2004) as each method has its own advantages and disadvantages (Table 1). Newer techniques are often used in combination with older techniques. The foundation of a number of molecular techniques is the small subunit (SSU) 16S rRNA/rDNA gene from prokaryotes or SSU 18S rRNA/rDNA gene from eukaryotes because these are highly conserved and provide a species-specific signature aiding in identification (Meyer et al 2010). The majority of molecular techniques involve polymerase chain reaction (PCR), a technique developed by Kary Mullis in the 1980s that revolutionized science (Valasek and Repa 2005). The PCR copies and amplifies DNA in steps know as denaturation, annealing and elongation (Freeman et al 1999). Real-time PCR and competitive PCR are commonly used to detect and quantify rumen micro-organisms.

At present, a *metagenomic* approach toward rumen microbiology investigation is being adopted. This approach involves studying the genomes of all organisms within entire rumen microbial communities collectively (Singh et al 2008). The DNA extracted from a microbial community is cloned in a host, producing a clone library. This library can be screened by PCR or hybridization methods to identify genes encoding for specific steps in known metabolic pathways (McSweeney et al 2009). The metagenomic approach has the advantage of producing a catalogue of genetic

information on the entire ecosystem and can identify novel gene sequences (McSweeney et al 2009).

Gene expression analysis is a method that can be used to investigate the functional activity of rumen micro-organisms. The expression of genes that contribute to a function can be achieved by reverse transcription PCR. Yu and Foster (2005) describe gene expression analysis techniques for ruminant studies in further detail. Problems in extracting RNA and the priming of cDNA synthesis have slowed the development of gene expression analysis (McSweeney et al 2009).

DNA microarrays are increasingly being adopted as a rapid, high throughput method of detecting and enumerating rumen microbial systems. The two primary types of DNA microarrays in use are phylogenetic oligonucleotide microarrays and functional gene arrays (McSweeney et al 2009). Microarrays work on the hybridization principle and consist of glass slides that have been spotted with thousands of DNA oligosaccharides of specific genes, which are referred to as probes (Taniguchi et al 2001). Complementary DNA (cDNA) from the target or unknown sequence from the micro-organism being investigated is mixed with two different fluorescent dyes, applied to the slide and hybridizes to the complimentary oligosaccharides, emitting fluorescence in the process (Taniguchi et al 2001). Comparing the fluorescent intensity from each of the spotted probes provides the relative expression levels of thousands of genes in one assay, a significant advantage over more traditional blot hybridizations (Taniguchi et al 2001).

The majority of previous studies have used DNA based methods to identify and classify microbial diversity because degradation of RNA commonly occurs during extraction and co-extraction of phenolic compounds is common (McSweeney et al 2009). A new RNA extraction protocol has been developed, allowing the use of RNA to examine microbial diversity (Kang et al 2009). RNA-based approaches more accurately represent bacterial growth activity then DNA approaches (Wagner 1994).

The development of the automated ribosomal intergeric spacer region (ARISA) method has allowed for increased knowledge of the genetic diversity of ruminal fungi (Denman et al 2008; Edwards et al 2008). Previously the study of fungal genetic diversity has been difficult; however, ARISA now enables the discrimination between fungi to the genus level (McSweeney et al 2009).

The design and subsequent publishing of new primer sets for amplifying specific rumen bacteria is facilitating rapid investigation into these bacteria. Primer sets are now available for the following bacteria: *Anaerovibrio lipolytica*, *Butyrivibrio fibrisolvens*, *Eubacterium ruminantium*, *Prevotella albensis, P. brevis*, *P. bryantii*, *P. ruminicola*, *Ruminobacter amylophilus*, *Selenomonas ruminantium*, *Streptococcus bovis*, *Succinivibrio dextrinisolvens*, *Treponema bryantii*, *Genus Prevotella* (Tajima et al 2001; Ouwerkerk et al 2002; Stevenson and Weimer 2007; Weimer et al 2008).

Many molecular technologies involve and can be limited by DNA sequencing, which is a labour intensive and time consuming procedure. New-generation sequencing, for example pyrosequencing, is increasingly being used as a more cost-effective, high throughput sequencing method, with improved accuracy (McSweeney et al 2006). Pyrosequencing is based on the principle of sequencing by synthesis. When a nucleotide is incorporated during synthesis of the complementary DNA strand (cDNA) from the DNA strand being sequenced, a pyrophosphate molecule is released, triggering an enzymatic reaction emitting light that is detected by a camera and analysed to determine the sequence as the nucleotides added are known (Ronaghi 2001).

In summary, recent advances in molecular techniques have improved our knowledge of rumen microbiology; however, only a small percentage of the microbial community has been identified.

Table 1. Summary of techniques used to study rumen microbial ecosystems (adapted from Zoetendal et al 2004, Deng et al 2008)

Type	Method	Abbrev.	Uses	Description	Advantages	Limitations
Culture	Roll-tube		Isolation Enumeration	Based on cultivation	Isolates populations	Labour intensive Not representative Requires knowledge of growth requirements Only a small portion of microbes are culturable 16S/18S rRNA/rDNA-based analysis required for identification Low sensitivity
	Most-probable-number	MPN	Enumeration	Based on several dilutions and incubations of cultures	Only estimates live mirco-organisms	Low sensitivity Labour intensive Time consuming Not representative Only a small portion of microbes are culturable
Hybridization	Dot blot hybridization eg Southern and Northern		Hybridization Detection Relative abundance	PCR products separated by gel electrophoresis and hydridized with probes on a filter membrane	More accurate than micro arrays	Sequence information required Labour intensive at the species level Large amounts of RNA required
	DNA micro arrays		Detection Enumeration	cDNA mixed with two fluorescent dyes applied to thousands of spots of DNA oligoscharides	Thousands of genes studied simultaneously High specificity	Low sensitivity
	Florescence *in situ* hybridization	FISH	Detection Enumeration Comparative analysis	Fluroscent labeled probes hydridise to target sequences	Many probes can be used at once High sensitivity	Sequence information required Labour intensive at species level Lack of probes
	Suppressive subtractive hybridization	SSH	Isolation of DNA fragments Comparative analysis	Suppressive PCR Common DNA sequences eliminated	Can differentiate between two genetically similar organisms cDNA can be used as probes to screen libraries High efficiency	Subtraction fragment redundancy Labour intensive
PCR	Competitive polymerase chain reaction	cPCR	Detection Quantifies absolute abundance	Compares known copies of internal standards to target sequence	High sensitivity	Labour intensive Requires preparation of internal standards
	Real-time PCR	qPCR	Detection Quantifies absolute abundance	Monitoring DNA amplification by fluorescence	Quantifies wide dynamic ranges High sensitivity No post PCR steps Minimal contamination risk High throughput Easy, reliable and reproducible	Expensive equipment False negatives Relies on accuracy of standards and quality of PCR products
Fingerprinting	Restriction fragment length polymorphisms	RFLP	Monitors community shifts Comparative analysis	Discriminates by variation in restriction enzyme sites	Very sensitive High throughput	Subject to PCR biases Clone library required for identification Semi-quantitative
	Denaturing	DGGE	Monitors	Based on DNA melting	Doesn't require radioactivity	Subject to PCR biases

	gradient gel electrophoresis and Temperature gradient gel electrophoresis	TGGE	community shifts Comparative analysis	points	Efficient and accurate at identifying mutations Less labour intensive than blot methods Inexpensive	Clone library required for identification Semi-quantitative
Phylogenetic	Clone libraries		Phylogenic identification New microbe discovery	Databank of known DNA sequences	Enables phylogenetic classification and discovery of new organism Easy access	Labour intensive Subject to PCR bias Expensive
Sequencing	Pyrosequencing		Sequences	Detects light emitted as a nucleotide is added	High accuracy No need for gel-electrophoresis or labeled primers Inexpensive Wide variety of applications	

15.3 Appendix III

Survey 1– Increasing Production Efficiency for cattle in Northern Australia

1. Name of interviewee……..

2. Date of interview……

3. Institution or Organisation of Interviewee…….
- i) Address: ……..
- ii) Phone: ……..
- iii) Email: ……..

4. Area of interest -
- i) Rumen modification or supplement use in cattle……
- ii) Other bovines or camelids (Bantang cattle, camelids, buffalo.)
- iii) Exotic species. (marsupials etc) ……..
- iv) Expertise or experience of interviewee……
- v) Other……

5. Where do you see the greatest potential to increase efficiency of rumen function in cattle fed on tropical pastures?…….....

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6. Are you aware of any modifiers or /supplements that are presently available that could make a significant difference to cattle production systems in northern of Australia?. Please provide the following information on these;

Modifier or supplement	**Availability (1 poor to 5 readily available)**	**Pasture-based or feedlot or both**

Comments:……
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7. What delivery systems would be required to provide that modification to tropical pasture-based and feedlot cattle? And in your opinion which one is the most effective method? Please provide the information on delivery systems in the following table;

Delivery systems	**Pasture-based**	**Effectiveness (1 poor to 5 very high)**	**Feedlot**	**Effectiveness (1 poor to 5 very high)**

Comments:
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8. In regard to a short-term (i.e. 5-year) horizon for research, which rumen modification technologies do you think have the greatest potential to modify cattle production systems in the north of Australia (manipulations of the animal. not pasture)?

Modifier or supplement	**Pasture-based (Estimates with median and range)**			**Feedlot (Estimates with median and range)**		
	Cost/ head ($)	Increase in weight gain efficiency (%)	Adoption in 5 years from onset (% cattle)	Cost/ head ($)	Increase in weight gain efficiency (%)	Adoption in 5 years from onset (% cattle)

Comments:……
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9. In regard to medium term i.e. 15 year horizon research, which rumen modification technologies do you think have the greatest potential to modify cattle production systems in the north of Australia (manipulations of the animal not pasture)?

Modifier or supplement include delivery system detail	**Pasture-based (Estimates with median and range)**			**Feedlot (Estimates with median and range)**		
	Cost/ head ($)	Increase in weight gain efficiency (%)	Adoption in 5 years from onset (% cattle)	Cost/ head ($)	Increase in weight gain efficiency (%)	Adoption in 5 years from onset (% cattle)

Comments:……
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10. In regard to longer term research (25-30 year horizon), and bearing in mind that results would necessarily need to be of a greater magnitude for effective investment, which technologies appear to have the most potential from an animal perspective to improve productivity?

Technologies	**Likelihood of adoption (estimates with median & range)**	**Magnitude of improved efficiency (estimates with median & range)**

Comments:……
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11. Can you recommend others working in this field that may be available to provide us with additional insights?

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12. In considering potential options that may be effective at improving the efficiency of metabolism of cattle in northern Australia, please rate the following areas (1 to 5) in terms of the following 4 aspects:

i) Implementation cost
ii) Efficacy – expressed as percentage weight gain OR increased conception rate
iii) Increased profit (benefits)
iv) Potential adoption rate

(each of these is rated on a scale 1 to 5 (1 is the lowest and 5 is the highest)).

Existing rumen modifiers include the following:

1. Cost of implementation

Products/supplements	1	2	3	4	5
Ionophores (eg. Monensin, Lasalocid, Salinomycin)					
Antibiotics (eg Virginiamycin, Tylosin)					
Bambermycin (eg. Flavomycin)					
Yeast (eg. Diamond V, YeaSac)					
Probiotics (Protexin)					
Micro-minerals or vitamins (eg. Copper, Cobalt, Vitamin A)					
Macro-minerals (eg. Phosphorus, Calcium)					
Protein or non-protein nitrogen addition					
Others (eg. polyethylene glycol)					

Comments:……
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……
……

2. Efficacy

Products/supplements	1	2	3	4	5
Ionophores (eg. Monensin, Lasalocid, Salinomycin)					
Antibiotics (eg Virginiamycin, Tylosin)					
Bambermycin (eg. Flavomycin)					
Yeast (eg. Diamond V, YeaSac)					
Probiotics (Protexin)					
Micro-minerals or vitamins (eg. Copper, Cobalt, Vitamin A)					
Macro-minerals (eg. Phosphorus, Calcium)					
Protein or non-protein nitrogen addition					
Others (eg. polyethylene glycol)					

Comments:……
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3. Increased income

Products/supplements	1	2	3	4	5
Ionophores (eg. Monensin, Lasalocid, Salinomycin)					
Antibiotics (eg Virginiamycin, Tylosin)					
Bambermycin (eg. Flavomycin)					
Yeast (eg. Diamond V, YeaSac)					
Probiotics (Protexin)					
Micro-minerals or vitamins (eg. Copper, Cobalt, Vitamin A)					
Macro-minerals (eg. Phosphorus, Calcium)					
Protein or non-protein nitrogen addition					
Others (eg. polyethylene glycol)					

Comments:……
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4. Adoption rate

Products/supplements	1	2	3	4	5
Ionophores (eg. Monensin, Lasalocid, Salinomycin)					
Antibiotics (eg Virginiamycin, Tylosin)					
Bambermycin (eg. Flavomycin)					
Yeast (eg. Diamond V, YeaSac)					
Probiotics (Protexin)					
Micro-minerals or vitamins (eg. Copper, Cobalt, Vitamin A)					
Macro-minerals (eg. Phosphorus, Calcium)					
Protein or non-protein nitrogen addition					
Others (eg. polyethylene glycol)					

Comments:……
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13. How would you rank the overall benefits and adoption rate of these modifiers or supplements? Take into account the level of current knowledge, technology required for implementation, fit with current nutrition management practices, level of investment required, return on that investment in benefits to the industry. Rank these from one to eight (one is low eight is high).

Products/supplements	Rank	Reasons
Ionophores (eg. Monensin, Lasalocid, Salinomycin)		
Antibiotics (eg Virginiamycin, Tylosin)		
Bambermycin (eg. Flavomycin)		
Yeast (eg. Diamond V, YeaSac)		
Probiotics (Protexin)		
Micro-minerals or vitamins (eg. Copper, Cobalt, Vitamin A)		
Macro-minerals (eg. Phosphorus, Calcium)		
Protein or non-protein nitrogen addition		
Others (eg. polyethylene glycol)		

Comments:……
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14. What is your view of the potential for developments in:

i) Manipulation of bacterial populations – especially by bacteriophages

ii) Transgenic insertions into ruminal bacterial populations

iii) Manipulations of fungal populations

iv) Manipulations of protozoal populations

v) Post-ruminal manipulations

15. What is your view of the potential for:

i) vaccinal control of rumen populations

ii) probiotic delivery i.e. specific bacteria and specify these.

iii) Plant bioactive compounds

iv) Enzyme co-factor use

v) Animal genetic selection

16. List or discuss any regulatory issues, industry features, trade issues, extension needs or scientific issues that could impact on the benefits of any of these modifiers or supplements.

Survey 2 - Questionnaire – Increasing Production Efficiency for cattle in Northern Australia

1. Name of interviewee……..

2. Date of interview……

3. Contact details.....……..
   i) Address:

   ii) Phone:
   iii) Email:

1. Occupation
   a. Wholesaler.....……..
   b. Reseller.....……..
   c. Feed manufacturer .....……..
   d. Other……..

5. What region/s of the Northern Beef Industry do you represent or service?

South West Qld	Central Coastal Qld	Central Highland Qld	Central West Qld	Northern Qld	North West Qld	North NT	North WA	Other

6. In your region what **proportion or number of <u>grazing beef producers</u>** in northern Australia are **<u>currently</u> (ie the past 12 months)** using the following technologies?

Technology	Percent of Properties (%)	Classes of stock where product is used - estimated percentage usage (E.g.: 20%)					Sum
		Bulls	Breeders	Heifers	Steers & bullocks	Calves & (weaners)	
Protein meal (eg cottonseed)							%100
Non-protein nitrogen (eg urea)							%100
Energy source (eg molasses, PEG)							%100
Ionophores							%100

(eg monensin, lasalocid)							
Antibiotics (eg virginiamycin, tylosin)							%100
Bambermycin (eg Flaveco, flavomycin)							%100
Macrominerals (eg P or Ca or S or salt)							%100
Microminerals (eg Cu, Co, Se)							%100
Probiotic (Protexin)							%100
Yeast (eg Diamond V)							%100
Others							%100

7. In your region what **proportion or number of <u>feedlot producers</u>** in northern Australia are **<u>currently</u> (ie the past 12 months)** using the following products? Please provide the following information on the products through which these are delivered:

Technology	**Percent of Properties (%)**	**Classes of stock where product is used - estimated percentage usage (E.g.: 20%)**		**Sum**
		weaners (< 12 months age)	**(> 12 months old)**	
Protein meal (eg cottonseed)				100%
Non-protein nitrogen (eg urea)				100%
Energy source (eg molasses, PEG)				100%
Ionophores (eg monensin, lasalocid)				100%
Antibiotics (eg virginiamycin, tylosin)				100%
Bambermycin (eg Flaveco, flavomycin)				100%
Macrominerals (eg P or Ca or S or salt)				100%
Microminerals (eg Cu, Co, Se)				100%
Probiotic (Protexin)				100%
Yeast (eg Diamond V)				100%
Others				100%

8. What delivery systems (blocks, boluses, licks, etc.) are **<u>currently</u>** used for supplementation of **rumen modifiers and feed additives** to grazing beef cattle in northern Australia? And in your opinion which one is the most effective method and cost-effective?

Technology	**Delivery mode (list all common)**	**Effectiveness (1 poor to 5 very high) Score for each in list**	**Cost-effectiveness (1 poor to 5 very high) Score for each in list**
Protein meal (eg cottonseed)			
Non-protein nitrogen (eg urea)			
Energy source (eg molasses, PEG)			
Ionophores (eg monensin, lasalocid)			
Antibiotics (eg virginiamycin, tylosin)			
Bambermycin (eg Flaveco, flavomycin)			
Macrominerals (eg P or Ca or S or salt)			
Microminerals (eg Cu, Co, Se)			
Probiotic (Protexin)			
Yeast (eg Diamond V)			
Others			

Comments:……
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9. In your opinion, who is most used for advice on the use of rumen modifiers/feed supplements in your region?

	Yes/No	Ranks (1= Least; 5=Most)				
		1	**2**	**3**	**4**	**5**
Farmers						
Nutritionists						
Agronomists						
Veterinarians						
Feed/manufacturers sale representatives						
Animal Health Advisor						
Govt. staff (DPI extension officer)						
University staff						
Other						

10. In your opinion which class of cattle will benefit more from supplementation? (1 being lowest and 6 highest). Comment if you wish.

Class of cattle	**Benefits** (1 being lowest and 6 highest)
Breeders	
Steers & Bullocks	
Heifers	
Bulls	
Calves & weaners	
Feedlot	

11. What are the main reasons for the use of feed additives and supplements by producers in your region?

	Ranks (1= Least; 5=Most)				
	1	**2**	**3**	**4**	**5**
Improve the survival rate (eg, reduce the mortality rate) during the dry sea					
Improve the weight gain or reduce the amount of weight loss during the dry season					
Improve the fertility rate					
Other (specify)					

Comments:……
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……

12. What nutrient deficiencies affecting animal production do you know exist in your region? Please rate the level of deficiency (1 being no deficiency and 5 very deficient) for each mineral:

Mineral	**South West Qld**	**Central Coastal Qld**	**Central Highland Qld**	**Central West Qld**	**Northern Qld**	**North West Qld**	**North NT**	**North WA**
Protein / Nitrogen								
Energy								
Calcium (Ca)								
Phosphorus (P)								

Salt/Sodium (NaCl)								
Selenium (Se)								
Sulphur (S)								
Cobalt (Co)								
Copper (Cu)								
Iodine (I)								
Manganese (Mn)								

13. What are the main commercial products (eg. M8U) that are **currently** sold to the producers in your region for different classes of cattle? Please provide a list of products, dose rate, class of cattle and season?

Commercial products	Class of cattle	Dose rate (per head)	Delivery method	Season (dry vs wet)

Comments:……
……
……
……

14. In your opinion which delivery method is most common, feasible and cost-effective in your region? Please rate the selected delivery method (1 being lowest and 5 highest). Please comment on obstacles to use of these delivery methods in your region.

Delivery methods	Adoption rate	Feasibility	Cost-effectiveness	Comment
Blocks				
Loose mix				
Water inclusion				
Pellets				
Molasses inclusion				

Comments:……
……
……
……

15. What are the common transport methods for delivery of supplements to the producers? Please rate the selected transport method (1 being least and 5 most common). In your opinion is the cost of transport major limiting factors for the use of supplement in your region?

Transport methods	Adoption rate	Feasibility	Cost-effectiveness	Comment
Manufacturers vehicle				
Wholesaler /reseller vehicle				
Hired vehicle				
Producer's transport				
Helicopter				
Mail or courier				
Others				

Comments:……
……
……
……

16. What are the other products that you would like to sell in your region but are not currently available? In your opinion why the producers prefer to use these new products?

New products	Availability in Australia	Availability in your region	Reason for the preference

Comments:……
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……
……

17. Please rate the following products/supplements on a scale of 1 to 5 (1 is lowest and 5 is highest) in terms of potential benefits (increased profits versus cost).

Products/supplements	1	2	3	4	5
Ionophores (eg. Monensin, Lasalocid, Salinomycin)					
Antibiotics (eg Virginiamycin, Tylosin)					
Bambermycin (eg. Flavomycin)					
Yeast (eg. Diamond V, YeaSac)					
Probiotics (Protexin)					
Micro-minerals or vitamins (eg. Copper, Cobalt, Vitamin A)					
Macro-minerals (eg. Phosphorus, Calcium)					
Protein (eg cottonseed)					
Non-protein nitrogen addition (eg. Urea)					
Energy source (eg molasses, PEG)					
Others (eg. polyethylene glycol)					

Comments:……
……
……
……

18. Are the benefits of the use of modifiers/feed supplements measured and recorded to validate the efficacy of the products?

□ Yes□□ No If yes, how?

Comments:……
……
……
……

19. In your opinion, what are the greatest obstacles to uptake of the following feeding or rumen modification technologies (rate each factor 1 to 5)?

Products/supplements	Basic cost	Transport cost	Labour	Knowledge of effect	Availability
Ionophores (eg. Monensin, Lasalocid, Salinomycin)					
Antibiotics (eg Virginiamycin, Tylosin)					
Bambermycin (eg. Flavomycin)					

Yeast (eg. Diamond V, YeaSac)					
Probiotics (Protexin)					
Micro-minerals or vitamins (eg. Copper, Cobalt, Vitamin A)					
Macro-minerals (eg. Phosphorus, Calcium, salt, sulphur					
Protein (eg cottonseed)					
Non-protein nitrogen addition (eg urea)					
Energy source (eg molasses, PEG)					
Others (eg. polyethylene glycol)					

Specify if other eg stability products.....
.....
.....
.....

20. Can you identify improvements you would like to see in these, and would these improvements enhance the sale/purchase of the supplements in your region?
.....
.....
.....
.....

Unstructured responses to survey questions

Table 3- Potential research topics for improving the efficiency of rumen function in cattle fed tropical pastures

- Understand the efficiency of conversion (of nutrients) from the soil/ plant interface to final product. - Ecosystem maintenance is critical, fragile and unpredictable, adaptation is critical - Provision of good feed is the overwhelming principle governing management - Need variable weaning systems- need to finish cattle prior to the dry season (periods of poor pasture) - Need to understand the biological system, particularly through modelling approaches using system- computer models - Substrates, nitrogen, sodium, micronutrients, cobalt, selenium are critical
- Supplementation - Distribution systems (probiotics – may have promise)
- Improve fibrolytic process - Better transition in environment – ie from the wet to dry season
- Increase microbial protein production - currently low RDN - Increase DMI - i) Understand microbial populations ii) substrate supply is critical
- Fibre utilisation needs to be improved - Co-factor provision is also vital
- Increase intake - limited intake - eliminate dry season - Change digestibility of the pasture - Both substrate and manipulations to improve the digestibility of pasture are important
- Rumen modifiers and monensin - how to modify to decrease methane and CO_2 using DNA technology, but effective solutions depend on delivery systems
- Proper mineral supplementation - meeting physiological requirements eg P, Ca, Mg but Phosphorus is #1
- Use of supplements – there are opportunities to replace forage base - i) Increase microbial protein/production - ii) Pasture supplementation - production feeding and replace base pasture - Room to increase adoption of supplements <5% production fed - Costs of supplement a big problem - no grain. Cattle are given much sugar cane on coast. In some areas supplement availability is low and costs are high eg NT/Pilbara (N/P)
- Production is difficult because the major nutrients are limiting - Intake low because of low digestibility - Traditional supplementary feeding – stocking density is low - Modifiers – opportunities are limited in reality - Ruminant ecosystem - knowledge is at present low only recently advanced. Reductive acetogenesis being investigated but there are limitations. System is extremely complex and big changes are not easy to achieve
- Reproduction – return on investment is greatest from controlling reproduction - reversibly controlling oestrus – control season by season using this approach
- See a role for feed additives
- Increasing the adoption/use of phosphorus supplementation in animals grazing phosphorus deficient country i.e.

	cattle breeding country
-	Supplementation of grazing cattle over the growing season with the appropriate rumen modifiers and development of suitable vehicles for administration of such compounds at that time of year
-	Wet season supplementation of phosphorous
-	Mass progress is likely with better quantitative application of low cost/low labour inputs
-	Better use of NPN/Phosphorous inputs > concentrates/protein meals
-	Grass – feed deficits
-	Stocking rate adequacy
-	Water and bull management
-	Target net beef production
-	Keep cattle confined and feed specific diet with appropriate rumen modifiers and supplements

Table 4. Short (< 5 yr), medium (15 yr) and long term (25-30 yr) horizon for research and modification technologies with the greatest potential to modify cattle production systems in northern Australia

Theme	Short-term (< 5 yr)	Medium (15 yr)	Long term (25-30 yr)
Environmental	- Map plant communities - Focus on sustainability - Define and target soil fertility risk - Phosphorous will become limiting over time - apply to deficient contry - Environmental management to reduce aspects of heat or extreme wet - Non-toxic sources of nitrogen and cheaper sources of phosphorous		- Quantitative pasture management - Sustainable stocking rates - Research into the animal/ plant interface
Delivery Systems	- General improvement required ie. for oils, grains, urea and P - Block systems have a high application - Application of urea via water dispensers - Mix to deliver effective inputs including, minerals, protein, ionophores and flavomycin - Scientific basis for using blocks/licks - trial demonstrated an extra 100 g per day growth - Slow release - Water medication	- Improve phosphorous delivery	- Straw utilization
Utilisation of existing technologies	- Re-investigate basic technologies - Bentonite -may control mycotoxins - Leucaena - innoculation - Bolus technology - improve and re-use it -Probiotics - M. eldsenii to improve adaption to grain based diets - no weight response Estimated response 0.1 -0.3kg/day response in feedlots - Rumen modifiers - Extension to increase adoption of ionophores Incorporate NPN with energy and co-factors - Urea in water - Application of nutritional technologies - Understand nutrient intake with NIR - Integrated R and D to weight gain or loss		
New technologies/delivery methods	- Casava foliage - Algae in drinking water - possible to capture co-factors - Bioactives – reduce methane emissions - Bacteriophages	- Bioactives, bacteriocins, nisin -Evaluate these in regards to food grade additives in the food chain - Probiotic/management to deliver microbial protein production - Vaccines eg antimethanogen	- Bacteriocins - Attack archae these using bacteriophages to provide knockdown and allow reductive acetogenesis -Target knockdown of species - Plant extracts to provide potent antimethogens

	- Bagasse treatment - allowed reasonable performance with up to 30% inclusion	- enhance immune responses to vaccines - Fungal adaptations - Novel organisms - t lactate utilisers eg Selenomonas ruminantium, fibrolytic bacteria eg *B fibriosolvens* - Enzyme or active that could digest fibre - Remote drafting systems, use of NLIS to control access to supplements - Slow release systems for delivery of ionophores	- Perfection of transfer of rumen organisms, especially for lignin digestion and methane emissions
Genetics/GMOs	- Greater emphasis on tropical cattle types - *Bos indicus* cross cattle	- Plant manipulation to improve nutritional attributes - Genetically modified organism are proven for delivery - Reductive acetogenesis via genetic material from kangaroos and other species.	- Modified bacteria and external enzymes are possibilities, but rated as only 15% chance of successful implementation - Investigate what genetic complement acts as agonists or antagonists - How to define 'genotype' in rumen biology, Combine compared to SNIP based definition of host - Genetic selection
Other	- Collate existing materials - Prohibitive current costs of supplementation will change - Methods to capture more carbon in the cow - Increase weight gain to increase reproductive efficiency and increase longevity- $35/animal - increase by about 50-75% in calf, and provide a weight gain benefit - Use of modified microorganisms for Leucaena - Aim to reduce underfeeding by management control oestrus – turn off or switch on	- Find mechanistic research to build models, in part to identify research options and long term management tools - Duckweed - Legume inputs - System integration modeling *Pongonia glabra* as a source of bypass protein - Comparative species analyses - Overcoming acidosis in the feedlot - Methods to capture more carbon into the cow - Cost effective individual animals treatments to overcome the issue of variable intakes ie. new type of bolus that include pulse dosing with anthelmintics or trace minerals - Improved understanding of rumen micro-organisms leading to, for example better ways of manipulating populations	-Early wean as young as 1 month needs greater adoption - Manipulation of rumen ecosystem - May need to couple substrate with modifier - Reproduction - Comparative microbiology/physiology of camels - Market specifications and meat quality – aim to fit the market eg. Grain finished - Application of quantitative nutrition

Table 5. Potential of development of new technologies to modify cattle production systems in northern Australia

The manipulation of bacterial populations- especially by bacteriophages	Transgenic insertions into ruminal bacterial populations	Manipulation of fungal populations	Manipulations of protozoal populations	Post-ruminal manipulations
Confident that this should be studied	Not too optimistic - ecosystem competition-low probability- low priority	Low Biomass - fibre digestion- may be useful-free lipid-fungi	May not be strong - Bidirectional protein supply- modulate the systems	Limited intestinal capacity for carbohydrates
Support carefully defined research - rated low	Fluoracetate an example - not too valuable for efficiency- rated low	Sulphur - fungi, maybe worthy of high rating	May have benefit - could be useful in North	Possible - middle rank
Probably low - could have a high potential	Worthy of maintaining	Low - but unsure	Medium potential	Probably low
High potential	High potential	Low - because of limited flow on	High	Parasitized high, changes in immune responsiveness (eg tick)
Knowledge level of action is very low, find the population first, is phage ecology not well known. MLA - perhaps low but some options medium	Potentially a good impact - medium to high	Elite fungal species increasing weight gain	Medium (reference J Firkins) - more plausible to study cf 50% biomass	Colonic function VFA
Very important - antibiotic/bacteriocin/archae maybe temporary system	Should be looked at	Should be looked at	Might have promise but track record poor	Economics/need to maintain rumen vaccine
Interesting - worth investigating	Worth investigating	Worth investigating	Worth investigating	No
Concern regarding adoption	Concern regarding adoption	No	No	Reproductive vaccines – high hopes there
Not high	Nitrogen limiting concern whether you can change & sustain populations	Doubtful	Less than full defaunation was effective	Potential to investigate in camels/bantang
Supportive	Potential is there, limited by regulation	Limited	Feedlot, but not pasture	Vaccinal approaches - especially reproduction
See these as high on list of potential developments	How do you get these to establish in extensive systems and prevent reversion?	Theoretical potential	Possible	May see less growth promotant use
How do you monitor the success of this in extensive pastoral systems?	Huge potential in the long run	Possible	Huge potential in the long run	Altering nutrient uptake or digestion
Especially by bacteriophages also vaccination		What role do fungi play?		High – amino acids/HGP automatic – potential to advise
Huge potential in the long run		Huge potential in the long run		

Vaccinal control of rumen populations	Probiotic delivery ie specific bacteria and specify	Plant bioactive compounds	Enzyme co-factor use	Animal genetic selection
Lack of results to date	Variations in ecosystems resistant to change	N/A	B vitamins, thiamine, may be under consideration	May be worth considering
Armidale has dropped these - very high	No	Difficult to implement - low	Low	Selection ? The environment is happening
N/A	Moderate	Low - possibly medium	Medium to low	Most of potential will be slow - there is a great variation in feed conversion efficiency
Low	High for starch based diets	High potential - condensed ?/saponins	N/A	high, but slow. Animals microbial protein
A sceptical optimist - needs to be done by vaccine specialists	Potential for benefit	Potential and GM manipulation to increase- an easy sell eg saltbush, leucaena, acacia	Potential to control cofactors to adverse bacteria input strategy. Understanding the host effect between microbes/host- not just via immune responses	How to make the favourable host genotype expand. How detrimental or positive is the host. SNIP technology
Not rated highly - biological impossible	Very positive	Merit - could these be refined-catalytic nutrients, define endpoint	Room for interaction eg cellulase - microbial insertion or feed cellulase	Animal genome - microbial composition of gut
Definitely interesting	Could be an option	Less easy	Good	Always important
Low	Good	Good	Primarily in feedlots	Good
	Specific eg leucaena - low gains on pasture		Unsure, may have potential	May be some room to explore - part of differences in animal performance High/low production differences
Limited	Has potential	Has potential	Pigs/poultry positive - not sure regarding cattle	"Variation' exists/ may be room to investigate - very slow
Potential	Conceptually	Plants designed to enhance production	Better fit with post-rumen manipulation	Support that
Long shot, needs to be species-specific, how do you maintain this and prevent reversion	Working on these - over time with a greater awareness - control of pathogens, acceptance is increasing, no work in Northern cattle. Pre-dosing for movement stress Control of pathogens/bacteriophage to clear - probiotic to fill the niche and provide healthy microflora Human analogies	Possible		When all else fails
High potential	Shown to be effective	Not aware of any		High potential
		High - methane – 'natural product'		Huge potential in the long run

Table 6. Regulatory issues, industry features, trade issues, extension needs or scientific issues that could impact on the benefits of any of these modifiers or supplements

Failure to maintain mechanistic modelling field and feedlot. Production system- potential to test in the field
Extension failures - lack of understanding/ sophistication among some extension needs to educate Greening management to increase soil fertility
Rumen modification May be consumer concern eg Hormonal growth promotants Human health problems Trade issues are always possible Regulation - gene modification Wildlife sources could be a risk
GM concerns Delivery/infrastructure for delivery Technological lack of knowledge, labour and training Environmental consequences eg pasture change Clean green image needs to be maintained
GM option - a little optimistic Farsberg pig with phytase gene insertion is receiving increased acceptance Plant acceptance - much greater GM do-able for plants Societal acceptance nisin - produced by food grade bacteria - antibacterial (Jim Rusneli?) Naturally occurring so far ok Need to have teams to integrate the metagenomic strategies with the physiology/nutrition Centre for ecogenomics research at University of Queensland Dik Dik/Blue Daika - very high biomass of protozoa Microbial diversity- structure function
Public perception difficulty with transgenesis
Extension highlighted Still need government-based extension
Problem: The failure to uptake existing technologies is a major limitation to new research Failure adapt limits progress Regulate supplement companies - concerned about quality of production in the North
Concern re long term availability of ionophones re EU attitudes. Also a problem for new organisms There is a need to understand compensatory growth as key part of the strategy to achieve gains When do you feed for production response? Maintenance is a cost over the dry season. Feed in the dry or late wet Feed only comparative loss Feed after second wet Feed to go in last period for target/feed Oct Calves - Summer/Wet - May/June/DRY turnoff Summer 2/wet - Finish Feedlot Summer 3/wet - DRY 2 TARGET live trade - Paddock finish 3 Summer 4/wet - Bullocks US Older can get through in Oct V. Feb Wean down to 100kg - late calves need or compounded supplement ~ 10% of calves - often 2 musters in August – segregate MSA premium 10% Increase flexibility has an interest value →weight for age thresholds Targeted groups increasing
Antimicrobials including ionophores may not be available in the future due to social perception Concern regarding feed lots and emergence of O157 - 5% shed this in a trial Gene regulators with transgensis.
Discrepancy in registration requirements for monensin blocks vs. loose licks
HGP - MSA grading 2 points deduction for all HGP use - may be too broad. Need not have that impact, panel test etc. Input timing GM organisms - a powerful technology for the North. Developing better understandings of the extended ecosystem Sustained release technology in cattle - with subcutaneous or intra ruminal Size of market is small & unique - not justifiable to invest often Regulatory system is unique and resource hungry and limits investment - high cost to get products to market - low margin - low adoption rates - no real spin offs into market - failure to measure benefits - know what responses are advisory services are 'siloed' - very segmented

APVMA register block and register additive - a major inhibition to development of remote area supplements Can only use registered blocks Cost of freight is very substantial into the regions - infrastructure requirements. Transport/storage is a challenge re seasonal fluctuation Problems with isolation/communication Infusion of international funds to purchase properties - will this increase adoption rates APVMA only registered 4 new actives- up to 1000 days for many products to clear Could reduce the period of getting products to market
Over the next ten to 15 years the two most beneficial practices that could be implemented are (i) greater adoption of and more effective use of phosphorus supplementation and (ii) more wide spread use of rumen modifiers over the growing season The benefits of phosphorous supplementation have been made clear over many years especially since the early 1990's, but despite this it is generally not carried out effectively Quick calculations on the number of animals grazing P deficient country and the amount of P supplement sold over the wet season shows things don't add up Why this is the case is not entirely clear and is currently the subject of a major MLA project The wet season is the post productive time of the year for northern graziers and it is the time when they need to make the most of their pastures Phosphorus is an obvious one, as previously mentioned, and the other option is the use of rumen modifiers such as flavomycin or monensin These compounds have the potential to increase production by about 10% on top of what phosphorus will do The challenge is to get these compounds to animals over the wet season when accessibility is quite difficult and on some country getting animals to eat supplements at this time of the year can also be difficult The need to register medicated lick block supplements, say blocks containing monensin or flavomycin, is also a major barrier to implementation of this type of technology While it is legal to incorporate some of these actives into a loose mix type product without registration, it is against the Agvet Code to incorporate them into lick blocks without registration It can be more efficient and convenient to feed out lick blocks compared with loose mixes as they don't require as much supervision and constant topping up which is an obvious benefit over the wet season with its inherent accessibility problems
Regulatory issues with blocks compared to loose licks – the Stock Feeds Act is out of date and the definitions need re-doing ESIs for blocks Free choice supplements shouldn't need to be registered
Size Australian market Phages - AQIS Trade Risk especially EU requirements Variable quality of advice + "siloing" of advice Unique Australian management systems. Very focused on rumen manipulation as greatest opportunity to greater efficiency in extending managed cattle in Northern Australia. Suggest: 1. Post ruminal nutrient utilization 2. Management of reproductive performance likely to: - return greater ROI to producers and - suitable for application to sustained delivery technology which will address access issues
Environmentally friendly systems PEG – vegetation- woody weed re-growth
Most have a high risk associated
NCE's require full development costing +/- US$100 million

Table 1. List of scientists and service providers interviewed

No	Name	Affiliations
1	A/Prof. Athol Klieve	Qld University
2	Mr Doug Pollock	Schering Plough (LNT)
3	Dr Geoff Niethe	Meat Livestock Australia
4	Dr Lisa Wade	Elanco Animal Health
5	Dr Michael Goldberg	Virbac
6	Dr Stephen Page	Advanced Veterinary Therapeutics
7	Mr Vincent Posada	Consultant
8	Mr Chris Lawlor	International Animal Health
9	Mr David Chudleigh	Pfizer Animal Health
10	Dr Graham Faichney	Sydney University ex CSIRO
11	Dr John Doyle	Consultant (Integrated Animal Production)
12	Mr Jon Hunt	Bomac
13	Mr Jules D'Assonville	Consultant
14	Prof .Ian Hume	Emeritus Professor Sydney University
15	Prof Ron Leng	Emeritus Professor – Consultant
16	Prof. Dennis Poppi	Qld University
17	Prof. James Rowe	Sheep CRC
18	Prof. Mark Morrison	CSIRO Biosciences Group
19	Dr Stuart Denham	CSIRO Biosciences Group
20	Dr Raffat Aljassim	Uni Qld
21	Dr Chris McSweeney	CSIRO
22	Dr Stuart McLennan	Qld DPI
23	Greg Bortolussi	CSIRO, QLD

Table 2. List of industry suppliers, wholesalers, re-sellers, feed companies and State Government Departments interviewed

No	Industry/department	Region & Contact name
	Nutrition Companies	
1	Causeway	Central & North Qld Peter McHugh
2	Coleman's	Central & North Qld David Coleman
3	Top Stock	Central & North Qld Fred Barletta
4	Stocklick	Central & North Qld Bill McGuinness
5	Home Hill	Central Qld Peter Dahlenberg
6	Riverina	Central & SW Qld David Hunter
7	Better Blend	SW Qld Andrew Steele
8	Nutramix	SW QLD Matthew Wainwright Hugh Graham
8	Agricon	QLD, NT, WA Harry Hornbuckle
9	Coopers LNT	QLD, NT, WA Peter Lourey / Craig Stevenson / Griff Dalgleish
10	Ridley (Rumevite)	QLD, NT, WA Russel Lyons
11	4 Seasons	QLD, NT, WA Chick Olsson James Dickson
12	Olsson	Drier areas of Qld and NT Dr Wayne Backhouse
	Resellers	
13	Elders	Regional Office MacKay – Craig Paterson
14	Landmark	Regional Offices MacKay – Tony Dwyer Brisbane – Jonathan Horrighan
15	**FutureBeef – Qld**	Krista Cavallaro – FutureBeef Manager, Animal Science, **Agri-Science QLD**
	Supplement manufacturers	
16	Mr Richard Romano	Elanco Animal Health
17		Pfizer
18		IAH
19		OzBioPharm
20	Mr Peter Doyle	Phibro
21		Adisseo
22	Dr Bob Elliot	DSM Alltech
23	**Primary Industries – QLD**	Mick Sullivan – Rockhampton Alan Laing – Ayr Bernie English – Kairi Alex Sturton – Charleville
24	**Dept of Resources – NT**	Barry Lemcke – Darwin Neil MacDonald Trudi Oxley
25	**Dept of Ag – WA**	Peter Smith – Kununurra

The following people were contacted in regard to additional discussions or discussions around specific topics in association with the project.

Emeritus Professor Derek Lindsay, UK in regard to compensatory growth and growth promotants.

Professor Hans Jung, USDA Forage Laboratory Wisconsin in regard to potential to manipulate fibre digestion.

Professor Jeff Firkins, The Ohio State University USA in regard to fibre manipulation and improving performance on higher digestable pastures.

Jana Kraft University of Virginia Polytechnique USA in regard to fibre manipulation and improving performance on higher digestable pastures.

Professor Keith Gregg Curtin University in regard to transgenetic bacteria and improving efficiency of production on poor quality pastures.

Dr. John Black, John Black & Associates Consultants, Australia in regard to modeling rumen function.

Emeritus Professor Bill Chalupa University of Pennsylvania in regard to modeling rumen function.

Dr. Charles Sniffen, Fencrest, USA in regard to modeling of rumen function.

Professor Peter Van Soest in regard to means of improving rumen function and ways to modify this using materials obtained from other herbivores.

Emeritus Professor Ian Hulme University of Sydney, in regard to potential to use materials from other herbivores in cattle

Dr Mark van der List, Boehringer USA, in regard to vaccine development and use

Professor Keith Entwistle, University of Queensland, in regard to water supply

Professor Herman Raadsma University of Sydney in regard to genetic modification.

Additional relevant discussions were held with the following who generously spared their time.

Dr. Stewart McLennan
Professor Denis Poppi
Associate Professor Athol Klieve
Professor Mark Morrison
Emeritus Professor Frank Annison
Professor Dale Bauman

These are thanked for the extra time that they put into the project and the kindness of their responses.

15.4 Appendix IV

Table 1. Commercial products currently sold to cattle producers in north of Australia

Company	Products	Type	Unit size (kg)	Cost/Unit ($)	Cost/kg ($)	Intake Cattle (g)
4 Seasons	Stubblebuster	Block	20	21.25	1.06	115
	Protein 50	Block	25	31.67	1.27	285
	Pro-40	Block	30	31.80	1.06	150
	Pro-70	Block	30	33.95	1.13	150
	Pro-90	Block	30	36.65	1.22	150
	Pasture 16	Block	20	24.00	1.20	115
	Trace	Block	20	17.90	0.90	80
	Trace + 12% Sulphur	Block	30	28.19	0.94	120
	Trace + Double Iodine	Block	20	20.75	1.04	85
	Sulphur 16	Block	30	30.67	1.02	175
	Purephos	Block	30	38.00	1.27	175
Agricon	Cowmix 5%	Loose Mix	25	30.90	1.24	150
	Cowmix 10%	Loose Mix	25	32.70	1.31	150
	Phosmix	Loose Mix	25	33.40	1.34	100
	Phosplus	Loose Mix	25			150
	Prosup 5-30% Urea	Loose Mix	25			200
	Protomol	Loose Mix	25	29.00	1.16	
	Drimol	Block	40	42.40	1.06	200
	Optigro 7	Block	40			300
	Calcifort + 10	Block	40			200
	Phos N Pro	Block	40			200
	Wetphos	Block	40			200
	Fortamin	Block	40			200
	Optiphos	Block	40			200
	Magfertet	Block	40			300
	Supersulph	Block	40			
	Feedlot 40	Liquid	1000			1000
	Pasture 17	Liquid	1000	440.10	0.44	1000
Better Blend	Vitamol	Liquid	1000	345.00	0.35	2000
	Better Blend Dry Lick DL-5	Loose Lick	20	20.70	1.04	250
	Better Blend Dry Lick DL-7.5	Loose Lick	20	21.10	1.06	250
	Better Blend Dry Lick DL-10	Loose Lick	20	21.50	1.08	250
	Better Blend Phos 6	Loose Lick	20	19.50	0.98	100
	Better Blend Phos 9	Loose Lick	20	23.10	1.16	100
	Better Blend Phos Plus	Loose Lick	20	20.00	1.00	200
Bundaberg	Pasture Plus	Liquid	750	410.00	0.55	500
	Prolix - 100% Sweet	Liquid	788	535.84	0.68	600
	Prolix - 30% Sour	Liquid	788	535.84	0.68	600
	Prolix - 50% Sour	Liquid	788	535.84	0.68	600
	Prolix - 70% Sour	Liquid	788	535.84	0.68	600
	Prolix - 100% Sour	Liquid	788	535.84	0.68	600
	Peak F - Silage Base	Liquid	750	420.00	0.56	364
	Peak F - Grain Base	Liquid	750	420.00	0.56	573
Causeway	Example product	Loose Mix				80
CLF	Molafos 12	Liquid	1000	315.00	0.32	2000
	Molafos 15	Liquid	1000	325.00	0.33	2000
	Molafos Grower D	Liquid	1000		0.00	3000
	Molafos M	Liquid	1000	294.00	0.29	1000
	Molafos Transition	Liquid	1000	310.00	0.31	2000
Coleman's	Dryphos 1	Loose mix	40	42.45	1.06	100
	Dryphos 2	Loose mix	40	39.60	0.99	150
	Colphos	Loose mix	40	39.80	1.00	
	Koolyn	Loose mix	40	29.70	0.74	300
	Supurea Dry Mix	Loose mix	40	30.80	0.77	200
	Cape	Block	20	18.05	0.90	670
	Basalt	Block	20	14.95	0.75	670
	Pro2	Block	20	15.20	0.76	
	Supurea	Block	20	18.90	0.95	200
	Kynocol	Block	20	26.60	1.33	100
	Kynocol + Urea	Block	20	27.70	1.39	100
Elders	Dry $ Drought	Powder	25	49.09		150
	Early Lactation	Powder	25	59.09		150
	Pre Lactation	Powder	25	79.64		90
	Green Feed	Powder	25	71.36		80
	Dry assist	Pellet	25	62.73		
	Joining	Pellet	25	60.00		140
	Green Assist	Pellet	25	64.55		
	Intensive Cattle	Pellet	25	53.27		

	Travel & Yard	Pellet	25	68.45		800
	Weaning Cattle	Pellet	25	58.13		200
Home Hill	Standard Lick	Loose Lick	25	15.00	0.60	175
Lienert	Supplamins GP + Urea		25			183
	Beef		50			
	Cows		100			
	Weaners		80			
	Supplamins GP			25.00		163
	Beef		50			
	Cows		100			
	Weaners		80			
	Supplamins Mid-Mag			25.00		224
	Beef		50			
	Cows		100			
	Weaners		80			
	Supplamins Cattle			25.00		231
	Beef		50			
	Cows		100			
	Weaners		80			
	Supplamins Hi Mag			25.000		224
	Beef		50			
	Cows		100			
	Weaners		80			
LNT	Boost	Block	15	23.40	1.56	180
	Phosrite	Block	40	62.60	1.57	100
	Ultraphos	Block	15	23.40	1.56	100
	Territory Tuff Phosrite	Block	100	148.70	1.49	100
	Uramol	Block	20	29.80	1.49	70
	Secure	Block	15	22.50	1.50	100
	Calcium- Molasses Block	Block	15	13.10	0.87	
	Grass Tetany Block	Block	15	21.50	1.43	
	Turbo-Pro	Loose lick	25	32.20	1.29	500
Nutramix	Production Promix 0% Urea	Loose Mix	25	16.91	0.68	1000
	Production Promix 4% Urea	Loose Mix	25	16.91	0.68	1000
	Production Promix 8% Urea	Loose Mix	25	18.00	0.72	1000
	Production Promix 16% Urea	Loose Mix	25	18.00	0.72	1000
	Beef Promix 8% Urea	Loose Mix	25	18.67	0.75	500
	Beef Promix 16% Urea	Loose Mix	25	19.95	0.80	400
	Beef Promix 24% Urea	Loose Mix	25	20.95	0.84	300
	Beef Economix 8% Urea	Loose Mix	25	16.17	0.65	500
	Beef Economix 16% Urea	Loose Mix	25	17.37	0.70	400
	Beef Economix 24% Urea	Loose Mix	25	17.37	0.69	300
	Fertility Plus No Urea	Loose Mix	25	21.23	0.85	500
	Fertility Plus 4% Urea	Loose Mix	25	21.23	0.85	500
	Fertility Plus 8% Urea	Loose Mix	25	22.35	0.89	500
	Beef Phosphomix 4% Urea	Loose Mix	25	20.72	0.83	500
	Beef Phosphomix 8% Urea	Loose Mix	25	20.72	0.83	500
	Beef Phosphomix 16% Urea	Loose Mix	25	21.88	0.88	400
	Weaner Promix 4% Urea	Loose Mix	25	19.30	0.77	600
	Weaner Promix 8% Urea	Loose Mix	25	20.26	0.81	600
	Mulga Promix 4% Urea	Loose Mix	25	18.45	0.74	
	Mulga Promix 8% Urea	Loose Mix	25	18.45	0.74	500
	Mulga Promix 16% Urea	Loose Mix	25	19.64	0.79	400
	Mulga Promix 24% Urea	Loose Mix	25	19.64	0.79	300
Olssons	Dry Season 10 % Urea	Block	15	21.00		110
	Lactovite +Cu + Hi I + Se	Block	20	24.00		30
	Superphos + Se	Block	20	27.00		200
	Trace Element + Se	Block	20	20.00		30
	Cob and Co	Block	20	24.00		150
	Milkmaster	Block	15	22.00		150
Performance Feeds	Anipro PBS Weaner - Sweet	Liquid	1000	820.00	0.82	500
	Anipro PBS Cow & Calf - Sour	Liquid	1000	820.00	0.82	500
	Anipro PBN Weaner - Sweet	Liquid	1000	820.00	0.82	500
	Anipro PBN Cow & Calf - Sour	Liquid	1000	820.00	0.82	500
	EPro PBN	Liquid	1000		0.00	2000
	Anipro Prelac	Liquid	1000		0.00	1000
	Weatherpro GP Grazer for Cattle	Loose Lick	20	40.00	2.00	85
	Performance Bovine	Loose Lick	20	65.00	3.25	85
	MagPlus	Loose Lick	20	47.00	2.35	85
RAP	Rumevite EC Dry Feed	Block	20	21.00	1.05	200
	Rumevite Maxi-Graze	Block	20	23.45	1.17	200
	Rumevite 30% Urea + P	Block	20		0.00	174

	Rumevite Maxi-Breed	Block	20	30.00	1.50	174
	Rumevite Mineral w/ Cu	Block	20		0.00	175
	Rumevite Maxi-Trace	Block	20	24.90	1.23	175
	Rumevite Mineral Salt	Block	20	16.36	0.82	75
	Rumevite Co Cu Salt	Block	20	18.00	0.90	75
	Rumevite Fermafos Lick	Block	20	27.00	1.35	105
	Foforlic SSS Dry Season 48 Lick	Loose mix	25	16.50	0.66	180
	Foforlic SSS Dry Season 99 Lick	Loose mix	25	19.00	0.76	150
	Foforlic SSS Dry Season 98 Lick	Loose mix	25	20.50	0.82	200
Riverina	Beefmaker Pasture Suspension	Suspension	1000	450.00	0.45	500
	Truegraz Gold	Suspension	1000	390.00	0.39	1000
	Truelik Sweet	Liquid	1000	600.00	0.60	1000
	Truelik Sour	Liquid	1000	600.00	0.60	1000
	Beefmaker Molapro	Meal	20		0.00	3000
	Beefmaker Pasturepro	Loose Lick	40		0.00	1000
	Beefmaker Pasturepro Calphos	Loose Lick	40	25.80	0.65	200
	Beefmaker Pasturepro Green	Loose Lick	40		0.00	1000
	Beefmaker Pasturepro Ten	Loose Lick	40	20.84	0.52	300
	Beefmaker Pasturepro Twenty	Loose Lick	40	28.08	0.70	100
	Beefmaker Pasturepro Thirty	Loose Lick	40		0.00	80
	Beefmaker Pasturepro Mulga Plus	Loose Lick	40		0.00	250
	Beefmaker Pasturepro North QLD	Loose Lick	40		0.00	80
	Warwick Dry Lick (Cattle)	Loose Lick	40	27.60	0.69	300
Stocklick	Wet Season Lick	Loose mix	1000	735.00	0.74	100
	Dry Season Lick	Loose mix	1000	625.00	0.63	200
	Weaner Lick	Loose mix	1000	600.00	0.60	250
	Weaner Feed	Loose mix	1000	490.00	0.49	1000
	Production Mix	Loose mix	1000	585.00	0.59	500
	Molasses - M8U+R	Liquid	1000	220.00	0.22	2000
	Molasses - M4U+R	Liquid	1000	197.00	0.20	2000
Top Stock	Dry Season - DL 100B	Loose Mix	1000	675.00	0.68	300
	15% EarlySe	Loose Mix	1000	675.00	0.68	300
	DL 30-W Weaner	Pellet	1000		0.00	

Table 2. Chemical composition of Curly Mitchell grass, Flinders/Mitchell grass hay and mixed grass samples collected from Northern Australia

Composition (% DM)	Curley Mitchell Grass	Flinders/Mitchell Grass Hay	Mixed Grass
Crude Protein	5.6	4	4
Soluble Protein	41	44	32
ADICP	0.8	1	0.9
NDICP	1.5	1.4	1.5
Acid Deterent Fiber	44.9	53.6	51.3
Neutral Degerent Fiber	68.5	69.8	71.1
Lignin	6.6	6.7	7.1
Ash	12.98	11.43	10.35
Crude Fat	2	2.3	1
ESC	2.7	5.5	2.8
Starch	1.2	1.1	0.4
Calcium	0.35	0.47	0.29
Phosphorus	0.09	0.24	0.06
Magensium	0.12	0.14	0.1
Potassium	0.65	1.25	0.3
Sulfur	0.23	0.1	0.07
Sodium	0.21	0.033	0.04
Chloride Ion	0.23	0.24	0.1
Iron (ppm)	456	399	944
Zinc (ppm)	31	58	25
Copper (ppm)	17	13	8
Manganese (ppm)	43	23	287
Available Protein	4.8	3.1	3.1
Adjusted Crude Protein	5.6	4	4
NFC	12.4	13.7	15
TDN	48	49	47
Nel (Mcal/Lb)	0.38	0.38	0.35
NEM (Mcal/Lb)	0.35	0.37	0.34
NEG (Mcal/Lb)	0.11	0.13	0.09
Relative Feed Value	73	63	64
Molybdenum (ppm)	0.7	6.8	1.1
DCAD (mEq/100g)	-3	20	2
Horse DE (Mcal/Lb)	0.75	0.76	0.75