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Quantification of Feedlot Manure Output for Beef-Bal Model Upgrade

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Foreword

The increased costs of energy and the potential greater prices paid for renewable energy is making methane capture from animal manures more economically feasible. The lot feeding industry is a large potential source of manure. Manure production from intensive cattle production is currently estimated at approximately 1 million tonnes each year. It is assumed that manure would be taken directly from the pen to the covered anaerobic pond or digester for methane capture to complement current management practices. Therefore, understanding the breakdown of manure at the pen level is imperative to identifying how much methane has been lost already within the pen, and how much will be available for methane capture.

Predictive models such as BEEF-BAL can be used to quantify manure output and to predict volatile solids (organic matter) and hence methane production from feedlots. These models can also be used by developers and proponents to assess the economic feasibility of investment in methane capture technology from a particular enterprise. This information can also be utilised to appropriately design the systems for that enterprise.

BEEF-BAL is not currently widely used by proponents/investors in the intensive livestock industries for predicting VS and manure output. This project was designed to improve the capacity of BEEF-BAL to effectively predict manure output from feedlots and to quantify volatile solids and moisture losses under current manure management practices.

The volatile solids content of the manure on the pen surface was found to rapidly decrease. After 20 days a reduction of between 60 and 70 % in VS in the pad manure compared to fresh manure was measured. From a manure methane harvesting perspective the rapid decline of VS after excretion will impact on the economic feasibility of capturing this potential energy source.

The practicalities of obtaining actual manure excretion data from field conditions were highlighted. Difficulties encountered included removal of manure from pens due to storm events prior to manure harvest and ensuring the pen is cleaned back to the same condition as at the start of the experiment. The key issue with harvested manure was that it was often contaminated with foreign material from the base of the pen. This significantly affected the results.

From this study, BEEF-BAL could not provide comparable data on manure excretion due to difficulties in obtaining actual manure excretion data. Due to harvested manure being contaminated with soil and/or pen foundation gravel.

Lot feeders should keep records of the quantity of manure harvested and the mosituree content at the time of harvest.

Funding for this project was received from the Australian Government through the Rural Industries Research and Development Program. In-kind assistance was also given by lot feeders who provided valuable data to the project.

This report is an addition to RIRDC's diverse range of over 1900 research publications and it forms part of our Bioenergy, Bioproducts and Energy Methane to Markets R&D program, which aims to meet Australia's research and development needs for the development of sustainable and profitable bioenergy and bioproducts industries.

Most of RIRDC's publications are available for viewing, free downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

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FSA Consulting is a professional consultancy providing agricultural, environmental and engineering services to intensive livestock industries, broadacre farmers, abattoirs and industry. FSA Consulting has wide-ranging experience in environmental assessment and management. FSA Consulting also has considerable expertise in providing natural resource management services, having undertaken consultancies for industries as diverse as intensive livestock, aquaculture, broadacre farmers, meat processors, mushroom compost producers and sewage treatment plants.

The senior author, Mr Rodney Davis, is an agricultural engineer who is a specialist in environmental sustainability issues for intensive livestock industries. Rodney's work areas include contracted research and development; assessing the environmental performance of individual farms and providing specific guidance for improvement; undertaking industry-specific research to provide solutions to particular environmental challenges; and developing industry environmental and planning guidelines and codes of practice. He has consulted widely with the pork, egg, meat chicken, dairy and beef feedlot industries.

Acknowledgments

FSA Consulting would like to thank the management of the feedlots that participated in this study. The names of these feedlots have been kept confidential due to the commercial nature of some of the data provided to the research team and presented in this report. Nevertheless, the co-operation of these feedlots was crucial to the success of this project and is greatly acknowledged.

Abbreviations

AGO – Australian Greenhouse Office

ASABE – American Society of Agricultural and Biological Engineers (formerly ASAE)

ASAE – American Society of Agricultural Engineers

BOD - Biological Oxygen Demand

COD - Chemical Oxygen Demand

DAMP - Digestibility approximation of manure production

DCC – Department of Climate Change

DMD – Dry matter digestibility

DMDAMP – Dry matter digestibility approximation of manure production

FS – Fixed solids

GHG – Greenhouse gas

GE – Gross energy

IPCC – Intergovernmental Panel on Climate Change

K – Potassium

MCF – Methane conversion factor

N – Nitrogen

NGGI - National Greenhouse Gas Inventory

P – Phosphorus

QPIF – Queensland Primary Industries and Fisheries (formerly DPI&F)

SCU – Standard cattle unit

TDN – total digestible nutrients

TS – Total solids

VFA – volatile fatty acids

VS – Volatile solids

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What the report is about

The increased costs of energy and the potential greater prices paid for renewable energy is making methane capture from animal manures more economically feasible. Combined with this is the greater intensification of the dairy industry with the use of feedpads/indoor barns, the growth in the beef cattle feedlot sector and pig production facilities generally increasing in size. With a better understanding of the manure production rates and the economically feasible size of these industries, a greater uptake of the existing technology to recover energy from these intensive animal industries will occur.

This study measured the manure production of a number of feedlots to gain more accurate and relevant data for the BEEF-BAL model and “Methane to Markets” project. The study provides measured data of total solids (TS), volatile solids (VS) and moisture content of feedlot manure at various stages of decomposition. These data were used to put back into BEEF-BAL model to improve the TS, VS and moisture content estimates that are currently used and validate the model.

Who is the report targeted at?

Accurate waste estimation techniques are required to allow developers and proponents to predict volatile solids (organic matter) and hence methane production from intensive livestock industries and to assess the economic feasibility of capturing methane from a particular enterprise. This information will also allow the size of systems to be designed to match the size of the enterprise.

Background

In the future, it is likely that feedlots will need to report their GHG emissions. Methane emission capture has been identified as a suitable method for mitigation of methane emissions from intensive livestock waste. For this to be an economically viable option, there needs to be quantification of manure breakdown rates, and volatile solids losses, under Australian conditions.

Manure production from intensive cattle production is currently estimated at 0.9 tonne DM/hd/yr at about 35% moisture. This totals to approximately 1 million tonne of manure each year for reuse from Australian feedlots.

It is assumed that manure would be taken directly from the pen to the covered anaerobic pond or digester for methane capture to complement current management practices. Therefore, understanding the breakdown of manure at the pen level is imperative to identifying how much methane has been lost already within the pen, and how much will be available for methane capture.

Predictive models such as BEEF-BAL can be used to quantify manure output and subsequently to assess the economic viability of investment in methane capture technology. BEFF-BAL requires data on herd numbers, feed ingredients and quantity fed. The digestibility of each feed ingredient is used to predict the TS, VS and FS (or ash) excreted by an animal using mass balance principles. The ‘DMDAMP’ model has not been validated in Australia in terms of manure production, and TS and VS prediction and requires an evaluation to measured data. Validation of the ‘DMDAMP’ model within BEEF-BAL will improve its capacity to effectively predict manure outputs from feedlots.

It is important to identify manure accumulation rates (and subsequently breakdown rates) at differing stages of the manure processing cycle for a number of applications. VS and moisture losses during the manure breakdown process determine the reduction in manure from excretion, to pen surface and subsequent stockpiling. Quantifying these losses under current management practices is vital for accurate manure production assessment. Comparisons of current feed processing techniques and impact on manure production need to be confirmed and the BEEF-BAL model updated to improve its outputs.

Aims/objectives

This project was designed to provide measured feedlot manure production data for comparison against predicted manure output from the BEEF-BAL model. Manure production data was measured at an individual pen level from a number of pens within six study feedlots. TS, VS and moisture content of manure at various stages of decomposition was measured under current management practices.

The outcomes of this are to provide more accurate measurements of waste production in feedlots to assess the economic feasibility of capturing methane from feedlots.

Methods used

The methodology for this project was as follows:

- Undertake a literature review in the area of manure estimation for intensive beef cattle livestock industry.
- Select six feedlots across Australia which are representative of climatic zones, feeding regimes and manure management processes.
- Review the design and management of these feedlots to select those where reliable data could be collected.
- Develop a methodology to provide a feedlot ‘manure budget. This included developing a sampling methodology plan that allows representative sub-samples to be collected.
- Collect manure accumulation rates and manure decomposition data from each feedlot.
- Collect cattle herd and performance data, diet composition and volume fed from each feedlot.
- Analyse and compare measured data with predicted data.

Results/key findings

Six feedlots across Australia which are representative of climatic zones, feeding regimes and manure management processes were selected as study sites for this project. However, over the course of study access to one study feedlot was unable to be obtained to collect manure accumulation and manure deterioration samples and the site was abandoned. At another feedlot, whilst manure accumulation and manure deterioration samples were collected over a 12 month period, cattle and feed intake data for each respective batch and pen were unable to be obtained. Hence, comparison with BEEF-BAL could not be made.

A methodology was developed based on a grid sampling pattern to provide a feedlot ‘manure budget’. The grid sampling pattern allowed representative sub-samples to be collected from across the pen. The appropriateness of the grid pattern for obtaining representative samples was assessed with electromagnetic (EM) induction. The EM survey data reinforced that the grid sampling pattern would provide representative samples being taken from these pens.

Manure accumulation rates and manure decomposition data from four feedlots were collected a number of times between pen cleaning over a 12 month period.

Manure depth was quite variable across the pen due to deposition rates and moisture content at the time of measurement. Under dry conditions, on average, about 20 mm of manure had accumulated across the pen after 25 days. Manure accumulated gradually to about 30 mm after 75 days. With continued dry conditions the manure pack gradually increases to around 35 mm after a further 100 days. These data indicate that the manure pack compacts very tightly under dry conditions. Further, it is likely that some manure is removed from the pen as dust under very dry conditions.

Conversely, under wet conditions, on average a manure depth of 30 mm was measured across the pen after about 25 days. After 75 days, a manure depth of 50 mm on average was measured. When the compact manure pack is moistened due to rainfall it can increase the dry compacted depth two-fold. The wetter the pen surface, the greater the variation across the pen. Higher depth measurements indicate areas of higher manure deposition and pugging of the manure due to cattle concentration.

The VS content of the manure on the pen surface was measured. Samples were obtained directly after pen cleaning, prior to harvest and in between. The following can be concluded from the manure decomposition stage of the study.

- After 20 days a reduction of between 60 and 70% in VS in the pad manure compared to fresh manure was measured.
- After 35 days a reduction of 70% in VS in the pad manure compared to fresh manure was measured.
- After 80-100 days a reduction of 75% in VS in the pad manure compared to fresh manure was measured.

From a manure methane harvesting perspective the rapid decline of VS after excretion will impact on the economic feasibility of capturing this potential energy source. The data collected in this study suggests that the manure needs to be harvested within a few days of excretion. Typically, cleaning and removal of manure from one average size pen (150 head) takes half a day. Hence, there are significant practical implications of implementing a pen cleaning rotation per pen of less than a week across a large feedlot. To achieve this pen cleaning frequency, equipment (multiple loaders, trucks etc) and labour resources significantly greater than those which currently exist would be required.

BEEF-BAL overpredicted the dry matter % of the ration by approximately 10%. This result can be explained by the inherent variability in the actual moisture content of the ration components which are unknown. In BEEF-BAL, the user inputs the composition analysis of individual ingredients. Whilst, feedlots frequently analyse ration samples (e.g. protein, ash, energy etc) the individual ingredients are not analysed. Therefore, in lieu of actual individual ingredient analyses, standard values from literature are used. This is a source of error.

The BEEF-BAL predicted ash level % of the ration was comparable with an actual ash level % from ration analysis. Less variation in ash levels between standard tabulated values and actual levels for each ingredient when compared with moisture content variation may explain this.

The BEEF-BAL predicted TS% of fresh manure was comparable to measured values. However, the ash content of fresh manure was overpredicted by a factor of two. The overprediction of ash by BEEF-BAL translates into a reduction in the prediction of VS by mass balance. The percentage of VS in fresh manure predicted by BEEF-BAL was found to be about 13 % lower than that measured in actual manure. However, it is noted that the VS of fresh manure was not measured rather the VS of faeces was measured, and corrected for the VS contribution of urine.

It is concluded that the BEEF-BAL model can provide a good estimate of ration dry matter %, ash%, and TS% of excreted manure where “real data” can be input on production details, diet ingredients fed and amount of feed used.

Harvested manure data was obtained from four feedlots. TS and VS excreted were estimated from harvested manure data and compared with BEEF-BAL predicted values. Estimated data was comparable to predicted data at only one feedlot. At this feedlot, manure excretion ranged between

800 and 1200 kg/SCU/year. Dry conditions and maintaining a manure interface layer ensured that the material harvested is manure only thus resulting in comparable data.

At feedlots which cleaned their pens back to the gravel base, the measured TS was over 5 times that of the predicted value. In addition, the VS/TS ratio of the excreted manure was about half that of fresh manure. Data from these feedlots suggest that the material harvested contains material other than manure. This additional material (e.g. rocks and/or soil) influences the results by increasing quantity of material harvested and lowers the organic content.

The practicalities of obtaining actual manure excretion data from field conditions were highlighted. Difficulties encountered included removal of manure from pens due to storm events prior to manure harvesting and ensuring the pen is cleaned back to the same condition as at the start of the experiment. The key issue with harvested manure was that it was often contaminated with foreign material from the base of the pen. This significantly affected the results.

From this study, BEEF-BAL could not provide comparable data on manure excretion where the manure harvested was contaminated with soil and/or pen foundation gravel. Ensuring that only manure is removed from the pen is difficult to achieve in practice. The uneven conditions of the pen surface (e.g. depressions, holes etc) along with operator controlled height control on mobile plant translates into variability in cleaning performance and the inevitable contamination of harvested manure.

The following can be concluded from the nitrogen losses during breakdown from fresh to composted manure.

- The measured total N content of fresh manure (faeces adjusted for urine) ranged from 5.0% to 8.5 %. BEEF-BAL predicted total N excretion was typically about 2% less than measured values.
- Sources of error within measured and BEEF-BAL input data can explain the differences found between measured and predicted values of total nitrogen excretion. Firstly, the actual total N of excreted manure is not directly measured. Rather, fresh faeces are sampled and an adjustment based on data from literature is made. Secondly, errors are introduced through the ingredient analysis for total N content as standard values are used rather than actual values. These errors are a plausible explanation for the differences found between the measured and predicted values.
- The total N excreted as a percentage on N intake across all feedlots was found to range from 89.4 % (Feedlot F) to 97.3 % at Feedlot E. These data compare favourably with the literature which suggests about 90 % of the N intake is excreted.
- The greatest loss of total N was measured on the pen surface. Between 64 and 71 % of the total N fed to feedlot cattle was lost to the atmosphere.
- Across all study feedlots, the ammonia-N level in fresh faeces was typically less than 10%. This compares with typical values from the literature of about 50% ammonia-N for faeces. This indicates that ammonia-N is rapidly lost from faeces after deposition.

Implications and Recommendations

Whilst, the lot feeding industry is a large potential source of manure the key issue will be whether economical quantities of methane will be readily available from this source.

This study has demonstrated that VS declines rapidly after excretion. Hence, a significant quantity of methane is lost on the pen surface and this will impact on the economic feasibility of harvesting this energy source.

From a practical and economic perspective, implementing a frequent pen cleaning regime to harvest manure prior to losing VS to the atmosphere will be a challenging.

From this study the following recommendations can be made:

- From a manure methane harvesting perspective the rapid decline of VS after excretion will impact on the economic feasibility of harvesting this energy source. Hence, further detailed work on VS decomposition should be undertaken and the impact on manure management regimes (e.g. impact of contamination with rocks/or soil, implementing a manure interface layer) assessed.

- Review the current version of BEEF-BAL (V9.1_TI) and the potential mass balance error. This error is involved in the calculation of nutrient and FS intake of the whole diet (dry matter basis), when using the nutrient content of ingredients (as-fed basis).

- Ensure that BEEF-BAL is kept up-to-date with the latest digestibility and nutrient content of feed ingredients. It would also be useful to investigate the updating of this model with energy balance predictive methods, as this information is more readily available in the Australian literature compared with dry matter digestibility values for individual feed ingredients.

- It is recommended that future work on validating the BEEF-BAL model and DMDAMP should be conducted under controlled conditions (e.g. metabolic crate) or in small research type feedlots where conditions can be better controlled.

Introduction

Current estimates are that manure management from animals accounts for approximately 3.2% of Australia's greenhouse gas (GHG) emissions. Using the DCC (2007) methodology, the majority of these emissions are from uncovered effluent treatment lagoons – predominantly anaerobic lagoons. Readily-available and easy-to-use models for predicting manure production from intensive animal industries will allow improved economic feasibility assessments to be conducted on methane capture and energy generation. Lagoons could be covered for methane capture and this would both reduce GHG emissions and reduce odour emissions. These odour emissions are often the cause of community amenity impacts.

Using estimates provided by GHD Pty Ltd (2008), increased costs of energy and greater prices paid for renewable energy will make methane capture and subsequent energy generation from animal manures (piggeries, dairies and beef cattle feedlots) more economically feasible. This is combined with the greater intensification of the dairy industry with the use of feedpads, as well as the growth in the beef cattle feedlot sector. Additionally, pig production facilities are generally increasing in size to where energy recovery becomes economically viable. With a better understanding of the manure production and economically feasible size of these industries, a greater uptake of the existing technology to recover energy will likely occur.

Tools are required to allow developers and proponents to predict volatile solids (organic matter) produced from intensive livestock industries and to assess the economic feasibility of capturing methane from a particular enterprise. This information will also allow the size of systems to be designed to match the size of the enterprise. These tools are not currently widely available to proponents/investors in the intensive livestock industries and the tools that do exist have had little field validation. This project, combined with other Methane to Markets projects, will allow these tools to be tested for their accuracy in predicting manure production for various scenarios.

Methane to Markets Program

This program aims to encourage and enable development, adaptation and use of methane capture and use technology in the Australian intensive livestock industries. There are four program objectives. These are:

- Development and adaptation of methane capture and use technology for application in the Australian intensive livestock industries.
- Reduction of the uncertainty, risk and cost of installing methane capture systems.
- Effective communication of the project outcomes.
- Facilitation of commercialisation of on-farm systems for methane capture and use technology.

The RIRDC "Methane to Markets" program is currently prioritising research on predicting methane generation from dairy, piggery and feedlot intensive livestock systems.

This report is part of a series of projects in the RIRDC's Australian Methane to Markets in Agriculture Research and Development Program (RIRDC 2009). The program aims to encourage and develop the use of methane capture and use technology in Australian intensive livestock industries by

i. reducing the uncertainty, risk and cost associated with installing methane capture systems

ii. facilitating the commercialization of on-farm methane systems capture and use technology and

iii. effectively communicating these outcomes to intensive livestock producers.

Projects associated with this report include:

- PRJ-002705 – *Biogas production by covered lagoons; part 1 – piggery, Bears Lagoon* (Birchall 2009)
- PRJ-002831 – *Estimates of Manure Production from Animal for Methane Generation (McGahan et al. 2009)*
- APL Project No. 2108 – *Improved piggery effluent management systems incorporating highly loaded primary ponds* (Skerman et al. 2008)

A brief summary of each project is provided in Table 1.

TABLE 1 – SUMMARY OF RESEARCH PROJECTS ASSOCIATED WITH THIS REPORT (PRJ – 004377)

Project No.	Research Organisation	Project Description	Project status
PRJ-002705	Coomes Consulting Group	A twelve month continuous monitoring program at Bears Lagoon Piggery to measure TS, VS COD, COD soluble, TKN, Ammonia and VFA's for influent and effluent and biogas methane composition of a covered anaerobic pond. The data is being used to verify an anaerobic digestion model being developed by the Advanced Water Management Centre (UQ) which aims to reduce the uncertainty, risks and costs of installing highly loaded lagoons to capture and reuse biogas (Birchall 2009).	complete
PRJ-002831	FSA Consulting	This project provides information on the accuracy and limitations of predictive models in sizing energy recovery systems from intensive animal industries. This will potentially reduce expensive on-ground testing of individual systems before methane capture systems can be designed and installed. Accurate predictions of manure production will also assist industry in managing their effluent. With the greater acceptance and use of energy recovery systems with intensive agriculture, the potential benefits will be in reducing GHG emissions, providing sustainable energy and reducing community amenity (odour) impacts.	complete
PRJ-004377	FSA Consulting	The collection of feedlot manure production data including TS, VS and moisture content to estimate losses under current production practices. This data will be used to improve the quality of BEEF-BAL outputs by validating the DMDAMP section of the model.	incomplete
APL Project No. 2108	QLD DPI&F (QPIF)	Performance evaluation of highly loaded piggery ponds in relation to effluent treatment (removal of solids), sludge accumulation and odour emissions. The report also provides draft recommendations for the design and management of highly loaded primary ponds (Skerman et al. 2008).	complete

Greenhouse Gas Emissions (GHG) from Feedlots

In the future, it is likely that feedlots will need to report their GHG emissions. The IPCC calculations for feedlot GHG emissions are based on VS excretions and are not Australia-specific (IPCC 2006). The current DCC methods (DCC 2007) for feedlot GHG emissions are also based on VS excretions. VS measurement is an important parameter to fully understand in order to ensure these calculations are relevant for Australian climatic conditions and management practices. Sound knowledge of VS in manure could be economically important to the feedlot industry when GHG emission reporting is implemented for agriculture.

The total licensed capacity of Australian feedlots is 1.2 million head (ALFA 2009). Manure production is currently estimated at 0.9 tonne DM/hd/yr at about 35% moisture (Skerman 2000). This totals to approximately 1 million tonne of manure each year for reuse from Australian feedlots.

Methane emission capture has been identified as a suitable method for mitigation of methane emissions from intensive livestock waste. For this to be an economically viable option, there needs to be quantification of manure breakdown rates, and VS losses, under Australian conditions. It is assumed that manure would be taken directly from the pen to the covered anaerobic pond or digester for methane capture to complement current management practices. Therefore, understanding the breakdown of manure at the pen level is imperative to identifying how much methane has been lost already within the pen, and how much will be available for methane capture.

Predictive models such as BEEF-BAL can be used to quantify manure output and subsequently to assess the economic viability of investment in methane capture technology. BEEF-BAL was designed initially as a nutrient budgeting tool for feedlot operations, but has been modified to include the Dry Matter Digestibility Approximation of Manure Production (DMDAMP) model for predicting the organic component of waste composition and quantification. The dry matter digestibility (DMD) approximation of manure production (DMDAMP) predicts the amount of TS, VS and FS (or ash) excreted by animals using DMD (van Sliedregt et al. 2000). The model requires data on herd numbers, feed ingredients and quantity fed. The digestibility of each feed ingredient is used to predict the TS, VS and FS (or ash) excreted by an animal using mass balance principles. The ‘DMDAMP’ model has not been validated in Australia in terms of manure production, and TS and VS prediction and requires an evaluation to measured data. Validation of the ‘DMDAMP’ model within BEEF-BAL will improve its capacity to effectively predict manure outputs from feedlots.

Feed digestibility improvements in feedlots using secondary processing, such as steam flaking, no doubt have enhanced feed digestibility and potentially reduced manure production. Current regulatory conditions for feedlots may be overestimating waste production at 1 tonne DM/hd/yr. This estimate does not account for improvements in feed processing and feed conversion efficiency. Little research, specific to Australian conditions has been undertaken to compare feed processing changes and manure production.

It is important to identify manure accumulation rates (and subsequently breakdown rates) at differing stages of the manure processing cycle for a number of applications. These applications include for pen cleaning purposes at feedlots, and as an input for the MEDLI model for estimating pen runoff and manure production (Atzeni et al. 2001). VS and moisture losses during the manure breakdown process determine the reduction in manure from excretion, to pen surface and subsequent stockpiling. Quantifying these losses under current management practices is vital for accurate manure production assessment. Comparisons of current feed processing techniques and impact on manure production need to be confirmed and the BEEF-BAL model updated to improve its outputs. More accurate measurement of waste production in feedlots is also required to complement the “Methane to Markets” project outcomes.

Literature Review

To estimate the methane generation potential of manure, it is necessary to estimate the organic content of the manure and predict the production rate. Organic content can be measured by various parameters but the most common is VS. Methane production can be related to VS by using the maximum methane producing capacity (B_o) for manure produced by livestock (m^3 CH_4/ kg VS) and the Methane Conversion Factor (MCF). This report will review manure prediction models and methods for estimating VS and will identify any new developments that might lead to improvements in the models.

Historical Development of Manure Prediction Models

Over the past 40 years, there has been a progression in the development of methods and models to predict manure production from intensive livestock facilities. This progression has been driven by the environmental issues prevailing at the time. The manure prediction models have changed in scope and complexity (and assumed accuracy) as the breadth and detail of the environmental issues have increased over time.

Components of Manure

Manure constitutes urinary excretions as well as the fraction of the diet consumed by an animal that is not digested and excreted as faecal material, i.e. manure is urine plus faeces. Manure is composed of TS, which contains macro and micro nutrients, and water. TS which is composed of organic matter (measured as VS) and FS (or ash). TS is determined by drying a sample at 105°C until a stable weight is achieved. The method to measure VS in the laboratory is to burn dried manure samples at 550 ºC (APHA 1989) or 440°C or 750°C (ASTM 2008). The VS portion of the sample is burnt off and only the FS (or ash) remains. The VS are determined by mass balance.

Pond Organic Loading Rate Models

The first environmental issue that required a manure prediction model was the organic loading rate design for intensive livestock waste treatment ponds (or lagoons as they are referred to in the USA). The objective was to size the pond so that the organic matter – characterised as BOD or VS – was adequately treated in the pond prior to discharge or disposal by irrigation. The need for these models followed the adoption of various “clean water” regulations by the EPA in the USA. The earliest methods for estimating manure production were simply to express manure production as a fixed amount (kg VS/head/day) or as a percentage of liveweight. For example, manure production from feedlot cattle was estimated to be about 6% of body weight (ASAE 1988). However, these methods did not take account of feeding regime, growth rates and ration content. These models simply linearly related manure production to animal liveweight. Typical examples were ASAE (1988) and MWPS (2000).

Experience with these models indicated that the manure production estimates were too crude and that many treatment ponds either had serious odour problems or filled quickly with sludge.

There was wide variation in reported values from the literature on how much TS, VS, nitrogen (N) and phosphorus (P) a feedlot animal excretes. These values were based on the assumption that manure production is directly proportional to animal mass. Table 2 shows the TS, VS, N and P production for a 600 kg liveweight beef/feedlot animal, from four different sources.

TABLE 2 – COMPARISON OF SOLIDS AND NUTRIENT PRODUCTION FOR A 600 KG LIVEWEIGHT BEEF/FEEDLOT ANIMAL (KG/YR)

Manure Component	ASAE (1988)	MWPS (1985)	Barth et al. (1999)	Watts et al. (1994c)
Total Solids	1861.5	1857.1	1294.3	1300.0
Volatile Solids	1576.8	1576.8	1191.4	1105.0
Nitrogen	74.5	75.3	65.7	76.7
Phosphorus	20.1	54.3	20.6	20.8

The ability of these methods to predict the waste produced by feedlot animals is questionable due to the large variation in reported values and the fact that most assume a linear relationship of manure production with liveweight. Sinclair (1997) reported that there was no apparent relationship between liveweight and urine or faeces production. As dry matter intakes did not increase linearly with liveweight, manure production would not increase with liveweight. Van Horn et al. (1994) and Morse et al. (1994) also report no direct relationship between manure production and animal weight. Van Horn (1992) suggests most nutrient excretion standards at that time used ASAE standards (ASAE 1988) and were based on the body weight of the animals. He found that, for dairy cows, this did not account for the effect of the variations in feeding level, voluntary feed intake, supplement levels, and milk production on subsequent excretion levels. After reviewing data, Van Horn (1992) concluded excretion estimates based on dietary intake of a nutrient, minus amount secreted in milk was a good method for predicting total animal excretion of minerals by mature dairy cows and one on which to base manure management systems.

DAMP Model

The most significant improvement in the prediction of livestock manure production came when Clyde Barth published three papers in 1985 (Barth 1985a, b, Barth & Kroes 1985) . The aim of this work was to provide a design methodology for livestock ponds that would overcome the odour and sludge accumulation problems.

Barth (1985a) proposed the Digestibility Approximation of Manure Production (DAMP) technique, which was arguably, the first technique that aimed to predict the organic content of excreted manure using animal performance data. DAMP is a systematic approach to estimate the TS, VS and FS or ash component of animal manure based on known diet and digestibility data. This technique applies to any class of animal or bird. It assumes that FS and VS components of concentrates and protein supplements were available according to the reported value for percent total digestible nutrient (TDN). For each subclass of animal, DAMP requires, as input, the amount fed and percent wastage, percent dry matter, ash content, percent TDN, and percentage of the FS available in the organic and mineral component of the diet of each feed component offered.

Barth (1985a) found that, in general, for pigs, the data of ASAE and the USDA SCS estimated greater waste production for breeding stock than DAMP. Data of MWPS (1985) was similar to DAMP for breeding animals. For growing animals, ASAE, SCS and MWPS data estimated greater waste production for larger animal sizes and less waste production for smaller animal sizes than DAMP. For dairy cattle, ASAE, SCS and MWPS manure production characteristics compared favourably with DAMP for cows at higher levels of milk production when an allowance of 5% waste was included. DAMP produced lower estimates of manure production for cows at low and intermediate levels of milk production. For beef cattle, the MWPS estimate of grower animal (159 to 340 kg) manure production compared favourably with DAMP with a 5% feed wastage included. All other estimates of beef manure production by ASAE, SCS and MWPS were much greater than DAMP estimates.

As historical background, the TDN system was developed in the early 1900s (Dumas et al. 2008). The evolution of the TDN system is described in detail in Maynard (1953). All nutrients (crude protein, crude fibre, nitrogen-free extract, crude fat) are scaled to the energy equivalent of carbohydrate. In non-ruminant animals, TDN is a measure similar to metabolic energy and not to digestible energy. In ruminants, the net energy also has a component related to the methane and fermentation heat lost. The reference system of the TDN does not take into consideration the metabolisability of the diet. This means that all feedstuffs are assumed to be used equally efficiently for maintenance and lactation, regardless of TDN composition.

For many years, Barth (1985a) was the standard technique of estimating organic load on effluent treatment ponds and was the initial digestibility method for the mass-balance models developed in Australia.

Nutrient Mass Balance Models

The DAMP model only predicts organic matter production in manure. In Australia in the late 1980s and early 1990s, there was a need to not only understand organic matter excretion but also nutrient excretion. Environmental regulators were asking for explanations of sustainable nutrient (N, P, K) utilisation at intensive livestock facilities. This led to the development of mass-balance models for manure production (e.g. Watts et al. 1994b, Watts et al. 1992).

These models applied a mass-balance approach to nutrients (N, P, K) and included DAMP to estimate the organic matter component of manure production. These models typically characterised the animal ration by including individual percentages of ration ingredients and typically characterised the herd by modelling the full range of animal types, growth rates, feed intakes and liveweight. An important improvement was that the PIG-BAL model included provision for the estimation of feed wastage as this waste feed became part of the manure load on the waste treatment system.

In Australia, these models were known as PIG-BAL for pigs (QPIF 2004c), BEEF-BAL for feedlots (QPIF 2004a) and DAIRY-BAL for dairy (QPIF 2004b).

DMDAMP Model

Over time, it became apparent that the DAMP model needed improvement. Sinclair (1997) used the DAMP model to predict manure production for feedlots and expressed concerns with regard to the models ability to provide practically accurate estimations of the basic manure characteristics of TS, VS and FS. His reasons included that the mineral availability assumptions used by Barth (1985a) were to some degree biologically invalid and that the use of TDN values in the DAMP model require the input of North American feed tables because no TDN values are available for Australian feed ingredients.

McGahan and Casey (1998) proposed a modified version of the DAMP model called the Dry Matter Digestibility Approximation of Manure Production (DMDAMP) to predict the amount of TS, VS and fixed solids (FS) excreted by pigs. This method uses dry matter digestibility (DMD) instead of TDN values of individual ingredients to predict TS output. VS output was calculated using mass balance principles on the FS component of the feed, minus the FS retention of the animal.

In the last 10 years, there has been significant development of the feedlot industry, with the specialist feeding of animals for specific markets. At the same time, there has also been extensive research in the areas of animal growth and composition, the factors that influence feed intake and digestibility, feed composition and waste management.

The amount of manure in terms of TS, VS, and nutrients (N and P) produced is the most appropriate system on which to measure the potential environmental impact of a feedlot. Thus a model that allowed the waste production to be predicted in a consistent, scientifically valid manner for different feeding and management regimes was required.

Mass Balance Principles for Predicting FS and Nutrient Excretion

The theory behind the mass balance approach for predicting waste output from feedlots is that by knowing the amount of a particular component (FS, N, P etc) of an ingredient offered in the ration and by subtracting the amount retained by the animal, the amount excreted can be determined. The critical factor in being able to use this mass balance approach to predict the output of a particular component is to know the retention of that component by the animal (i.e. the body composition of the animal). Several studies that investigated the body composition of cattle by carcass dissection and chemical analysis, regression equations, slaughter balance or retention per kilogram of liveweight gain were reviewed and a summary of which is presented in Table 3.

TABLE 3 – MINERAL CONTENT OF CATTLE (% OF LIVEWEIGHT)

	N (%)	P (%)	K (%)	Salt (%)	FS (%)
Starter/Intermediate	2.7	0.67	0.17	0.14	0.50
Grower/Finisher	2.4	0.70	0.18	0.15	0.40
Source	a	b,c	b,c	b,c	b,c,d

Table 3 is adapted from the following references, where figures expressed on an empty-weight basis being converted to a liveweight basis by assuming a gut fill factor of 10% for animals less than 500 kg and 6% for animal greater than 500 kg. Koelsch and Lesoing (1999) used a similar approach.
.

a) Simpfendorfer (1974) cited in National Research Council (1996) using the equation Body Protein $Y = 0.235\ (EBW) – 0.00013\ (EBW)^2 – 2.418$, where nitrogen = protein/6.25
b) Maynard et al. (1979), SCA (1990), National Research Council (1996)
c) Rumsey (1982) and Rumsey et al. (1985)
d) Ferrell and Jenkins (1998a, b)

Sinclair (1997) provides a formula for P excretion which is related to intake only.

Total P excretion (g/d) = 8.23 + 0.433 x P Intake

Digestibility Model (DMDAMP) for Predicting Solids Excretion

As with the DAMP model proposed by Barth (1985a), the DMDAMP model requires as input the mass, percentage dry matter and percentage FS of each feed component offered. The distinct differences with these models are:

- DMDAMP uses the dry matter digestibility of each feed ingredient, not the TDN value.

- FS excreted is calculated by mass balance (FS fed – FS retained = FS excreted).

Knowing the digestibility of each feed ingredient, the digestibility of the whole diet is used to predict the TS, VS and FS or ash excreted by an animal.

TS excreted = DMI x (1- DMD of the ration) Eqn (1)

where:

DMI is the dry matter intake (kg/head/day)

The amount of FS excreted is the difference between the amount in the diet and the amount retained by the animal as live-weight gain. VS is simply TS minus the FS.

The modification of DAMP to DMDAMP is proposed as a more accurate method of predicting the digestibility of a ration and hence waste output because TDN is a term most commonly used in North American as an indicative value of the quality of a feed ingredient or ration, not a direct measurement of digestibility. Dry matter digestibility (DMD) is a coefficient or percent of dry matter, which is digestible (Equation 2). Predictive equations, laboratory analysis (pepsin cellulose technique) or digestion trial can be used to predict DMD and is available for many feed ingredients in Australia.

$$DMD = (\text{Feed DM} - \text{Faeces DM}) / \text{Feed DM} \qquad \text{Eqn (2)}$$

The modification of DAMP to DMDAMP provides a prediction of the digestibility of a ration and expected waste output which can be compared with digestion trials, and/or laboratory analysis. The two important inputs required in the DMDAMP model are the feed intake of the animal and the digestibility of the ration.

Feed Intake Data used in DMDAMP

Data collected by the Cattle and Beef Industry CRC for cattle of the three most common feedlot categories (Domestic, Korean and Japanese, 300-420 kg, 400-560 kg, and 400-650 kg respectively) demonstrated that for feedlot cattle, intake does not increase linearly with liveweight, but is curvilinear. For Australian conditions, DMI/head/day is likely to be 8 kg initially, peak at 12 kg, plateau and declines to 9 kg for cattle over a liveweight range of 300 to 650 kg. The point where DMI plateaus occurs with physiological maturity, 28% total body fat and the energy concentration of the ration. Figure 1 illustrates the curvilinear relationship between feed intake and days on feed (increasing energy concentration), interpolated from measured feed intake data and National Research Council (1996).

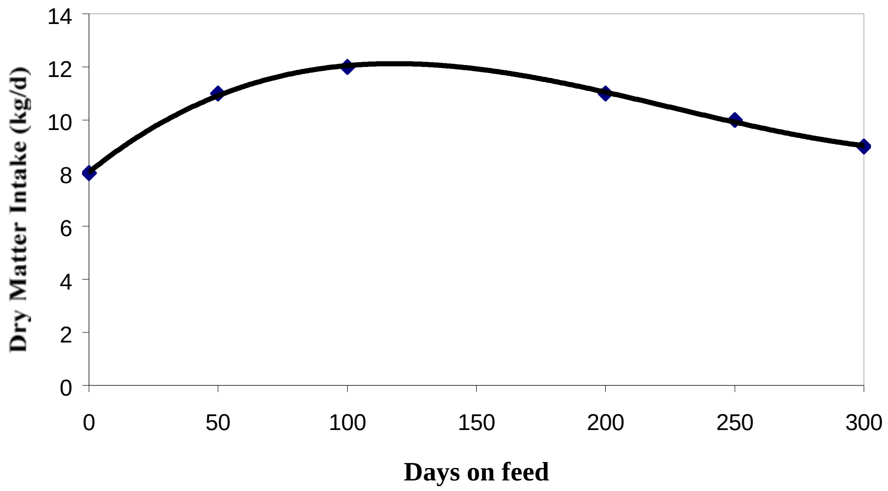

FIGURE 1 – RELATIONSHIP BETWEEN DMI (KG/DAY) AND DAYS ON FEED

Digestibility of Rations used in DMDAMP

Feedlot animals are typically fed a number of rations, including starter; intermediate; grower and finisher; with forage to concentrate ratios of 60:40, 30:70 and 20:80 respectively on an 'as-fed basis'. The digestibility of feed is defined as the proportion that is not excreted in the faeces and which is absorbed and utilised by the animal, and is closely related to its chemical composition. Grains show far less variation in composition (DMD range from 70-95%) than do forages (DMD range from 20-80%).

The nature and composition of individual ingredients, as well as the digestive processes that occur when feeds are mixed together affect the digestibility of feed consumed by ruminants, this is known as the 'associative effect'.

Associative effects occur in ruminants as a result of the concentrate to roughage ratio. McDonald et al. (1988) reported where a roughage (DMD of 0.6) and a concentrate of (DMD of 0.8) are mixed in equal parts, and the resultant overall digestibility is not necessarily 0.7.

Mould et al. (1983) found that when a hay was ground and fed with rolled barley, contributing two-third of the diet DM, the hay DMD could be reduced between 20 and 37% and the digestibility of the whole diet was reduced by over 9%. The reduction in hay digestibility was less when it was given in chopped form and when the barley was whole rather than rolled. Baldwin et al. (1977) and Mertens (1987) developed complex models of ruminant digestion, relating to intake, digestibility, rates of passage and other factors, which affect nutritive values. Mertens (1987) relates discount factors for the digestibility of feedstuffs to the NDF content and rate of passage. Orskov (1986) suggests that the processing of grain and the concentrate to roughage ratio affect the intake and digestibility of barley diets, with some discount factor for hay, but not the grain.

In developing a waste prediction model based on the overall DMD of a series of mixed rations, it is necessary to make some allowance for the expected associative effect. The review of literature revealed a lack of quantitative data, however there appears to be a pronounced effect on the digestibility of roughages as opposed to grain or concentrate within a mixed ration.

Incorporating DMDAMP Theory and Mass Balance Principles into BEEF-BAL

BEEF-BAL is a Microsoft Excel® worksheet model that can be used to determine the waste characteristics from a feedlot (QPIF 2004a). It calculates the TS, VS, FS, N, P, K and total salts in the manure from a feedlot, where the cattle are fed a ration of known composition and intake. The DMDAMP model within BEEF-BAL is used to calculate TS excreted and mass balance principles are used to determine the N, P, K, total salt and FS excreted.

BEEF-BAL can simulate different feeding regimes and has the ability to predict waste production for several classes of stock (i.e. Domestic, Korean, and Jap-Ox). For each animal class, the liveweight into the feedlot, average daily gain, days on feed and dry matter intake (kg) for each stage of feeding (starter, intermediate, grower and finisher) are required. The user can modify these inputs to suit an individual production system.

With relationships describing the decomposition of solids and loss mechanisms of nitrogen, BEEF-BAL also predicts the amount of solids and nutrients left for land utilisation. This information is then used to calculate appropriate application areas for effluent and solids.

Validation of DMDAMP

To validate the total DMD figures for rations within DMDAMP, a number of studies were collated which met the following criteria:

- Cattle with a liveweight range from 200-600 kg were used.
- The rations contained feedstuffs available in Australia and thus could be included in the model.
- The rations covered a range of forage to concentrate ratios.
- DMD and/or OMD results were reported in the paper and were obtained from the determination of faecal output by either total collection or grab samples with a marker.

The rations fed to trial animals from studies that complied with the criteria above were entered according to ingredient composition into DMDAMP. Due to the associative effect of mixing roughages with concentrates, a series of discount factors were applied to the roughages in the diet from 0/0 or no discount, through to 10/20%, 20/40% 30/60% and 40/80%. Where 10, 20, 30 and 40% discount applies to the DMD of all roughages in rations containing greater than 30% grain or concentrate and 20, 40, 60 and 80% discount applies for the DMD of all roughages in diets containing more than 60% grain or concentrate respectively. The total DMD predicted was compared with the reported value in the reference and tabulated against the forage to concentrate ratio. Statistical analysis by linear regression was performed using the Analysis Toolpak in Microsoft Excel®.

From all the data available with concentrate to roughage ratios ranging from of 0:100 through to 100:0, the incorporation of the discount factors 30/60% proved to have the best line of fit with an R^2 of 0.82, against all other discounts of 10/20%, 20/40%, and 40/80%. The 30/60% discount is a significant improvement on no discount (R^2 of 0.64) thus verifying the need to account for the associative effect in order to provide an accurate prediction of waste output based on the digestibility of the ration. When the data was restricted to a concentrate to roughage ratio of 40:60 through to 0:100, or that typical of feedlot rations, the statistical results show further improvement with the 30/60% discount having a final R^2 of 0.85.

The discount factor that provided the best fit of predicted versus measured data (30/60%) is plotted in Figure 2. The majority of values fall below the 1:1 line, which indicates DMDAMP slightly underestimates DMD and consequently overestimates manure production. The only Australia study with applicable results was that of Sinclair (1997) and consisted of a concentrate blend (predominantly barley and sorghum) and barley straw. DMDAMP overestimated the DMD of this ration by 3.5%.

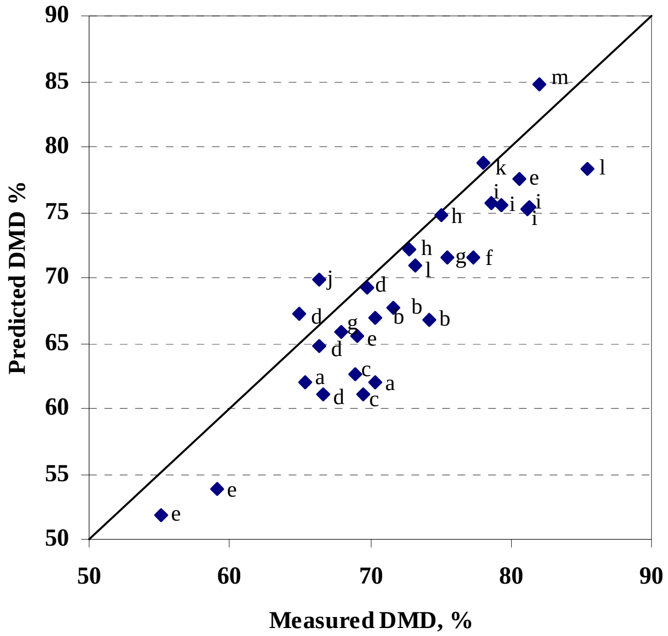

FIGURE 2 – REPORTED VERSUS PREDICTED (BEEF-BAL) RATION DRY MATTER DIGESTIBILITIES

Data for Figure 2 comes from the following references.

a) Glenn et al. (1989)

b) Mir and Mir (1994)

c) Weidmeier et al. (1992)

d) Kampman and Loerch (1989)

e) Bines and Davey (1970)

f) Maciorowski et al. (2000)

g) Martin et al. (1999)

h) Surber and Bowman (1998)

i) Wessels and Titgemeyer (1997)

j) Sinclair (1997)

k) Turgeon et al. (1983)

l) Zinn (1993)

m) Murphy et al. (1994)

The variation between the measured and predicted total ration DMD values can be attributed to:

- The variation in the DMD for individual feed ingredients. Feedtest Laboratories Pty Ltd (personal communication, 2000) report a variation of 10-20% for grains and 5-50% for forages and roughages.

- The “associative effect” of mixing grain and forages together, diets of different composition will have different DMD’s. For this reason DMDAMP uses the average value for all ingredients. A 10% reduction in the DMD of barley (from 82% to 72%) included in the finisher ration will reduce the total DMD of the ration by 7.6% however it will increase the resultant manure production by 22%.

Several authors have noted variations in DMD of an individual ration. Sinclair (1997) fed the same ration, with the treatments being different levels of phosphorous, DMD ranged from 65.5 to 67.4%. Stock et al. (1987) fed a large number cattle over a finisher period on a 78% corn concentrate and 12% corn silage diet for 100 days. During this time, faecal samples (taken at 7, 35 and 70 days of the finisher period only) revealed DMD variations between 1.7 to 7%.

Predicting Waste Output of Different Classes of Feedlot Cattle

BEEF-BAL incorporating DMDAMP was used to predict waste production from six classes of stock i.e. Domestic 70 days on feed (DOF), Domestic 100 DOF, Korean 150 DOF, Jap-Ox 200 DOF, Jap-Ox 250 DOF and Jap-Ox 300 DOF. The two rations used in the model were sorghum and barley based (Table 4). The discount factors of 30 and 60% were applied to these rations.

Feed consumption for each class of animal, during each stage of feeding was interpolated according to the DOF from Figure 1.

For example, a Korean steer will consume approximately 8.3 and 9.0 kg DMI/head/day in the starter and intermediate stages respectively. The DMI/head/day of 11.0 kg for the grower stage is the average from the graph of the next 65 days, and the finisher intake of 11.8 kg/head/day is an average of the last 70 days (from 80 to 150 DOF). A summary of the input assumptions for the different classes of stock is presented in Table 5.

The predicted excretion of TS, VS, N and P in kg/yr for each class of animal is shown in Table 6 for the sorghum and barley rations.

TABLE 4 – FEED FORMULATION (SORGHUM AND BARLEY DIETS) USED TO ESTIMATE MANURE OUTPUT FROM DMDAMP MODEL FOR DIFFERENT CLASSES OF CATTLE

	Sorghum Diet				Barley Diet			
	Starter	Inter.	Grower	Finisher	Starter	Inter.	Grower	Finisher
Sorghum grain	35.0	55.0	70.0	74.6				
Barley grain					21.0	46.0	66.0	76.0
Cotton seed meal	5.0	5.0	5.0	5.0	2.0	2.0	2.0	2.0
Sorghum hay	51.0	31.0	16.0	10.0	-	20.0	15.0	10.0
Lucerne hay					65.0	20.0	5.0	-
Molasses	5.0	5.0	5.0	5.0	7.0	7.0	7.0	7.0
Ag. Lime	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Muriate of potash	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3
Salt	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Bentonite	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Sulphate of ammonia	0.3	0.3	0.3	0.3	0.1	0.1	0.1	0.1
Dicalcium phosphate	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Urea	1.0	1.0	1.0	1.0	0.8	0.8	0.8	0.8
Minerals/Premix	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
DMD	55.8	62.7	64.7	67.9	66.0	66.6	66.9	72.9

Note: DMD values have been discounted depending on concentrate to roughage ratio.

TABLE 5 – ASSUMPTIONS USED TO PREDICT WASTE FOR THE DIFFERENT CLASSES OF FEEDLOT ANIMALS

Class of animal	Domestic	Domestic	Korean	Jap-Ox	Jap- Ox	Jap- Ox
Days on feed	70	100	150	200	250	300
Liveweight in (kg)	300	350	380	420	420	420
Liveweight out (kg)	420	510	600	660	710	750
Avg. Daily Gain (kg)	1.7	1.6	1.5	1.2	1.15	1.1
Days on starter ration	7	7	10	15	15	15
Amount fed (DM) – Starter	8.1	8.1	8.3	8.5	8.5	8.5
Days on Inter. Ration	14	14	15	15	15	15
Amount fed (DM) – Inter.	8.7	8.7	9.0	9.5	9.5	9.5
Days on grower ration	0	0	65	70	70	70
Amount fed (DM) – grower	10.0	10.5	11.0	11.7	11.7	11.7
Days on finisher ration	49	79	70	100	150	200
Amount fed (DM) – finisher	10.3	11.1	11.8	11.5	11.0	10.5

TABLE 6 – PREDICTION OF FEEDLOT WASTE FOR THE DIFFERENT CLASSES OF ANIMAL USING BOTH SORGHUM AND BARLEY BASED RATIONS

Class of animal	Domestic (70 DOF)	Domestic (100 DOF)	Korean (150 DOF)	Jap-Ox (200 DOF)	Jap-Ox (250 DOF)	Jap-Ox (300 DOF)
Sorghum Ration						
TS Excreted (kg/yr)	1208	1284	1366	1387	1380	1374
VS Excreted (kg/yr)	953	1013	1081	1094	1086	1080
N Excreted (kg/yr)	71.0	76.0	81.0	84.0	85.0	85.5
P Excreted (kg/yr)	10.4	11.2	12.1	12.8	12.9	13.0
Barley Ration						
TS excreted (kg/yr)	1023	1087	1204	1220	1203	1193
VS excreted (kg/yr)	745	794	894	901	887	877
N excreted (kg/yr)	65.0	68.5	73.0	76.7	76.6	76.5
P excreted (kg/yr)	9.1	9.7	10.5	11.2	11.3	11.3

The predicted waste output was higher for the sorghum based ration than the barley based ration because of the lower digestibility of sorghum grain. The predicted DMD of the sorghum based finisher ration was 67.9% and the barley based finisher ration had a DMD of 72.9%. This effectively increased the TS production for a Korean class animal from 1204 kg/yr to 1366 kg/yr, an increase of 11.85%. Similarly, the VS production for a Korean class animal increased from 894 kg/yr to 1081 kg/yr, an increase of 18%.

The TS and VS production for the different classes of feedlot animals follows a pattern similar to that of feed intake. A comparison of the waste output for both diets in terms of TS and VS production, shows there is little difference between the different classes of animal, particularly for the long fed (> 150 days on feed) classes of cattle.

The predicted TS and VS for a Korean animal at 600 kg liveweight on the sorghum rations is within the range suggested by Barth et al. (1999) and Watts et al. (1994c) in Table 1, for a 600 kg beef animal. Like these two references, the results are lower than those predicted by ASAE (1988) and MWPS (1985). The predicted VS of the barley rations is slightly lower than any values mentioned in Table 2. However the composition of the rations on which these four references predicted the solids output for a 600 kg beef animal is unknown.

Nitrogen excreted ranges from 71 to 85.5 kg/year for sorghum rations and 65.0 to 76.5 kg/year for barley rations for 70 day domestic through to 300 day Jap-Ox animals. These figures agree with the average of approximately 75 kg/year suggested in Table 1, by ASAE (1988), MWPS (1985) and Watts et al. (1994c). The P levels excreted ranged between 10.4 and 13.0 kg/year for the sorghum rations and 9.1 to 11.3 kg/year for barley rations again across all classes of cattle from the 70 day domestic to 300 day Jap-Ox. While the references in Table 1 quoted an average 20 kg/year of phosphorous, Gardner et al. (1994) estimated P excretion between 2.3 and 5.1 kg/head/year for Local Trade cattle and between 8.3 to 14.9 kg/head/year for Jap-Ox animals. Sinclair (1997) found P excretion to be directly related to P intake, and that overall 70-80% of P intake was excreted. In his trial, total P excretion rates ranged between 17.3 g and 26 g/head/day, which equates to between 6.3 and 9.5 kg/head/year for the liveweight range 250-350 kg.

Volatile Solids as a Measure of Potential Environmental Impact

Table 7 shows the relative comparison of TS and VS production for different classes of feedlot animal, compared to a Korean animal. For the entire sorghum based feeding regime, the ratio of TS and VS produced compared to a Korean animal increases from 0.88 for a 70 day fed domestic animal, plateaus off at 1.01 for a 200-300 day fed Jap-Ox. For the barley based feeding regime the ratio of TS and VS produced compared to a Korean animal increases from 0.83 for a 70 day fed domestic animal, plateaus off from 1.01 to 0.98 from 200 to 300 day fed Jap-Ox animal respectively. This response is related to feed intake, which also increases as the animal is gaining body fat and then declines with increasing energy concentration of the diet and body fat levels above 28%.

TABLE 7 – RELATIVE WASTE PRODUCTION FOR THE DIFFERENT CLASSES OF CATTLE COMPARED TO A KOREAN ANIMAL, USING SORGHUM AND BARLEY-BASED RATIONS

Class of animal	Domestic (70 DOF)	Domestic (100 DOF)	Korean (150 DOF)	Jap-Ox (200 DOF)	Jap-Ox (250 DOF)	Jap-Ox (300 DOF)
Sorghum						
Relative TS Production a	0.88	0.94	1.00[a]	1.01	1.01	1.01
Relative VS Production b	0.88	0.94	1.00[b]	1.01	1.00	1.00
Barley						
Relative TS Production a	0.85	0.90	1.00	1.01	1.00	0.99
Relative VS Production b	0.83	0.89	1.00	1.01	0.99	0.98

[a] TS excreted (each class of animal) / TS excreted by Korean Steer (turnoff=600kg liveweight).
[b] VS excreted (each class of animal) / VS excreted by Korean Steer (turnoff=600kg liveweight).

The relationship between classes of animal is similar for both TS and VS. The VS component of manure causes the most environmental concerns for a feedlot enterprise, and thus is the best measure of its potential environmental impact.

ASABE Models

Although Clanton et al. (1988) recognised the value of mass-balance models for nutrient estimation, it has only be in recent years that manure prediction models in the USA have been modified to improve the estimates of nutrient content and to include mass-balance principles (Erickson et al. 2003b, Fulhage 2003) . Consequently, the old ASAE manure standard (ASAE 1988) has been significantly updated (ASABE 2005). The new ASABE standard has also improved the digestibility model to improve VS predictions. This model determines "as-excreted" manure and does not include a component for wasted feed or bedding material.

This standard:

- characterises typical manure, "as-excreted" based on typical diet,
- estimates manure excretion based on animal performance, dietary feed and nutrient intake according to individual life stage situation,
- provides typical data on manure when removed from manure storage or animal housing.

The standard characteristics of typical manure provides information on TS, VS, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Nitrogen, Phosphorus, Potassium, Calcium, total manure and moisture per kg/finished animal. Table 8 presents the estimated typical manure as excreted.

TABLE 8 – ESTIMATED TYPICAL MANURE (URINE AND FAECES) AS EXCRETED (ASABE 2005)

Animal Type and Production Grouping	Total solids	Volatile solids	Nitrogen	Calculated VS/TS ratio
		kg/finished animal (f.a.)		
Beef – Finishing cattle	360.0	290.0	25.0	0.81
Nursery pig (12.5 kg)	4.8	4.0	0.4	0.83
Swine – Grow-finish (70 kg)	56.0	45.0	4.7	0.80
		kg/day – animal (d-a)		
Gest. Sow (200 kg)	0.50	0.45	0.032	0.90
Lact. Sow (192 kg)	1.20	1.00	0.085	0.83
Boar (200 kg)	0.38	0.34	0.028	0.89

Beef cattle

VS are calculated only for beef cattle and are called organic matter (OM). Equation 3 and 4 predict organic matter (or VS) excretion:

OM_E = [DMI*(1-ASH/100]*(1-OMD) +17*(0.06*BW_{AVG}) Eqn (3)

$OM_{E-T} = n^n{}_{x=1}$ [DMI_x * DOF_x *(1-ASH_x/100)]*(1-OMD_x/100) + $n^n{}_{x=1}$ DOF_x*17*(0.06* BW_{AVG}) Eqn (4)

where:

OM_E is the organic matter (or VS) excretion per animal per day (g of organic matter / day / animal)

DMI is the dry matter intake (g DM / day)

ASH is the ash concentration of total ration (% of DMI)

OMD is the organic matter digestibility of total ration (% of OMI)

BW_{AVG} is the average live body weight for the feeding period (kg)

OM_{E-T} is the total organic matter (or volatile solids) excretion per finished animal (g of organic matter / finished animal)

DOF is the days on feed for individual ration (days)

x is a ration number

n is the Total number of rations fed

Manure Models to Estimate Greenhouse Gas Emissions (IPCC)

The previous sections have described manure estimation models that were derived to provide design data for waste treatment facilities at intensive livestock enterprises. Somewhat independently, manure estimation models were developed to provide the basis for prediction of greenhouse gas emissions from intensive livestock facilities.

The estimation of VS excretion rate using the IPCC (2006) method is based on energy intake, digestibility and ash content. The VS excretion rate is estimated for all livestock species as (Equation 5).

$$VS = [GE * (1 – (DE\% / 100) + (UE * GE)] * [(1-ASH) / 18.45] \qquad \text{Eqn (5)}$$

Where:

VS = volatile solid excretion per day on a dry-organic matter basis, (kg VS/day)

GE = gross energy intake, (MJ/day)

DE% = digestibility of the feed in percent (e.g.60%)

(UE * GE) = urinary energy expressed as fraction GE. Typically, 0.04 GE can be considered urinary energy excretion by most ruminants (reduce to 0.02 for ruminants fed with 85% or more grain in the diet or for swine). If country-specific data are available, it is preferable to use these.

ASH = the ash content of manure calculated as a fraction of the dry matter feed intake (country specific data recommended)

18.45 = conversion factor for dietary GE per kg of dry matter (MJ/kg). This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock.

To undertake a national greenhouse gas inventory, each country should estimate gross energy (GE) intake and its fractional digestibility (DE) as appropriate to that production system.

For cattle, GE and DE are given in equations in (IPCC 2006). Feedlot cattle fed with over 90% concentrate diet have a digestibility ranging from 75 to 85%.

For swine, country specific data are required to estimate feed intake. The feed digestibility of swine varies with class:

Mature Swine –confinement: 70-80% DE%

Growing Swine – confinement: 80-90% DE%

Gross energy GE calculation

GE is the summation of the net energy requirements and the energy availability characteristics of the feeds. IPCC (2006) considered Equation 6 to be a good practice for calculating GE requirement for cattle, buffalo and sheep using the results of equations for energy requirement.

$$GE = \{[((NE_m + NE_a + NE_l + NE_{work} + NE_p)/ REM) + (NE_g /REG)]/ (DE\%/100)\} \qquad \text{Eqn (6)}$$

where:

GE = gross energy, (MJ/day)

NE_m = net energy required for animal maintenance, (MJ/day)

NE_a = net energy for animal activity, (MJ/day)

NE_l = net energy for lactation, (MJ/day)

NE_{work} = net energy for work, (MJ/day)

NE_p = net energy required for pregnancy, (MJ/day)

REM = ration of net energy available in a diet for maintenance to digestible energy consumed, (MJ/day)

NE_g = net energy needed for growth, (MJ/day)

REG = ratio of net energy available for growth in a diet to digestible energy consumed, (MJ/day)

DE% = digestible energy expressed as a percentage of gross energy, (MJ/day)

Net energy for animal maintenance

The net energy for animal maintenance, Equation 7, is the amount of energy needed to keep the animal in equilibrium where body energy is neither gained nor lost (Jurgen 1988).

$$NE_m = Cf_i * (Weight)^{0.75} \qquad \text{Eqn (7)}$$

Where:

NE_m = net energy required for animal maintenance, (MJ/day)

Cf_i = a coefficient which varies for each animal category as shown in Table 9, (MJ/day/kg)

Weight = live-weight of animal, (kg)

TABLE 9 – COEFFICIENT FOR CALCULATING NET ENERGY FOR MAINTENANCE (NE_M) (IPCC 2006)

Animal category	Cf_i (MJ/d/kg)	Comments
Cattle (non-lactating cows)	0.322	
Cattle (lactating cows)	0.386	This value is 20% higher for maintenance during lactation
Cattle (bulls)	0.37	This value is 15% higher for maintenance of intact males

Mean winter temperature will affect the net energy for maintenance. The coefficient, Cf_i, must be adjusted with Equation 8 (IPCC 2006).

$$Cf_i\ (in\_cold) = Cf_i + 0.0048 \times (20 - {}^{\circ}C) \qquad \text{Eqn (8)}$$

Where:

Cf_i = a coefficient which varies for each animal category (Coefficient for calculating NE_m), MJ/day/kg

°C = mean daily temperature during the winter season

Net energy for animal activity

The net energy for activity, Equation 9, is the energy needed to obtain their food, water and shelter; it is based on the feeding situation. It is calculated as a fraction of the net energy for maintenance.

$$NE_a = C_a \times NE_m \qquad \text{Eqn (9)}$$

Where:

NE_a = net energy for animal activity, (MJ/day)

C_a = coefficient corresponding to animal's feeding situation (Table 10)

NE_m = net energy required by the animal for maintenance, (MJ/day)

TABLE 10 – ACTIVITY COEFFICIENT CORRESPONDING TO ANIMAL'S FEEDING SITUATION

Situation	Definition	C_a
Cattle (unit for C_a is dimensionless)		
Stall	Animal are confined to a small area (i.e., tethered, pen, barn) with the result that they expend very little or no energy to acquire feed	0.00
Pasture	Animals are confined in areas with sufficient forage requiring modest energy expense to acquire feed	0.17
Grazing large areas	Animals graze in open range land or hilly terrain and expend significant energy to acquire feed	0.36

Source: National Research Council (1996) and AFRC (1996) cited in IPCC (2006)

Net energy for lactation

The net energy for lactation, Equation 10, is expressed as a function of the amount of milk produced and its fat content expressed as a percentage (National Research Council (2001) cited in IPCC (2006)).

$$NE_l = \text{Milk} \times (1.47 + 0.40 \times \text{Fat}) \qquad \text{Eqn (10)}$$

Where:

NE_l = net energy for lactation, (MJ/day)

Milk = amount of milk produced, (kg of milk/day)

Fat = fat content of milk, (% by weight)

Net energy for work

The net energy for work estimate the energy required for draft power for cattle (Equation 11). Bamualim and Kartiarso (1985) cited by IPCC (2006) show that about 10% of day's NE_m requirements are required per hour for typical draft power work for animals.

$NE_{work} = 0.10 \times NE_m \times Hours$ Eqn (11)

where:

NE_{work} = net energy for work, (MJ/day)

NE_m = net energy required by the animal for maintenance, (MJ/day)

Hours = number of hours of draft power work per day

Net energy required for pregnancy

The energy for pregnancy for cattle is the total energy requirement for a 281-day gestation period averaged over an entire year. Equation 12 calculated it as a fraction of the net energy for maintenance.

$NE_p = C_{pregnancy} \times NE_m$ Eqn (12)

Where:

NE_p = net energy required for pregnancy, (MJ/day)

$C_{pregnancy}$ = pregnancy coefficient (0.10)

NE_m = net energy required by the animal for maintenance, (MJ/day)

Ratio of net energy available in a diet for maintenance to digestible energy consumed

The ratio of net energy available in a diet for maintenance to digestible energy consumed (REM) is predicted using Equation 13 (Gibbs and Johnson (1993) cited in IPCC (2006)).

$REM = \{1.123 - (4.092 \times 10^{-3} \times DE\ \%) + [1.126 \times 10^{-5} \times (DE\%)^2] - (25.4/DE\%)\}$ Eqn (13)

Where:

REM = ration of net energy available in a diet for maintenance to digestible energy consumed, (MJ/day)

DE% = digestible energy expressed as a percentage of gross energy

Net energy needed for growth

The net energy needed for growth, Equation 14, is based on National Research Council (1996) cited in IPCC (2006).

$NE_g = 220.02 \times (BW/(C \times MW))^{0.75} \times WG^{1.097}$ Eqn (14)

Where:

NE_g = net energy needed for growth, (MJ/day)

BW = the average live body weight (BW) of the animals in the population, (kg)

C = a coefficient with a value of 0.8 for female, 1.0 for castrates and 1.2 for bulls

MW = the mature live body weight of an adult female in moderate body conditions, (kg)

WG = the average daily weight gain of the animals in the population, (kg/day)

Ratio of net energy available for growth in a diet to digestible energy consumed

The ratio of the net energy available for growth available in a diet to digestible energy consumed (REG) is estimated by Equation 15 (Gibbs and Johnson (1993) cited in IPCC (2006)).

$$REG = \{1.164 – (5.160x10^{-3} \text{ x DE \%}) + [1.308 \text{ x } 10^{-5} \text{ x (DE\%)}^{2}] – (37.4/\text{DE \%})\} \qquad \text{Eqn (15)}$$

Where:

REG = ratio of net energy available for growth in a diet to digestible energy consumed, (MJ/day)

DE% = digestible energy expressed as a percentage of gross energy, (MJ/day)

NRC method for estimation of GE

National Research Council (NRC) provides methods for estimating nutrient requirements for pigs (National Research Council 1998), beef cattle (National Research Council 1996) and dairy cattle (National Research Council 2001). Maintenance, pregnancy, lactation and growth energies are reported in tables according to the diet for beef cattle and dairies.

Alternate method for estimation of GE

The gross energy of the diet is calculated from the chemical composition. The energy value of crude protein, crude fat and carbohydrate is given as 24, 39 and 185 MJ/kg respectively. The calculated gross energy intake is given in Equation 16 (Nolan et al. 2000):

$$GE = 23.5 \text{ x } CP + 39.5 \text{ x } FAT + 17.5 \text{ x } CAR \qquad \text{Eqn (16)}$$

where:

GE = gross energy intake, (MJ/day)

CP = crude protein intake, (kg/day)

FAT = fat intake, (kg/day)

CAR = carbohydrate intake, (kg/day.)

The crude protein content is calculated from the nitrogen content of the diet multiplied by 6.25 (Equation 17). The fat intake is assumed to be 2%. The carbohydrate intake is the balance of the fat and carbohydrate components.

$$CP = N \text{ x } 6.25 \qquad \text{Eqn (17)}$$

where:

N = Nitrogen intake (kg/day)

Manure Prediction Models Currently used in Australia

BEEF-BAL

BEEF-BAL (QPIF 2004a) was originally constructed as a tool to provide an estimate of quantity and composition of feedlot manure (both liquid and solid fractions) available for application after harvesting and storage. BEEF-BAL is also used extensively to provide waste estimates for of new and expanding feedlot development applications throughout Australia.

BEEF-BAL is a Microsoft Excel® spreadsheet model that is used to predict the amount of solids (total and volatile) and nutrients (nitrogen, phosphorus and potassium) excreted by feedlot cattle based on the improved model of DMD approximation of manure production (DMDAMP – van Sliedregt et al. (2000)) and mass balance principles (Watts et al. 1994a).

BEEF-BAL can simulate different feeding regimes and has the ability to predict waste production for several classes of stock (e.g. Domestic, Korean, and Jap-ox). The model requires data on herd size, diet and quantity of feed fed. For each animal class, the liveweight into the feedlot, average daily gain, days on feed and dry matter intake (kg) for each stage of feeding (starter, intermediate, grower and finisher) are required. The user can modify these inputs to suit an individual production system.

With relationships describing the decomposition of solids and loss mechanisms of N, BEEF-BAL also predicts the amount of solids and nutrients left for land utilisation. This information is then used to calculate appropriate application areas for effluent and solids. This model also accounts for associative effects that occur only in ruminants as a result of the nature and compositions of individual ingredients, as well as the digestive processes that occur when feeds are mixed together that affect the digestibility of feed consumed by ruminants.

This model is not often used by the industry because it requires intensive data on the animal's diet. It has not yet developed to a commercial standard for the general use by the public. It is provided by the Department of Employment Economic Development and Innovation (DEEDI) - formerly DPI&F, to researchers and consultants on the understanding that the program is provided on an "as-is" basis. DEEDI advises that it should be used with caution and professional judgement should be exercised in drawing conclusions from the model outputs. The version used in this study was Version 9.1_TI.

BEEF-BAL Model Inputs

The BEEF-BAL model, in its various forms, has been used in Australia for nearly twenty years. However, the documentation of the science behind the model is poor. BEEF-BAL is comprised of a series of modules, including:

- System Input Parameter Modules
- Feedlot Design
- Market Type and Herd Production
- Rations and Ingredients
- Feed Intake

Feedlot Design

In some states in Australia, feedlot capacity is defined in terms of "standard cattle units" (SCU) rather than number of head. Table 11 provides data to convert cattle liveweight to SCU.

TABLE 11 – STANDARD CATTLE UNITS (SCU) CONVERSION TABLE (ARMCANZ 1997)

Live Weight of Beast (kg) (a)	Number of SCU (a/600)*0.75
750	1.18
700	1.12
650	1.06
600	1.00
550	0.94
500	0.87
450	0.81
400	0.74
350	0.67
300	0.59

The BEEF-BAL model requires input data on various feedlot design parameters including:

- Maximum capacity in SCU (see Table 11)
- Other (hospital) pen area (m^2)
- Hard (high runoff) area (e.g. roads) (m^2)
- Soft (low runoff) area (e.g. grass) (m^2)
- Stocking density (SCU/ m^2) to calculate total production area

Market Type and Herd Production

Most large commercial feedlots in Australia will feed cattle to meet a range of market types and specifications. BEEF-BAL can model up to four different market types within a single feedlot. The BEEF-BAL model requires input data on the following parameters for each market type:

- Entry weight (kg)
- Daily weight gain (kg/hd/d) to calculate
- Average Daily Gain (ADG) (kg/day) and Days on feed (DOF) (days)
- Mortality rate (% of cattle entering the feedlot that die)
- Occupancy (mean number of cattle-on-hand divided by production pen capacity)

This input data provides outputs on:

- Exit weight (kg)
- Average liveweight (kg)
- Liveweight gain (Exit weight – entry weight)
- Cattle in per year
- Cattle out per year

Rations and Ingredients

BEEF-BAL includes a library of individual feed ingredients and their analysis on a dry matter basis. The model allows various rations to be formulated using these ingredients. There are fields to enable the input of 4 rations (starter, intermediate, grower and finisher). Grower and finisher rations are provided for each of the four cattle market types as well. The model calculates various parameters for each total mixed ration (TMR).

For each ration type, the model calculates:

- Dry matter content (DM) (%)
- Ash content (% of DM)
- Volatile solids content (% of DM)
- Nitrogen, phosphorous and potassium content (% of DM)

Feed Intake

BEEF-BAL allows for a different feed intake, expressed as dry matter intake (DMI), for each market type. Using DMI and ADG, the feed conversion ratio (FCR) can be calculated for each market type. It also calculates the amount of feed fed (as fed basis) using the inputs of feed ingredient DM percentage. The amount of nutrients (N, P and K) fed in t/yr and g/hd/d is also reported.

BEEF-BAL Model Outputs

BEEF-BAL model output modules include:

- Manure Prediction
- Animal, Pen and Feedlot Nutrient Balance
- Manure Harvesting, Stockpiling and Composting
- Runoff Collection, Storage and Irrigation

The primary purpose for the development of the BEEF-BAL model is to predict the amount of manure produced in terms of dry matter (TS) and nutrients (N, P and K). The current version of BEEF-BAL (V9.1_TI) uses the DMDAMP methodology to estimate TS excretion and mass balance principles (Intake – Uptake in liveweight gain) to predict FS, N, P and K excretion. VS are calculated as the difference between TS and FS.

Losses of DM (TS) from the pad and the manure stockpile are calculated by the user simply inputting VS:TS ratios at these various stages to calculate a DM loss by assuming FS remains constant. Nitrogen remaining at various stages (harvested from pad and remaining in the stockpile) is also estimated by the using simply inputting a total loss percentage of N during these stages. No guidance is provided to the user on what these inputs should be.

Figure 3 illustrates the functionality of BEEF-BAL_V9.1_TI.

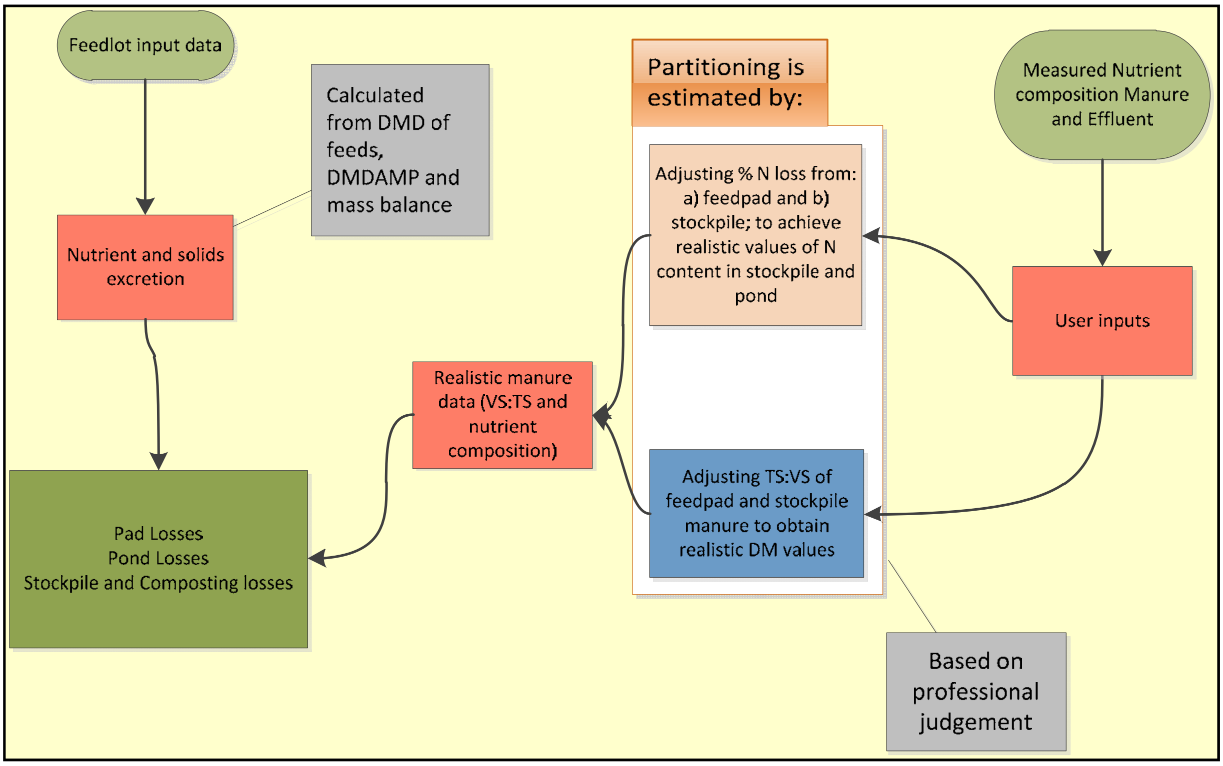

FIGURE 3 – REQUIRED USER INPUTS AND FUNCTIONALITY OF BEEF-BAL_V9.1_TI.

Manure Models to Estimate Greenhouse Gas Emissions (DCC)

The Department of Climate Change and Energy Efficiency (DCCEE) undertakes national greenhouse gas inventories for Australia. For livestock manure management systems, the method used provides specific VS rates according to livestock population (DCC 2009). The VS prediction equations use dry matter intake and dry matter digestibility data developed to calculate enteric CH_4 production. The equation and guidelines for VS estimation for beef cattle feedlots are given in this section. The DCC method draws heavily on van Sliedregt et al. (2000) and McGahan and Casey (1998).

Beef Cattle in Feedlots

For beef cattle feedlots, VS are estimated with Equation 8 using dry matter intake, digestibility and ash content. Table 12 gives the feed intakes for feedlot cattle that are assumed from NGGI calculations.

$$VS = I \times (I - DMD) \times (1 - A) \qquad \text{Eqn (18)}$$

where:

I	=	dry matter intake (Table 12), kg/day
DMD	=	digestibility expressed as a fraction (assumed to be 80%)
A	=	ash content expressed as a fraction (assumed to be 8% of faecal DM)

TABLE 12 – FEEDLOT CATTLE INTAKE (I) (KG/DAY)

Feedlot Cattle Class/ Average time in Feed	1990-1995	1996+
Domestic/ 75 days	7.20	9.8
Export/ 140 days	8.47	11.7
Japan ox/ 250 days	11.50	11.0

Source: DCC (2007)

No Australia data currently exist on the CH_4 emission from the feedpad. DCCEE (2010) estimates CH_4 production to be in the range of 1.69 – 5.63 g of CH_4 per kg of VS excreted, using a B_o of 0.17 kg CH_4 / kg VS, a CH_4 density of 0.662 m^3/kg and MCF ranging from 1.5% (southern Australia) and 5% (Queensland and Northern Territory). This is equivalent to 1.27 – 4.22 kg CH_4 / hd / yr (assuming SCU excretes 900 kg VS annually).

IPCC (2006) estimates CH_4 production to be in the range of 1.13 – 2.25 g of CH_4 per kg of VS excreted, using a B_o of 0.17 kg CH_4 / kg VS, a CH_4 density of 0.662 m^3/kg and MCF ranging from 1.0% (cool regions) and 2% (warm regions). This is equivalent to 0.84 – 1.69 kg CH_4 / hd / yr (assuming an excretion of 750 kg VS annually).

Summary – Current Australian Methods

In BEEF-BAL, the waste details are presented in the DMDAMP and nutrient balance analysis sheets. The TS, VS, FS and nutrient component of the manure is presented for different classes of animal.

In DCC (2007) models for high density of animals in feedlots, VS production is estimated using intake and dry matter digestibility data developed to calculate enteric methane production.

In ASABE (2005) standards, organic matter is estimated with an equation for beef cattle only and VS/TS ratios are also provided.

In IPCC (2006), the VS excretion rate calculation is a necessary step to estimate a CH_4 emissions factor from the type of manure management. The VS excretion rate equation is given based on gross energy intake, digestibility, urinary energy and ash content.

Conversion Factors for Manure to Methane

To determine the methane production from manure, it is necessary to convert VS content to methane generation. This is done by applying the B_o factor and the MCF factor.

B_o Factor

B_o is the maximum methane-producing capacity for manure produced by an animal and has the units of m^3 CH_4/kg VS (IPCC 2006). B_o varies with animal type (via differences in digestive capacity) and feed type.

IPCC (2006) provides typical B_o values for different livestock species and locations. Table 13 shows IPCC values for B_o for pigs, dairy cattle and beef cattle in Australia (Oceania).

TABLE 13 – MAXIMUM METHANE-PRODUCING CAPACITY OF THE MANURE (B_O) - OCEANIA (IPCC 2006)

Animal	B_o m^3 CH_4/ kg VS
Swine	0.45
Dairy cattle	0.24
Non-dairy cattle	0.17

Moller et al. (2004) note that "methane productivity" from manure can be measured in terms of VS destroyed, VS loaded, volume, or animal production. Methane productivity measured in terms of VS destroyed (m^3 CH_4/kg VS_{DES}) corresponds to the **theoretical methane yield** (B_u) if there is complete degradation of all organic components of the manure. The theoretical methane potential can be calculated from Bushwell's formula. Methane productivity in terms of VS loaded (m^3 CH_4/kg VS_{load}) as residence time approaches infinity is referred to as the **ultimate methane yield** (B_o). The **ultimate methane yield** will always be lower than the **theoretical methane yield** because a fraction of the substrate is used to synthesise bacterial mass, a fraction of the organic material will be lost in the effluent, and lignin-containing compounds will only be degraded to a limited degree (Moller et al. 2004). Inhibition of the biological process by inhibitors such as ammonia and volatile fatty acids (VFA) is another factor contributing to the actual methane yield being lower than the potential yield which would be obtained if inhibition was not present. It has been observed that both the ultimate methane yield (B_o) and the volumetric methane production (L CH_4/ m^3 manure) of manure from different origins can be very variable. (Moller et al. 2004) notes that the **ultimate methane yield** (m^3 CH_4/kg VS) is affected by various factors, including:

- species, breed and growth stage of the animals.
- feed.
- amount and type of bedding material.
- degradation processes during pre-storage.

This discussion about the definition of B_o by Moller et al. (2004) highlights the lack of clear definitions in this area. Most researchers assume that B_o refers to fresh manure directly from the animal prior to any breakdown and without additions from bedding and wasted feed. This is a parameter that is intrinsic to the animal and independent of the housing and feeding system. However, the discussion by Moller et al. (2004) suggests that B_o takes into account housing and feeding systems. This has clear implications for actual methane yield predictions from a manure treatment system depending on the MCF applied.

B_o is determined by anaerobically digesting a sample of manure and measuring the methane yield. However, Vedrenne et al. (2008) points out that there is no standard methodology for the determination of B_o and different researchers have used different methodologies. The variations in methodology include:

- Incubation temperature (varies from 35°C to 55°C).

- Source and amount of inoculums added.

- Timing and amount of mixing of the sample.

- Amount of dilution of the sample.

- Incubation time (50 to 157 days).

Not surprisingly, both Vedrenne et al. (2008) and Karim et al. (2005) have found that variation of any of these parameters affects maximum methane yield. Hence, apart from variations between species and feed type, B_o data will vary depending on experimental protocol and should be evaluated with a knowledge of the experimental procedures adopted.

For example, ICF Consulting (1999) provides B_o values for beef, dairy and swine for various diets as collated from a range of researchers (see Table 14). This table shows the variability of the data.

Table 15 presents data from a recent experiment in France with a maximum and minimum B_o value for swine and dairy cattle slurry (Vedrenne et al. 2008). The swine value from France is lower than the value from IPCC, perhaps because they include a slurry component. For dairy cattle, the IPCC value is about the average of the France values.

Amon et al. (2004) determined B_o for dairy cattle manures where the feed and milk yield varied. They found a range of B_o from 0.132 to 0.166 m^3 CH_4/kg VS. They concluded that lignin in the manure reduced the specific methane yield. The higher the feeding intensity and the milk yield, the greater was the reduction in methane yield through an increase in lignin content.

Moller et al. (2004) determined both **theoretical methane yield** and **ultimate methane yield (B_o)** for pigs and dairy cattle. The theoretical methane productivity is higher in pig (0.516 m^3 CH_4/kg VS) and sow (0.530 m^3 CH_4/kg VS) manure than in dairy cattle manure (0.469 m^3 CH_4/kg VS), while the ultimate methane yield in terms of VS is considerably higher in pig (0.356 m^3 CH_4/kg VS) and sow manure (0.275 m^3 CH_4/kg VS) than in dairy cattle manure (0.148 m^3 CH_4/kg VS).

TABLE 14 – MAXIMUM CH_4-PRODUCING CAPACITY FOR U.S. LIVESTOCK MANURE

Animal Type	Diet	Converted B_o (m^3CH_4/kg VS)	References cited
Beef	7% corn silage, 87.6% corn	0.29	(Hashimoto et al. 1981)
	Corn-based high energy	0.33	(Hashimoto et al. 1981)
	91.5% corn silage, 0% corn	0.17	(Hashimoto et al. 1981)
		0.23	(Hill 1984)
		0.33	(Chen et al. 1980)
Dairy	58-68% silage	0.24	(Morris 1976)
	72% roughage	0.17	(Bryant et al. 1976)
		0.14	(Hill 1984)
	Roughage, poor quality	0.10	(Chen et al. 1988)
Swine	Barley-based ration	0.36	(Summers & Bousfield 1980)
	Corn-based high energy	0.48	(Hashimoto 1984)
		0.32	(Hill 1984)
	Corn-based high energy	0.52	(Kroeker et al. 1979)
	Corn-based high energy	0.48	(Stevens & Schulte 1979)
	Corn-based high energy	0.47	(Chen 1983)
	Corn-based high energy	0.44	(Iannotti et al. 1979)
	Corn-based high energy	0.45	(Fischer et al. 1975)

Source: ICF Consulting (ICF Consulting 1999)

TABLE 15 – MEASURED MAXIMUM METHANE-PRODUCING CAPACITY OF THE MANURE (B_O)

Slurry	B_o	
	Min	Max
Swine	0.244	0.343
Dairy cattle	0.204	0.296

Source: Vedrenne et al. (2008)

Table 16 summarises the reported range of B_o for pigs, dairy cattle and beef cattle compared to the default value used in the Australian NGGI methods. It can be seen that range of reported values varies by at least twofold for each species. Clearly, it is difficult to choose an appropriate value at this time, yet it has a profound effect on the prediction of maximum potential methane yield from manure.

TABLE 16 – REPORTED RANGE OF BO FOR PIGS, DAIRY CATTLE AND BEEF CATTLE

Species	B_o (m^3 CH_4/ kg VS)		
	lower value	upper value	DCC default
Pigs	0.24	0.52	0.45
Dairy cattle	0.10	0.30	0.24
Beef cattle	0.17	0.33	0.17

No papers providing B_o data measured in Australia have been found. At the moment, there is no Australia specific value of B_o and this information would be essential to provide more accurate estimation of methane production for piggeries, beef feedlots and dairies under Australian conditions.

MCF Factor

MCF is methane conversion factor (MCF) that reflects the portion of B_o that is achieved (IPCC 2006). The system MCF varies with the manner in which the manure is managed and the climate, and can theoretically range from 0 to 100%. Both temperature and retention time play an important role in the calculation of the MCF. Manure that is managed as a liquid under warm conditions for an extended period of time promotes methane formation. These manure management conditions can have high MCFs, of 65 to 80%. Manure managed as dry material in cold climates does not readily produce methane, and consequently has an MCF of about 1%. Table 17 shows IPCC (2006) selected MCF factors for manure management systems.

DCC (2007) assumes that the only source of methane emissions from a feedlot is "solid storage and dry lot". It is assumed that there are no methane emissions from holding ponds (lagoons), manure spreading (daily spread) and effluent irrigation (liquid system). The drylot MCF values for 'warm' regions for Queensland and the Northern Territory (5%) and MCF values for 'temperate' regions for all other States (1.5%). This is different from IPCC (2006) where drylot factors are 1% up to 14°C, 1.5% in the range of 15°C to 25°C, and 2% for over 25°C average annual temperature.

In reality, the MCF factor would be expected to vary with a range of parameters. Lodman et al. (1993) undertook a series of experiments to measure methane emissions from manure pads in a grazing context and from feedlot surfaces. Their experimental methodology would now be regarded as inadequate and, hence, some of their absolute numbers on methane emissions are questionable, they did draw relevant conclusions on relative methane emissions rates from feedlot surfaces under differing conditions. They found that the variables that contributed most to differences in methane emissions from feedlot pens were temperature, moisture content and diet of the animal. Emissions increased with increasing temperature, higher moisture contents in the manure and with diets that had a larger proportion of grain rather than forage.

TABLE 17 – SELECTED MCF FACTORS FOR MANURE MANAGEMENT SYSTEMS

<table>
<tr><th colspan="20">MCF VALUES BY TEMPERATURE FOR MANURE MANAGEMENT SYSTEMS</th></tr>
<tr><th rowspan="3">System[a]</th><th colspan="19">MCFs by average annual temperature (°C)</th></tr>
<tr><th colspan="5">Cool</th><th colspan="11">Temperate</th><th colspan="3">Warm</th></tr>
<tr><th>≤ 10</th><th>11</th><th>12</th><th>13</th><th>14</th><th>15</th><th>16</th><th>17</th><th>18</th><th>19</th><th>20</th><th>21</th><th>22</th><th>23</th><th>24</th><th>25</th><th>26</th><th>27</th><th>≥ 28</th></tr>
<tr><td>Pasture/Range/Paddock</td><td colspan="5">1.0%</td><td colspan="11">1.5%</td><td colspan="3">2.0%</td></tr>
<tr><td>Daily spread</td><td colspan="5">0.1%</td><td colspan="11">0.5%</td><td colspan="3">1.0%</td></tr>
<tr><td>Solid storage</td><td colspan="5">2.0%</td><td colspan="11">4.0%</td><td colspan="3">5.0%</td></tr>
<tr><td>Dry lot</td><td colspan="5">1.0%</td><td colspan="11">1.5%</td><td colspan="3">2.0%</td></tr>
</table>

Source: IPCC (2006)

TABLE 18 – SUMMARY OF STUDIES MEASURING METHANE EMISSIONS FROM MANURE MANAGEMENT IN FEEDLOTS

Source of emissions	Country	Method	Study period	Temperature	Treatments	Recorded value	Std. Error	Units	Methane Emission kg CH4/hd/yr	Observation period	Reference
Beef feedlot manure (stockpile)	Canada	IHF continuous	Sept 2003 - Oct 05	not reported		600	-	g CH_4-C $(7d)^{-1}$	9.7	7 (all measures), and 10 (IHF continuous days for CO_2 and CH_4	Sommer et al. (2004)
		IHF periodic				357	± 12	g CH_4 -C $(7d)^{-1}$	5.8		
		Chamber				34.9	± 11.1	g CH_4 -C $(7d)^{-1}$	0.56		
Beef feedlot (feedpad)	Canada	Periodic spot gas sampling	02 Oct 2001 (Start)	Manure 4.3° C	low forage	0.66	-	g CH_4-C $(hd.d)^{-1}$	0.32		Boadi et al. (2004)
					high forage	1.06	-	g CH_4-C $(hd.d)^{-1}$	0.52		
Dairy manure (liquid, solids)	Switzerland	Chamber	unknown	Buckets in ambient 20°C	Grass low protein; liquid manure	38.8	± 6.35	g CH_4-C $(hd.5\ weeks)^{-1}$	0.54	Storage for 5 and 7 weeks for series 1 and 2	Kulling et al. (2003)
				Water bath; 41° C decreasing by 2° C/ week	Grass low protein; solid manure	37.3	± 6.35	g CH_4-C $(hd.5\ weeks)^{-1}$	0.52		
				Buckets in ambient 20°C	Grass high protein; liquid manure	11.4	± 3.15	g CH_4-C $(hd.7\ weeks)^{-1}$	0.13		
				Water bath; 41° C decreasing by 2° C/ week	Grass high protein; solid manure	37.4	± 3.15	g CH_4-C $(hd.7\ weeks)^{-1}$	0.43		
Composting of feedlot manure	Canada	Chamber	May, 1997	Mean daily ambient; 10 to 25°C; Passive max 62°C, decreasing to	Passive (no turning)	6.3	-	Kg CH_4-C $(t\ manure)^{-1}$	18.9	99 days	Hao et al. (2001)
					Active (6 turns)	8.1	-	Kg CH_4-C $(t\ manure)^{-1}$	24.3		
Composting of feedlot manure	Canada	Chamber	July, 2000	Mean daily ambient (1 to 49 d)= 8.7 to 25.8°C; (50 to 99d) = -3.0 to 21.5°C	Straw bedding material	8.92	-	Kg CH_4-C $(t\ manure)^{-1}$	26.8	99 days	Hao et al. (2004)
					Wood-chip based bedding material	8.93	-	Kg CH_4-C $(t\ manure)^{-1}$	26.8		
Beef cattle manure	Canada	Chamber	Consecutive summers (beef following dairy)	not reported	Stockpile (mixed)	2.85	-	g CH_4-C kg^{-1} DM	2.3	3 months	Pattey et al. (2005)
					Composted (aerobic)	0.14	-	g CH_4-C kg^{-1} DM	0.11		
Dairy cattle manure	Canada	Chamber		not reported	Stockpile (mixed)	7.92	-	g CH_4-C kg^{-1} DM	6.4	3 months	Pattey et al. (2005)
					Composted (aerobic)	1.52	-	g CH_4-C kg^{-1} DM	1.2		

TABLE 19 – COMMENTS RELATING TO PUBLISHED EMISSION VALUES IN TABLE 18

Reference	Comments
Sommer et al. (2004)	Values from initial days of stockpiling.
	No treatments, objective was to compare measurement techniques.
	N_2O, CH_4 and CO_2 emissions measured from static chamber method were 12 to 22% of those measured by IHF technique.
	Difference was attributed to convection differences in convection created from the composting manure.
Boadi et al. (2004)	Bedding straw (wheat) was added weekly to the pens.
Loh et al. (2008)	DMI and excretion values not measured.
Luo & Saggar (2008)	DMI and N intake estimated at 12 kg pasture, at 2.5 to 3.0% N.
	Measurements from a stand-off pad, containing bark chip and sawdust.
	High rainfall meant the pad was mostly saturated during study period.
Külling et al. (2003)	Cited as source article for IPCC estimate of N_2O emission factor.
	Measured values from grass treatment (11.2%) cited in this report, hay treatment values not reported.
	Manure collected from 6 lactating dairy cows.
	Cows fed *ad libitum,* DMI range is not specified.
Hao et al. (2001)	Emissions of CH_4 and N_2O were measured from windrows of turned and passively composted feedlot manure.
Hao et al. (2004)	Windrows from both treatments turned 8 times.
	Non-significant treatment differences (CH_4 and N_2O).
	Assumptions: 1 feedlot steer produces 1 Mt manure annually.
Pattey et al. (2005)	50% bedding material (straw and wood shavings).
	Diet and ration not specified. Small herd, equivalent to 20 animal units.
	No animal information supplied (breed, age, environment and conditions, diet and intake, physiological stage).

Where possible, the values provided in Table 18 have been converted to a CH_4 emission rate (kg CH_4/hd/yr) and compared with values provided by DCCEE (2010) and IPCC (2006) to provide an order of estimate for CH_4 losses during stockpiling and composting. The following assumptions were used to enable the comparison:

- VS excretion rate = 750 kg/hd/yr.
- VS:TS ratio of fresh manure = 0.80.
- Percentage VS lost to pond = 2%.
- Pad losses of VS = 50%.

All of the studies included in Table 20 were conducted in the Northern Hemisphere. Temperature differences are likely to contribute to higher VS content of the manure before stockpiling. As such, the relevance to Australian stockpiled manure may be limited. The CH_4 emission rates from the literature range from 0.11 to 26.8 kg CH_4/hd/yr, with the majority below reported values by IPCC (2006) and DCCEE (2010).

TABLE 20 – METHANE EMISSION RATES FROM PUBLISHED LITERATURE

Reference	Comments	Methane emission rate (kg CH_4/hd/yr)
DCCEE (2010) – Solid storage	MCF = 1.5% (southern Australia)	0.24
	MCF = 5% (Qld and NT)	2.38
IPCC (2006) - Composting	Cool – MCF = 0.5%	0.24
	Temperate – MCF = 1.0%	0.48
	Warm – MCF = 1.5%	0.71
IPCC (2006) - Stockpile	Cool – MCF = 2.5%	0.95
	Temperate – MCF = 4.0%	1.90
	Warm – MCF = 5.0%	2.38
Sommer et al (2004) - Stockpile	Continuous measurement	9.7
	Continuous measurement	5.8
	Continuous measurement	0.56
Boadi et al. (2004) - Feedpad	Low forage	0.32
	High forage	0.52
Kulling et al. (2003) – Bucket storage experiment	Grass low protein; liquid manure	0.54
	Grass low protein; solid manure	0.52
	Grass high protein; liquid manure	0.13
	Grass high protein; solid manure	0.43
Hao et al. (2001)	Passive composting	18.9
	Active composting	24.3
Hao et al. (2004)	Straw bedding	26.8
Pattey et al. (2005) – Beef cattle	Stockpile (mixed)	2.3
	Composted (aerobic)	0.11
Pattey et al. (2005) – Dairy cattle	Stockpile (mixed)	6.5
	Composted (aerobic)	1.3
	Wood chips	26.8

Characteristics and Quantity of Feedlot Pen Manure

For many years, the “standard” amount of manure removed from feedlot pens in Australia was quoted to be 1,000 kg DM/hd/yr (2.74 kg DM/hd/day). In recent years, some lot feeders have indicated that their manure harvesting records suggest that the real number could be half of this (500 kg DM/hd/yr or 1.37 kg DM/hd/day). It is reasonable to argue that improved diet formulation and feed processing methods have improved diet digestibility so that less manure is excreted per head.

While there are many studies that report the characteristics of feedlot pen manure, surprisingly few studies have been conducted over the years looking at the quantity of manure removed from feedlot pens. Recently, Kissinger et al. (2006) and several others measured manure removal from a number of feedlot pens using a methodology similar to that used in this study. Kissinger et al. (2007) undertook a literature review of the available data on the characteristics and quantity of manure removed from feedlot pens. A summary of his review is provided in Table 21. Care should be taken in interpreting the results from these studies as there are significant variations in:

- Feedlot pen characteristics
- Manure management methods
- Manure sampling and handling protocols
- Manure testing methods

TABLE 21 – ESTIMATES OF EXCRETED AND HARVESTED MANURE FROM CATTLE FEEDLOTS (KISSINGER ET AL. 2007)

Reference	Animal Characteristics	Housing / Ration	Moisture (% wet basis)	TS	VS	N	P	K
				kg/head/day unless otherwise indicated				
Excreted Manure								
Gilbertson et al., 1974	420-kg feeder, Eastern NE	Hi energy		1.76	1.65			
NRCS, 1992a	420-kg feeder	Hi forage	88	2.84	2.53	0.13	0.046	0.10
	420-kg feeder	Hi energy	88	2.48	2.28	0.13	0.039	0.088
	272-kg calf	Calf	87	2.05	1.74	0.082	0.027	0.054
ASAE, 2005	446-kg feeder	High energy	92	2.4	1.9	0.16	0.022	0.11
Lorimor et al., 2000	499-kg feeder	High energy	92	2.8	2.6	0.24	0.042	0.12
	340-kg feeder	High energy	92	1.9	1.8	0.17	0.028	0.083
	499-kg feeder	High forage	92	3.8	3.4	0.28	0.042	0.14
	340-kg feeder	High forage	92	2.6	2.4	0.19	0.028	0.094
	204-kg calf		92	1.5	1.3	0.063	0.020	0.041
Harvested Manure								
NRCS, 1992a	454-kg feeder	Open lot	45	4.35	2.18	0.095	0.063	0.014
		Surfaced – hi forage	53	2.49	1.75			
		Surfaced – hi energy	52	1.13	0.79			
ASAE, 2005	446-kg feeder	High energy	33	7.5	2.3	0.088	0.038	0.094
Gilbertson et al., 1974	420-kg feeder	Roofed – hi energy	78	1.81	1.56	0.058	0.014	0.026
	408-kg feeder	Eastern NE open lot – hi energy	55	6.37	2.37			
Gilbertson, 1972	18.5 m^2/hd Eastern NE	Eastern NE open lot	54	6.0–7.1	1.5	0.062–0.070	0.0048–0.0056	0.017–0.020
Kissinger, 2005			[a]	[b]	[b]	[b]		
	Summer – 467 kg (132 pens)	Eastern NE open lot	30±15	4.7±4.4	1.1 ± 1.0	0.059±0.057		
	Winter – 465 kg (112 pens)		39±21	8.8±8.6	2.2 ± 1.5	0.100±0.066		
Sweeten et al., 1985	15.5 m^2/hd	TX open lot – Heifers – 152 day feeding period	[a] 22–40%		[c] 26–72%	[c] 2.6%		
Sweeten et al., 1985	20-23 m^2/hd	Eastern CO open lots – 152 day feeding period	[a] 48±19%		[c] 65±24%	[c] 2.6±0.5%		
	17-20 m^2/hd		38±26%		37±35%			
Sweeten et al., 1985		Eastern CO feedlot – 152 day feeding period	[a] 52±10%		[c] 62±11%	[c] 2.7±0.4%	[c] 1.5±0.6%	

[a] Mean ± 2 standard deviation expressed as a % wb.
[b] Mean ± 2 standard deviations expressed as kg/head/day.
[c] Mean ± 2 standard deviations expressed as a % db.

Sweeten et al. (1985) analysed manure harvested from several different feedlots in the USA in 1979 and 1980. Samples were analysed for ash content (non-volatile solids), moisture content, total nitrogen, sulphur and heat of combustion. They were trying to determine if there was a variation of manure quality as a function of depth of manure within the manure pack and the quality of manure harvested with an elevating scraper or wheel loader. They found considerable variation in manure quality. Table 22 shows results from one site. Average manure depth is stated to be 115 mm average above the soil layer. For the surface layer, VS is 72.5% but this decreases to only 26.5% in the interface layer. This means that the manure in the interface layer is either well degraded or it is mixed with soil. This would be common at feedlots in the USA at that time when limited feedlot pad preparation was undertaken and soil was often harvested with the manure. Photograph 1 shows a US feedlot where the virtually no earthworks are undertaken and the pens are simply located on bare uncompacted soil. In this situation, it is common to harvest considerable soil with manure during pen cleaning.

In the second part of the project, manure was removed from pens at Feedlot A and Feedlot B using a wheeled loader. The loader operator was instructed to leave a 25 mm thick "uncollected" layer of manure above the soil. The VS content of the removed manure at Feedlot A (65%) was much higher than at Feedlot B (36.8%). It was assumed that, in Feedlot B, previous wet conditions had led to a significant amount of soil being mixed in with the pen manure. The VS content of the "uncollected" layer was 20.7% and 35.1% for Feedlots A and B respectively.

TABLE 22 – PEN MANURE CHARACTERISTICS AT DIFFERENT DEPTHS

Manure Zone	No of samples	Moisture content (%)	Ash (%)	VS (%)
Loose surface layer	4	21.5	27.5	72.5
Moist loosely-compacted layer	3	39.7	32.6	67.4
Moist interface layer	3	21.7	73.5	26.5

Source: Sweeten et al. (1985)

This data highlights the need to be fully aware of the circumstances behind pen manure samples. Low VS contents can either be due to prolonged manure breakdown or due to mixing of manure with soil. For example, Miller (2001) undertook a study looking at the compounds in feedlot "soil" that might contribute to odour emissions. The organic matter (assumed to be VS) of their manure sample taken from the feedlot pens was 32.4% (DM basis) with a Total N of 1.82%. This low VS content clearly indicates that this sample is a combination of manure and soil. Kissinger et al. (2007) reports the results of manure harvesting data from six Nebraska feedlots. The average TS and VS removal was 5.3 and 1.5 kg/hd/day respectively. This implies a VS content of the removed material to be 28%, on average, indicating a large proportion of soil in the harvested manure. However, they did report a large range for VS/TS from 19% to 55%. They noted that different management practices resulting in different proportions of soil removed during pen cleaning.

Kissinger et al. (2006) summarised the data from 18 separate manure harvesting experiments in Nebraska. As they have cold, relatively dry winters and warm, wet summers, the data was summarised into summer and winter experiments. The average amount of dry matter removed in summer experiments was 4.7 kg DM/hd/day but this almost doubled to 8.8 kg DM/hd/day in winter. The average moisture content of removed manure was 30.4% in summer and 38.6% in winter. The amount of VS removed increased from 1.1 kg VS/head/day in summer to 2.2 kg VS/hd/day in winter. The VS/TS ratio for summer manure removed was 24.1% while it was only slightly different in winter (27.5%). Assuming similar DM excretion from the summer cattle compared to the winter cattle, it must be assumed that the greater VS removal per head in winter is due to decreased VS breakdown in the pens in winter due to cold conditions. However, the results are confused by the apparently higher content of soil in winter-removed manure. If the summer and winter manure removal rates are annualised, the DM removal rates are equivalent to 1.7 and 3.2 t DM/hd/yr respectively.

The VS/TS ratio in the harvested manure in the Kissinger et al. (2006) trials ranged from 9.5% to 52.4%. Material with only 9.5% VS must be mainly soil. However, the removed material that was 52.4% VS is probably degraded manure with a small soil content. This wide range of VS content in material harvested from feedlot pens demonstrates the influence of pen design and management on the quality of manure removed from the pens.

Kissinger et al. (2006) also provides data on VS loss in runoff. In the summer experiments, an average of 6.2% of excreted VS is lost from the pens in runoff. In the winter experiments, the excreted VS loss in runoff averaged only 1.9%.

In summary, in the last 25 years, the only good quality studies undertaken to determine the amount of manure removed from feedlot pens have been undertaken in Nebraska. The manure removal ranges from about 4.7 kg DM/hd/day to 8.8 kg DM/hd/day (1.7to 3.2 tDM/hd/yr) depending on climatic and pen harvesting conditions. The VS content of the harvested manure ranges from 10% to 55% depending on the amount of VS breakdown and the soil content of the manure.

Photograph 1 shows a typical US feedlot where little earthworks have been undertaken to prepare the feedlot pen surface and there is no surface compaction or placement of gravel. Photograph 2 shows another common activity is US feedlots. Earth mounds are constructed in the middle of feedlot pens to provide a dry refugee for cattle during wet conditions. Under these circumstances, when manure is removed, particularly under wet conditions, considerable soil can be taken with the manure. This is often referred to as “feedlot soil”. By contrast, most new Australian feedlots have a pen surface that was compacted, often gravelled and levelled prior to cattle entry. Pen cleaning usually aims to leave a shallow layer of manure or no manure at all so as not to disrupt the compacted pen surface (see Photograph 3). Hence, in most Australian feedlots, the amount of soil removed during pen cleaning is minimal. This should be reflected in a higher VS content in Australian harvested pen manure than in US or Canadian feedlots.

PHOTOGRAPH 1 – US FEEDLOT WITH PEN SURFACE OF UNCOMPACTED SOIL

PHOTOGRAPH 2 – FEEDLOT PEN WITH EARTH MOUNDS

PHOTOGRAPH 3 – TYPICAL AUSTRALIAN FEEDLOT PEN CLEANED TO SMOOTH GRAVEL BASE

Characteristics of Feedlot Stockpile and Compost Manure

The value of feedlot manure is largely determined by the composition of the manure. Table 23 shows typically measured concentrations of various elements in stockpiled feedlot manure. These results show a wide variation in the reported data. Thus typical manure concentrations of nutrients and salts are usually provided within a range of values. This is because of the wide variations in design, management, diets and climatic conditions between feedlots.

TABLE 23 – CHARACTERISTICS OF STOCKPILED FEEDLOT MANURE WITHIN AUSTRALIA; AVERAGE AND (RANGE)

Component	Units	Average and (Range)*
Dry matter	% w.b.	72.97 (53.7 - 92)
Volatile solids	% d.b	67.6 (55 - 75.9)
Ash	% d.b	32.4 (24.1 - 45)
pH		6.95 (5.6 - 9.2)
Total Nitrogen	% d.b	2.18 (1 – 3)
Ammonium Nitrogen	% d.b	0.038 (0.036 – 0.169)
Total Phosphorus	% d.b	0.8 (0.4 – 1.3)
Potassium	% d.b	2.32 (1.5 – 4.0)
Sodium	% d.b	0.61 (0.3 – 1.3)
Chloride	% d.b	1.35 (0.7 – 2.3)
Conductivity	dS/m	12.36 (3.9 – 22)
SAR		5.9 (0.8 – 18.8)

* Skerman (2000) and Gardner et al. (1994) - interpreted from Powell (1994a).

The reported nitrogen content of stockpiled manure can be compared with output values reported by BEEF-BAL.

Nitrogen Balance of Feedlot Pen

The determination of the nitrogen balance of a feedlot pen is a two-step process. The first step is to determine the excretion of nitrogen by cattle. The second step is to partition that nitrogen to various locations.

Nitrogen Excretion of Cattle

Experimental Determination of Nitrogen Excretion

In experimental studies, nitrogen excretion has been determined by two methods:

- Direct nitrogen measurement in excreted manure
- Mass balance residual of nitrogen intake and nitrogen retention in cattle.

Sinclair (1997) is an example of a study where nitrogen excretion was determined by directly measuring urine and faeces and subsequently determining the nitrogen content of the manure. Table 26 presents the data collected by Sinclair (1997). This data shows that about 57% of the excreted nitrogen was in the urine. In a digestibility trial done by Bierman et al. (1999), the percentage of excreted nitrogen in urine was 44.7%, 49.1% and 66.9% across three treatments.

Erickson et al. (2002), Farran (2004), Luebbe et al. (2008) and Luebbe et al. (2009) all use the same mass balance approach to determine nitrogen excretion. In these studies, feedlot cattle were fed in open pens with a range of treatments. Nitrogen intake was determined by accounting for dry matter intake (DMI) and the N concentration of the dietary ingredients. Nitrogen retention in the animal was based on animal performance and weights using retained energy and retained protein equations from National Research Council (1996). Nitrogen excretion was the difference between nitrogen intake and nitrogen retention.

Figure 4 shows the nitrogen excretion of cattle (expressed as a % of nitrogen intake) from several studies. Figure 5 shows the same nitrogen excretion data but expressed as g nitrogen excreted per kg liveweight per day. In all these studies, the “control” treatment represents a typical commercial feedlot ration. The treatments used are as below.

- Treatments 0.26%P, 0.30%P, 0.35%P, 0.45%P and 0.50%P are from (Sinclair 1997)
- Treatments 0 bran, 15 bran and 30 bran are from (Erickson et al. 2002)
- Treatments Control 1, Bran 1, Control 2 and Bran 2 are from (Farran et al. 2004)
- Treatments Control 3, 15 WGD, 30 WDG, Control 4, 15 WDG and 30 WDG are from (Luebbe et al. 2008) where wet distillers grain (WDG) was fed at different percentages in the ration.
- Treatments NGE WIN, POS WIN, NEG SUM and POS SUM are from (Luebbe et al. 2009)

On average, 85% of nitrogen that is fed is excreted, with a range of 80-90%.

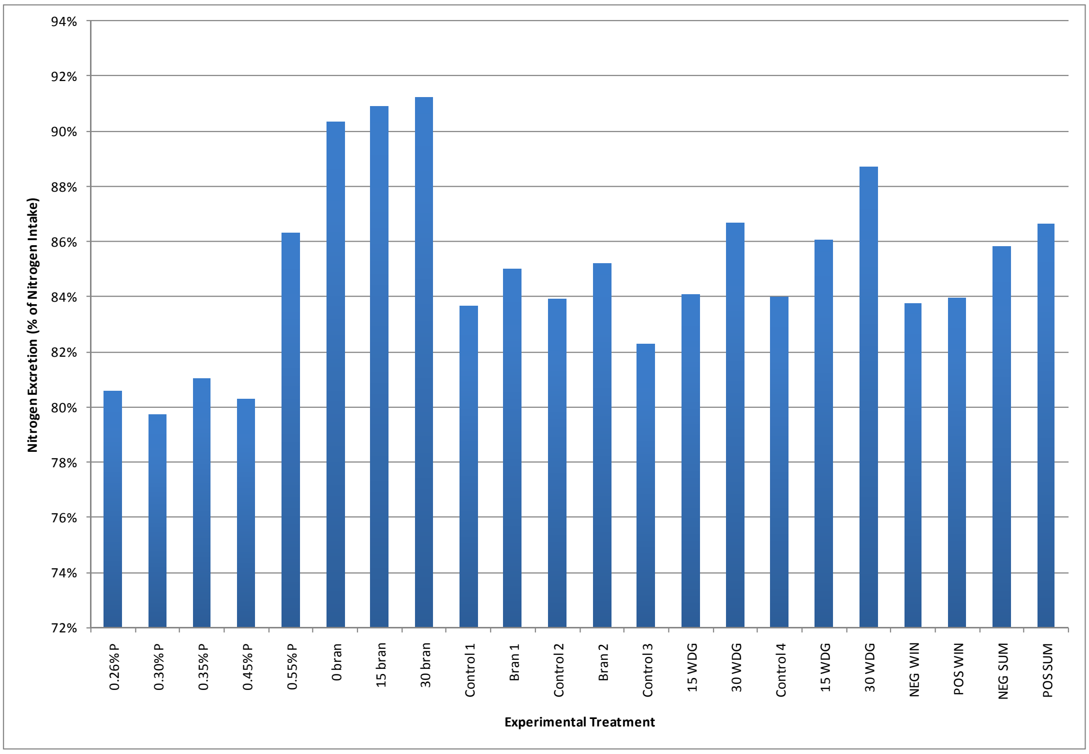

Figure 4 – Nitrogen Excretion of Cattle (% of Intake) – numerous studies

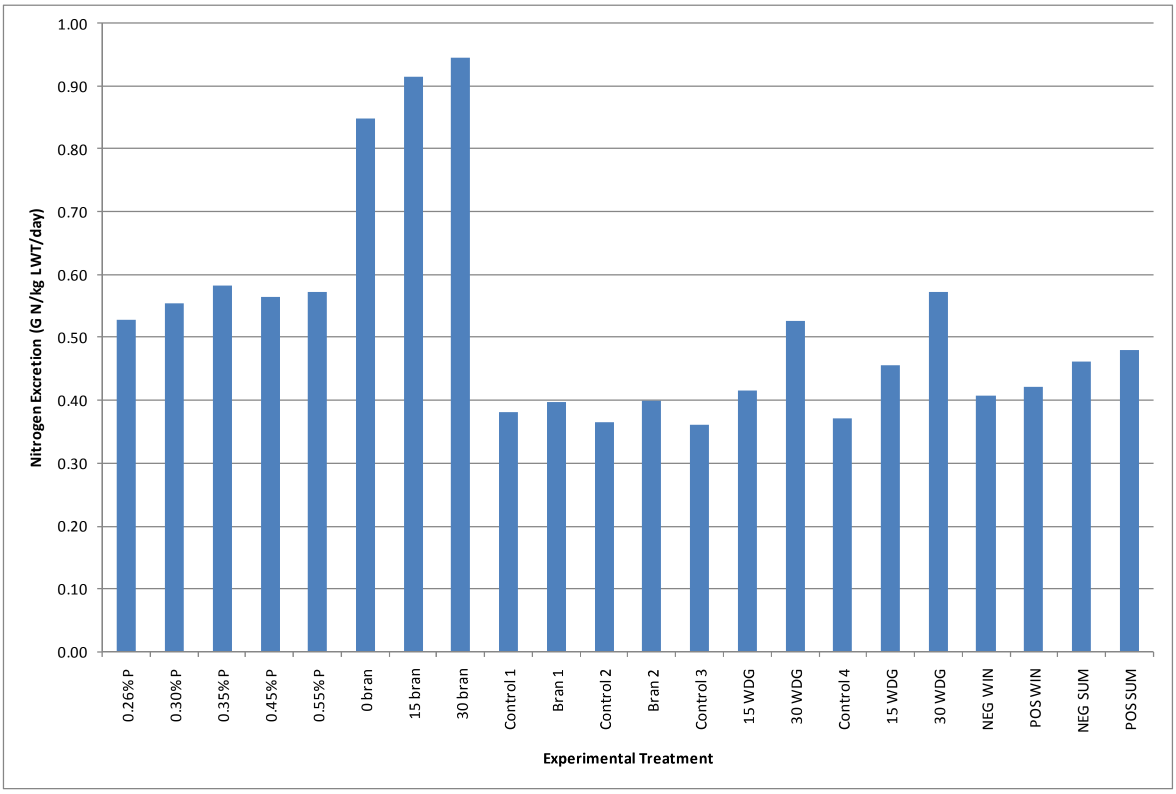

Figure 5 – Nitrogen Excretion of Cattle (gN /kg LWT/day) – numerous studies

Nitrogen Losses from a Feedlot Pen

The nitrogen excreted onto a feedlot pen surface is partitioned to three locations. These are:

- Volatilisation to the atmosphere
- Transported out of the pen in runoff
- Harvested out of the pen in manure

Nitrogen Volatilisation to the Atmosphere

The greatest ammonia emissions from feedlots occur from the surface of open pens. Between 50 and 55% of the total N fed to feedlot cattle can be lost to the atmosphere as ammonia (Flesch et al. 2007). Bierman et al. (1999) reported that 57 to 67% of the total nitrogen excreted is volatilised by the time that feedlot pens are cleaned, which is typically every 6 to 12 months.

Faecal nitrogen is 50% organic nitrogen and 50% ammonia (Mackie et al. 1998). However, urine contains up to 97% urea nitrogen, which is readily converted by microbial urease to ammonia following excretion from cattle (Mobley & Hausinger 1989). As ammonia is potentially highly volatile, there is scope for large nitrogen losses from the pen surface. However, the volatilisation loss is dependent on a range of parameters including:

- Manure and air temperature
- Manure moisture content
- Manure pH
- Carbon : nitrogen ratio of the manure
- Manure management (e.g. pen cleaning frequency).
- Use of additives in feed and pen surface to reduce volatilisation

Kissinger et al. (2006) summarised the data from 18 separate manure harvesting experiments in Nebraska. As they have cold, relatively dry winters and warm, wet summers, the data was summarised into summer and winter experiments. In each experiment, they determined the nitrogen excreted onto the pen surface as the residual between nitrogen fed and nitrogen retained in the cattle. They measured nitrogen in runoff and the nitrogen in harvested manure. From this data, they calculated the nitrogen lost by volatilisation (expressed as a % of the nitrogen excreted) as the residual.

They found that, in summer trials, on average, 69% of the excreted nitrogen was lost by volatilisation. This dropped to 47.2% lost in the winter trials. They attributed this difference primarily to different ambient temperatures.

Effect of Carbon to Nitrogen Ratio

Erickson et al. (2002) undertook a study three experiments to evaluate digestibility effects of rations on nitrogen volatilisation from pens. The hypothesis was that the inclusion of more bran in the ration would increase the amount of carbon excreted onto the pen surface, thus increasing the carbon : nitrogen ratio of the manure. Adding carbon to manure decreases nitrogen loss by lowering pH when manure is stored anaerobically or by microbial immobilisation when stored aerobically (Erickson et al. 2002).

Put simply, nitrogen volatilisation decreased from 74% to 54% during October to May as bran increased, which was consistent with the hypothesis. However, no differences were observed for N balance from May to October. It appeared that the nitrogen volatilisation loss was also affected by temperature and rainfall, which varied from Experiment 1, 2 and 3. Erickson et al. (2002) noted that numerous researchers have concluded that N volatilisation is positively correlated with moisture content and is rapid during drying conditions and these conditions masked the effect of addition bran in the ration.

Adams et al (2004) undertook a similar experiment to Erickson et al. (2002) but included the application of sawdust to the feedlot pens as an additional treatment. They found that, in winter, the volatilisation loss from the control pen was 49.4% and this decreased to 29.1% for the bran treatment and 26.8% for the sawdust treatment. This indicates that the addition of carbon decreases nitrogen volatilisation markedly. However, the average temperature during the winter experiment was only 0.6°C, which are conditions never encountered in Australia. For the summer experiment, the mean temperature was 22°C. The volatilisation loss from the control pen in summer was 62.2% and this decreased to 56.4% for the bran treatment but increased to 64.8% for the sawdust treatment. They believed that the increase in volatilisation due to temperature increase dominated the nitrogen balance.

Nevertheless, the addition of carbon to the pen surface, either through the ration or the addition of bedding, has the potential to reduce nitrogen volatilisation from pen surfaces.

Effect of Manure Management

Farran et al. (2004) undertook a study to investigate the effect of pen cleaning frequency on nitrogen losses from a pen surface. The hypothesis was that, if nitrogen losses due to volatilisation could be reduced by more frequent pen cleaning, the fertiliser value of the manure would be enhanced. Pens were either cleaned monthly or one at the end of a 166-day feeding period. They also varied diet with the control diet being a typical feedlot diet with dry-rolled, high-moisture corn and corn bran diet which aimed to increase organic matter (volatile solids) excretion to the pens. The hypothesis behind the diet treatments was that a higher carbon : nitrogen ratio in the manure would decrease nitrogen losses.

When nitrogen loss from the pen surface is expressed as a percentage of nitrogen excretion, the results of their study are:

- 45.1% N loss – control diet, monthly cleaning
- 25.2% N loss – bran diet, monthly cleaning
- 39.8% N loss – control diet, end-of-feeding cleaning
- 47.9% N loss – bran diet, end-of-feeding cleaning

An interaction occurred between diet and pen cleaning frequency on manure N and N losses from pens. Manure N was greatest with steers fed BRAN and pens cleaned monthly ($P < 0.05$) indicating OM from BRAN along with a more frequent pen cleaning was effective in retaining N. Higher manure N translated into a reduction in N lost when calves were fed BRAN and pens were cleaned monthly. Nitrogen losses were reduced ($P < 0.01$) from 45.1 to 25.2% of N excreted (44% reduction) by feeding BRAN if pens were cleaned monthly. However, if pens were cleaned once at the end, N losses from the pen surface were greater when steers were fed BRAN compared to CONTROL ($P = 0.06$). This was a result of greater N intake and N excretion, yet similar manure N for steers fed BRAN compared to CONTROL. It is not clear why; however, this observation of similar manure N with BRAN feeding contradicts trials with cattle fed during similar times of the year.

Wilson et al. (2004) conducted a trial over the summer periods of 2001 and 2002 to determine if more frequent pen cleaning reduced nitrogen loss from pens. Their methodology is similar to Farran et al. (2004). They found that, in 2001, monthly pen cleaning resulted in 63.6% N loss which was less than 78.4% N loss for a single cleaning at the end of the feeding period. In 2002, monthly pen cleaning resulted in a 55.5% N loss which was also less than the 68.0% N loss from a single cleaning at the end of the feeding period.

These studies indicate that, if manure is removed more frequently from pens and not left exposed to the atmosphere, nitrogen loss from the pen surface can be reduced. However, care needs to be taken to ensure that the saved nitrogen is not immediately lost in the subsequent manure stockpile / composting process.

Effect of Ration Additives

Sherwood et al (2006) undertook a nitrogen mass balance study of feedlot pens to analyse the effect of feeding clinoptilolite zeolite clay to cattle. The hypothesis was that the addition of zeolite to the ration would bind the ammonia on the feedlot pen surface thus reducing ammonia losses and increasing the nitrogen content of the manure. They found that a 1.2% inclusion of clinoptiloite in the feedlot ration did not affect the nitrogen balance of the feedlot pen.

Nitrous Oxide Losses

Currently, there are few studies with data on N_2O emissions from the feedpad that are able to express N_2O-N loss from the feedpad as a percentage of N excreted. Further, there are no Australian data, relative to Australian feedlots. In a Canadian study, Boadi et al. (2004) measured N_2O emissions from the feedpad using chamber methodology (gas sampling and analysis). However, it is not possible to express this as a percentage of total N excreted or fed, since total N excreted or fed is not reported.

IPCC Prescribed Emission Factors for N_2O Loss from Drylots (Feedpad)

Currently, the IPCC estimates of N_2O emissions from a drylot are based on an emission factor of 2.0% of total excreted manure (IPCC 2006). This emission factor (as stated in the IPCC guidelines) is derived from an expert panel, and based on a manure storage experiment by Külling et al. (2003). It is unclear what conclusions were made by the expert panel regarding the results presented by Külling et al. (2003). It is however, assumed that the 2.0% emission factor has been derived from N_2O-N loss from the storage (over 7 weeks) of liquid manure fraction from both dietary treatments. The methodology of Külling et al. (2003) is summarised below.

Lactating dairy cows (n = 6) were used to measure the total N loss and gas emissions arising from manure collected under controlled conditions when fed forage based diets. The experiments were conducted within Switzerland in two time periods. The two dietary treatments (fed *ad libitum*) were (i) grass-based and (ii) hay based (11.1% crude protein (CP) DM, 6 MJ net energy /kg DM), with grain supplementation (12.8 % CP DM, 7.9 MJ net energy for lactation /kg DM). Protein content of the grass diet differed between time periods 1 and 2: 11.2 and 22.9% CP DM, and 5.8 and 5.9 MJ net energy for lactation. Manure was separated into a liquid, slurry and farmyard manure type storage, and stored for 7 weeks to determine GHG losses. Liquid and slurry manure fractions were stored at 20°C and 70% ambient humidity. Farmyard manure (solid manure) fraction was stored at heated temperature to simulate heat production during long-term stock piling. Farmyard manure was kept at 41°C, reducing by 2°C each week of the experiment.

The formation of a crust on liquid and slurry storage experiments was acknowledged by the authors as a contributing factor to the emission of N_2O from liquid and slurries. The formation of a persistent crust on the liquid manure samples was acknowledged as a contributor to higher N_2O emissions, when compared to previous studies in manure storage (Külling et al. 2003). Others suggest that covering of slurry manure storage with organic material (straw) may increases the net total N_2O emissions (Amon et al. 2006, Sommer et al. 2000), which may act similarly to the crust which formed on the liquid storage treatment by Külling et al. (2003). Külling et al. (2003) observed that the effect of differing CP within the grass diet on N_2O emission was varied according to manure storage method.

In a similar study to Külling et al. (2003), Amon et al.(2006) observed that GHG emissions from manure slurry are predominantly in the form of NH_4, and most GHG emissions from the application of manure to as fertiliser are in the form of N_2O.

This report questions the validity of assumptions made to derive the emission factors of N_2O from dry lots, by inference, from the results from Külling et al. (2003). It is believed that the differences between the described methodology implemented by Külling et al. (2003) and pen surface of feedlots in Australia raises doubt on the emission estimates of N_2O. Others have similarly expressed concerns on the uncertainty of prescribed emission factors for both manure storage (Amon et al. 2006), and livestock production systems (Kebreab et al. 2006). For manure storage systems, the emission of N_2O depends on the N and carbon content of manure, on the duration of the storage and on the type of treatment (Amon et al. 2006). Similarly, the emission from manures *in-situ* varies with the type of animal, diet, management of manure and climate conditions (Kebreab et al. 2006). This highlights the need to effectively quantify N_2O emissions (and other GHG sources) from Australian feedlots.

Drivers of Nitrous Oxide Emissions from Australian Feedlots

From an Australian agricultural perspective, there is a need to examine the emissions factors used to estimate N_2O emissions on a national level (Dalal et al. 2003). Similarly (and contributing to the same), is the need to evaluate the emission factors used to estimate N_2O emissions from Australian feedlots. Understanding the effectors of N_2O emissions is essential to designing and conducting effective experiments to measure and quantify the potential for N_2O production from feedlots.

The relevant pathways of N_2O production for beef production are through nitrification and denitrification. For N_2O emissions from pastures, the ratio of N_2O to N_2 is determined by processes within the soil, including:

- temperature
- pH
- oxygen supply, or water-filled pore space; (WFPS, to determine anaerobicity)
- decomposable soil carbon
- nitrogen substrate supply
- salinity (Dalal et al. 2003, Eckard et al. 2010).

Currently most of the investigations regarding N_2O within agriculture are concerned with the nitrification (and denitrification) processes within agricultural soils. The production of N_2O from pasture and grazed soils is not within the scope of this review, but has been repeatedly cited as a significant source of N_2O emissions (Chadwick et al. 1999, Luo et al. 2010, Oenema et al. 1997, Saggar et al. 2004, Saggar et al. 2007). It is recognised that for the purposes of understanding N_2O emissions originating from the feedpad within Australian feedlots, the same biochemical pathways of N_2O production are relevant (Kebreab et al. 2006). However, intrinsic differences exist between a beef feedpad to a soil profile.

Cole et al. (2009) comprehensively investigated the chemical characteristics of the manure and soil layers within 3 feedlots in Texas (USA) over 4 seasons. They observed chemical, physical and microbial differences between a soil profile and feedlot pad surface (Cole et al. 2009). The causes of these differences are listed below:

- Continuous deposition of excreta and higher stocking density.
- Microbial communities are likely different to those within soil. Within feedlots, soil bacteria (as dominant within most soils) may be replaced by faecal bacteria that are more tolerant to NH_3.
- Uptake of N by plants within normal soil profiles is likely to influence N transformations (Cole et al. 2009).

In addition, the use and compaction of gravel during construction of modern Australian feedlots is likely to contribute to the physical differences. In summary, the N_2O production from the manure pack on the feedpad may have a greater similarity to manure storage systems rather than a soil profile. It is likely that these differences influence the production of N_2O on the feedpad.

Future studies would need to investigate the relative influence of these individual factors on N_2O production within the feedlot. Because the physical and chemical characteristics of the layers within the feedpad can influence N transformations, N distribution and N losses, attempts to measure N_2O losses from feedlots should (where possible) be combined with measuring the physical and chemical characteristics within the source medium.

Ratio of N_2O to N_2 production

Observed differences in the production ratios of N_2O to N_2 have been observed between different frequency of cattle traffic and deposition of excreta for intensively housed cattle in Europe. An over wintering area (pastures where high densities of cattle are located for relatively long periods during winter) are potentially significant sources of N_2O emissions. Overwintering management can cause a gradient of impact (accumulation of excrement) from the intensively housing of cattle, ranging from most impacted areas closest to the feed areas (and animal house) to much less impacted areas in the middle, to almost unaffected areas where animal traffic was minimal (Simek et al. 2006). In some cases, contrary to expectations, N_2O emissions were smaller in an area heavily impacted by cattle than one moderately impacted by cattle (Hynst et al. 2007, Simek et al. 2006). Nitrous oxide emissions at the site severely impacted by excreta deposition were positively correlated with soil NO_3^- and negatively correlated to soil temperature. Most of the N_2O emissions from the highly impacted site were during early spring at relatively low temperatures (Hynst et al. 2007).

These observations appears logical, considering soil temperature was at or slightly below 0°C during winter months. The effect of European winter temperatures (5 to -5°C during winter months) would be a significant factor on results obtained in these studies. It is difficult to make direct comparison between Australian feedlots and winter conditions in the Northern Hemisphere, since seasonality and climate conditions can significantly affect the ash content and quality of manure (Sweeten et al. 1985). For example, Kissinger et al. (2007) report that for American feedlots, almost twice the amount of manure can be collected following a winter feeding period compared to a summer feeding period (8.8 vs 4.7 kg DM/head/day). The case in point is that the interactions between the factors influencing N_2O emissions from manure are complex.

Nitrous oxide production from stored and composted manure is contributed to by multiple processes, based on variations in oxygen availability, substrate availability, pH and bacterial processes (Hao et al. 2001). In summary, the production and emission of N_2O from managed manures requires the presence of either nitrites or nitrates in an anaerobic environment preceded by aerobic conditions necessary for the formation of these oxidised forms of N. In addition, conditions preventing reduction of N_2O to N_2, such as a low pH or limited moisture, must be present (Dong et al. 2006). Similar to manure storage and soils, the pen surface of a feedlot can vary between anaerobic and aerobic conditions (and a combination of both), such that a dynamic interaction of multiple processes are involved in the production of N_2O (Cole et al. 2009, Kebreab et al. 2006, Stevens et al. 1998). Nitrification and denitrification are likely to be occurring at the same time, and therefore probable that multiple processes are contributing simultaneously to N_2O and N_2 formation from soil and feedpad (Stevens & Laughlin 1998, Stevens et al. 1998).

Nitrification

Nitrification occurs under aerobic conditions, and involves a two-step process where ammonium is first oxidised to nitrite, and nitrite is then converted to nitrate, as shown in Figure 6. Nitrous oxide is a by-product of this process (Kebreab et al. 2006, Stevens et al. 1998).

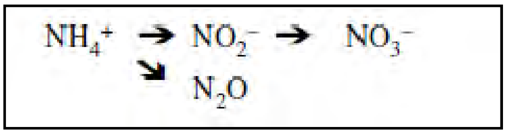

FIGURE 6 – PROCESS OF NITRIFICATION

Denitrification

Denitrification is the reduction of nitrate to di-nitrogen gas (N_2), which is the final end product when reduction is complete (Kebreab et al. 2006) as shown in Figure 7. It is well established that denitrification occurs under anaerobic conditions (Hao et al. 2001). This process is can be altered by several conditions as outlined previously.

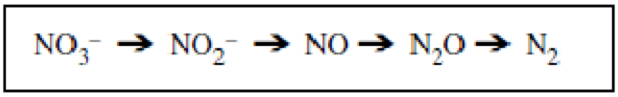

FIGURE 7 – PROCESS OF DENITIRIFCATION

There is a general agreement in the scientific literature that the ratio of N_2O to N_2 increases with increasing acidity, nitrate concentration and reduced moisture (Dong et al. 2006). The effect of moisture or water filled pore space is a significant determining factor in the N_2O to N_2 ratio (Figure 8).

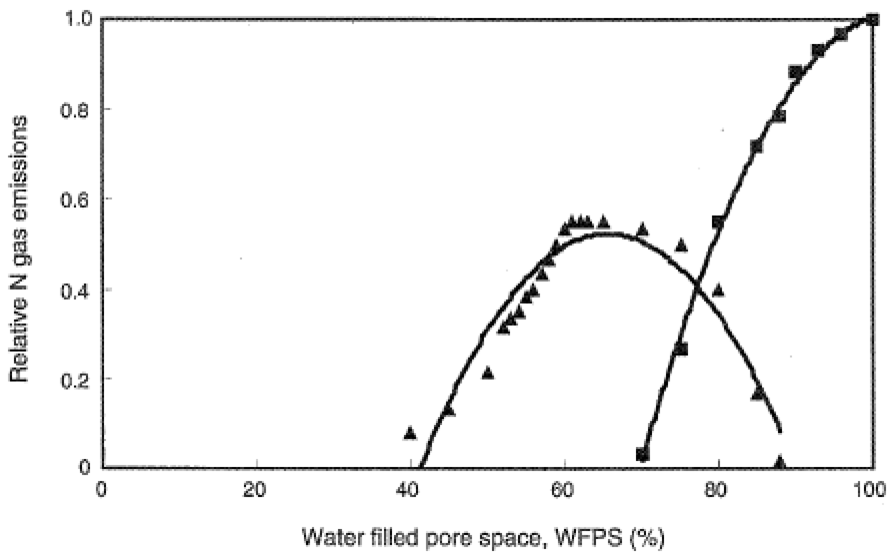

FIGURE 8 – A GENERALISED RELATIONSHIP BETWEEN WATER-FILLED PORE SPACE (WFPS) OF SOILS AND THE RELATIVE FLUXES OF N_2O AND N_2 FROM NITRIFICATION AND DENITRIFICATION (DALAL ET AL. 2003).

Temperature

The denitrification process has been observed to occur between 2 to 50°C, with every increase of 10°C causing the rate of denitrification to double (Galbally 1989, cited in Kebreab et al. 2006). For a study comparing storage types for dairy and beef manures, temperature measurements (surface and core) accounted for most of the variation in N_2O emissions from composted (aerobic) and stockpiled (balance of aerobic and anaerobic) treatments (Pattey et al. 2005). Thus, temperature is influential to the ratio of N_2 to N_2O, and is likely to be a determining factor in N_2O produced from the feedpad.

Several studies have been conducted in Canada regarding emissions from composting manure. The requirement for research in Canada may be influenced by low temperatures (particularly during winter) which have been observed to increase the volume of manure during winter compared to summer feeding periods (Kissinger et al. 2007). It is likely that more manure is removed during pen cleaning in Canada compared to Australian feedlots. Lower temperatures in Canada are likely to decrease volatilisation, thereby increase the total volume of manure removed from the feedpad during pen cleaning. Additionally, bedding material is typically added to Canadian feedlots which would increase total manure volume, affecting the physical and chemical characteristics of fresh manure and also its composted end product (Hao et al. 2004). Incorporating straw can decrease bulk density and increase aeration (Kebreab et al. 2006). Therefore, caution should be taken when inferring data from studies conducted under winter conditions in the Northern Hemisphere to Australian conditions.

There is a deficit of Australian information and research regarding the contribution and interaction between the individual factors that influence the ratio of N_2 to N_2O on the feedpad. Of two published studies conducted in Australia to quantify GHG emissions from feedlots, only one has measured N_2O. It is not likely that findings of studies in Northern Hemisphere climates will be equally transferable to Australian conditions, due to differences in temperature and other climatic variables. This highlights the need for quantification of not only the emissions of N_2O from the feedpad, but the conditions conducive to production of N_2O over N_2.

Nitrogen Loss in Runoff

Nitrogen is lost from pens in runoff – either in solution or in the entrained manure. This loss is typically a small component of the nitrogen balance of a pen.

Erickson (2002), Farran et al. (2004), Luebbe et al. (2008, 2009) all use the same approach to determine nitrogen loss in runoff. In their experimental work, nitrogen in runoff was quantified by sampling each runoff event and measuring total runoff volume. In these experiments done in Nebraska, the feeding period ranged from 114 to 196 days with some experiments in winter and some in summer. The amount of rainfall, and hence runoff, varied between experiments. Figure 9 shows the nitrogen lost in runoff in these studies (expressed as a percentage of excreted nitrogen). It ranges from almost 0% to almost 5%. Kissenger et al. (2006) summarised the data from 18 of these manure harvesting experiments in Nebraska. As they have cold, relatively dry winters and warm, wet summers, the data was summarised into summer and winter experiments. Summer pens averaged 2.7% of nitrogen excretion in pen runoff while winter pens averaged 1.8% nitrogen loss.

Bierman et al. (1999) calculated the nitrogen lost in runoff in their feedlot study that ran over 87 days. The percentage of excreted N that was lost in runoff was 4.6%, 5.9% and 19.4% in three treatments. The third treatment had significantly more runoff thus explaining the high N loss % in the runoff.

There are no studies available in Australia that have measured nitrogen loss from pens in runoff. However, a first order estimate can be made. Assuming that 100 cattle are held in a pen at a stocking density of 15 m^2/head, with an annual rainfall of 650 mm and assuming a runoff co-efficient of 30%, the runoff would be 0.29 ML. If the nitrogen content of the runoff was 400 mg N/L, 117 kg of nitrogen would be lost from the pen surface. If the cattle excrete 80 kg of nitrogen per head per year, the annual excretion is 8000 kg N and the runoff represents only 1.5% of this excretion. If the runoff contained significant amounts of entrained manure, the effective nitrogen concentration of the runoff would be higher, as would the % loss, say 2%.

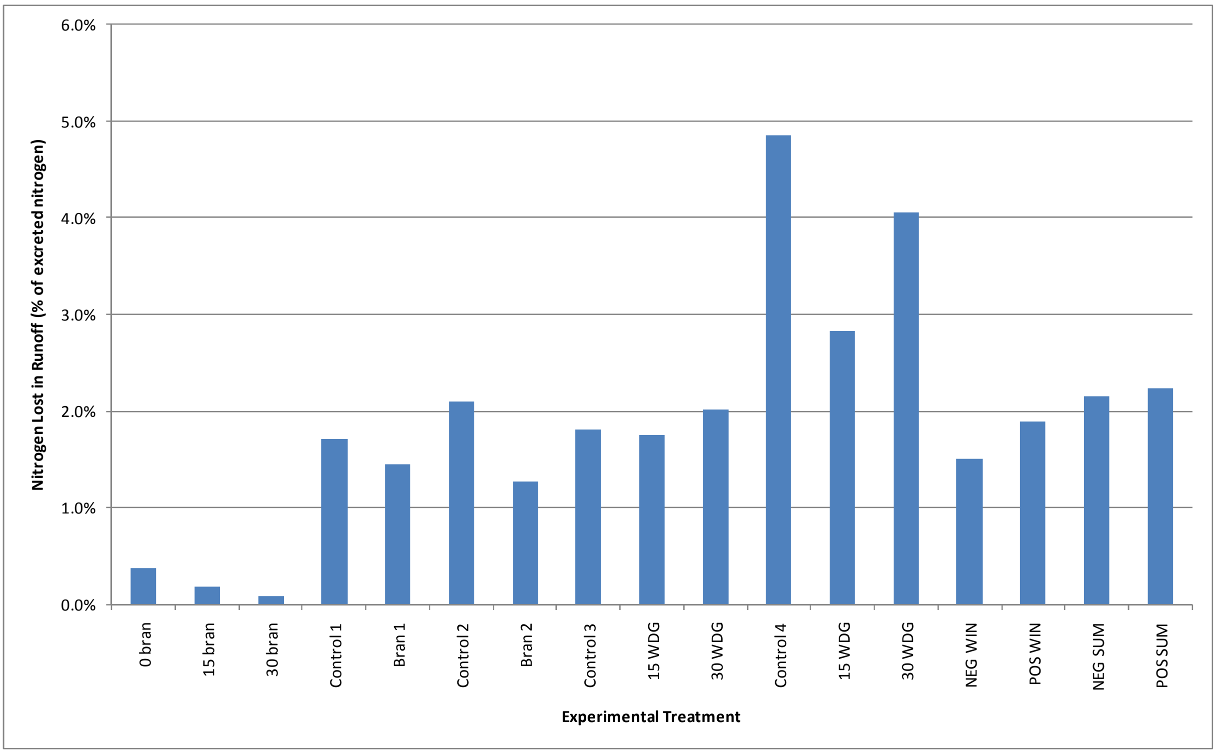

FIGURE 9 – PEN NITROGEN LOST IN RUNOFF (% OF EXCRETED N) – NUMEROUS STUDIES

Nitrogen Harvested in Pen Manure

Using a theoretical mass balance, it is estimated that for each SCU, 24 kg of N will be removed from the feedpad annually. This represents approximately 27% of the estimated 87.5 kg excreted per SCU to the feedpad.

Nitrogen Losses from Manure Stockpiles and Composting

Manure collected from Australian feedlots is commonly stored in compacted stockpiles or is composted in windrows (Kuhlman 1992, Powell 1998). Stockpiled and composted manure is more friable, with smaller particles (Raviv et al. 1987) compared to feedpad manure and can be more evenly spread over land areas. Manure storages vary greatly in their ability to conserve N. Temperature, moisture, pH, and carbon : nitrogen ratio are important in determining the amount of N lost from the manure (Eghball & Power 1994b).

Manure stored in compacted stockpiles is subject to anaerobic decomposition, which generates a substantial amount of heat (Sweeten 1989). Current data suggests that stockpiled manure has over 90 % of the total N in the organic form, while the remainder is in the inorganic ammonium-N or nitrate-N forms. Ammonium-N levels are generally less than 5% of the total N. Stockpiling provides potential reductions in bulk, odours, weed seed viability and disease organisms. However, it does allow the gaseous loss of N, an increase in ammonium concentration (Kirchmann 1991) and leaching of other nutrients (McCalla et al. 1977, Powell 1998).

The variation in moisture, total N and P concentrations between fresh feedpad samples and stockpiled samples from southern Queensland lots is shown in Table 24. Moisture variation of manure is dependent upon climate, age of manure, and storage conditions (Lott 1995) Unlike P, N content decreases with increasing manure age. Powell (1994b) states the rate of N loss is slightly higher than the loss of total dry matter in the stockpile. Furthermore, mass balance calculations suggest that the N loss from the stockpile can range from 15% to 40% due to variations in moisture content, temperature and carbon : nitrogen ratios.

TABLE 24 – COMPARISON OF COMPOSITION OF PEN FRESH AND STOCKPILED MANURE FROM SOUTHERN QUEENSLAND FEEDLOTS (ADAPTED FROM LOTT 1995)

	Pen Fresh	Stockpiled
Number of samples	40	53
Moisture %	34	24
Total N %	2.37	2.03
Total P %	0.75	0.83

Alternatively, manure stored under predominantly aerobic conditions (or actively composted) results in greater water loss (Powell 1994b) and decomposition of cellulose and fibre (Follet & Crissant 1990). On average 4-6 t of dry feedlot manure can be converted to 1 t of sterilised finished compost (Chesnin 1977). Power et al. (1994) estimated up to 25% loss of N due to volatilisation, which is within the range (20-40%) recorded by Eghball and Power (1994a) during the composting process. Likewise, Eghball et al. (1997) reported N losses during outdoor composting in Nebraska over three consecutive summers ranging from 19-42%. Ammonia volatilisation accounted for >92% of the N loss whilst combined nitrate and ammonium runoff loss was <0.5%. Erickson et al. (2003a) showed that composting manure from animals fed bran, the addition of carbon products in the feedpad, frequent pen cleaning and the addition of carbon to manure prior to composting reduces the N loss via NH_3 volatilisation. Disadvantages of composting compared to stockpiling include reduced availability of N to plants, processing time, costs for handling, equipment, labour, land base and odours generated (Eghball 2000).

A summary of studies measuring NH_3 and N_2O from stored and composted manure is included in Table 25. Currently, data of N_2O and NH_3 losses from manure management for Australian feedlots has not been published. Results from studies in Northern Hemisphere are likely to be of limited value for Australian conditions, largely due to lower temperatures and different manure management.

TABLE 25 – REPORTED VALUES OF N LOSS (NH_3-N AND N_2O-N), AS A PERCENT OF TOTAL N TO MANURE STOCKPILE. SOURCED FROM IPCC AND DCCEE, AND REVIEWED LITERATURE

	N loss (%'age of N Stored)			
Emission source	Value	Range	Comments	Reference
NH_3-N (%'age of N Stored)	45	10.0 - 65.0	Source: Table 10.22 of IPCC 2006	IPCC (2006)
	30		From dairy; no beef cattle value provided	DCCEE (2010)
	25	15.0 - 40.0	Review of literature for NPI Review	FSA Consulting (2006)
	25			*BeefBal*
Range values		**10 - 65**		
N_2O-N (%'age of N Stored)		0.62 - 1.07	Passive storage vs. turning	Hao et al. (2001)
		0.39 - .68	Straw bedding vs. woodchip bedding material	Hao et al. (2004)
	4.3		Cattle manure. UK Straw bedding system stockpile. 12 months	Thorman et al. (2007)
	2.6		Swine manure. UK Straw bedding system stockpile. 12 months.	Thorman et al. (2007)
	12.3†		**Fresh** solid dairy manure, low protein grass. 5 wks storage.	Kulling et al. (2003)
	46.0†		**Fresh** solid dairy manure, hay + grain supplement. 5 wks storage.	Kulling et al. (2003)
	7.12†		**Fresh** solid dairy manure, high protein grass. 7 wks storage.	Kulling et al. (2003)
	8.45†		**Fresh** solid dairy manure, hay + grain supplement. 7 wks storage.	Kulling et al. (2003)
	10.00	5.0 - 20.0	Intensive composting (frequent turning)	IPCC (2006)
	0.60	0.3 - 1.2	Static piles with forced aeration	IPCC (2006)
	1.00	0.5 - 2.0	Passive windrow - infrequent turning	IPCC (2006)
	0.50	0.25	Solid storage	IPCC (2006)
Range values		**0.27 - 20**		

† High N_2O-N (as percentage of total N to stockpile), since freshly excreted manure was used within simulated storage experiments. See Table 19 for further comments regarding Kulling et al. (2003).

N volatilisation rates from feedlot stockpiles or composting areas are typically 15 - 40%. Research suggests a loss rate in the order of 25% would be applicable for Australian conditions.

Fate of Nitrogen Fed to Feedlot Cattle

From the above sections, the following general conclusions can be drawn.

1. About 92% of nitrogen fed to feedlot cattle is excreted and 8% is retained in liveweight gain.

2. About 2% of nitrogen excreted onto the pen surface is lost in runoff (approximately 0.5 kg/ SCU).

3. About 70% of nitrogen excreted onto the pen surface is volatilised to the atmosphere as ammonia, nitrous oxide and other nitrogen compounds (approximately 24 kg/ SCU).

4. The remaining excreted nitrogen is harvested from the pens in manure

Figure 10 shows this typical portioning of the nitrogen fed to feedlot cattle. Clearly, nitrogen in runoff is a minor factor. Greenhouse gas emissions in the form of nitrous oxide would occur both from the pen surface and from subsequent handling of the manure. There are certain management activities, such as more frequent pen cleaning, which will increase the proportion of nitrogen harvested in the manure. Provided that manure is managed to minimise the subsequent nitrous oxide emissions, these management activities will lead to greenhouse gas reductions from feedlots due to reductions of nitrogen lost from the pen surface.

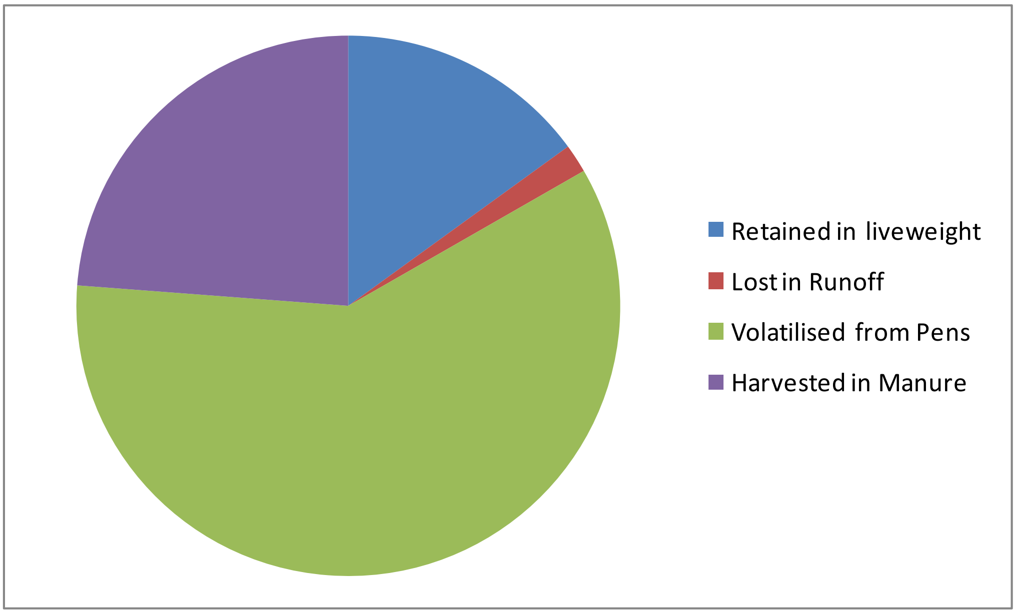

FIGURE 10 – FATE OF NITROGEN FED TO FEEDLOT CATTLE (TYPICAL DATA)

Sampling and Testing of Feedlot Manure

Sampling - Conventional

Manure samples are notoriously variable in composition. Hence, a sound manure sampling and testing protocol is required to ensure that the results are representative and statistically valid.

Dou et al. (2001) conducted a study to investigate sample variability and reliable nutrient analysis for several manure types and handling systems. They found that “book values” for manure nutrient concentrations was “problematic” as book values varied from measured farm data for a small amount to several fold. They did not test feedlot manure and the nearest option to a feedlot pen was floor samples from a broiler shed. In that case, they concluded that 75 sub-samples would be needed to achieve a result that would be within ±10% of the true mean. They concluded that “apparently, the number of samples needed for accurate (within ±10% of experimental means) and reliable (99% probability) nutrient testing is nearly impractical as a routine practice on farms if no agitation is applied”. Agitation is mixing of manure. This study reinforces the need to take multiple samples in order to get a representative sample of feedlot manure but that, even with many samples, a sampling error remains.

Peters et al. (2003) provides recommended procedures for sampling livestock waste. For stockpiled litter (their closest source to feedlot manure), they recommend taking 10 sub-samples from different locations around the pile at least 450 mm below the surface. The combined sample should be thoroughly mixed in a plastic bucket prior to place a composite sample in a zip lock bag.

Sampling – EMI Method

Recently, a new method has emerged to provide a targeted method of sampling variable manure across a feedlot pen. Eigenberg et al. (2005) used electromagnetic induction (EMI) to measure apparent soil conductivity (EC_a) across a feedlot pen surface and then to correlate differences in EC_a with VS and nutrients.

Figure 11 shows the results of EMI mapping of a feedlot pen on three different days (Eigenberg et al. 2005). It clearly shows the location of the mound in the middle of the pen which is typical of US feedlot. Figure 11 clearly shows the variability of manure characteristics across a pen surface and these are not apparent visually when sampling a pen surface. Eigenberg et al. (2005) used ESAP software to determine sampling locations that would best represent the range of EC_a values across. Manure was sampled at those locations and VS was determined. A statistical relationship can then be determined between EC_a and VS (Figure 12) so that a VS map of the pen surface can be prepared. More recently, Woodbury et al. (2009) mapped feedlot pens where cattle were fed corn-based and wet distillers grain-based rations. They applied the same technology to map VS across the pen surface and produced data on different VS concentrations across the pen (Figure 13). This data shows that VS could vary from <25% to >45% within one pen.

Handling and Storage

Dou et al. (2001) stated that “all samples were immediately placed in a portable cooler and transferred to the laboratory by the end of the day. Samples were stored frozen (-25°C) until further processing”. Peters et al. (2003) recommends storing manure samples in a freezer if not delivered to the laboratory immediately.

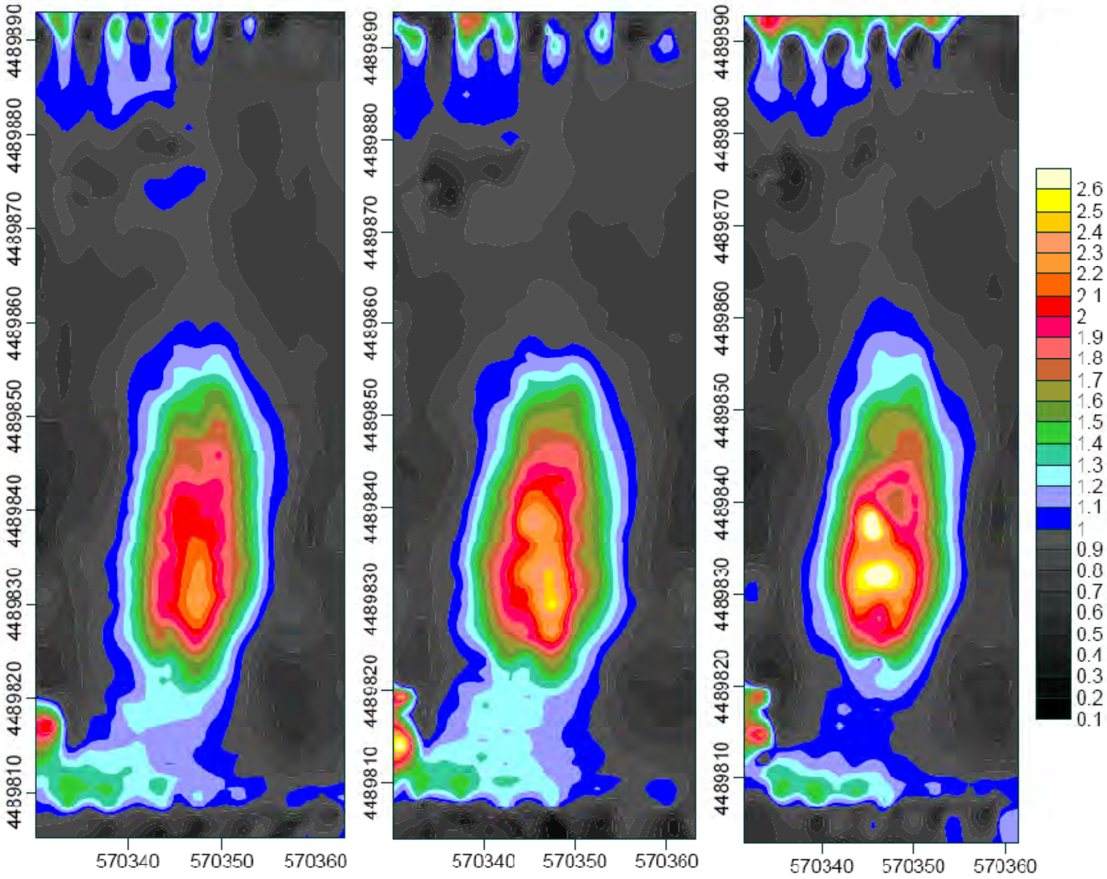

FIGURE 11 – APPARENT EC$_A$ MAPS FOR A FEEDLOT PEN (3 DIFFERENT DAYS) (EIGENBERG ET AL. 2005)

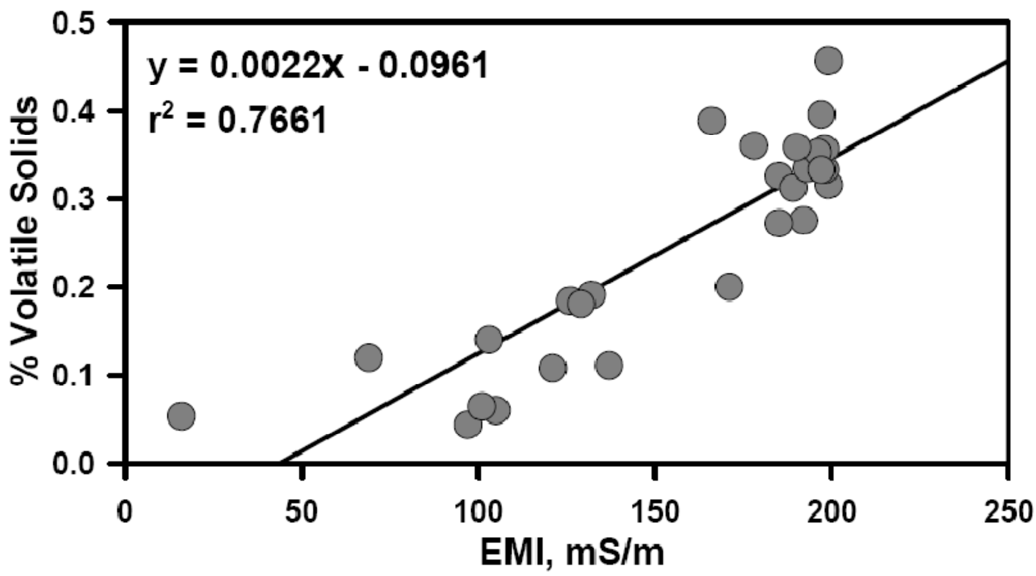

FIGURE 12 – RELATIONSHIP BETWEEN EC$_A$ AND VS (EIGENBERG ET AL. 2005)

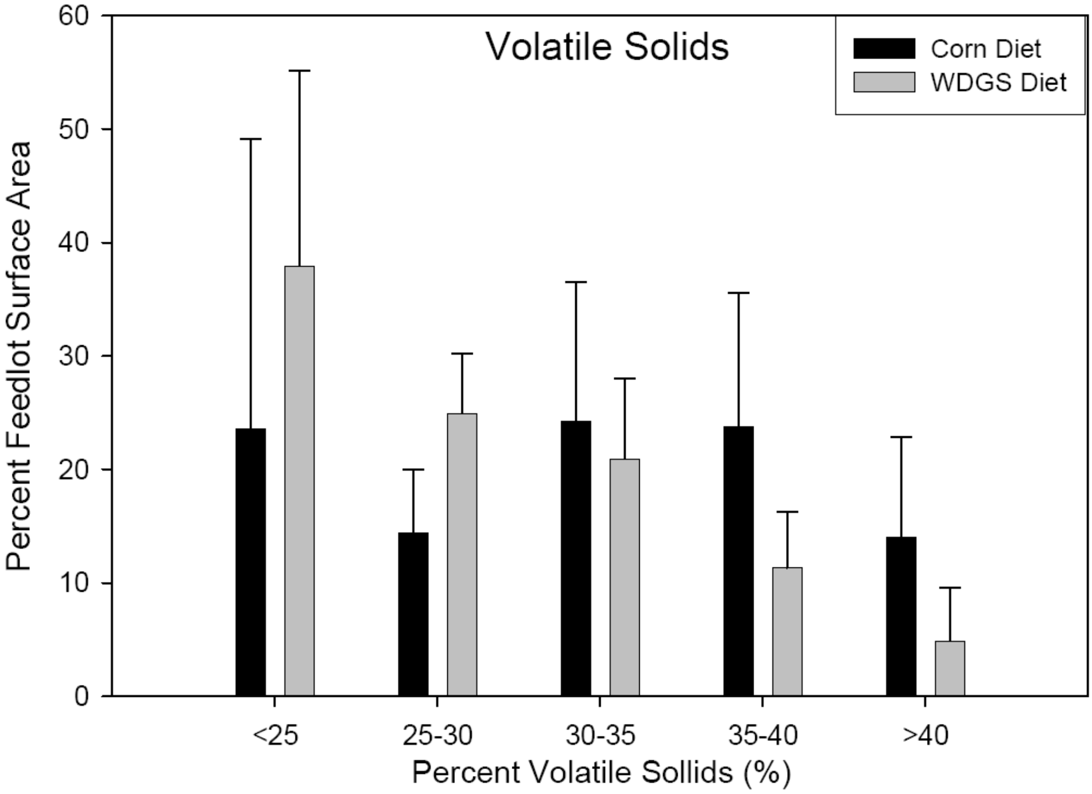

FIGURE 13 – AVERAGE SURFACE VOLATILE SOLIDS CONTENT FROM FEEDLOT PENS FED EITHER A CORN-BASED OR A WET DISTILLERS GRAINS WITH SOLUBLES DIET (WOODBURY ET AL. 2009)

Dry Matter (Total Solids) Determination

Dry Matter (DM) or TS is that matter remaining after water is completely evaporated from the sample (Peters et al. 2003). For soils, this is a relatively straightforward process. Most standards specify drying at 105°C for either 24 hours or until the weight of the dried sample is constant, e.g. Standards Australia (1992).

However, for samples containing a large percentage of organic or volatile material, it is likely that some of the volatile organics will be lost during the drying process. Certainly, anyone who has actually dried manure samples would know that more compounds than just water are driven from the samples. Peters et al. (2003) reports the outcome of a program that conducted a manure sample exchange between 14 state university laboratories in the USA. They found that drying temperatures ranged from 50°C to 110°C and documented drying times ranged from 16 to 24 hours. Clearly, there is a lack of standard methodology used for manure samples. It is probably that the lower drying temperatures used by some laboratories is an attempt to minimise the loss of volatile organics during the drying process.

The whole issue of the effect of drying temperature on TS and VS determination is exemplified when Hollman et al (2008) stated that "*to our knowledge, no data exist in the scientific literature comparing DM excretion estimates to total solids estimates*". On the face of it, this statement seems nonsensical as most authors assume (as is done in this report) that DM (dry matter) is equivalent to TS. However, Hollman et al (2008) goes on to say that DM is typically determined by agricultural scientists by drying at 60°C while TS are determined by engineers by drying at 105°C and that these two methods do not necessarily produce the same result with more variability in results dried at 60°C.

Volatile Solids Determination

The method to measure VS in the laboratory is to burn (ash) dried manure samples at high temperature. Examples are 550 ºC (APHA 1989) or 440°C or 750°C (ASTM 2008). The VS portion of the sample is burnt off and only the ash remains. The VS are determined by mass balance. However, as previously noted, the VS determined using this process may be an under-estimate of the total VS due to the loss of VFAs during the initial drying process. This will be discussed in the following section.

Organic Components of Manure

Manure constitutes urinary excretions as well as the fraction of the diet consumed by an animal that is not digested and excreted as faecal material. Manure is urine plus faeces. Manure is composed of dry matter, which contains macro and micro nutrients, and water. The dry matter is the TS, which is composed of organic matter (measured as either VS or chemical oxygen demand (COD), and FS (ash).

In manure, a significant proportion of the organic matter can be in the form of volatile fatty acids (VFAs). Total VFA is usually the sum of acetic, propionic, butyric, isobutyric, isovaleric, valeric and caproic acids. As the name suggests, these acids are volatile – particularly the short chain acids such as acetic and propionic - and can disperse into the atmosphere after the faeces is excreted from the animal. The volatilisation rate of VFAs is dependent on pH, temperature and other factors.

Hao et al. (2005) examined the effect of diet on the characteristics of feedlot manure including the VFA content. The manure was taken from the pen floor after 113 days on feed and included wood chips which accounted for about 60% of the dry matter. They found that acetic acid accounted for 75 to 82% of VFA while propionic acid accounted for 12 to 18% of VFA. Together, these two acids made up 93 to 96% of VFA in the feedlot manure samples.

McGinn et al. (2002) investigated the effect of three barley-based diets on manure composition in a feedlot. They did not measure the VFA content of the manure but did measure VFA emissions from the manure using a collection chamber. The dominating VFA compounds were acetic (30 to 34% of total VFA), propionic (19 to 30%) and butyric (29 to 30%), followed by valeric (4 to 6%), isovaleric (2 to 3%), isobutyric (2%) and caproic (<1%). The percent of each VFA compound was consistent across all treatments. In the McGinn et al. (2002) study, the proportion of VFA made up of acetic and propionic in the emissions from manure is much smaller than in the acetic and propionic content within manure (Hao et al. 2005). This may be due to different VFA profiles within the manure or it may suggest that VFAs volatilise at a different ratio to their content in manure. This may have implications when drying manure samples.

The content of VFAs in manure samples is an important consideration when determining moisture content and VS content of the manure. As is explained in following sections, the moisture content of a sample is determined by heating the sample thus driving the moisture out of the sample. It is well known, but rarely quantified, that VFAs also leave the sample during drying.

For example, Pind et al. (2003) undertook a study of the anaerobic digestion of a cattle manure slurry. They measured the TS and VS of the manure using standard procedures (i.e. drying at 105°C) to be 76.6 g/L and 60.2 g/L respectively (VS/TS = 78.6%). They assume that 80% of the VFAs in the sample are lost during drying but do not provide a reference for this assumption. After applying this correction, they state that the corrected TS and VS are 83.6 g/L and 67.2 g/L respectively (VS/TS = 80.4%). Reanalysing their data, it appears that VFAs constitute 13 % of all VS and that VS was underestimated by 10% using standard laboratory drying procedures.

Another example is Vedrenne et al. (2008) who noted that, during TS determination, the volatilisation of a part of the organic fraction was suspected during drying of the manure at 105°C, leading to an underestimation of the TS and VS concentrations. They undertook an analysis of the total organic carbon in wet and dried (at 105°C) manure slurries and showed a loss of organic carbon after drying at

105°C (Figure 14). Analysis of carbon on wet slurry indicated a carbon content equal to 31 g L^{-1} while the carbon content of the same slurry, on the same basis but after drying, fell to 23.6 g L^{-1}. The organic fraction responsible for this loss was the VFA fraction in the manure. According to this observation and in order to avoid analytical errors, Vedrenne et al. (2008) developed a methodology to quantify exactly the TS and VS content. VFA were determined for all slurries before (on raw slurry) and after drying (after 2 h extraction of dried slurry with water). The difference between the two values was considered to correspond to the VFA lost during drying. As shown in Figure 14, the carbon mass balance confirmed their hypothesis and showed that the VFA fraction was the main loss during drying. Applying this methodology to all their samples, Figure 15 shows VFA volatilisations during drying and the respective VS underestimations for the 13 slurries studied. Contrary to Pind et al. (2003) who applied a fixed 80% correcting factor of VFA lost during drying, the proportion of VFA volatilisation was variable and represented from 0% to 88% of total VFA. Vedrenne et al. (2008) found no correlation between slurry characteristics (pH, TS, VFA contents) and VFA losses. The VS underestimations resulting from the VFA losses could reach 25%. This work clearly demonstrates that VS can be underestimated due to VFA loss during the initial drying of the manure sample but provides no guidance on an appropriate correction method.

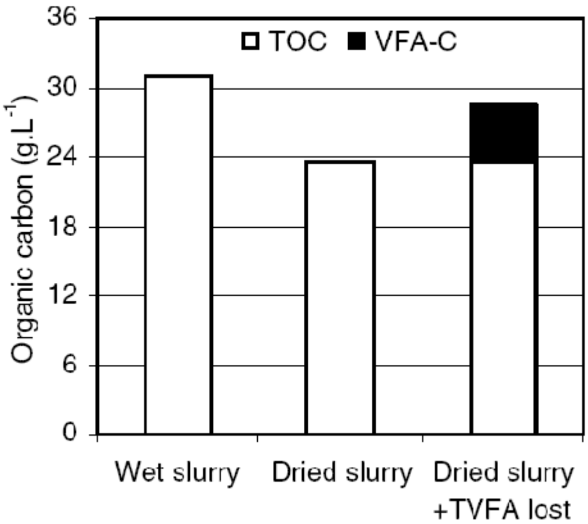

FIGURE 14 – LOSS OF VFAS DURING MANURE DRYING AT 105°C (VEDRENNE ET AL. 2008)

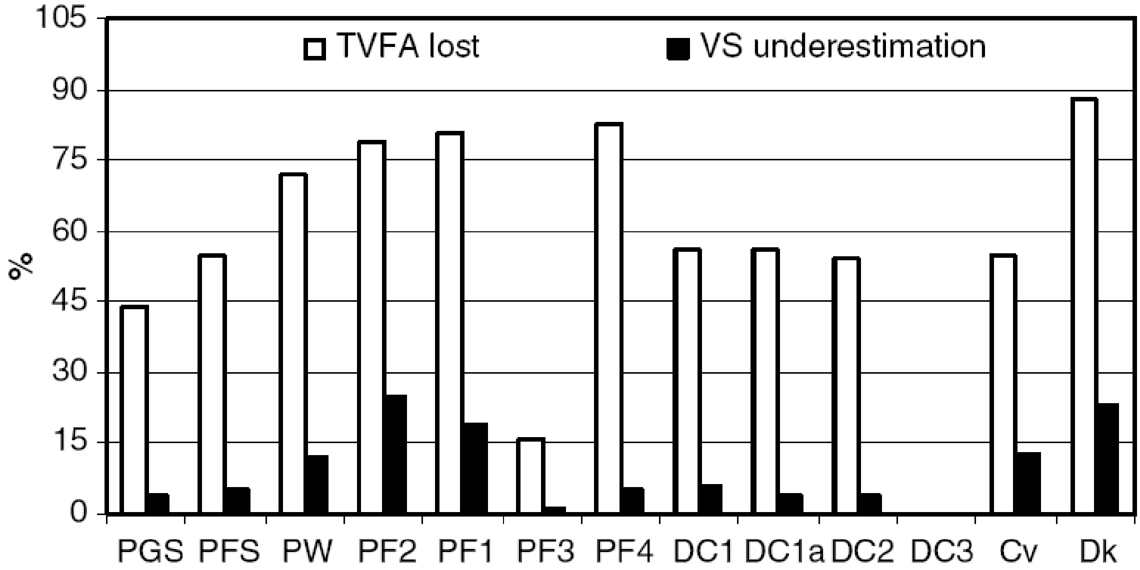

FIGURE 15 – VS UNDERESTIMATION DUE TO DRYING (VEDRENNE ET AL. 2008)

Relationship Between Faecal VS and Manure VS

Manure consists of faeces and urine. For field work in feedlot pens, it is not possible to sample urine but it is possible to sample fresh faeces. In this project, the objective is to measure manure VS content. Hence, it is necessary to determine if a correction factor needs to be applied if only faeces is sampled.

Sinclair (1997) undertook an experiment that aimed to determine the dietary concentration of P on both the amounts and routes of excretion of P from cattle. In their experiment, ten weaner steers were fed five different diets with varying P contents. Urine and faeces was measured separately for each animal. The dry matter and ash content of the faeces and urine was measured for each treatment. Hence, it is possible to determine the VS content of urine and faeces separately.

Table 26 shows the data presented by Sinclair (1997). This shows that the VS of the faeces alone averages about 82% but, when the urine is added, the VS of the total manure is about 79%, i.e. manure VS is about 97% of faeces VS.

TABLE 26 – FEED AND MANURE DATA FOR FIVE DIET TREATMENTS

		TREATMENT – Diet P Content				
Parameter	Units	0.26% P	0.30% P	0.35% P	0.45% P	0.55% P
Mean LWT	kg	304.9	304.7	304.2	305.5	302.2
DMI	kg DM/day	8.04	8.29	8.53	8.28	7.89
ADG	kg/d	1.16	1.16	1.16	1.16	1.16
FCR	kg DM/kg gain	6.9	7.1	7.4	7.1	6.8
P						
Intake	g/d	24.2	25.6	28	34.1	35.4
Faecal excretion	g/d	13.9	13.8	16.8	16.8	18.3
Urine	g/d	3.27	4.12	4.48	5.63	7.98
TOTAL	g/d	17.2	17.9	21.3	22.4	26.3
N						
Intake	g/d	200.2	212	218.6	214.5	200.7
Faecal excretion	g/d	69.2	72.7	75.7	74	71.9
Urine	g/d	92.1	96.3	101.4	98.2	101.3
TOTAL	g/d	161.3	169.0	177.1	172.2	173.2
% N in urine	%	57%	57%	57%	57%	58%
Faeces						
Total	kg/d	9.63	10.22	10.43	10.43	10.05
DM	%	27%	27%	28%	27%	27%
DM	kg/d	2.65	2.78	2.91	2.85	2.72
Ash	% DM	18.3%	18.1%	18.1%	17.4%	18.1%
VS	% DM	81.7%	81.9%	81.9%	82.6%	81.9%
VS	kg/d	2.16	2.28	2.38	2.35	2.23
Urine						
Total	kg/d	9.94	10.6	11.79	11.01	11.42
DM	%	4.83%	4.54%	4.33%	4.41%	4.52%
DM	kg/d	0.48	0.48	0.51	0.49	0.52
Ash	% DM	34.7%	34.0%	33.9%	33.5%	33.5%
VS	% DM	65.3%	66.1%	66.1%	66.5%	66.5%
VS	kg/d	0.31	0.32	0.34	0.32	0.34
Total Manure	kg/d	19.57	20.82	22.22	21.44	21.47
	% LWT	6.4%	6.8%	7.3%	7.0%	7.1%
	DM/d	3.13	3.26	3.42	3.34	3.24
Faeces VS	%	81.7%	81.9%	81.9%	82.6%	81.9%
Manure VS	%	79.2%	79.6%	79.5%	80.2%	79.5%
Manure VS / Faeces VS		96.9%	97.1%	97.1%	97.2%	97.0%

Source: Sinclair (1997)

Objectives

The objective of this project was to provide measured feedlot manure production data for comparison against predicted manure output from the BEEF-BAL model that was to be prepared in PRJ-002831 (McGahan et al. 2009). Specifically the project:

- Measured the TS, VS and moisture content of manure at various stages of decomposition under current management practices.
- Quantified manure production at an individual pen level from a number of pens within six study feedlots.
- Improved the quality of the BEEF-BAL model outputs by validating the DMDAMP section of the model.

The expected outcomes of the project are:

- More accurate measurements of waste production in feedlots will complement the “Methane to Markets” project outcomes and will allow the BEEF-BAL model to be validated and updated if required.
- A BEEF-BAL model that has been validated with measured field data.
- Comparisons of current feed processing techniques and their impact on manure production and modeling of this in the BEEF-BAL model.
- Communications to industry associations and research community.
- Final report

Methodology

This study proposes to measure the manure production of a number of feedlots to gain more accurate and relevant data for the BEEF-BAL model and “Methane to Markets” project. Two stages will be used to provide a feedlot ‘manure budget’. The study also has close synergies with other studies funded under the M2M program. One such study is the APL funded PhD study ‘Low cost Applications of Anaerobic Digestion to Livestock Wastes’. This study is currently being completed at the University of Queensland. An outline of the two stages and the PhD study is provided below.

Stage 1 - Manure Sampling of Fresh, Pen, Stockpile and Composted Manure

When manure is excreted onto the surface of a feedlot pen, it immediately begins to breakdown. This breakdown (loss of VS content) is accelerated following rainfall and continues when the manure is removed from the pens and is stockpiled or composted. From a methane generation viewpoint, it is essential to retain as much VS in the manure as possible. However, there is little data available on the rate of VS breakdown in feedlot manure. This stage of the project aimed to provide VS data on manure at key stages in the manure management process.

Stage 1 aimed to provide measured data of TS, VS and moisture content of the manure at various stages of decomposition. This stage involved sampling of different stages of the manure decomposition cycle and measurement of TS, VS and moisture content of fresh, pen, stockpile and composted manure. This will provide breakdown rates of manure under current management practices. These data will be used to put back into BEEF-BAL to improve the TS, VS and moisture content estimates that are currently used and validate the model. These data were also used in Stage 2 to quantify manure breakdown at different stages of the feedlot manure management system.

Total nitrogen and its forms was tested at the study feedlots at one sampling visit to measure the nitrogen losses during breakdown from fresh to composted manure. Four feedlots were sampled three times during the sampling period, one at the initial pen cleaning, one at the final pen cleaning and one in between.

Stage 2 – Pen Level Manure Quantification

This stage provided information on the amount of manure that is produced under current management practices. Stage 2 directly measured the volume of manure produced from individual pens in each feedlot. This stage was undertaken in four northern and two southern feedlots. Four feedlots with steam flaking feed processing and two feedlots with tempering or dry rolling feed processing were selected. Three pens were selected and cleaned to remove all existing manure. The clean pens were maintained with cattle and the feed intake of the cattle recorded. This stage involved sampling of TS, VS and moisture content of pen manure every two weeks (approximately 7 times) during the sampling period at four of the feedlots. This will gave information as to how fast manure breaks down within the pen. When the cattle are dispatched, or pen cleaning is due, the pen was cleaned and the quantity of manure weighed using a weighbridge on-site. The manure production estimates from BEEF-BAL were compared to the actual manure production taking into account VS breakdown. Prior to cleaning, an attempt was made to estimate manure thickness on the pad.

Comparisons were made between the climate, feed processing, and ration base effects on manure breakdown rates at each feedlot. The results were used to improve the capacity of the BEEF-BAL model to predict manure production for the application of methane emission capture in intensive livestock systems.

Cooperation with other Studies

This stage involved cooperation with a PhD study based at the University of Queensland's Advanced Water Management Centre. The PhD study is part of the methane to markets in agriculture (M2MA) program.

The PhD involves developing and fitting pseudo-mechanistic biological and physical-chemical models to the anaerobic digestion of wastes from dairies, feedlots, poultry chooks and piggeries.

One of the research objectives was to develop a generalised input characterisation model for wastes from piggeries, dairy farms and feedlots. The characterisation analysis involves testing for:

- Solids (TS/VS)
- Nitrogen (Total and ammonia)
- Phosphorous
- Volatile Fatty Acids
- COD (Total and soluble)
- Metals

Hence, there are synergies between the characterisation analyses of the PhD study and the manure production study. Initial samples for the PhD study were collected from feedlots in Queensland and Victoria. However, it became evident that a comprehensive sampling plan was needed to obtain samples that were representative. Stage 1 and Stage 2 of the manure production study developed a sampling methodology plan that allows representative sub samples to be collected. Using the methodology plan in Stage 1 and Stage 2 of this study, samples were collected and provided to UQ for analysis. Subsequent analysis results were provided to FSA Consulting for comparison.

Summary – Experimental Work

The steps in the project were:

- Select six feedlots across Australia which are representative of climatic zones, feeding regimes and manure management processes.
- Review the design and management of these feedlots to select those where reliable data could be collected.
- Select the preferred feedlots and complete negotiations at each site.
- Design a data collection system for each feedlot.
- Undertake data collection visits for manure production.
- Undertake detailed data collection visits for manure accumulation rates and manure decomposition.
- Collect cattle performance data, diet composition and volume fed from each feedlot.
- Analyse and compare measured data with predicted data.

Selected Feedlots

Following a lengthy process, six feedlots were selected to provide a representation from northern and southern Australia. Table 27 summarises the key characteristics of the selected feedlots. To maintain confidentiality, none of the feedlots are identified by name and will be referred to as Feedlots A to F.

The selected feedlots provide a range of climatic conditions from a northern feedlot in a hot, humid summer-dominant rainfall to southern feedlots in cooler, winter-dominant rainfall zones. Grain processing methods vary from simple dry rolling to steam flaking. Feedlots A, D, E and F use steam flaked grain, Feedlot B tempers grain and Feedlot C dry rolls grain.

The selection of feedlots to take part in the project was based on the following:

- Ration preparation type. Two feedlots were required that temper or dry roll and four that use steam flaking.
- Two feedlots were selected in southern climate zone.
- Four feedlots were selected in northern climate zone.
- Feedlots were selected on ability to provide three pens that had been cleaned to the base and stocked simultaneously.
- Feedlots had to be willing and able to provide cattle numbers, ration type and feed delivered for each pen.

The pens within the feedlot were selected according to the following:

- Pens with similar slope were selected. The preferred slope was 3% as steeper slopes may lose too much manure if runoff occurs.
- Pens with similar characteristics were chosen e.g. with or without shade, north/south facing.
- Pen floor was as even as possible. If there is a choice between older or new pens, the newer pens were selected.

The selection of cattle for each pen was based on market type and breed. The selection of pens with different market types was preferred if more than one market type was fed at a feedlot. If multiple pens with the same market type were selected the breeds was kept constant e.g. all Bos Taurus or all Bos Indicus cross.

TABLE 27 – CHARACTERISTICS OF SELECTED FEEDLOTS

Feedlot Name		A	B	C	D	E	F
Climate *							
Mean Annual Rainfall	mm	428	349	679	645	640	658
Rainfall Pattern		Winter dominant	Winter dominant	Summer dominant	Summer dominant	Summer dominant	Summer dominant
Mean Annual Evaporation	mm	1275	1380	2263	2044	2263	1716
Mean Max Temp – January	°C	30.4	31.4	31.6	30.4	31.6	33.2
Mean Min Temp – June	°C	13.9	14.9	5.7	4.0	5.7	3.7
Feedlot Capacity and Design							
Feed Processing							
Grain Processing Method		Steam Flaked	Tempering	Dry Rolled	Steam Flaked	Steam Flaked	Steam Flaked
Manure Management							
Cleaning Frequency		Fixed 8-12 weeks	As Required	As Required	As Required	As Required	As Required

Note: *Climate data retrieved from Bureau of Meteorology long term climate statistics and/or QDPI Rainman

Feedlot A

Feedlot A is located in Southern Australia. This company owned feedlot caters for its own domestic and export livestock supply requirements. It also contract feeds for external parties. Feed processing is undertaken in an on-site steam flaking mill and the typical rations used in the feedlot are based on wheat and/or barley, with cottonseed, wheat hay and oaten silage additives. Cattle are generally given five days on each of the starter, intermediate and grower rations before they are moved to finisher rations.

Climate

The mean monthly temperatures (maximum and minimum) and monthly rainfall probabilities for Feedlot A are shown in Figure 16. Feedlot A is considered to have a strongly winter-dominant rainfall. June is statistically the wettest month with a mean rainfall of 48.1 mm, although August records the most days of rainfall with a mean of 11.4. Summers are generally warm to hot and winters are usually mild. In summer, the maximum monthly temperatures range from 29 to 31°C. During winter, monthly minimum temperatures range from 8 to 9°C.

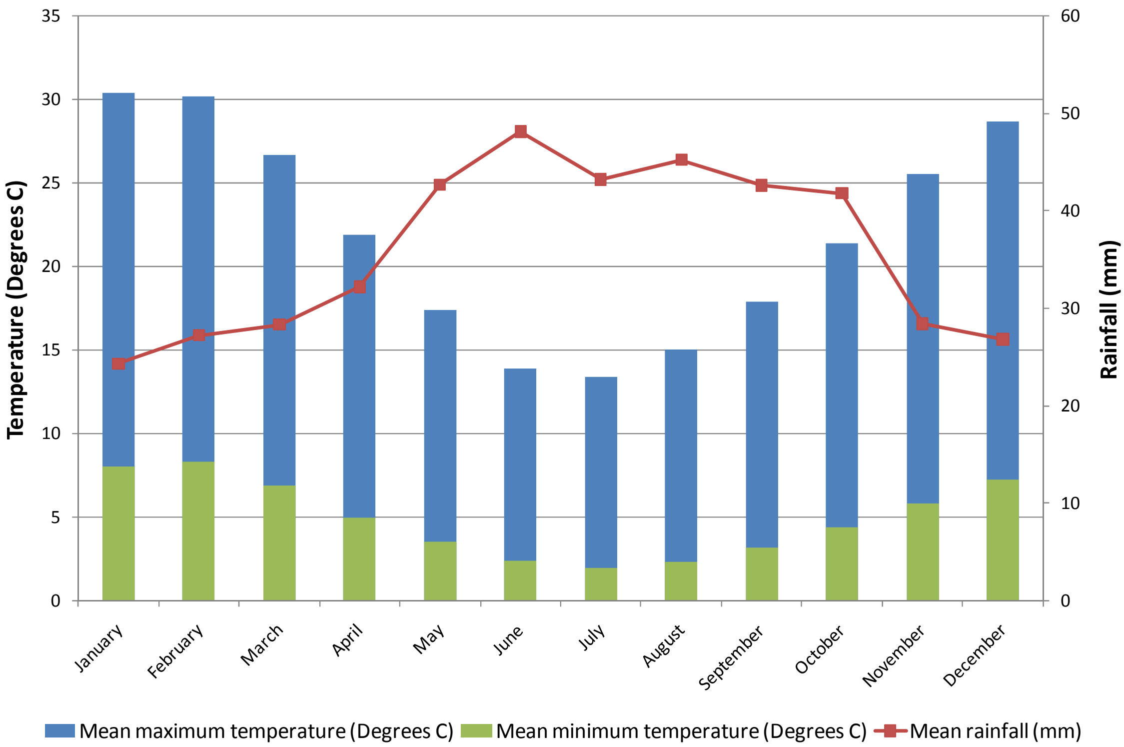

FIGURE 16 – MEAN CLIMATE CONDITIONS FOR FEEDLOT A

Pen Selection

Three feedlot pens were selected at Feedlot A for investigation; pens 29, 30 and 69. Pens 29 and 30 are adjacent pens approximately half way along a row of pens on the northern side of the feedlot, while pen 69 is located in the middle of a row in the southern side of the feedlot.

Pens 29 and 30 have consistent dimensions, with a width of 30 m (along the bunk), and a depth of 60 m (along the side fences). The pens have an area of approximately 1800 m^2, which provides space for 160 SCU at a stocking density of 11.25 m^2/SCU. Pen 69 has a width of 60 m (along the bunk) and a depth of 60 m (along the side fences). The pen has an area of approximately 3600 m^2, which provides space for 320 SCU at the same stocking density.

Whilst Feedlot A does have shade structures over some pens, this study did not include any pens with shade covering.

Manure Management Process

Feedlot A has adopted a consistent schedule for managing manure in feedlot pens. Pens are periodically cleaned every 8 to 12 weeks, with exact timing depending on weather conditions and cattle movements. Manure removed from the pens is taken to one of a number of stockpile areas for storage until needed for spreading onto cropping areas on adjacent land or sale to off-site customers.

Pen cleaning operations at Feedlot A are carried out by contractors using a front-end loader and an articulated dump truck on a dry hire basis. The front-end loader first uses a custom fabricated bucket attachment to clean manure from underneath fences and around water troughs. The attachment is then removed and the bucket used to scrape manure from the pen surface and load it into a dump truck waiting in the cattle lane.

PHOTOGRAPH 4 – CUSTOM FRONT-END LOADER ATTACHMENT FOR CLEANING UNDERNEATH FENCES

PHOTOGRAPH 5 – FRONT-END LOADER AND ARTICULATED DUMP TRUCK DURING PEN CLEANING OPERATIONS

When the truck is fully loaded, the manure is transported to the designated stockpiling area. Feedlot A has a number of separate manure stockpile areas for storage of material removed from the pens during cleaning activities. Manure is placed in windrows of approximately 2 – 3 m width and 1 – 2 m height, and is stored there until it is required for sale off-site or spreading on adjacent land. Prior to transport away from the feedlot, material is subjected to a screening process to remove any large foreign objects. This ensures a higher quality product for reuse.

PHOTOGRAPH 6 – TRUCK DELIVERING MANURE TO STOCKPILE AREA

PHOTOGRAPH 7 – MANURE SCREENING EQUIPMENT IN STOCKPILE AREA

Feedlot B

Feedlot B is also located in southern Australia. This company owned feedlot caters for its own domestic and export livestock supply requirements. Feed processing is undertaken in an on-site feed mill where grain is tempered. Typical rations used in the feedlot are based on barley and/or wheat. The feedlot comprises three individual pen sections for starter, intermediate and finisher cattle. The cattle entering the feedlot are located in the starter pens. They are transferred from the starter to intermediate section of the feedlot after 14 DOF. At 56 DOF they are transferred to the finisher section , where they remain until finish at approximately 80 days. It is the intermediate section of the feedlot where the measurements of manure production were measured and hence calculated.

Climate

The mean monthly temperatures (maximum and minimum) and monthly rainfall probabilities for Feedlot B are shown in Figure 17. Feedlot B is considered to have a strongly winter-dominant rainfall. August is statistically the wettest month with a mean rainfall of 35.9 mm and a mean of 9.5 days of rainfall. Summers are generally warm to hot and winters are usually mild to cold. In summer, the maximum monthly temperatures range from 30 to 31^{o}C. During winter, monthly minimum temperatures range from 4 to 5^{o}C.

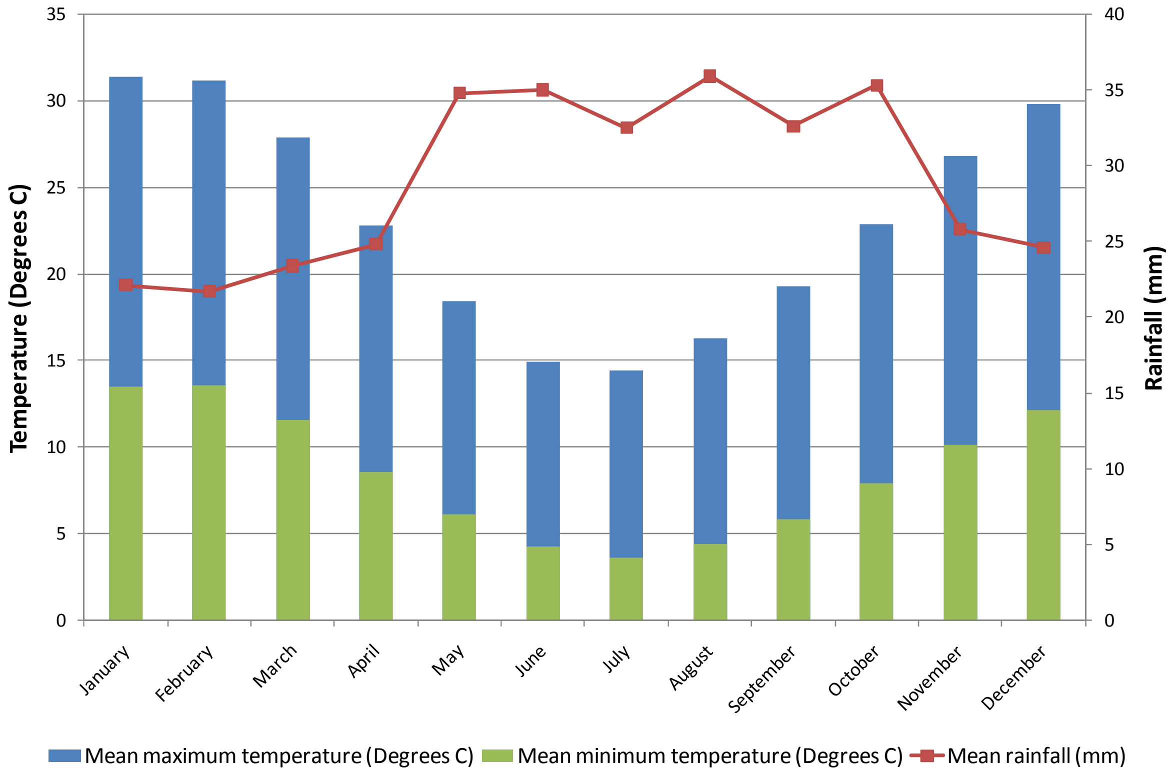

FIGURE 17 – MEAN CLIMATE CONDITIONS FOR FEEDLOT B

Pen Selection

Three feedlot pens were selected at Feedlot B for investigation. These were pens 33, 34 and 35. These are consecutive pens in the middle of a row of pens in the eastern section of the feedlot.

All three pens have consistent dimensions, with a width of 30 m (along the bunk), and a depth of 55 m (along the side fences). The pens have an area of approximately 1660 m^2, which provides space for 100 SCU at a stocking density of 16.6 m^2/SCU.

Feedlot B does not have shade structures over any of their feedlot pens so this study did not include any pens with shade covering.

Manure Management Process

The pen cleaning process at Feedlot B is on an 'as required' or opportunity basis. The frequency of pen cleaning depends on a number of factors, including manure accumulation and management requirements (e.g. stocking rate). Manure accumulation rates also depend on the animal size, ration composition and environmental factors. Typically, manure is allowed to accumulate to about 75 mm above the compacted limestone surface and no more than about 75 mm on a dry compacted basis. Once manure has accumulated to this depth the pen is cleaned.

During pen cleaning, all manure is completely removed back to the compacted limestone pen base. During this process, the pen surface is graded by the pen cleaning equipment to remediate any potholes which may have developed. It is not standard practice to clean pens after cattle have exited, however it may be undertaken depending on factors such as manure accumulation and pending wet weather.

Pen cleaning is undertaken by feedlot staff, using a tractor and a towed box scraper. Manure is scraped from the pens and dragged out into the cattle lane at the bottom of the pen. A front-end loader is then used to neatly mound the manure while it waits to be removed from the feedlot. Trucks operated by contractors are then loaded using the front-end loader and the manure is transported to another property for further processing.

PHOTOGRAPH 8 – TRACTOR-DRAWN BOX SCRAPER USED FOR PEN CLEANING

PHOTOGRAPH 9 – MANURE BEING MOUNDED IN CATTLE LANE BELOW PENS

The owners of Feedlot B also operate an extensive composting operation, which receives and processes manure from the feedlot operation. Manure is transported from the feedlot to the composting facility and deposited in windrows. The windrows are then actively monitored and managed to assist the composting processes, which includes periodic turning of the windrows and the addition of moisture. Windrows are turned mechanically by a dedicated compost turning machine. Once the composting process is complete, the product is sold as soil conditioner.

PHOTOGRAPH 10 – FEEDLOT MANURE BEING PLACED INTO WINDROWS FOR COMPOSTING

PHOTOGRAPH 11 – COMPOSTING WINDROWS AND COMPOST TURNING MACHINE

Feedlot C

Feedlot C is a small (> 2000 head licensed capacity) feedlot located west of Toowoomba in Qld. The feedlot supplies the domestic beef market. Feed rations are prepared using an on-site mill which dry rolls grain. Typical rations are based on sorghum, and cattle are generally on feed for 70 days.

Climate

The mean monthly temperatures (maximum and minimum) and monthly rainfall probabilities for Feedlot C are shown in Figure 18. Feedlot C is considered to have a strongly summer-dominant rainfall. December is statistically the wettest month with a mean rainfall of 93.1 mm and a mean of 8.2 days of rainfall. Summers are generally warm to hot and winters are usually cold. In summer, the maximum monthly temperatures range from 31 to 32^{o}C. During winter, monthly minimum temperatures range from 4 to 5^{o}C.

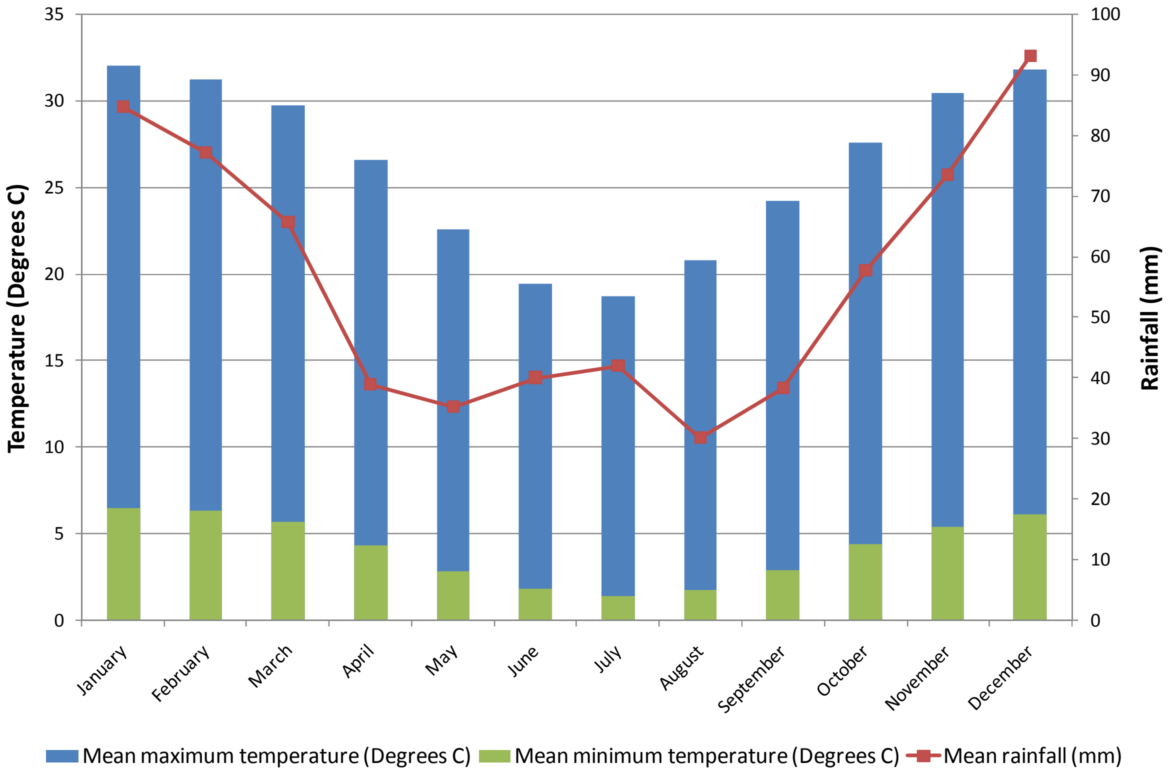

FIGURE 18 – MEAN CLIMATE CONDITIONS FOR FEEDLOT C

Pen Selection

Three feedlot pens were selected at Feedlot C for investigation. These were pens 3, 4 and 17. Pens 3 and 4 are adjacent pens at the end of a row of pens on the eastern side of the feedlot, while pen 17 is located at the end of a row in the southern section of the feedlot.

Pens 3 and 4 have consistent dimensions and are square, with a side length of approximately 35 m. The pens have an area of approximately 1250 m^2, which provides space for 100 SCU at a stocking density of 12.5 m^2/SCU. Pen 17 has a top width of 40 m (along the bunk) and a depth of 50 m (along the side fences). The pen has an area of approximately 2000 m^2, which provides space for 160 SCU at the same stocking density.

Feedlot C does not have shade structures over any of their feedlot pens so this study did not include any pens with shade covering.

Manure Management Process

Feedlot C has adopted an 'as required' pen cleaning regime. In this system, cleaning frequency depends on manure accumulation rate. Pen cleaning operations at Feedlot C remove manure down to the top of a 50 mm interface layer over the top of the compacted gravel pen base. Typically, pen cleaning involves scraping up the manure into stockpiles in the centre of the pen with a front-end loader -end loader. The front-end loader then transfers the manure into the body of a tip truck which transports the material to a stockpile area.

Manure is then periodically removed from the stockpiles and spread onto surrounding cropping land as growing seasons require it.

Feedlot D

Feedlot D is a medium sized (>5000 head licensed capacity) feedlot located west of Toowoomba in Qld. The feedlot feeds for both domestic and export markets. Rations are prepared using a steam flaking mill, and are typically comprised of sorghum and barley. Domestic cattle are fed for a 60 – 80 days, while export cattle are can be fed for anywhere between 120 days to 450 days depending on the specific market to being accommodated.

Climate

The mean monthly temperatures (maximum and minimum) and monthly rainfall probabilities for Feedlot D are shown in Figure 19. Feedlot D is considered to have a strongly summer-dominant rainfall. December is statistically the wettest month with a mean rainfall of 93 mm and a mean of 8.8 days of rainfall. Summers are generally warm to hot and winters are usually cold. In summer, the maximum monthly temperatures range from 30 to 31^{o}C. During winter, monthly minimum temperatures range from 2 to 4^{o}C.

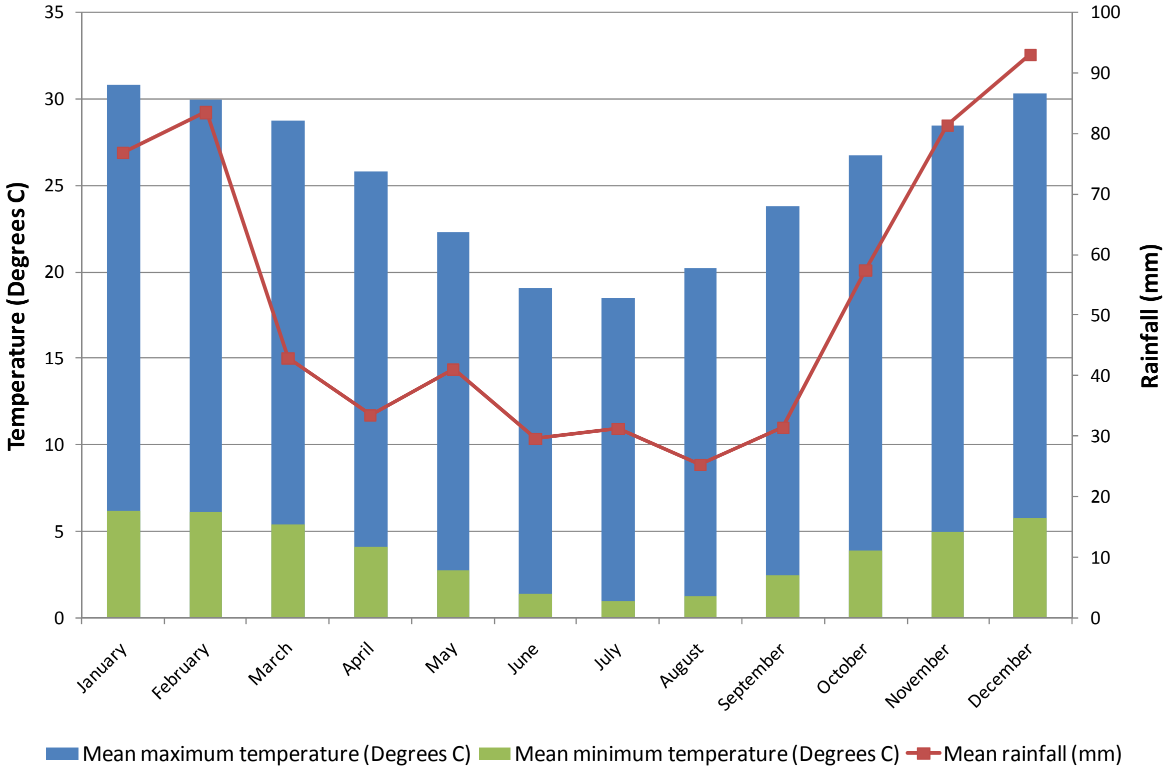

FIGURE 19 – MEAN CLIMATE CONDITIONS FOR FEEDLOT D

Pen Selection

Three feedlot pens were selected at Feedlot D for investigation; pens C1, C2 and F1.Pens C1 and C2 are consecutive pens at one end of a row of pens in the eastern section of the feedlot. Pen F1 is the first pen in a row in the centre section of the feedlot.

All three pens have consistent dimensions, with a width of 50 m (along the bunk), and a depth of 60 m (along the side fences). The pens have an area of approximately 3000 m^2, which provides space for 155 SCU at a stocking density of 19.3 m^2/SCU.

Feedlot D has shade structures over many of their feedlot pens, and all three pens in this study were shaded.

Manure Management Process

Feedlot D operates a manure management strategy on an ‘as required’ or opportunity basis. The feedlot surfaces consist of a uniformly graded compacted gravel base with a 50 mm thick compacted manure layer (an interface layer) on the surface. The interface layer is not removed during pen cleaning operations, which leaves a 50 mm manure layer over the compacted gravel base. The typical pen cleaning frequency is every 8 – 12 weeks. Feedlot D feeds for several market types and therefore some of the pens were cleaned several times before a batch of cattle was dispatched. The frequency is influenced by the stocking density in the pen, moisture content in the pad, and time between cleaning.

Pen cleaning involves piling of manure in the pen for temporary storage. The manure may be left piled in the pen for 2-10 days depending on the work program or availability for equipment. A tractor-drawn box scraper fitted with laser levelling equipment is used to scrape manure from the pen surface and pile the material in the centre of the pen. Manure is cleaned from underneath fence lines and around obstructions (water troughs, feed bunks and shade structure supports) by a skid steer loader.

PHOTOGRAPH 12 – TRACTOR-DRAWN BOX SCRAPER WITH LASER LEVELLING EQUIPMENT MOUNDING MANURE IN CENTRE OF PEN

PHOTOGRAPH 13 – CATTLE WALK OVER A MANURE MOUND IN CENTRE OF PEN

Mounded manure is removed from the pens using either a front-end loader or excavator, and transported to stockpiling/composting areas by an articulated dump truck. The manure is dumped and formed into windrows of approximately 1 – 2 m height and 3 – 4 m width for composting. Windrows are periodically turned by mechanical means, and additive materials (such as sawdust) are incorporated into the windrows to assist the composting process. Finished product is screened and stockpiled before being sold off-site.

PHOTOGRAPH 14 – MANURE STOCKPILING AND COMPOSTING AREA, WITH SAWDUST STOCKPILE (TO THE RIGHT)

PHOTOGRAPH 15 – COMPOSTING WINDROWS, WITH EXCAVATOR (IN THE BACKGROUND)

Feedlot E

Feedlot E is a medium sized (> 5000 head licensed capacity) feedlot located west of Toowoomba in Qld. The feedlot turns off an average of 30,000 cattle per year, supplying both domestic and export markets. Approximately 70% of the herd destined for Japan and Korea. Feed rations are prepared using a steam flaking mill and typical rations are based on sorghum, barley, maize and wheat, with cottonseed, sunflower and barley silage additives. Domestic cattle are generally on feed for 60-70 days, while export cattle are typically fed for 100 days.

Climate

The mean monthly temperatures (maximum and minimum) and monthly rainfall probabilities for Feedlot E are shown in Figure 20. Feedlot E is considered to have a strongly summer-dominant rainfall. December is statistically the wettest month with a mean rainfall of 93.1 mm and a mean of 8.2 days of rainfall. Summers are generally warm to hot and winters are usually cold. In summer, the maximum monthly temperatures range from 31 to 32^{o}C. During winter, monthly minimum temperatures range from 4 to 5^{o}C.

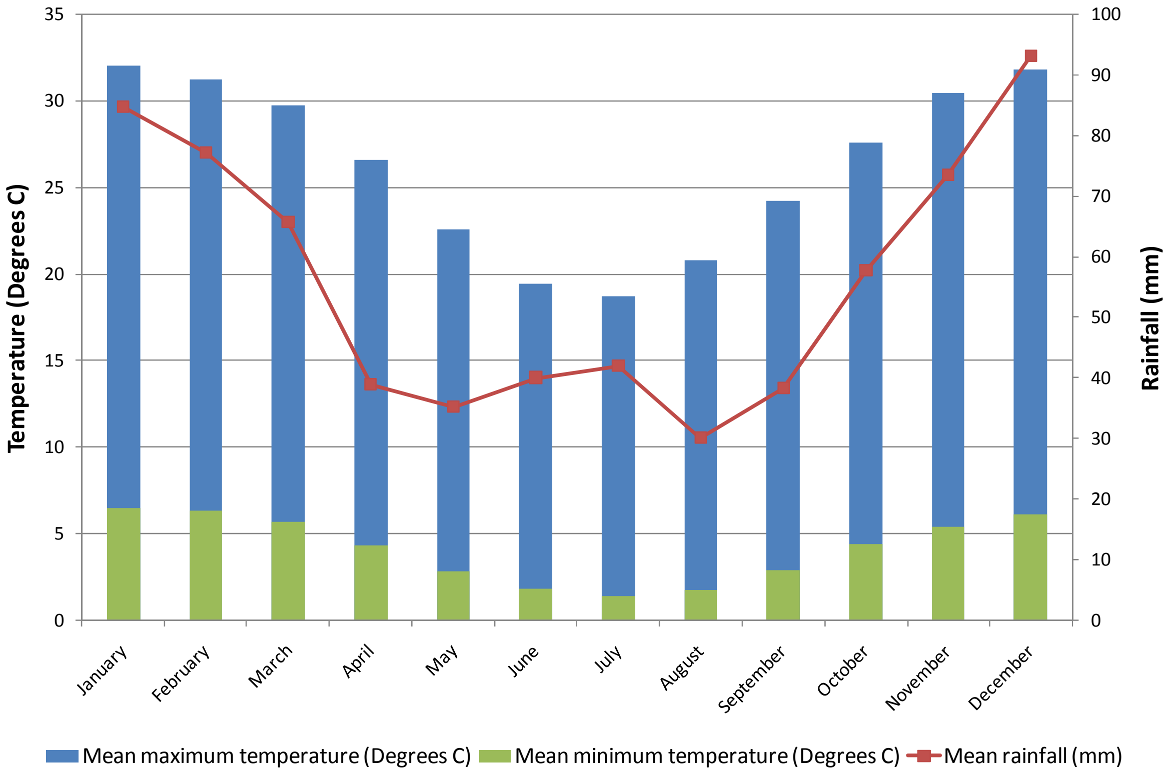

FIGURE 20 – MEAN CLIMATE CONDITIONS FOR FEEDLOT E

Pen Selection

Three feedlot pens were selected at Feedlot E for investigation; pens 1, 3 and 10. All three pens are in the same row of pens on the eastern side of the feedlot. Pen 1 is the first pen in the row, Pen 3 is approximately one quarter of the way along the row, and Pen 10 is the last pen in the row.

Pens 1 and 10 have consistent dimensions, with a width of 55 m (along the bunk), and a depth of 70 m (along the side fences). The pens have an area of approximately 3850 m^2, which provides space for 200 SCU at a stocking density of 17.5 m^2/SCU. Pen 3 is a half-sized pen, with a width of 25 m (along the bunk), and a depth of 70 m (along the side fences). The pen has an area of 1750 m^2, which provides space for 100 SCU at a stocking density of 17.5 m^2/SCU.

Feedlot C does not have shade structures over any of their feedlot pens so this study did not include any pens with shade covering.

Manure Management Process

Feedlot E manages manure on an 'as required' or opportunity basis. The cleaning frequency of the pen is about 15 weeks, or 100 days. This approximately coincides with a change of herd, and pens are therefore cleaned in between one batch of cattle being removed from the pen and a new batch of cattle entering the pen. Pen cleaning operations are carried out by feedlot staff using front-end loaders. The manure is mounded in the pens before being taken to be stockpiled, but may be left in the pen for a period of up to 12 months.

PHOTOGRAPH 16 – FRONT-END LOADERS INSIDE PEN DURING CLEANING OPERATIONS

PHOTOGRAPH 17 – RECENTLY CLEANED PEN SURFACE WITH SMALL MANURE MOUND IN CENTRE OF PEN

The mounded manure is moved to the stockpile area in April of each year. This allows all the harvested manure to be stockpiled and compacted at the same time, as opposed to adding manure to the stockpile throughout the year. It is estimated that a total of 13,000 - 16,000 tonnes of manure is harvested each year and taken to the stockpile area.

The manure is stockpiled in a large pile of approximately 3-4 m high and 50 m in diameter. It is then compacted and remains on site for 4-6 months before being sold. There are no added amendments, watering or turning of required for the stockpile manure. The manure is screened through an 8 mm sieve to remove contaminants such as stones or rocks and ensure a consistent product is offered for sale. Manure is typically sold off site from April to December each year.

PHOTOGRAPH 18 – MANURE STOCKPILE

PHOTOGRAPH 19 – STOCKPILED MANURE (TO THE LEFT) AND SCREENING EQUIPMENT (TO THE RIGHT) IN THE MANURE STOCKPILE AREA

Feedlot F

Feedlot F is a medium sized (> 5000 head licensed capacity) feedlot located south-west of Toowoomba in Qld. The feedlot supplies both domestic and export markets. Feed rations are prepared using a steam flaking mill and typical rations are based on barley, wheat, with maize silage and cereal hay additives. Domestic cattle are generally on feed for 60-70 days, while export cattle are typically fed for 100 days. The pens under inspection during this study were stocked with export cattle and fed for 100 days.

Climate

The mean monthly temperatures (maximum and minimum) and monthly rainfall probabilities for Feedlot F are shown in Figure 21. Feedlot F is considered to have a strongly summer-dominant rainfall. December is statistically the wettest month with a mean rainfall of 85.5 mm and a mean of 8.2 days of rainfall. Summers are generally warm to hot and winters are usually cold. In summer, the maximum monthly temperatures range from 32 to 33^{o}C. During winter, monthly minimum temperatures range from 2 to 3^{o}C.

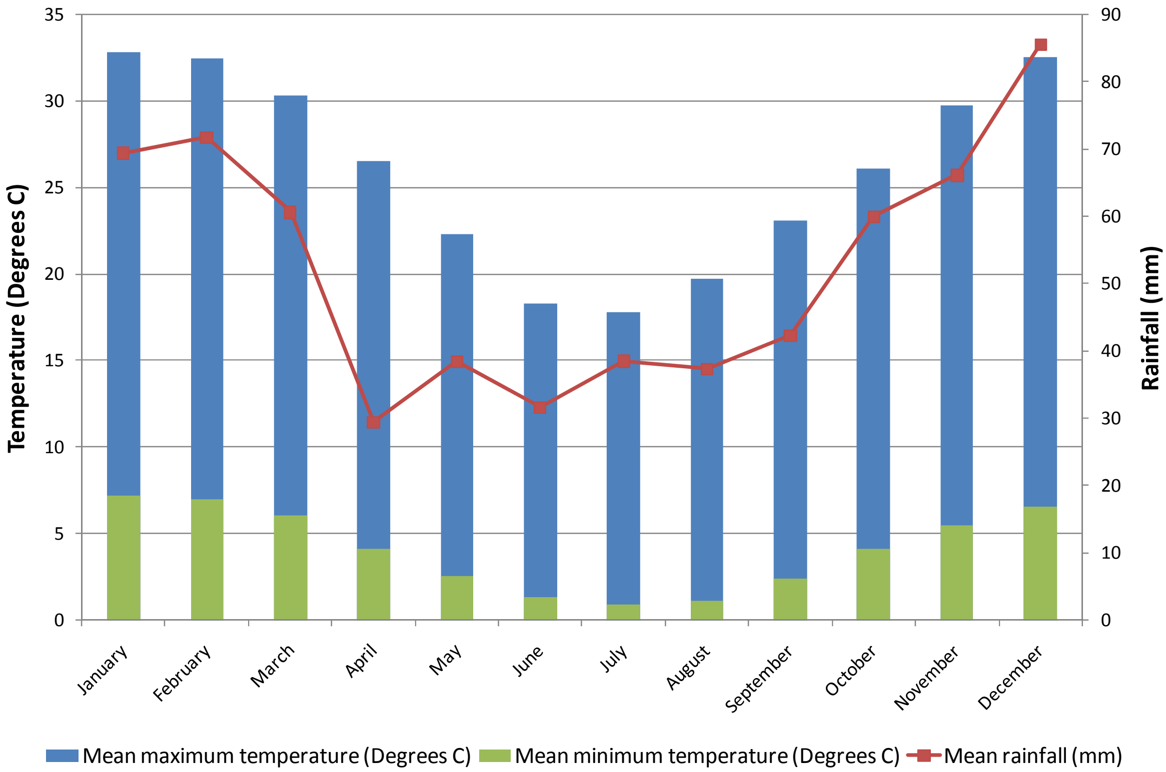

FIGURE 21 – MEAN CLIMATE CONDITIONS FOR FEEDLOT F

Pen Selection

Three feedlot pens were selected at Feedlot F for investigation; pens 122, 123 and 124. All three pens are in the same row of pens near the centre part of the feedlot. The three pens are consecutive in the row, and Pen 124 being the last pen in the row.

The pens have slightly inconsistent shapes, but in general have a width of approximately 45 m (along the bunk), and a depth of 60 m (along the side fences). The pens have an area of approximately 2700 m^2, which provides space for 155 SCU at a stocking density of 17.5 m^2/SCU.

Feedlot F has constructed shade structures over the majority of their feedlot pens, and all three pens involved in this study had with shade covering.

Manure Management Process

The pen cleaning process at Feedlot F is on an 'as required' or opportunity basis. The frequency of pen cleaning depends on a number of factors. These include manure accumulation and the operational (e.g. personnel or machinery required for different tasks) and environmental management of the feedlot. Typically, manure is allowed to accumulate to about 50 mm above the compacted clay surface and no more than about 75 mm on a dry compacted basis. Once manure has accumulated to this depth the pen is cleaned. It is not standard practice to clean pens after cattle have exited, however it maybe undertaken depending on factors such as manure accumulation and pending wet weather. Pen cleaning has previously been undertaken by contractors, however, during this study the pen cleaning operation was undertaken by feedlot staff and equipment. During pen cleaning, all manure is completely removed back to the compacted clay pen base. During this process the pen surface is graded by the pen cleaning equipment to remediate any pot holes which may have developed. About every two years the pen surface is redressed with compacted clay. Pen cleaning operations are typically carried out using a combination of tractor-drawn box scrapers, front-end loaders, graders, excavators, skid-steer loaders and trucks. The box scraper, front end loader and/or grader are used to scrape and push the manure into a mound at the rear of the pen. The manure is then loaded onto the trucks over the fence by the front end loader. An excavator is used to clean manure from underneath fence lines.

Trucks are used to transport manure from the pens directly to a large composting area. Manure is placed in windrows of approximately 0.75 – 1.5 m height and 2 – 3 m width. Usually, the manure is also blended with another material (such as woodchip, sawdust or hay) to assist the composting process and add bulk to the final product. Water is added to the windrows, which are regularly turned using a tractor-drawn compost turning machine. The final product is screened before sale off-site or spreading on surrounding cropping land.

PHOTOGRAPH 20 – FEEDLOT PEN BEING RESURFACED WITH COMPACTED CLAY

Photograph 21 – Excavator Cleaning Manure From Underneath Fences

Photograph 22 – Tractor-drawn Compost Turner Working On Manure Windrow

PHOTOGRAPH 23 – COMPOST SCREENING EQUIPMENT WITH COMPOST WINDROWS IN THE FOREGROUND

Manure Sampling and Assessment

The manure sampling part of the project was divided into two stages. The first stage involved the sampling of manure at different points in the manure management cycle (fresh, pen, stockpiled and composted manure). These samples were analysed for TS, VS, moisture content and nitrogen. The data collected from this sampling and analysis provides an accurate indication of breakdown rates of manure under current management practices.

The second stage involved sampling and monitoring of manure accumulating on the feedlot pen surface. The rate of accumulation was determined through a standardised measurement method, and samples taken from the pen surface were also analysed for TS, VS and moisture content. The data collected from this measurement, sampling and analysis allowed an assessment of the rate of manure production by the cattle in the pen.

To ensure the consistency of measurements between sampling events, the individual pens under investigation at each of the feedlots were initially set up with a number of reference marks. The reference marks were assumed to be representative of a particular block of the pen, as shown in Figure 22. These marks took the form of truck engine valves, hammered into the pen surface immediately after a pen cleaning event. The valves were inserted to the height of the cleaned surface. The valves were inserted in a grid pattern across the pen (see Figure 22), with reference visual guides marked on the fences to assist in locating the valves after they were covered with manure. The tops of the valves were also painted with a bright colour to assist identification.

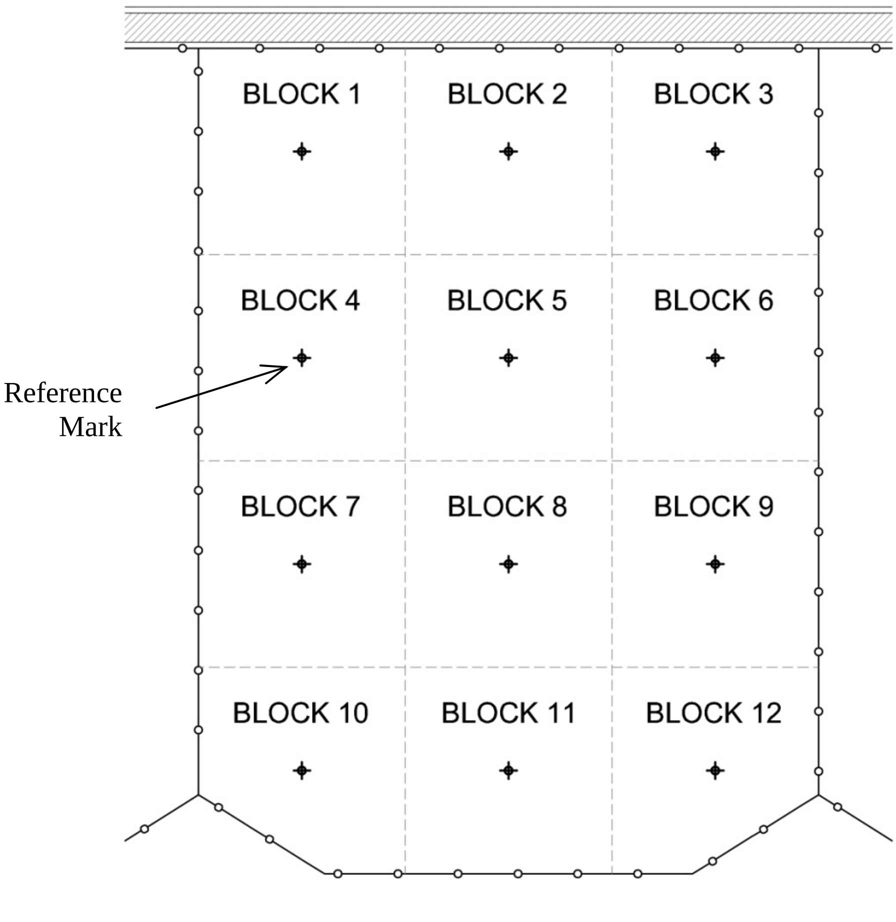

FIGURE 22 – TYPICAL FEEDLOT PEN SAMPLING LAYOUT

PHOTOGRAPH 24 – SETTING OUT GRID PATTERN FOR TRUCK VALVES

PHOTOGRAPH 25 – HAMMERING TRUCK ENGINE VALVE INTO PEN SURFACE

PHOTOGRAPH 26 – FLUORESCENT PAINT APPLIED TO TOP OF VALVE

Manure accumulation and sampling measurements followed the set up of the pens with appropriate reference marks. The sampling regimes and associated analyses for stages 1 and 2 are summarised in Table 28. Further detail on the sampling methods and analyses are provided in the following sections.

TABLE 28 – MANURE SAMPLING FOR STAGES 1 AND 2

Manure Type	STAGE 1 - DECOMPOSITION		STAGE 2 - ACCUMULATION	
	Analysis	Frequency	Analysis	Frequency
Fresh	TS, VS, Moisture, Total N and all its forms	3 (4 feedlots) 2 (2 feedlots)	-	-
Pad	TS, VS, Moisture, Total N and all its forms	3 (4 feedlots) 2 (2 feedlots)	TS, VS & Moisture	Fortnightly + after rainfall event
Stockpiled	TS, VS, Moisture, Total N and all its forms	3 (4 feedlots) 2 (2 feedlots)	-	-
Composted	TS, VS, Moisture, Total N and all its forms	3 (4 feedlots) 2 (2 feedlots)	-	-

Manure Decomposition

This stage involved sampling of different stages of the manure decomposition cycle and measurement of TS, VS, moisture content and nitrogen of fresh, pen, stockpiled and composted manure. This aimed to provide accurate breakdown rates of manure under current management practices while accounting for climate, feed preparation and ration base effects. These data were used to assess the accuracy of TS, VS and moisture content estimates from the BEEF-BAL model. The results will also allow a more rigorous assessment of the feasibility of methane emission capture systems in intensive livestock systems.

The sampling of manure for decomposition assessments was done according to the following broad guidelines:

Sampling Location

- The fresh manure was collected from freshly dropped piles.
- The pad manure was collected from the 12 separate sections of the pen (one in each block, see (Figure 22) to avoid samples only being collected from the most convenient locations (i.e. moist or uncompacted areas).
- The stockpile sample (in the pen or new windrow) was collected from a minimal depth of 10-20cm at 12 different locations around the stockpile. Care was taken to include the various laminations from the crusted manure in samples from stockpiles.
- The composted manure was collected from a depth of 10 cm, 20 cm, 30 cm, 40 cm and 50 cm at three locations within the final compost stockpile. Each sample was collected from a final stockpile of compost aged for an identical period.
- The total nitrogen analysis was undertaken at the six feedlots. Four of the feedlots were sampled three times during the sampling period, one at the initial pen cleaning, one at the final pen cleaning and one in between. The remaining two feedlots were sampled twice during the sampling period at initial and final pen cleaning to minimise travel costs.

Sample Collection

- The manure collected from each location was a bulked composite from at least 12 separate subsamples.

- Samples were collected using a small garden spade, and transferred into a plastic bag lined bucket. 3 to 4 scoops of manure were taken from each of the twelve sampling locations and placed into the bag inside the bucket. This generally filled a 10 L bucket to about half-full. The sample bag was then removed from the bucket, labelled according to the location and type of sample, sealed and placed in a second bag for safety.

- The manure was then sealed in a plastic container (insulated cooler box) and immediately covered with an ice pack, or refrigerated at 4°C to reduce volatilisation losses. Qld samples were delivered to the laboratory on the same day. Southern Australia samples reached the lab within 1 day of sampling. This falls within the recommended holding time according to the studies done by (Peters et al. 2003), as described in Table 29.

TABLE 29 – MAXIMUM HOLDING TIMES FOR MANURE AT 4°C

Analysis	Maximum holding period
pH	7 days
Dry matter/ Total solids	7 days
Ammonia nitrogen	7 days

Source: (Peters et al. 2003)

Sample Analysis

Samples were analysed at NATA accredited laboratories. The SGS Agritech laboratory in Toowoomba was responsible for analysing samples taken from the northern feedlots, while SWEP Analytical Laboratories in Melbourne were responsible for analysing samples from the southern feedlots.

PHOTOGRAPH 27 – BUCKET, BAG AND GARDEN SPADE DURING SAMPLING OF PEN SURFACE MANURE

PHOTOGRAPH 28 – SAMPLING MANURE FROM STOCKPILE AREA

PHOTOGRAPH 29 – FRESH MANURE PRIOR TO SAMPLING

PHOTOGRAPH 30 – TRAVEL REFRIGERATOR USED FOR SAMPLE TRANSPORT

Manure Accumulation

This stage involved the monitoring of manure accumulation on the feedlot pen surface with a view to accurately estimating the volume of manure produced in each pen. Each pen was cleaned prior to the start of the study, which provided the baseline for assessing the accumulation of manure once the pen was stocked. The results of this assessment were used to validate the manure production estimations produced by the BEEF-BAL model.

The measurements and sampling of manure for accumulation assessments were done according to the following broad guidelines:

- Each batch of cattle was sampled at least three times. Nominally, after two weeks, 6 weeks and immediately after dispatch and prior to pen cleaning. However, if the feedlot received a rainfall event an additional sampling was undertaken as soon as it was practically possible after the rain event.

- Manure depth measurements were made directly over the truck valves to provide a consistent point of measurement at each location.

- The pad manure was collected from within each block containing the truck value to avoid samples only being collected in areas where manure is moist and easy to collect.

The general locations of the truck values were identified within the pen using the spray-paint markings on fences and distances from fence lines. A hand-held metal detector was then used to accurately locate the valve underneath the manure layer. A small screwdriver was then used to push though the manure until it hit the truck value, indicating that the original base of the pen had been reached. The depth from the top of the manure layer to the top of the truck valve was measured with a ruler and recorded. The disturbed manure was replaced over the top of the valve.

PHOTOGRAPH 31 – METAL DETECTOR BEING USED TO LOCATE BURIED TRUCK VALVES

PHOTOGRAPH 32 – RULER AND SCREWDRIVER MEASURING MANURE DEPTH IN PEN

Manure Harvesting

This stage involved weighing the mass of manure removed from each pen during the pen cleaning operation.

At the end of each batch or at the as-required time of pen cleaning, each pen was cleaned as per the feedlot's standard pen cleaning operation. Typically, this involved scraping manure from under fences and off the pad as close as practically possible to initial level. During pen cleaning operations, all manure was removed from the pens and loaded into trucks. Each truck was weighed on the facility's weighbridge and the weight recorded. This allowed the total mass (and indirectly the total volume) of manure removed from the pen to be measured.

A sample of harvested manure was collected and analysed for TS and VS and moisture content.

PHOTOGRAPH 33 – FRONT END LOADER SCRAPING MANURE FROM PEN

Herd Performance and Feed Consumption Recording

The BEEF-BAL model requires data on herd size, performance, diet, quantity fed and waste. The composition of the diet fed and the amount that is utilised by the animal will largely determine the characteristics and volume of the waste excreted by lot-fed cattle. Hence, this model also accounts for associative effects, that occurs in ruminants as a result of the nature and compositions of individual ingredients, as well as the digestive processes that occur when feeds are mixed together that affect the digestibility of feed consumed by ruminants.

Herd performance and feed consumption data was collected for each individual study pen from each study feedlot to enable the respective input parameters for the BEEF-BAL model to be determined.

The herd performance data provided included the liveweight of incoming and shipped cattle, days on feed, average daily gain, dressing percentage, number of cattle entering each individual study pen along with the number shipped. The feed consumption data provided included the as-fed and dry matter quantity fed to each pen and the ration composition (e.g. broken into categories of grains, protein sources, roughages/silages, liquids and supplements).

The herd performance and feed consumption data was obtained directly from the respective feedlots in-house feedlot management software (e.g. Feedlot 3000) or manual records.

EMI Surveying of Manure Accumulation

Eigenberg et al. (2005) achieved success in mapping manure accumulation across feedlot pens using electromagnetic (EM) induction. Follow their success, it was decided to utilise this technique in this project. This technique was used to develop an understanding of spatial variation of manure properties in an attempt to validate the assumptions in the sampling methodology. This is a crucial element in assessing whether the samples from the adopted grid sampling methodology are representative and assessment of manure accumulation patterns.

The EMI survey was conducted using an EM38-MK2 (Photograph 34). The EM38-MK2 provides measurement of ground conductivity using dual coil spacings of 0.5 m and 1.0 m concurrently. This provides a sampling depth of approximately 0.75 m for the 0.5 m coil spacing and 1.5 m for the 1.0 m coil spacing in the vertical plane. In the horizontal mode, the two coils sample 0.38 m and 0.75 m simultaneously.

PHOTOGRAPH 34 – THE GEONICS EM38-MK2

The EM38-MK2 was mounted on a non-ferrous trailer (Photograph 36) to enable sampling close to the soil surface. Positional data was obtained using a GPS with an accuracy of +/- 5 m which was mounted on top of the trailer. The EM38-MK2 was connected to the GPS unit via an Allegro data logger, which acted as a data receiver for the GPS unit and EM38-MK2. Data was logged at 5 second intervals.

General operation protocol followed that outlined by Corwin & Lesch (2005a) and O'Leary & Peters (2006). The EMI survey was conducted by pulling the trailer along by hand at an average speed of approximately 5 km/hr (Photograph 35). Transect widths of approximately 1 m were used to produce a map with high soil conductivity (EC_a) resolution.

Data Analysis in the Field

The EMI survey output was imported to the ESAP-RSSD program via the Allegro data logger whilst in the field to enable timely and statistically relevant manure sampling designs. The program was used to process the dataset by excluding anomalies provide a preliminary assessment EC_a and to generate a manure sampling design with 6 sampling sites that captured the main variability in soil conductivity across the survey area. This allows the conductivity and manure sample results to be compared and analysed.

Sample Collection

Manure samples were collected using a hand trowel and screwdriver. Samples were collected from the surface to the pen base from 2 sub-samples taken 50 cm apart and bulked. Sample sites were located using a hand-held GPS (accuracy of +/- 5 m).

PHOTOGRAPH 35 – USE OF EM38 TO MAP MANURE DISTRIBUTION IN PEN

(note wheel tracks indicating the grid path mapped in the pen)

PHOTOGRAPH 36 – DETAIL OF EM38 USED TO MAP PEN MANURE

(note EM38 protected from sun heating and non-ferrous components of the trailer)

Results

Summary of Completed Experiments

Table 30 shows the number of completed cattle fed pen cleaning batches at each feedlot. A completed pen cleaning experiment (a batch) is where cattle entered a cleaned pen, feed and cattle data was collected, and manure removal data was collected at the end of the period. The experimental work continued over a nine month period from April to December 2009. Data was collected from 30 batches of cattle.

At Feedlot B, manure accumulation and manure deterioration samples were collected. Throughout the duration of the project repeated attempts were made to obtain cattle and feed intake data for each respective batch and pen. However, the cattle and feed data provided by the feedlot were not complete and not provided in a useable form. On-site meterological data was also unable to be obtained. Despite repeated requests to obtain further data, it was not provided. Hence, comparison with BEEF-BAL could not be made.

At Feedlot C, approval for the project was obtained from the feedlot owners and initial baseline data was collected and the experiment was commenced. However, within a few months, their interest in the project declined and access to the feedlot was unable to be obtained to collect manure accumulation and manure deterioration samples.

At Feedlot E, pens are normally only cleaned once per year. In this case, a special cleaning was undertaken for this project after a nine month period. A storm event just prior to manure harvest in Pen A and Pen B removed the majority of manure from these pens and deposited it in the drains and sedimentation basin. Therefore, no harvested manure data was able to be obtained. Pen C was cleaned prior to the storm event.

TABLE 30 – NUMBER OF COMPLETED PEN CLEANING BATCHES AT EACH FEEDLOT

Site	Pen A	Pen B	Pen C
Feedlot A	3	3	2
Feedlot B	2*	2*	2*
Feedlot C	0	0	0
Feedlot D	3	3	1
Feedlot E	0	0	1
Feedlot F	2	2	2

*No cattle and feed data were obtained.

Climatic Conditions

At most sites, the experiment was conducted during a period of below average rainfall. Table 31 to Table 34 show the actual rainfall that occurred during each batch compared to the average rainfall for that site over that period.

TABLE 31 – RAINFALL DATA – FEEDLOT A

	Pen A			Pen B			Pen C		
	B1	B2	B3	B1	B2	B3	B1	B2	B3
Start date	24/3/09	20/5/09	15/10/09	24/3/09	21/7/09	13/10/09	24/3/09	14/5/09	19/10/09
End date	13/5/09	20/7/09	16/12/09	29/6/09	12/10/09	16/12/09	13/5/09	8/8/09	16/12/09
Total Average Rainfall	56	91	64	128	118	67	56	126	58
Total Actual Rainfall	26	77	90	50	64	104	26	63	90

TABLE 32 – RAINFALL DATA – FEEDLOT D

	Pen A			Pen B			Pen C		
	B1	B2	B3	B1	B2	B3	B1	B2	B3
Start date	29/3/09	3/7/09	26/09/09	3/4/09	21/7/09	26/9/09	29/3/09	21/6/09	22/09/09
End date	20/6/09	5/9/09	22/11/09	20/6/09	19/9/09	28/11/09	20/6/09	21/9/09	25/11/09
Total Average Rainfall	103	74	115	97	60	129	103	111	127
Total Actual Rainfall	89	47	78	82	44	78	89	75	78

TABLE 33 – RAINFALL DATA – FEEDLOT E

	Pen A			Pen B			Pen C		
	B1	B2	B3	B1	B2	B3	B1	B2	B3
Start date	27/5/09	-	-	27/5/09	-	-	28/5/09	-	-
End date	12/1/10	-	-	12/1/10	-	-	12/1/10	-	-
Total Average Rainfall	411	-	-	411	-	-	411	-	-
Total Actual Rainfall	209	-	-	209	-	-	209	-	-

TABLE 34 – RAINFALL DATA – FEEDLOT F

	Pen A			Pen B			Pen C		
	B1	B2	B3	B1	B2	B3	B1	B2	B3
Start date	6/3/09	20/8/09	-	11/3/09	13/8/09	-	21/3/09	21/6/09	-
End date	15/6/09	6/12/09	-	13/8/09	21/11/09	-	23/6/09	21/9/09	-
Total Average Rainfall	102	211	-	182	166	-	140	156	-
Total Actual Rainfall	141	75	-	141	75	-	141	75	-

Cattle and Feed Data

Cattle Data

Table 35 through to Table 38 summarise the cattle and feed data for each pen cleaning experiment. In these tables, the parameters are:

LWT in	Mean Liveweight of the cattle at the start of the experiment (kg)
LWT out	Mean Liveweight of the cattle at the end of the experiment (kg)
NOC	Mean number of cattle in the pen over the period (head)
DOF	Days on feed – the period between cattle entry and exit / manure removal (days)
DMI	Mean dry matter intake of feedlot (kg/head/day)
ADG	Average daily gain during the experiment (LWTout-LWTin)/DOF (kg/head/day)
FCR	Feed Conversion Ratio (DMI/ADG)

TABLE 35 – CATTLE AND FEED DATA – FEEDLOT A

	Pen A			Pen B			Pen C		
	B1	B2	B3	B1	B2	B3	B1	B2	B3
LWT in	453	394	383	438	497	433	319	316	316
LWT out	565	521	515	647	634	618	439	424	424
NOC	141	151	144	147	143	147	307	310	300
SCU	126	136	128	155	138	147	242	229	229
DOF	50	61	63	98	49	87	50	62	42
DMI	10.2	10.4	10.4	12.0	11.2	12.0	8.8	8.9	8.9
ADG	2.24	2.09	2.1	2.13	2.8	2.1	2.4	1.8	1.8
FCR	4.5	5.0	5.0	5.7	4.0	5.7	3.7	5.1	5.7

At Feedlot A, trial cattle comprised domestic (light and heavy trade) and export cattle. Trade cattle entered the feedlot at less than 350 kg and were fed until a target exit weight of 425 kg was achieved. Heavy trade cattle entered the feedlot heavier than light trade cattle and were fed on to around 500 kg. Export cattle entered the feedlot at around 450 kg and were fed up to a target weight of around 625 kg.

Ration composition data for each pen over the trial period were provided from FY 3000 the in-house feedlot management software for Feedlot A. These data were provided on a daily basis for starter, intermediate, grower and finisher rations. Each ration comprised the percentage of each commodity, % dry matter, % crude protein and energy level. The diets for all pens comprised barley, barley silage, wheat hay, cottonseed meal, whole cottonseed, molasses, vegetable oil and liquid supplements.

TABLE 36 – CATTLE AND FEED DATA – FEEDLOT D

	Pen A			Pen B			Pen C		
	B1	B2	B3	B1	B2	B3	B1	B2	B3
LWT in	362	351	328	365	342	326	325	418	510
LWT out	487	453	446.8	496	457	444	418	510	576
NOC	189	118	156	198	149	174	144	145	145
SCU	161	95	125	171	121	138	109	128	140
DOF	83	66	60	74	61	65	90	88	64
DMI	9.3	8.8	8.5	9.6	9.2	8.6	9.6	9.5	8.5
ADG	1.5	1.6	2.0	1.8	1.9	1.8	1.0	1.0	1.0
FCR	5.7	5.7	4.3	5.4	4.9	4.7	9.2	9.2	8.2

At Feedlot D, trial cattle comprised domestic (light trade) and long fed wagyu cattle (Pen C). Trade cattle entered the feedlot at around 350 kg and were fed until a target exit weight of 450 kg was achieved. Wagyu cattle entered the feedlot at around 325 kg and will spend over 365 days on feed.

Ration composition data for each pen over the trial period were provided from a ration history report from FY 3000 the in-house feedlot management software for Feedlot D. These data were provided for each ration type at every change in ration ingredients within a ration type. This feedlot had 11 types of rations for starter, intermediate, grower and finisher domestic and long fed market types. Each ration comprised the percentage of each commodity, % dry matter, % crude protein and energy level. The rations comprised sorghum, sunflower meal, corn silage, sorghum straw, vegetable oil, molasses, trace elements and liquid starter or finisher supplements. The percentage of each commodity within each ration type varied depending on market type. For example, long fed cattle were fed a higher proportion of roughage compared to domestic cattle.

TABLE 37 – CATTLE AND FEED DATA – FEEDLOT E

	Pen A			Pen B			Pen C		
	B1	B2	B3	B1	B2	B3	B1	B2	B3
LWT in	-	-	-	-	-	-	492	-	-
LWT out	-	-	-	-	-	-	648	-	-
NOC	-	-	-	-	-	-	185	-	-
SCU							195		
DOF	-	-	-	-	-	-	96	-	-
DMI	-	-	-	-	-	-	12.7	-	-
ADG	-	-	-	-	-	-	1.6	-	-
FCR	-	-	-	-	-	-	7.8	-	-

At Feedlot E, trial cattle comprised export cattle. Export cattle entered the feedlot at less than 500 kg and were fed until a target exit weight of 650 kg was achieved after about 100 days on feed.

Ration composition data for each pen over the trial period were provided from a ration history report from Feedlot E's in-house feedlot management software. These data were provided for each ration type at every change in ration ingredients within a ration type. This feedlot had 11 types of rations for starter, intermediate, grower and finisher domestic and export market types. Each ration comprised the percentage of each commodity, % dry matter, % crude protein and energy level. The rations comprised sorghum, corn, wheat, cottonseed, cotton hulls, corn silage, sorghum straw, vegetable oil, molasses, protein meal, trace elements and liquid starter or finisher supplements.

TABLE 38 – CATTLE AND FEED DATA – FEEDLOT F

	Pen A			Pen B			Pen C		
	B1	B2	B3	B1	B2	B3	B1	B2	B3
LWT in	428	465	-	448	449	-	484	457	-
LWT out	637	703	-	627	657	-	668	672	-
NOC	160	118	-	159	162	-	154	191	-
SCU	167	132		163	173		166	207	
DOF	101	109	-	90	101	-	95	99	-
DMI	11.0	12.2	-	11.3	11.8	-	11.3	11.9	-
ADG	2.1	2.2	-	1.9	2.1	-	1.9	2.2	-
FCR	5.4	5.6	-	5.5	5.4	-	5.8	5.5	-

At Feedlot F, trial cattle comprised export cattle. These cattle entered the feedlot at around 450 kg and were fed until a target exit weight of 650 kg was achieved after about 100 days on feed.

Ration composition data for each pen over the trial period were provided from a ration history report from FY 3000 the in-house feedlot management software for Feedlot E. These data were provided for each ration type at every change in ration ingredients within a ration type. This feedlot had 4 types of rations for starter, intermediate, grower and finisher cattle. Each ration comprised the percentage of each commodity, % dry matter, % crude protein and energy level. The rations comprised sorghum, corn, wheat, cottonseed, forage silage, maize silage, lucerne, cereal hay, palm oil, molasses, protein meal and liquid starter or finisher supplements.

Manure Accumulation

Throughout each batch, the depth of manure accumulating over each truck valve in each trial pen was measured periodically and finally just prior to manure harvesting. Nominally, 12 measurements were made per pen as shown in Figure 22. However, not all 12 valves were able to be located at every sampling time due to the valve being damaged (removed top) or removed completely by the action of cleaning equipment. If removed a replacement valve was reinserted. The manure depth was recorded at each sampling location and an average taken to represent the pen manure depth. The minimum, maximum and average of the 12 measurements for each batch for Feedlots A, B, D, E and F are shown in Table 39. No data was collected from Feedlot C. The manure depth was quite variable across the pen due to deposition rates and moisture content at the time of measurement. The wetter the pen surface, the greater the variation across the pen. Higher depth measurements may indicate areas of higher cattle concentration and pugging of the manure.

TABLE 39 – MANURE DEPTH DATA

	Pen A			Pen B			Pen C		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
	mm	mm	mm	mm	mm	mm	mm	mm	mm
Feedlot A –B1	11	71	35	50	430	250	5	30	20
Feedlot A –B2	70	95	85	60	100	85	10	125	70
Feedlot A –B3	100	560	225	87	300	95	30	75	25
Feedlot B – B1	5	40	15	10	32	20	5	35	25
Feedlot B – B2	10	40	26	10	45	25	25	45	35
Feedlot D – B1	5	35	15	5	40	80	5	55	25
Feedlot D – B2	15	45	25	10	60	70	20	75	45
Feedlot E – B1	-	-	-	-	-	-	30	90	55
Feedlot F – B1	25	90	55	5	115	65	35	85	60
Feedlot F – B2	10	45	30	30	75	45	20	45	40

Figure 23 shows the manure depth in each pen since pen cleaning (Day 0) for Feedlots A, B, D, E and F. No data was collected from Feedlot C. Feedlots A and B are southern Australia feedlots with winter dominant rainfall. Feedlot F is a northern feedlot which experienced above average winter rainfall during the trial. Feedlots D and E experienced below average rainfall over the duration of the trial. Hence, Feedlots A and F recorded a higher manure depth at the same period when compared with Feedlots D and E. The shallow manure in Feedlot D at 80 days reflects well compacted manure under extremely dry conditions compared to the wet, spongy manure pack at Feedlot A. Overall, an average manure depth of less than 50 mm was recorded. Under dry conditions, this was typically less than 30 mm. Figure 23 illustrates that after about 25 days about 20 mm of manure gradually accumulating to 30 mm by about 75 days under dry conditions. With continued dry conditions the manure pack gradually increases to around 35 mm after a further 100 days. These data indicate that the manure pack compacts very tightly under dry conditions. Further it is likely that some manure is removed from the pen as dust under these conditions. Conversely, when the compact manure pack is moistened due to rainfall it can increase the dry compacted depth two-fold as shown.

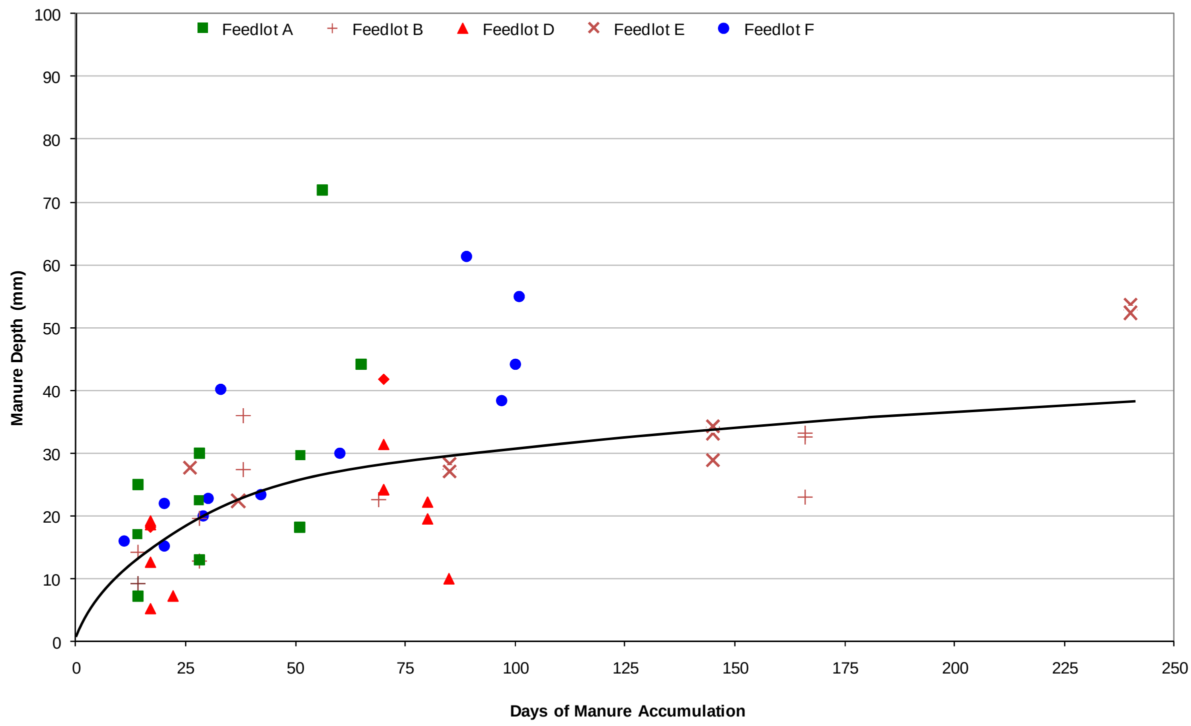

FIGURE 23 – MANURE DEPTH VS DAYS SINCE CLEANING (ALL PENS)

Harvested Manure

Manure harvested from each pen cleaning event was weighed and a sample analysed for a number of parameters. Table 40 to Table 43 summarise the harvested manure data for each pen cleaning batch. In these tables the parameters are:

$Weight_{(wet)}$	Measured wet weight of harvested manure (kg)
MC	Moisture content of harvested manure (%)
$Weight_{(dry)}$	Calculated dry weight of harvested manure (kg)
% VS	Percent of volatile solids in harvested manure (%)

At Feedlot A, Pen A and Pen B were identical in physical size and cattle capacity whilst Pen C held twice the number of cattle of Pen A and Pen B. The pens are cleaned back to the gravel base. The dry manure harvested from each pens A and B ranged from 21 t to 49 t. Due to wet conditions at the completion of Batch 2 in Pen A and Batch 1 in Pen B the harvested manure recorded a very high moisture content of around 85 % . This represents a moisture content greater than fresh manure.

TABLE 40 – HARVESTED MANURE – FEEDLOT A

	Pen A			Pen B			Pen C		
	B1	B2	B3	B1	B2	B3	B1	B2	B3
$Weight_{(wet)}$	63,260	301,780	107,980	346,490	83,460	86,600	127,720	551,080	86,820
MC %	66.9	87.2	72	85.8	51.7	58.9	51.9	80.8	61.9
$Weight_{(dry)}$	20,939	38,628	29,910	49,236	40,328	35,532	61,472	105,807	33,044
%VS	55.9	66.0	36.6	66.1	45.6	50.9	70.0	59.2	61.6

At Feedlot D, Pen A, Pen B and Pen C contained similar cattle numbers. Due to very dry conditions throughout the study period and the maintenance of a manure interface layer, the moisture content of the harvested manure was typically less than 20%. The dry manure harvested from each pens ranged from 9 t to 16 t.

TABLE 41 – HARVESTED MANURE – FEEDLOT D

	Pen A			Pen B			Pen C		
	B1	B2	B3	B1	B2	B3	B1	B2	B3
$Weight_{(wet)}$	16,550	13,500	14,450	16,700	10,100	18,050	18,250	12,000	10,900
MC	29	5.8	4.4	41	7.1	9.1	48.4	8.5	14.9
$Weight_{(dry)}$	11,701	12,717	13,814	9,836	9,383	16,407	9,417	10,980	9,276
%VS	53.7	66.2	63.0	45.8	58.6	59.8	62.3	49.0	66.4

At Feedlot E, the pen is cleaned back to the gravel base. Approximately 205 t of wet manure was removed at a moisture content of 38 %.

TABLE 42 – HARVESTED MANURE – FEEDLOT E

	Pen A	Pen B	Pen C
	B1	B1	B1
$Weight_{(wet)}$	ND	ND	204,640
MC	ND	ND	37.9
$Weight_{(dry)}$	ND	ND	127,081
%VS	ND	ND	45.8

At Feedlot F, Pen A, Pen B and Pen C contained a similar number of cattle. The pens are cleaned back to the gravel base. Due to very dry conditions throughout the study period, the moisture content of the harvested manure was typically about 20 %. The dry manure harvested from each pens ranged from 43 t to 72 t.

TABLE 43 – HARVESTED MANURE – FEEDLOT F

	Pen A		Pen B		Pen C	
	B1	B2	B1	B2	B1	B2
$Weight_{(wet)}$	93,600	54,481	67,820	81,941	82,600	71,378
MC	23.10	20	17.1	14.7	20.1	21.1
$Weight_{(dry)}$	71,978	43,585	56,223	69,895	65,997	56,318
%VS	50.2	52.4	43.2	52.1	52.6	63.3

Volatile Solids Breakdown Rates

Throughout the project, the VS content of the manure on the pen surface was measured. Initially, each pen was cleaned. Some pens were cleaned back to a gravel surface. Others were cleaned back to a manure interface layer. For the sake of this analysis, it is assumed that the VS content of material on the pen surface immediately after pen cleaning is equivalent to the VS content of fresh manure (about 82%). Over time, the VS in the manure breaks down and is released to the atmosphere as methane or carbon dioxide. The measured pen manure VS data can be analysed to determine the amount of the excreted manure left on the pen surface over time. Figure 24, Figure 25 and Figure 26 shows this data for three pens at Feedlot A, Feedlot D and Feedlot F respectively.

For Feedlot A, (Figure 24) the first manure sampling occurred about 14 days after pen cleaning. By this time, there had been a reduction in VS in the pad manure of between 20 and 40% compared to fresh manure. After 40 days a reduction of 60 % in VS in the pad manure compared to fresh manure was measured. At time of pen cleaning, the VS measured in the pad manure was greater than that measured in the harvested manure sample taken at that time. This indicates that the harvested manure sample may have been contaminated with material with a lower VS ratio (e.g. soil, rocks) or that the mixing of the manure pad reduces the VS ratio. After 85 days a reduction of 75% in VS in the pad manure compared to fresh manure was measured.

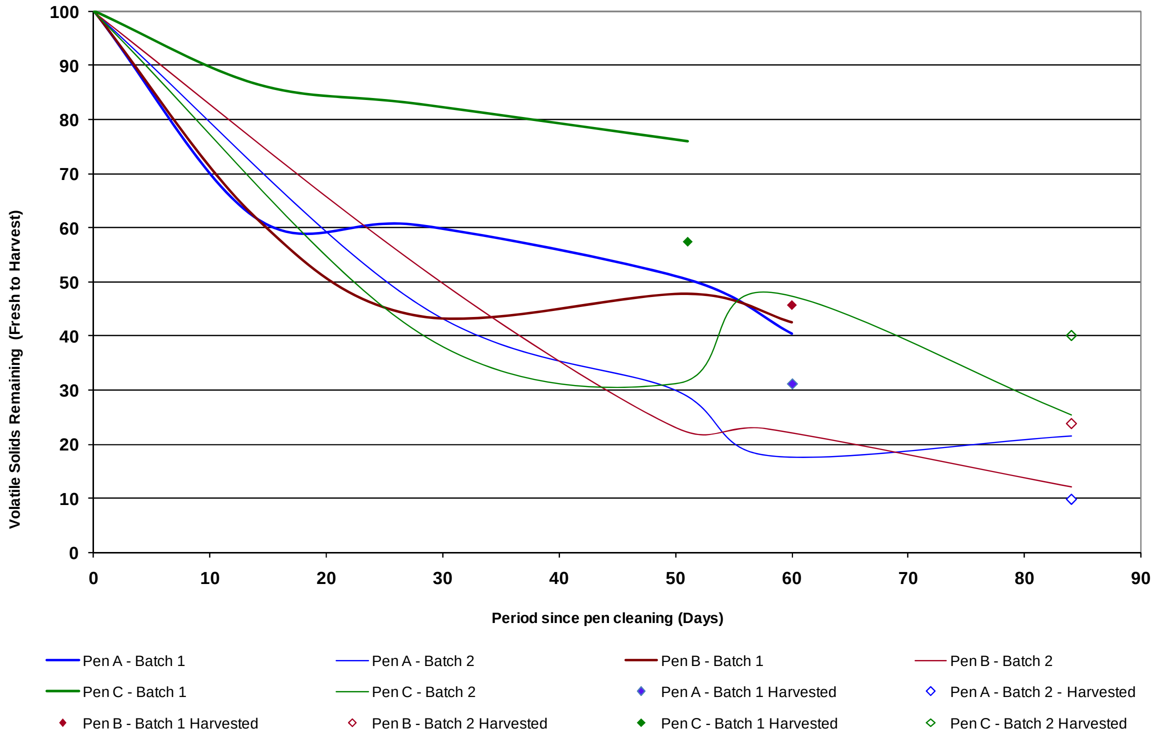

FIGURE 24 – VOLATILE SOLIDS REMAINING OVER TIME (FEEDLOT A)

For Feedlot D, (Figure 25) the first manure sampling occurred about 17 days after pen cleaning. By this time, there had been a reduction in VS in the pad manure of between 30 and 60% compared to fresh manure. After 80 days, a reduction of 70% in VS in the pad manure compared to fresh manure was measured. At time of pen cleaning, the VS measured in the pad manure was similar to that measured in the harvested manure sample taken at that time. This indicates that the harvested manure sample was unlikely to be contaminated with other material (e.g. soil, rocks). The pen cleaning process reinforces this result as a manure interface layer is maintained during the process. Thus ensuring that no pen base material is collected during the process.

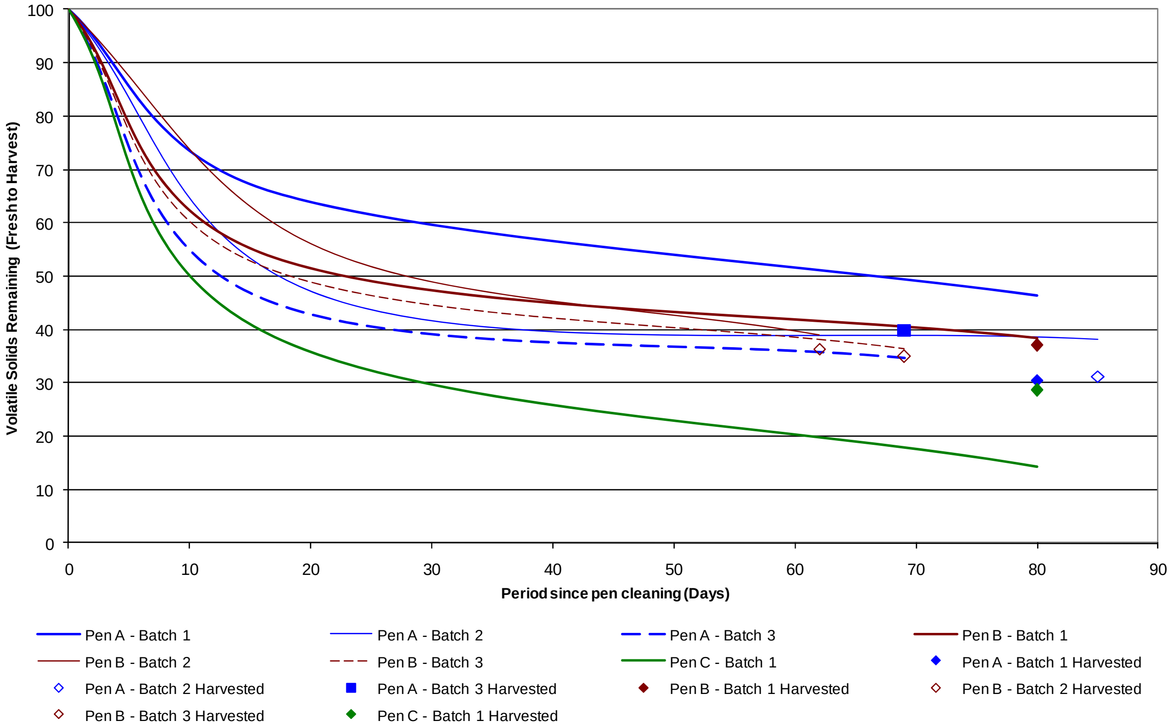

FIGURE 25 – VOLATILE SOLIDS REMAINING OVER TIME (FEEDLOT D)

For Feedlot F, (Figure 26) the first manure sampling occurred about 22 days after pen cleaning. By this time, there had been a reduction in VS in the pad manure of between 60 and 70% compared to fresh manure. After 35 days, a reduction of 70% in VS in the pad manure compared to fresh manure was measured. At time of pen cleaning, the VS measured in the pad manure was greater than that measured in the harvested manure sample taken at that time. This indicates that the harvested manure sample may have been contaminated with material with a lower VS ratio (e.g. soil, rocks) or that the mixing of the manure pad reduces the VS ratio. After 100 days a reduction of 75% in VS in the pad manure compared to fresh manure was measured. That is as little as 25% of the excreted VS remained after 100 days in the pen.

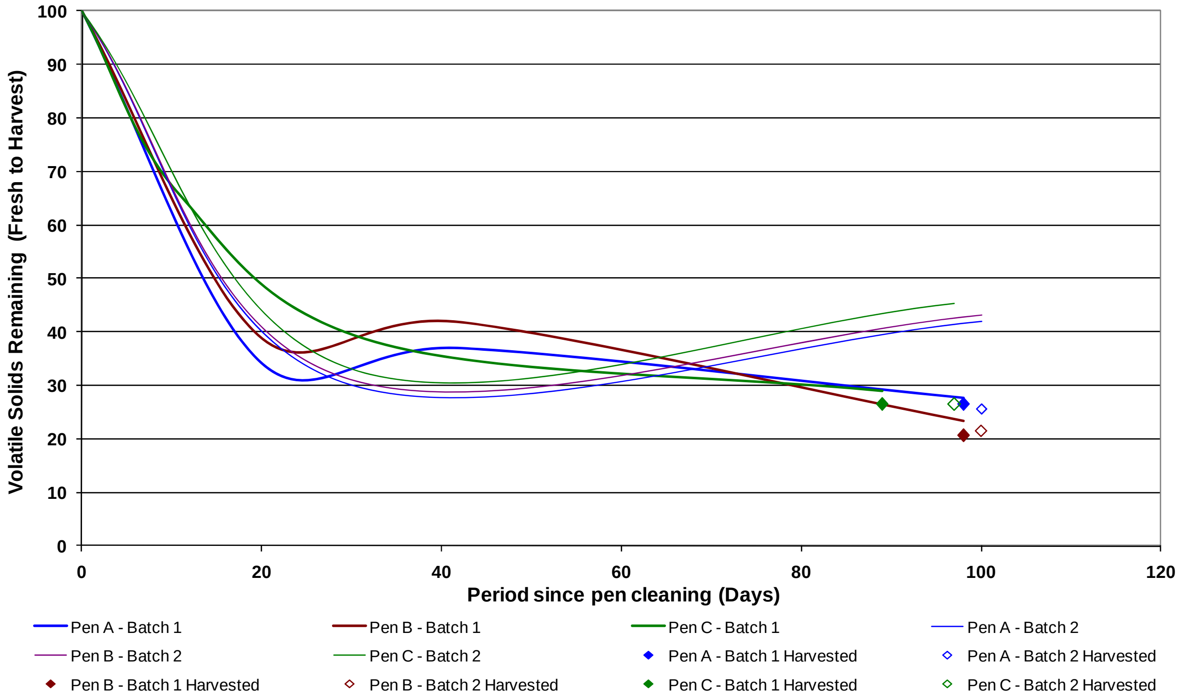

FIGURE 26 – VOLATILE SOLIDS REMAINING OVER TIME (FEEDLOT F)

Figure 27 shows the breakdown of VS by following the changes in an initial sample of fresh manure for Batch 1, Pen A at Feedlot A. Each bar represents a sampling visit. Fresh manure is about 80% moisture. Of the remaining dry matter component, about 83% is VS and 17% ash. It is assumed that, over time, the ash component remains on the pen surface as there was no runoff to remove solids. Moisture is rapidly lost from the fresh manure. The amount of moisture in the pen manure over time is then dependent mainly on rainfall. The amount of VS in the pen manure decreases over time as the VS is broken down but the ash component remains. Consequently, the VS% of the pen manure dry matter decreases from fresh manure (83% VS) to harvested manure (55% VS). This represents a loss of 75% of the initial VS in the manure.

Similar results were found with Feedlot D (Figure 28) and Feedlot F (Figure 29). Fresh manure is about 80% moisture. Of the remaining dry matter component, about 80 % is VS and 20 % ash. It is assumed that, over time, the ash component remains on the pen surface. Moisture is rapidly lost from the fresh manure. The amount of VS in the pen manure decreases over time. Consequently, the VS% of the pen manure dry matter decreases from fresh manure (80% VS) to harvested manure (52% VS). This represents a loss of 70 % of the initial VS in the manure. It should be noted that, even at 52% VS, the manure harvested from the Australian feedlots in this study contains more VS than all of the US feedlots cited in the literature review. This is due to pen design and management where soil is not removed with manure for most Australian feedlots.

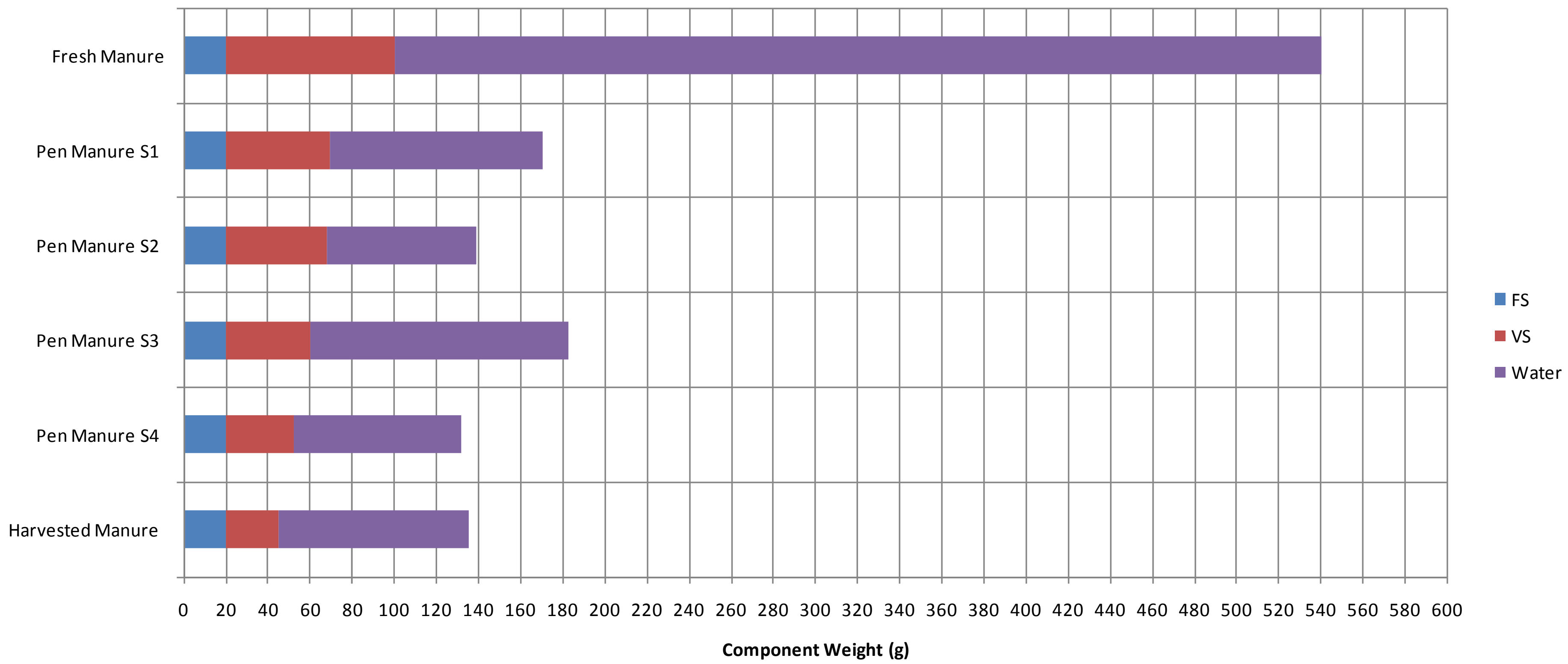

FIGURE 27 – PEN MANURE COMPONENTS OVER TIME (FEEDLOT A – BATCH 1)

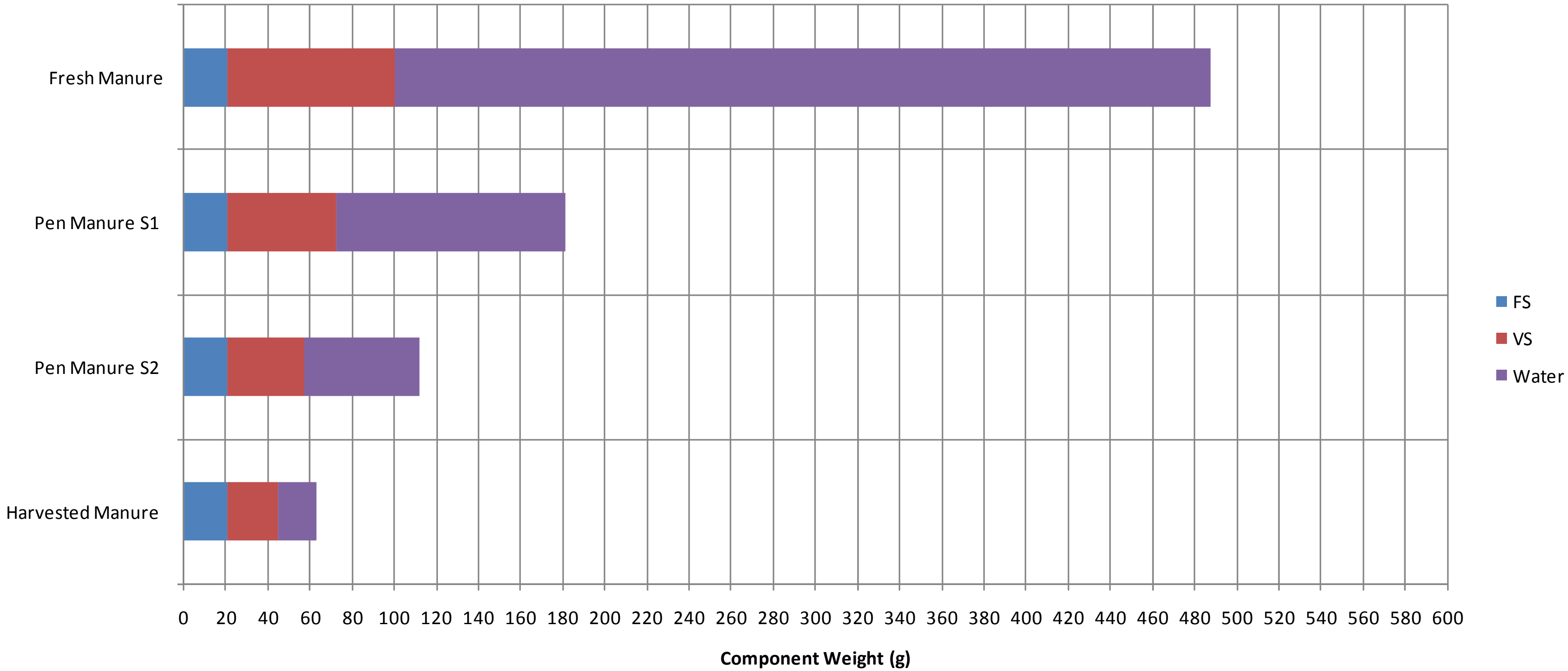

FIGURE 28 – PEN MANURE COMPONENTS OVER TIME (FEEDLOT D – BATCH 1)

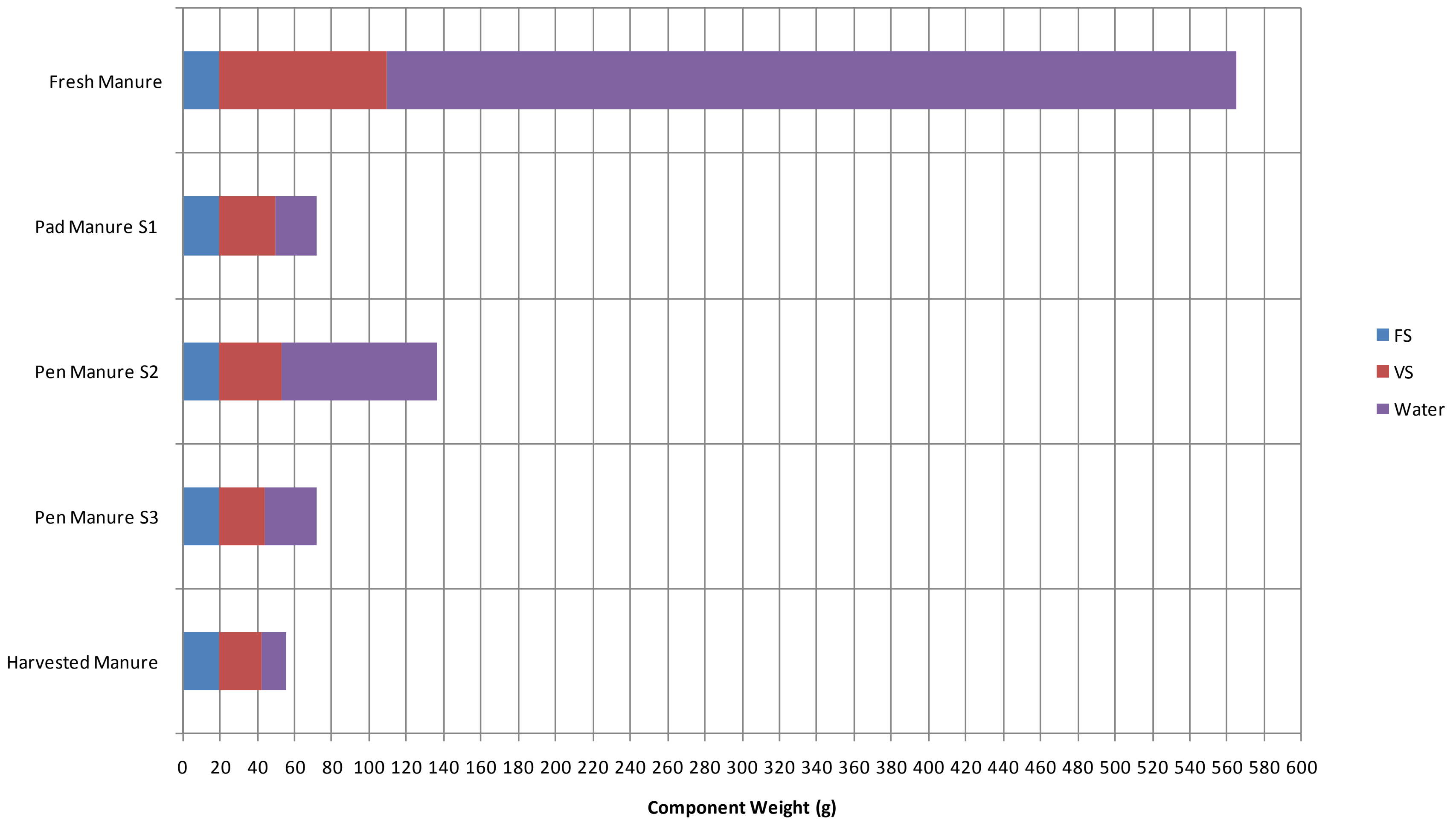

FIGURE 29 – PEN MANURE COMPONENTS OVER TIME (FEEDLOT F – BATCH 1)

Nitrogen

Nitrogen losses during breakdown from fresh to composted manure were assessed by undertaking a nitrogen balance of a pen and manure stockpile. Nitrogen is also lost from pens in runoff. However, this is typically a small component (<2% winter conditions) of the nitrogen balance of a pen and was not determined in this study.

Manure samples from four feedlots were analysed for total nitrogen and its forms at three sampling events throughout the duration of the study. Manure samples were taken from Pen A at the initial pen cleaning, one at the final pen cleaning and one in between. The samples represent faeces as it was difficult to obtain the urine component (of manure) directly from unconfined animals in the field.

Table 44 to Table 47 summarise the harvested manure data for Feedlots A, D, E and F respectively. In these tables the parameters are:

S1 – Initial Pen Cleaning

S2 – Midpoint Sample

S3 – End of the Batch

At Feedlot A (Table 44), samples were taken from Pen A during Batch 2.

Table 44 – Manure Total Nitrogen – Feedlot A Pen A

	Total N %	Total N mg/kg	Organic N %	Organic N mg/kg	Nitrate N %	Nitrate N mg/kg	Ammonia N %	Ammonia N mg/kg	VS %	TS %	MC %
					Fresh Manure						
S1	1.9	18,600	97.9	18,206	0.04	7	2.0	387	59.2	19.2	80.8
S2	2.3	22,600	94.9	21,462	0.26	59	4.8	1,080	83.4	20.2	87.9
S3	2.5	24,500	86.4	21,158	1.4	353	12.2	2,990	86.2	19.6	80.4
					Pad Manure						
S1	1.9	18,700	85.4	15,972	0.06	11	14.5	2,717	52.3	36.4	63.6
S2	1.2	12,200	83.1	10,139	0.17	21	16.7	2,040	36.6	57.7	42.3
S3	1.4	14,400	82.7	11,912	0.47	68	16.8	2,420	41.9	44.4	55.6
					Stockpile Manure						
S1	2	20,000	82.1	16,424	0.07	14	17.8	3,562	50.3	37.2	62.8
S2	1.9	18,900	85.6	16,171	0.15	29	14.3	2,700	44.6	48.3	51.7
S3	1.7	17,000	89.2	15,146	0.55	94	10.3	1,760	46.9	42.1	57.9
					Composted Manure						
S1	0.8	8,000	85.3	6,832	2.2	172	12.5	996	18.3	78.6	21.4
S2	1.0	9,720	80.6	7,830	8.0	780	11.4	1,110	20.9	82.6	17.4
S3	1.0	9,500	87.3	8,294	0.48	46	12.2	1,160	28.5	51.5	48.5

The total N content of fresh manure measured ranged from 1.9 to 2.5%, a similar level to that recorded by Sinclair (1997). Fresh manure data do not include estimates of urine-N, and therefore do not represent total excreted N estimates. The total N content of undisturbed pad manure ranged from 1.2 to 1.9%, similar to reported N values (i.e. 1.4 %) of harvested feedlot manure during summer in Nebraska (USA) (Kissinger et al. 2006).

The total N content of stockpiled manure ranged from 2.0 to 1.7 %, reducing over the term of manure storage. A sample was taken of aged stockpile manure (compost manure). The total N content of aged stockpile manure ranged from 0.8 to 1%. These data were incorporated within the nitrogen balance.

Ammonia-N represents a small fraction of total N. Ammonia-N ranged from 2 to 12% for fresh faeces. This compares with about 50% ammonia-N for faeces from the literature. This may indicate that ammonia-N is rapidly lost from faeces after deposition.

Table 45 shows the analysis results of manure samples taken from Feedlot D (Pen A) during Batch 2.

TABLE 45 – MANURE TOTAL NITROGEN – FEEDLOT D PEN A

	Total N %	Total N mg/kg	Organic N %	Organic N mg/kg	Nitrate N %	Nitrate N mg/kg	Ammonia N %	Ammonia N mg/kg	VS %	TS %	MC %
Fresh Manure											
S1	3.8	38,020	93.2	35,440	1.3	480	5.5	2,100	79.5	20.0	80.0
S2	3.6	36,010	94.5	34,060	2.4	850	3.1	1,100	82.5	21.2	78.8
S3	3.3	30,863	93.0	30,580	0.17	53	6.8	2,100	80	21.2	78.8
Pad Manure											
S1	4.0	39,965	78.4	31,320	0.11	45	21.5	8,600	84.8	72.9	27.1
S2	3.8	38,010	96.3	36,600	0.29	110	3.4	1,300	70.1	89	11.0
S3	3.5	34,905	97.9	34,160	0.13	45	2.0	700	88.7	37.8	62.2
Stockpile Manure											
S1	2.5	25,000	96.8	24,220	1.6	390	1.6	390	53.7	74.4	25.6
S2	2.4	24,000	96.7	23,200	2.5	610	0.79	190	40.6	75	25.0
S3	3.3	32,755	96.9	31,870	0.14	45	2.6	840	63	95.6	4.4
Composted Manure											
S1	2.5	25,075	91.0	22,830	0.18	45	8.8	2,200	46.1	69.6	30.4
S2	2.5	23,355	95.6	22,340	0.19	45	4.2	970	41.6	75.8	24.2
S3	1.9	18,935	91.9	17,390	0.23	45	7.9	1,500	41.6	59	41.0

The total N content of fresh manure measured ranged from 3.3 to 3.8%, higher total nitrogen contents than that measured for Feedlot A. Differences in the higher total N content of fresh manure is likely due to differences in the crude protein of diets between feedlots. In addition, differences in nitrogen requirement of the cattle at the different feedlots are also likely to contribute to N variations of fresh manure. These data have not been corrected to include estimates of urine-N.

The total N content of undisturbed pad manure ranged from 3.5 to 4.0 %. Total N content of manure from the feedpad was shown to decrease slightly over the feeding term, which may be explained by cumulative loss of total nitrogen over time. Loss pathways are likely to include volatilisation, dust, leaching and within runoff from the pen surface, however the proportional loss to each of these pathways is unknown. The total N content of harvested manure (stockpile manure) ranged from 2.5 to 3.3% slightly higher than measured values at Feedlot A. A sample was taken of aged stockpile manure (compost manure). The total N content of aged stockpile manure ranged from 1.9 to 2.5 %.

Ammonia-N represents a small proportion of total N for all manure sources, being less than 0.9% of the Total N. As for Feedlot A, this was expected since ammonia losses from fresh, pad and stockpiled manure comprise a significant portion of total N losses.

TABLE 46 – MANURE TOTAL NITROGEN – FEEDLOT E PEN A

	Total N	Total N	Organic N	Organic N	Nitrate N	Nitrate N	Ammonia N	Ammonia N	VS	TS	MC
	%	mg/kg	%	mg/kg	%	mg/kg	%	mg/kg	%	%	%
					Fresh Manure						
S1	3.2	32,300	92.7	29,920	2.7	880	4.6	1,500	80.0	21.3	78.7
S2	3.6	37,390	92.7	34,660	2.5	930	4.8	1,800	84.8	22.9	77.1
S3	3.7	37,480	89.7	33,620	1.5	560	8.8	3,300	88.5	28.0	72.0
					Pad Manure						
S1	2.7	27,380	79.2	21,680	3.6	1,000	17.2	4,700	62.4	63	37.0
S2	3.4	34,065	96.4	32,820	0.13	45	3.5	1,200	73.9	58.3	41.7
S3	4.1	41,000	85.6	35,090	5.4	2,210	9.0	3,700	86	54.6	45.4
					Stockpile Manure						
S1	2.6	26,565	87.8	23,320	0.17	45	12.0	3,200	55.8	77.5	22.5
S2	3.3	33,025	88.9	32,620	0.14	45	10.9	360	38.8	70.4	29.6
S3	4.1	40,755	84.7	34,510	0.11	45	15.2	6,200	84.4	62.1	37.9
					Composted Manure						
S1	3.3	33,045	93.9	31,000	0.14	45	6.0	2,000	68.7	67.1	32.9
S2	2.3	23,035	86.3	19,890	0.19	45	13.5	3,100	66.2	76.8	23.2
S3	3.0	29,645	94.6	28,000	0.15	45	5.3	1,600	63.2	59.8	40.2

Generally, total N content for Feedlot E (Table 46) from fresh manure, feedpad, stockpile and composted manure were similar to analysis from Feedlot D, and higher than total N of manure from Feedlot A. For feedpad and stockpiled manure, analysis of total N % was shown to increase slightly over time. This may be the result of increasing total N content of the fresh manure over the feeding term, leading to an increase in nitrogen accumulation at these study sites. Similar to Feedlots A and D, the ammonia-N content of manure were mostly lower than 0.5%, which may indicate significant ammonia losses from these manure sources over the feeding term.

TABLE 47 – MANURE TOTAL NITROGEN – FEEDLOT F PEN A

	Total N %	Total N mg/kg	Organic N %	Organic N mg/kg	Nitrate N %	Nitrate N mg/kg	Ammonia N %	Ammonia N mg/kg	VS %	TS %	MC %
					Fresh Manure						
S1	10.5*	104,930	98.5	103,000	0.6	630	0.95	1,000	82.9	21.9	78.0
S2	2.6	21,856	91.6	20,000	2.5	556	5.9	1,300	83.4	17.9	82.0
S3	2.4	24,095	89.9	21,650	0.19	45	9.9	2,400	81.6	18.9	81.1
					Pad Manure						
S1	2.4	24,005	92.4	22,160	0.19	45	7.4	1,800	63.1	61.0	39
S2	2.0	21,945	91.2	20,000	0.20	45	8.6	1,900	57.9	42.0	58
S3	1.8	17,805	97.3	17,310	0.25	45	2.5	450	55	90.6	9.4
					Stockpile Manure						
S1	4.5	45,075	92.6	41,730	0.10	45	7.3	3,300	70.2	59.7	40
S2	2.2	22,945	87.2	20,000	0.20	45	12.6	2,900	69.2	53.6	46
S3	1.8	17,817	97.1	17,300	0.26	47	2.6	470	54.8	84.4	16
					Composted Manure						
S1	2.0	19,957	92.9	18,540	7.0	1,400	0.09	17.0	25.4	68.7	21.3
S2	2.2	21,716	92.1	20,000	7.8	1,699	0.08	17.0	26.2	69.1	30.9
S3	0.7	7,141	87.8	6,263	0.95	68	11.3	810.0	20.6	84.0	16.0

The total N content of fresh manure measured ranged from 2.4 to 10.5%. The 10.5 % reading is over 4 times that measured for fresh faeces across the study. One possible reason for the high N value may be that the fresh faeces sample may have contained a large amount of urine directly prior to sampling. Fresh manure data do not include estimates of urine-N, and therefore do not represent total excreted N estimates. The total N content of undisturbed pad manure ranged from 1.8 to 2.4 %. The total N content of stockpiled manure ranged from 4.5 to 1.8 % and reduced over the term of manure storage. A sample was taken of composted manure. The total N content of these samples ranged from 2.0 to 0.7%. These data were incorporated within the nitrogen balance.

Fresh faeces ammonia-N was found to range from 5.9 to 9.9% of total nitrogen. Across all study feedlots, the ammonia-N level in fresh faeces was typically less than 10%. This compares with typical values from the literature of about 50% ammonia-N for faeces. This indicates that ammonia-N is rapidly lost from faeces after deposition.

A total N mass balance has been developed for the various stages of manure management. The process begins with feed intake and tracing N through each stage of manure management to the stockpile or composting. The partitioning of N to the pond is not accounted for. Nitrogen is traced through the feedlot system with a series of “back-calculated” partitioning estimates derived from the VS/TS component of each stage.

The BEEF-BAL model enables the estimation of excreted N. This can be compared with actual N excretion from the mass balance.

Fresh faeces from Pen A of each feedlot was sampled for total N three times over the duration of one batch. The fresh faeces were analysed for total N. For comparison with BEEF-BAL predicted excretion, the total N content of the fresh faeces was adjusted for urine using the data of Sinclair (1997). Table 48 shows the measured total N content of faeces adjusted for urine for Feedlots A, D, E and F.

The total N content of fresh manure of the 3 samples from Feedlot A, ranged from 4.3% to 5.7%. The BEEF-BAL predicted total N excretion for the cattle and ration fed was estimated to be 7.5%. From these data BEEF-BAL over-predicted the measured total N by about 2%.

At Feedlot D, the measured total N content of fresh manure ranged from 7.7% to 8.9 %, slightly greater than Feedlot A. BEEF-BAL predicted total N excretion to be 4.4 to 6.0% for the cattle and ration fed. From these data BEEF-BAL under-predicted the measured total N by about 2.5%.

The measured total N content of fresh manure ranged from 7.5% to 8.6 % at Feedlot E a similar level when compared to Feedlot D results. BEEF-BAL predicted total N excretion (5.3 to 6.4%) was about 2% less than that measured.

At Feedlot F, the initial sample at Feedlot F is considered an outlier as it is extraordinarily high reading compared with other samples fresh manure. It may be likely that this faeces sample also contained fresh urine prior to sampling.

There are two sources of inherent error within these comparisons which can explain the differences observed. Firstly, the actual total N of excreted manure is not directly measured. Rather fresh faeces is sampled and an adjustment based on data from literature is made. Secondly, errors are introduced through the ingredient analysis for N content as standard values are used rather than actual values. These errors are a plausible explanation for the differences found between the measured and predicted values.

TABLE 48 – ESTIMATES OF BEEF-BAL PREDICTED FRESH MANURE TOTAL NITROGEN VERSUS MEASURED FRESH MANURE TOTAL NITROGEN

	Feedlot A		Feedlot D		Feedlot E		Feedlot F	
	% Total N Measured	% Total N Predicted	% Total N Measured	% Total N Predicted	% Total N Measured	% Total N Predicted	% Total N Measured	% Total N Predicted
S1	4.3	7.5	8.9	4.4	7.5	5.3	24.4	7.7
S2	5.3	7.5	8.4	5.7	8.4	6.2	6.1	4.7
S3	5.7	7.5	7.7	6.0	8.6	6.4	5.6	5.0

Table 49 shows the estimations of the amount of nitrogen partitioned throughout the system for Feedlots A, D, E and F. Feedlot D and Feedlot F are the only feedlots which truely compost through active aeration of manure. Remaining feedlots stockpile harvested manure for up to 12 months prior to utilisation.

The total nitrogen excreted as a percentage on nitrogen intake across all feedlots was found to range from 89.4 % (Feedlot F) to 97.3% at Feedlot E. These data compare favourably with the literature which suggests about 90% of the nitrogen intake excreted.

The greatest loss of total N was measured on the pen surface. Between 64 and 71% of the total N fed to feedlot cattle was lost to the atmosphere (or a small percentage lost to the pond in Feedlot E) across the study feedlots.

The total nitrogen loss from fresh to stockpile as a percentage on nitrogen intake across all feedlots was found to range from 62.0% (Feedlot F) to 84.1% at Feedlot D. These data compare favourably with that found in the literature.

TABLE 49 – MASS BALANCE ESTIMATES FOR THE PARTITIONING OF NITROGEN (% OF INTAKE)

Source or emission of nitrogen	Feedlot A		Feedlot D		Feedlot E		Feedlot F	
	kg/hd/yr	**% of N Intake**	**kg/hd/yr**	**% of N Intake**	**kg/hd/yr**	**% of N Intake**	**kg/hd/yr**	**% of N Intake**
Animal mass balance								
N Intake	80.3	100.0	73	100.0	133.2	100.0	135.1	100.0
N in LW gain	8.3	10.2	6.2	11.1	3.7	2.7	13.9	10.6
N Excreted	73	**94.2**	66.8	**91.5**	129.5	**97.3**	121.2	**89.4**
Losses and partitioning on pad								
Volatilised from pad as NH_3	19.4	**24.1**	16.9	**23.2**	28.8	**21.6**	31.3	**23.2**
Total N Loss from Pad	25.6	35.2	23.6	35.3	38.5	29.3	43.4	35.8
Harvested N from Pad	47.4	**64.8**	43.2	**64.7**	94.2	**70.7**	77.8	**64.2**
Stockpile losses								
Harvested from Pad	47.4	64.8	43.2	64.7	94.2	70.7	77.8	64.2
Volatilised from stockpile as NH_3	0.8	**1**	0.8	**1**	7.2	**5.4**	2.2	**1.6**
Loss of N from Stockpile	19.5	41.3	15.7	36.3	24.9	26.8	21.5	27.7
Compost Losses								
N loss from compost	-	-	1.7	6.5	-	-	-	-
Total Loss from Fresh								
Total N	73.7	**78.3**	76.9	**84.1**	99.9	**76.0**	75.1	**62.0**

EMI Mapping of Feedlot Manure Accumulation

Feedlot D

Figure 30 shows the apparent electrical conductivity (EC_a) data for Pens A and B at Feedlot D. Figure 31 shows this data overlain on an aerial image of the site. There are distinct patterns evident in this mapping. The dark red strip through the middle of both pens corresponds to the shade structures in each pen. EMI measures differences in the conductivity of the pen surface. Conductivity is influenced by salt content, concentration of other cations and anions (e.g. nitrogen, phosphorus) or moisture content. Visually, there was no difference in pen moisture content under the shade structure compared to the open areas. Hence, it is likely that the difference in apparent electrical conductivity is reflecting the difference in manure deposition resulting in different concentrations of VS, nitrogen, phosphorus and salts under the shade. In the lower pen (B), there is also a dark red area adjacent to the feed bunk. This suggests that more manure has been excreted there but it is not clear why the same pattern is not apparent in the top pen.

The dark red areas around the edge of each pen may be an influence from the metal in the pen fencing (posts, wire) or may be an indication of accumulated manure along fence lines. More investigations are needed to fully interpret this data. However, this data does give some confidence that the manure sampling pattern used in this study (Figure 22) would result in a representative sample being taken from these pens.

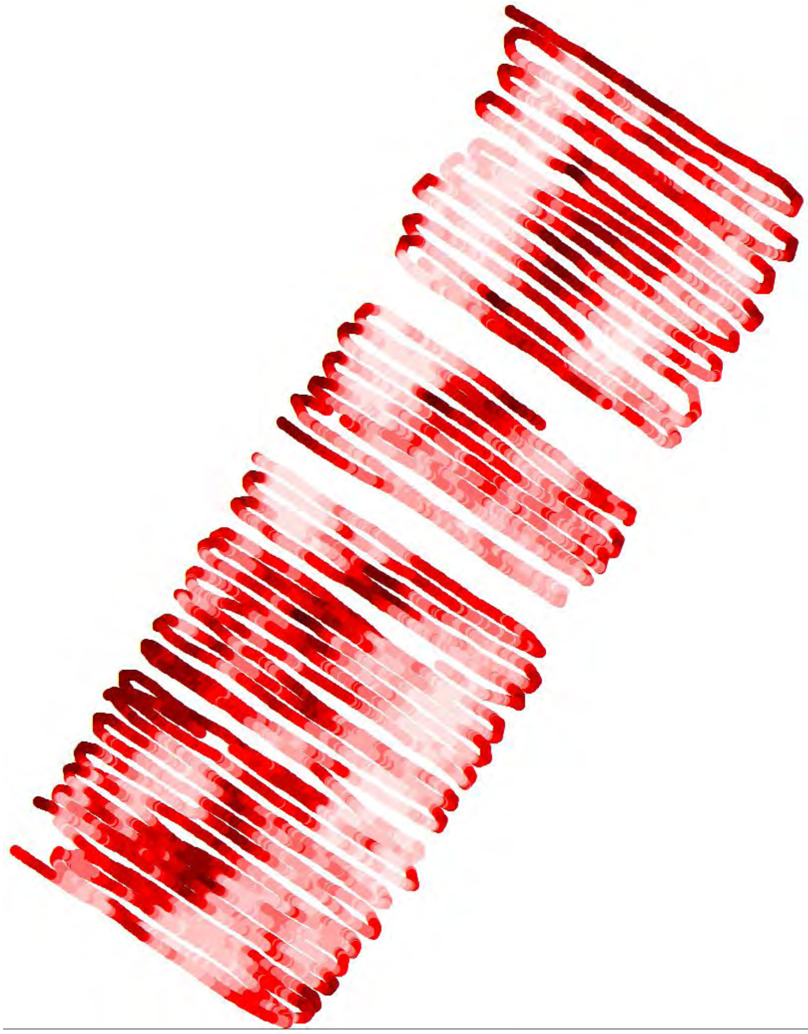

FIGURE 30 – RAW EMI DATA FOR PENS A (UPPER) AND B (LOWER) AT FEEDLOT D

FIGURE 31 – EMI DATA FOR FEEDLOT D OVERLAIN ON AERIAL IMAGE

(Note: this aerial image does not show the shade structures that now exist in the mapped pens)

Data Analysis and Interpretation

Manure TS and VS levels were assessed by taking soil samples across Pen A and Pen B. In each pen, six manure samples were collected following the method outlined, giving a total of 12 manure samples from the pen surface prior to harvest of the manure.

Aggregated results are shown in Table 50. The range in the data highlight the variability in manure properties observed. It should be taken into account that the sampling strategy was designed to capture variability in manure properties.

These data show that at the time of sampling the manure was very dry (i.e. greater than 75% dry matter).

TABLE 50 – SUMMARY RESULTS FOR MANURE SAMPLES COLLECTED IN PENS A AND B AT FEEDLOT D

Parameter	Pen A				Pen B			
	Mean	Median	Min	Max	Mean	Median	Min	Max
Total Solids, %	87.3	87.8	81.5	90.3	84.1	85.5	77.1	89.7
Volatile Solids, %	59.7	60	50.4	67.9	60.7	64.1	42.3	72.3
Moisture Content, %	12.8	12.3	9.7	18.7	15.9	14.5	10.3	22.9
Nitrogen, %	3.4	3.2	3.1	4.0	3.4	3.3	2.9	3.9

Following laboratory analysis, the manure results were input into the ESAP-Calibrate program. This program performs a multiple linear regression analysis to determine the correlation between EC_a and a range of soil parameters. The ESAP-Calibrate program uses a stochastic model to estimate the theoretical strength of correlations between EC_a and the manure property of interest. The program automatically fits a regression model and generates R^2 values for soil properties of interest, which are used to identify the key variables affecting EC_a. Once R^2 values have been generated, the distribution of properties highly correlated to EC_a were mapped using the ESAP-SaltMapper program to observe if any trends in existed in the pens.

Figure 32 shows the apparent soil conductivity (EC_a) of Pen A.

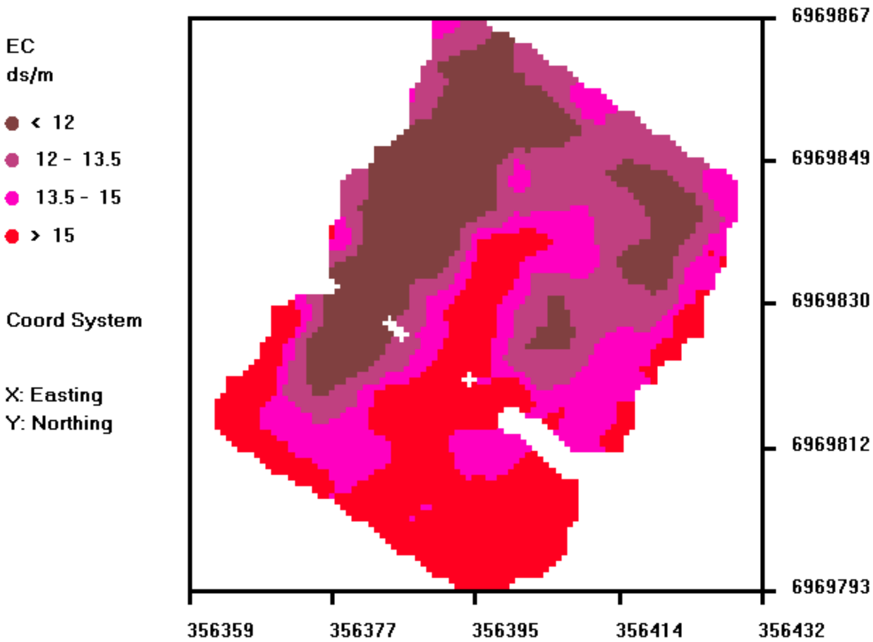

FIGURE 32 – PREDICTED ELECTRICAL CONDUCTIVITY – FEEDLOT D - PEN A

Based on the EC_a map and manure samples collected from the pen, selected manure parameters were mapped (Figure 33, Figure 34 and Figure 35).

The calibration with the measured and manure samples collected from the pen, selected manure parameters (TS, VS, and total N) were mapped (TS in Figure 33, VS in Figure 34 and total N in Figure 35).

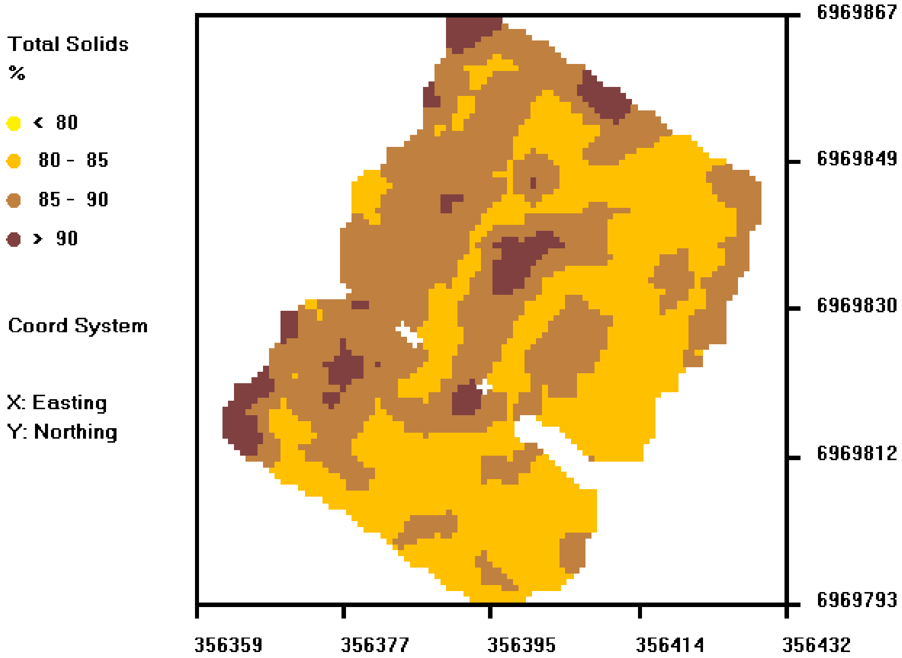

FIGURE 33 – PREDICTED TS DISTRIBUTION - FEEDLOT D - PEN A

Variation in TS (Figure 33) showed a sound regression relationship with EC_a in this pen (R^2 = 0.74), thus indicating that EC_a is able to describe most of the variability in TS within Pen A. Estimated TS composition within manure in Pen A is within the approximated range of 80 to 90%. The variability of TS over the pen surface is likely to be influenced by the provision of shade through the middle of the pen, and the location of the feed bunk. The percentage of TS estimated within Pen A has a greater concentration nearer the feed bunk and shade structure (located through the middle of the pen).

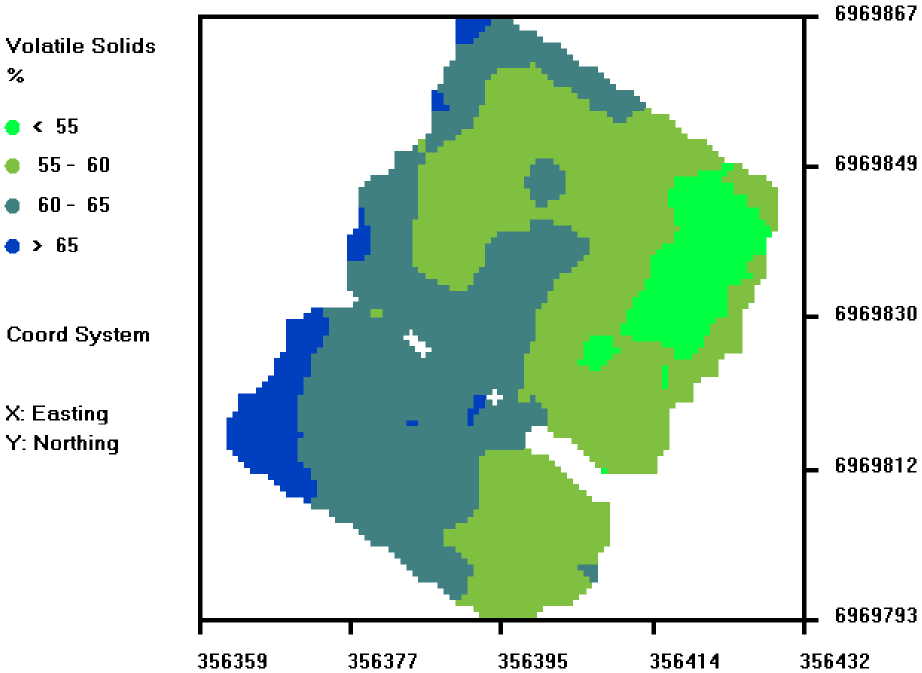

FIGURE 34 – PREDICTED VS DISTRIBUTION - FEEDLOT D - PEN A

Spatial variation in VS% on the feedpad (Figure 34) showed a strong regression relationship with EC_a in this pen ($R^2 = 0.99$), indicating that measured EC_a describes most of the variability of VS within Pen A. High levels of VS on the feedpad correspond to locations with high levels of manure deposition in the pen, since constituents of manure are influential to EC_a. These constituents include nitrate-N, chloride, sodium, potassium and organic matter. These locations are likely to be where cattle spend the majority of their time (i.e. under shade and near the feedbunk). Generally, the location of higher levels of VS estimated from the EM survey and analysis are at the feed bunk and under the shaded portion of the pen.

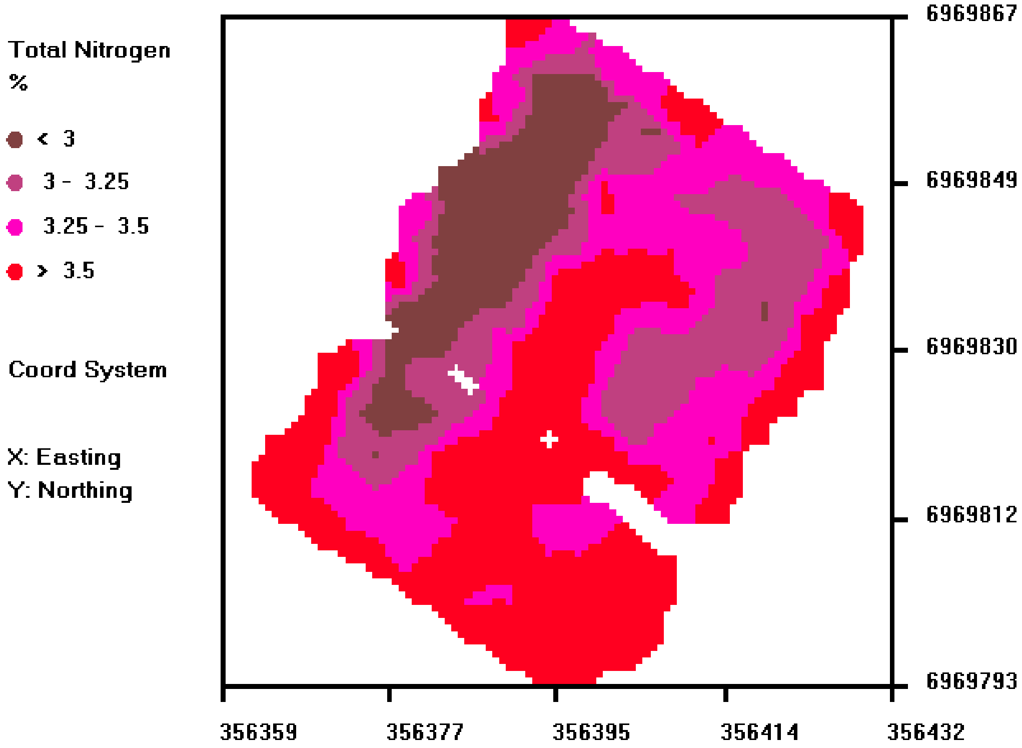

FIGURE 35 – PREDICTED TOTAL NITROGEN DISTRIBUTION – FEEDLOT D - PEN A

The variation in total N with EC_a is shown in Figure 35. Variation in total N showed a very strong regression relationship with EC_a in this pen ($R^2 = 0.99$), thereby indicating that EC_a describes the majority of the variation of total N in Pen A. Similar to estimated VS distribution, the regions of higher total N (Figure 35) correspond to the shade structures for Pen A. EMI measures differences in the conductivity of the pen surface. Nitrogenous compounds including nitrite and nitrate will contribute to the overall estimated EC_a.

Visually, there was no difference in pen moisture content under the shade structure compared to the open areas. Hence, it is likely that the difference in apparent electrical conductivity is reflecting the difference in manure deposition resulting in different concentrations of VS, nitrogen, phosphorus and salts under the shade.

Figure 36 shows the apparent soil conductivity (EC_a) of Pen B. The apparent soil conductivity (EC_a) distribution ranges from 14 to 16 ds/m.

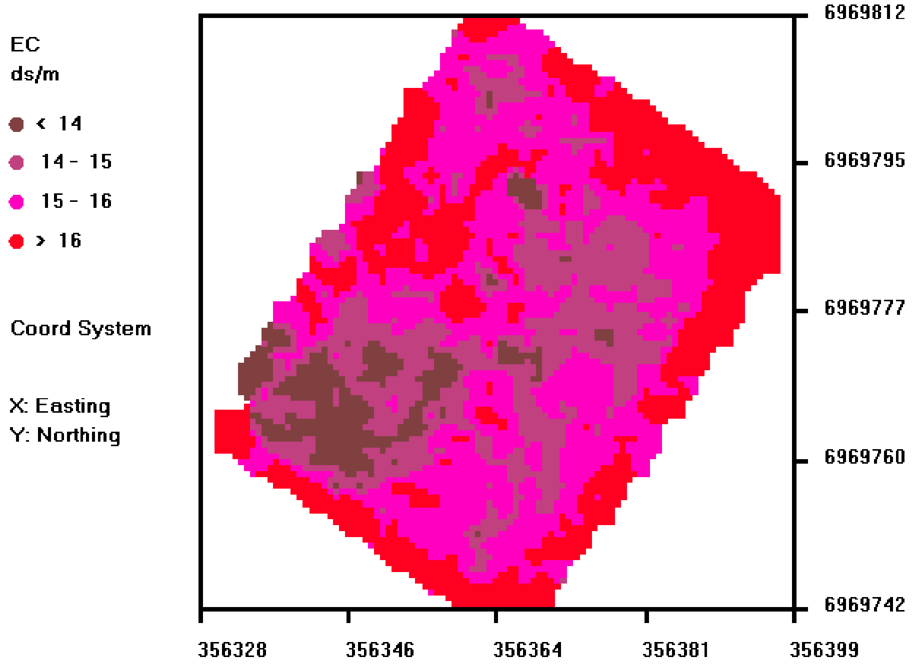

FIGURE 36 – PREDICTED ELECTRICAL CONDUCTIVITY – FEEDLOT D – PEN B

Based on the EC_a map and manure samples collected from the pen, selected manure parameters were mapped (Figure 37, Figure 38 and Figure 39).

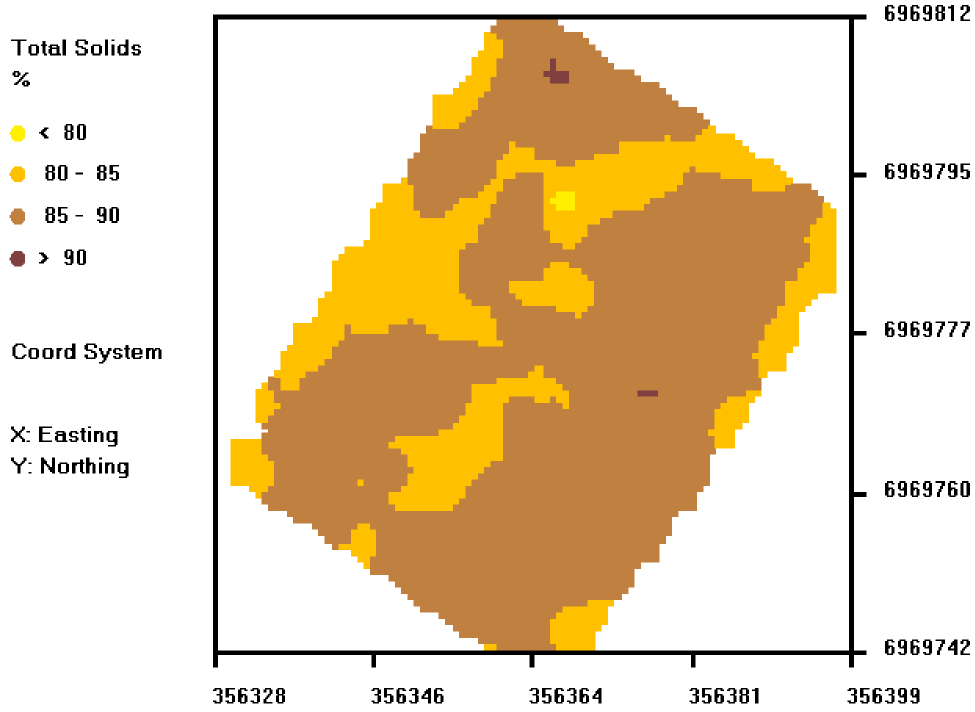

FIGURE 37 – PREDICTED TS DISTRIBUTION – FEEDLOT D - PEN B

Whilst, variation in TS (Figure 37) showed a sound regression relationship with EC_a in this pen (R^2 = 0.81), a dissimilar distribution pattern was found when compared to Pen A. The regression relationship indicates that EC_a is able to describe most of the variability in TS within Pen B. In Pen B the distribution of TS was relatively even across the pen with only a 5% variation recorded. Further, higher concentrations of TS around the feed bunk and shade areas was not observed.

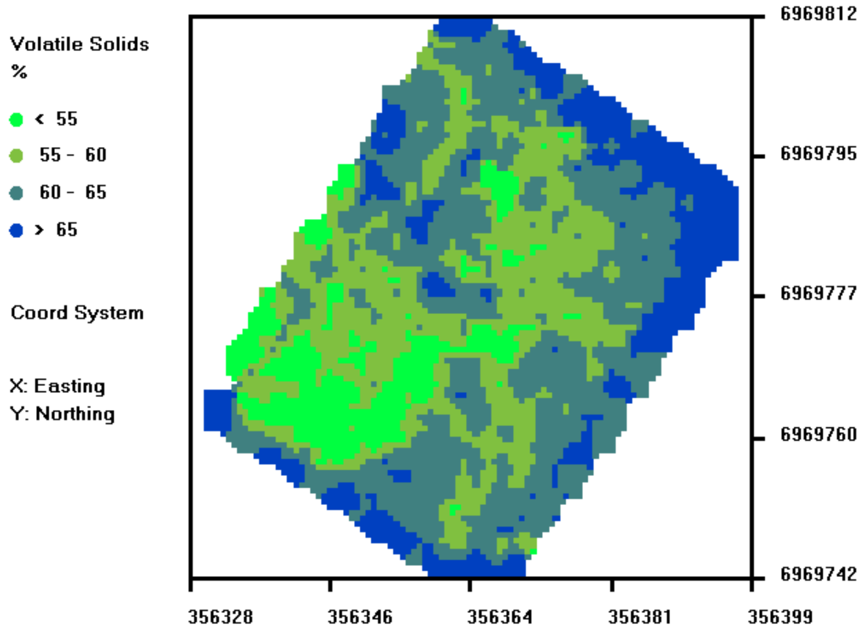

FIGURE 38 – PREDICTED VS DISTRIBUTION - FEEDLOT D - PEN B

Spatial variation in VS% on the feedpad (Figure 38) showed a strong regression relationship with EC_a in this pen (R^2 = 0.96), indicating that measured EC_a describes most of the variability of VS within Pen B. The VS/TS ratio on the pad was found to range from 55 to 65%. Higher levels of VS were measured towards the bottom of the pen, around the fencelines and in the northern end of the feed bunk, indicating a higher deposition of fresh manure.

The variation in total N with EC_a is shown in Figure 39. Variation in total N showed a very strong regression relationship with EC_a in this pen (R^2 = 0.99). Similar to estimated VS distribution, the regions of higher total N were found towards the bottom of the pen, around the fencelines and in the northern end of the feed bunk, indicating a higher deposition of fresh manure and urine.

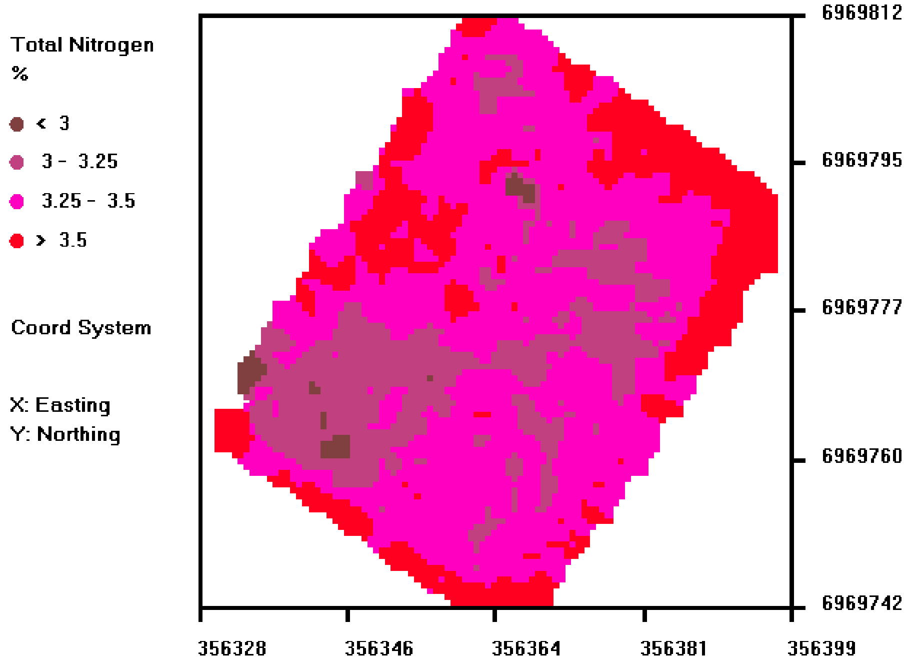

FIGURE 39 – PREDICTED TOTAL NITROGEN DISTRIBUTION – FEEDLOT D - PEN B

Feedlot F

Figure 40 shows the apparent electrical conductivity (EC_a) data for Pens B and C at Feedlot F. Figure 41 shows this data overlain on an aerial image of the site. There is a distinct graduation in EC_a from the feed bunk (left of image) to the bottom of the pen. The dark red strip is at the feed bunk end of the pen and it is likely that the difference in apparent electrical conductivity is reflecting the difference in manure deposition resulting in different concentrations of VS, nitrogen, phosphorus and salts around the feed bunk apron. A similar pattern is observed two-thirds of the way down the fence line reflecting the higher manure deposition around the water trough. The darker areas around the edge of each pen may be an indication of accumulated manure along fence lines. More investigations are needed to fully interpret this data.

However, this data reinforces that the grid sampling pattern approach to obtain the manure samples would result in representative samples being taken from these pens.

The lighter overall shading in Pen B (Lower pen) compared with Pen C (Upper pen) illustrates a difference in pen surface conditions at the time of sampling. For about 10 days prior to the time of EM surveying and manure sampling Pen B did not contain any cattle, whilst, Pen C did contain cattle at the time of surveying. Therefore, fresh manure and urine was present in Pen C at the time of sampling. Hence, it is likely that the difference in apparent electrical conductivity is reflecting the difference in fresh manure deposition resulting in different concentrations of VS.

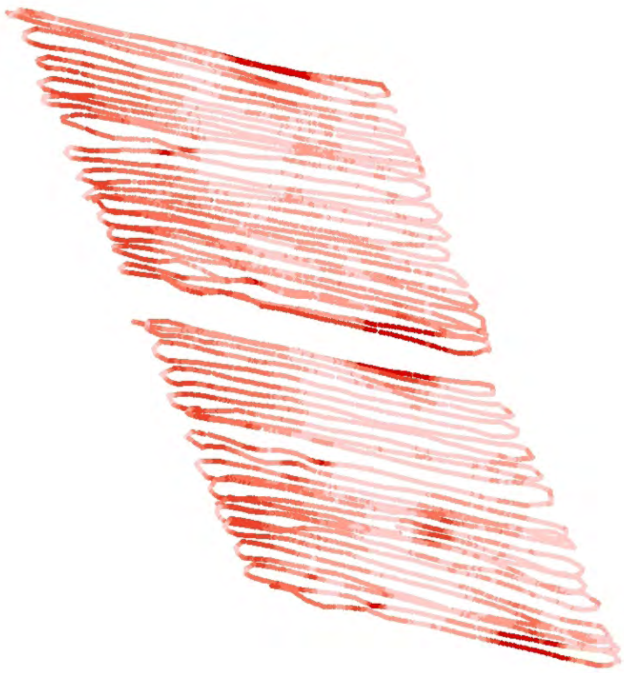

FIGURE 40 – RAW EMI DATA FOR PENS B (LOWER) AND C (UPPER) AT FEEDLOT F

FIGURE 41 – EMI DATA FOR FEEDLOT F OVERLAIN ON AERIAL IMAGE

Data Analysis and Interpretation

Manure TS and VS levels were assessed by taking soil samples across Pen B and Pen C. In each pen, six manure samples were collected following the method outlined, giving a total of 12 manure samples from the pen surface prior to harvest of the manure.

Aggregated results are shown in Table 53. The range in the data highlight the variability in manure properties observed. It should be taken into account that the sampling strategy was designed to capture variability in manure properties. These data show that at the time of sampling the pad manure was very dry.

TABLE 51 – SUMMARY RESULTS FOR MANURE SAMPLES COLLECTED IN PENS B AND C AT FEEDLOT F

Parameter	Pen B				Pen C			
	Mean	Median	Min	Max	Mean	Median	Min	Max
Total Solids, %	86.7	87.5	79.7	90.9	85.9	85.7	82.2	90.5
Volatile Solids, %	66.8	66.2	62.8	74	67.9	69.4	61.2	72.6
Moisture Content, %	13.4	12.5	9.1	20.3	14.2	14.3	9.5	17.8
Nitrogen, %	-	-	-	-	-	-	-	-

Following laboratory analysis, the manure results were input into the ESAP-Calibrate program. Once the correlations between EC_a and the manure property of interest completed the distribution of properties highly correlated to EC_a were mapped using the ESAP-SaltMapper program. Figure 42 shows the apparent soil conductivity (EC_a) of Pen B.

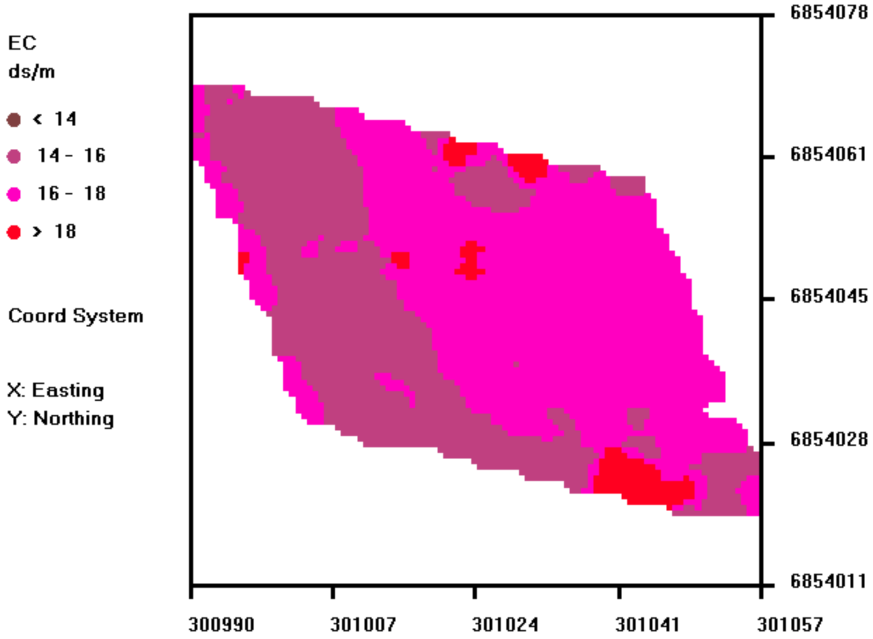

FIGURE 42 – PREDICTED ELECTRICAL CONDUCTIVITY – FEEDLOT F - PEN B

Based on the EC_a map and manure samples collected from the pen, selected manure parameters were mapped. These were TS (Figure 43) and VS (Figure 44).

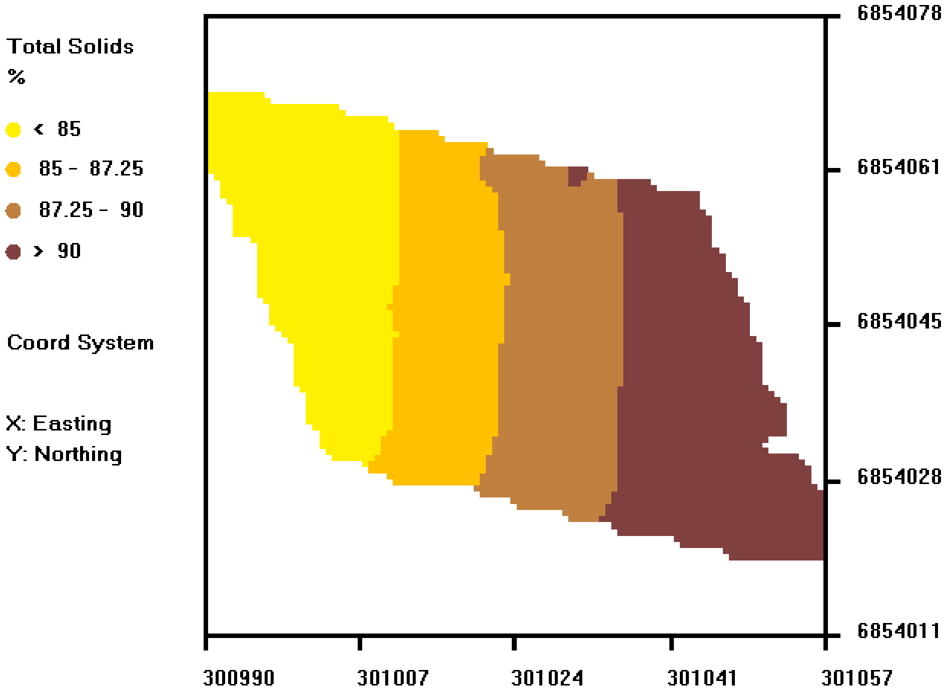

FIGURE 43 – PREDICTED TS DISTRIBUTION - FEEDLOT F - PEN B

Variation in TS (Figure 43) showed a sound regression relationship with EC_a in this pen (R^2 = 0.82), thus indicating that EC_a is able to describe most of the variability in TS within Pen B. Estimated TS composition within manure has a 5% variation across Pen B. There is a gradual increase in TS from the feed bunk end of the pen to the lower end of the pen. This pen did not contain cattle for 10 days prior to surveying and rainfall had washed some manure from the bunk to the lower end of the pen. Visual observations noted a higher volume of manure towards the lower end of the pen.

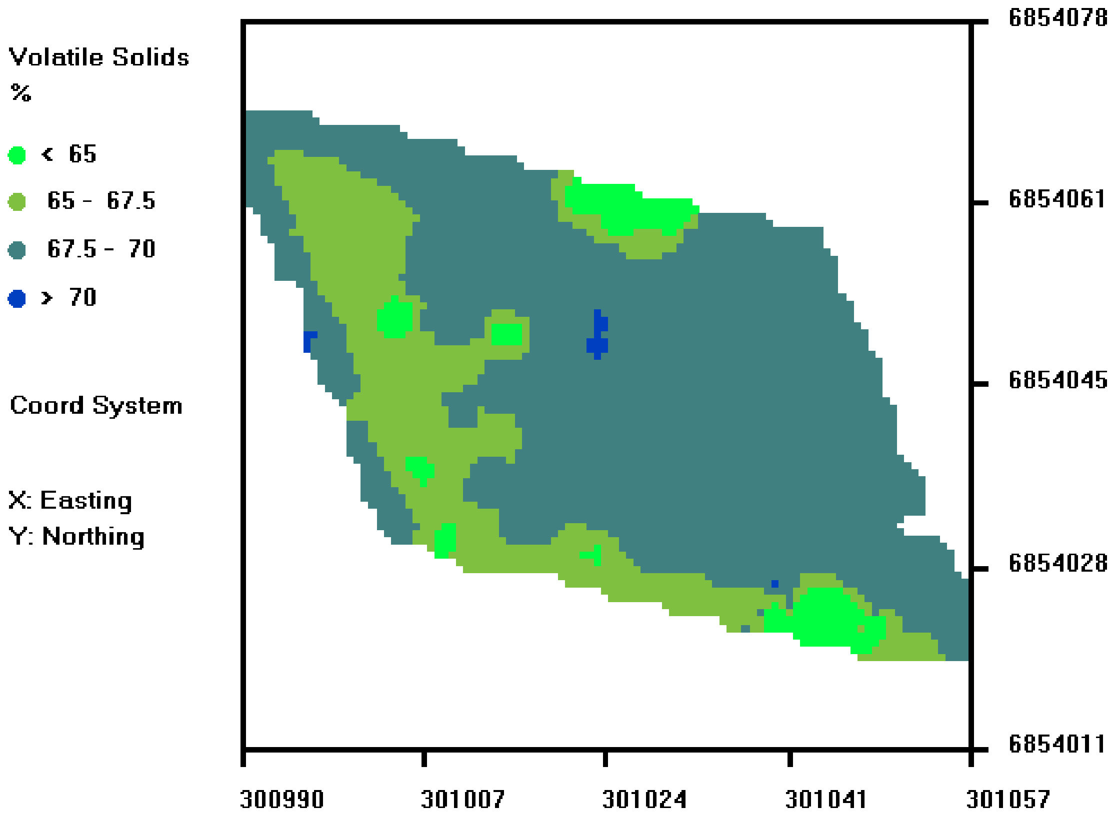

FIGURE 44 – PREDICTED VS DISTRIBUTION - FEEDLOT F - PEN B

Spatial variation in VS percentage on the feedpad (Figure 44) showed a strong regression relationship with EC_a in this pen (R^2 = 0.94), indicating that measured EC_a describes most of the variability of VS within Pen B. The VS/TS ratio on the pad was found to range from 65 to 70%, slightly higher than that measured in Pen C. Lower levels of VS were measured along the feed bunk and at two distinct locations along the fencelines (location of water troughs). Figure 44 shows a relatively even distribution of VS across the pen area.

Figure 45 shows the apparent soil conductivity (EC_a) of Pen C at Feedlot F.

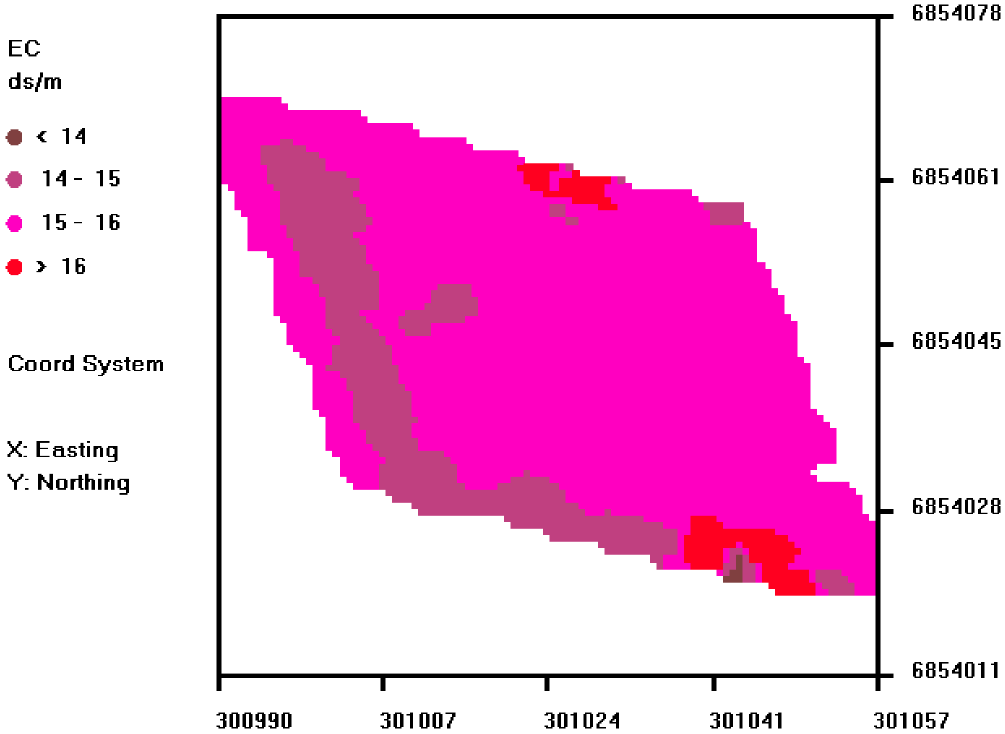

FIGURE 45 – PREDICTED ELECTRICAL CONDUCTIVITY – FEEDLOT F - PEN C

Based on the EC_a map and manure samples collected from the pen, TS (Figure 46) and VS (Figure 47) were mapped. A similar EC_a distribution was found for Pen C and Pen B.

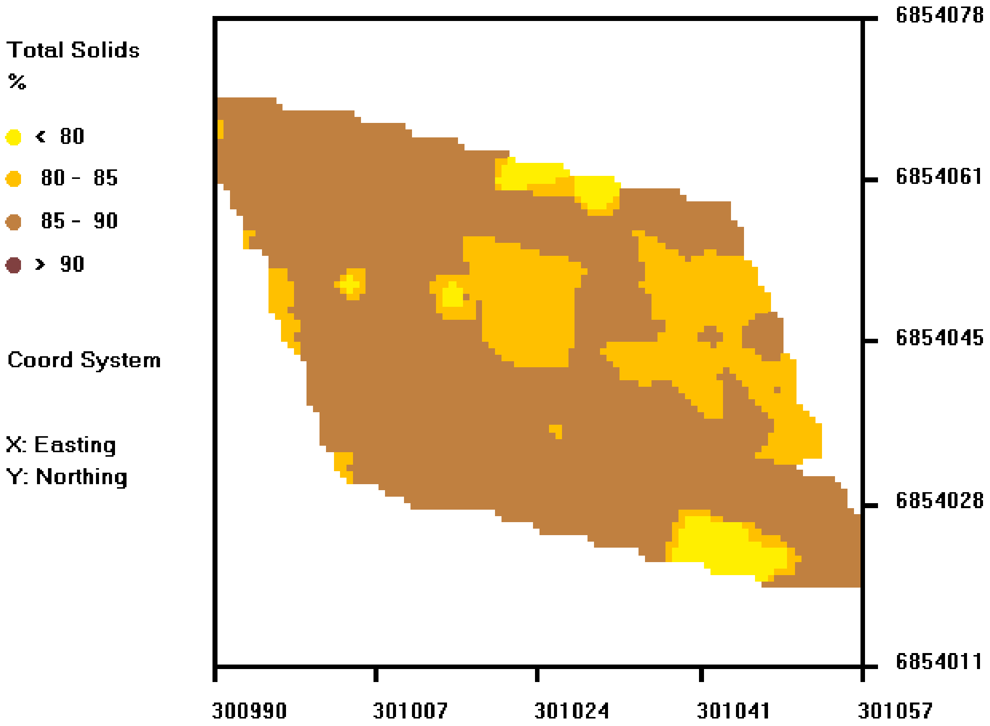

FIGURE 46 – PREDICTED TS DISTRIBUTION – FEEDLOT F - PEN C

Variation in TS as shown in Figure 46 showed a sound regression relationship with EC_a in this pen ($R^2 = 0.88$). This indicates that EC_a is able to describe most of the variability in TS within Pen C. Estimated TS composition within manure has a 10% variation across Pen B. Figure 46 shows a relatively even distribution of TS across the pen area with a reduction around the water troughs on the fencelines. This pen did contain cattle at the time of surveying.

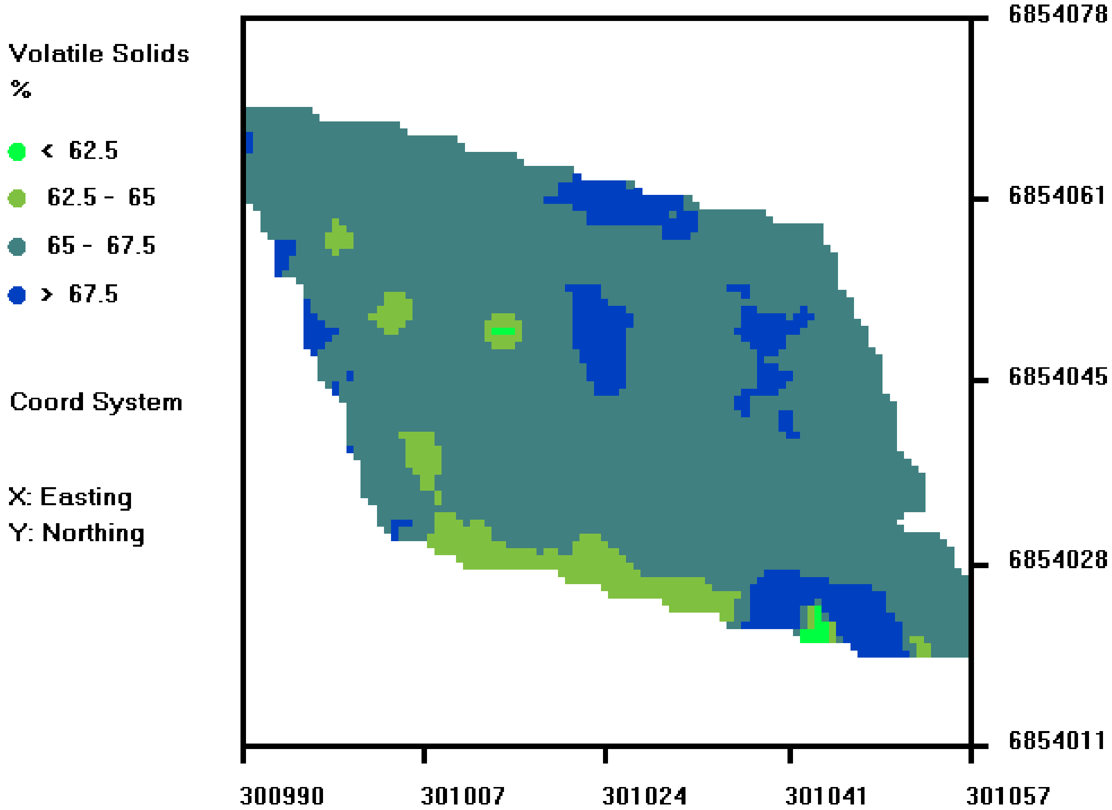

FIGURE 47 – PREDICTED VS DISTRIBUTION - FEEDLOT F - PEN C

Spatial variation in VS as shown Figure 47, showed a very strong regression relationship with EC_a in Pen C ($R^2 = 0.93$). The VS/TS ratio on the pad was found to range from 62.5 to 67.5%, slightly lower than that measured in Pen B. This pen did not contain cattle for 10 days prior to surveying and the lack of fresh manure deposition may be a plausible explanation for this.

In summary, the rationale for undertaking the EM survey was to assess the spatial distribution of manure properties across the pen area to assess whether the grid pattern implemented across the pen for sampling would provide representative samples from the total pen area. The spatial variation in TS, VS and total N showed a sound regression relationship with EC_a. This indicates that EC_a is able to describe most of the variability in manure parameters. The results of the EM survey highlighted higher areas of manure deposition around the feed bunk, fencelines and water trough areas.

The EM survey results reinforce and provide confidence that the manure sampling pattern used in this study (Figure 22) would result in a representative sample being taken from feedlot pens.

Comparison – BEEF-BAL Model Prediction versus Actual Data

The following sections take measured data on ration composition, cattle numbers and feed intake as input to BEEF-BAL so that predictions of manure production can be made. These predictions are then compared to manure harvesting data for each completed batch.

The current version of BEEF-BAL (V9.1_TI) includes a potential mass balance error. This error is involved in the calculation of nutrient and FS intake of the whole diet (dry matter basis), when using the nutrient content of ingredients (as-fed basis). This error was corrected for calculations in this work.

Feedlot A

Feed analysis data was obtained from the feedlot for a prepared ration, where possible. In the case of Feedlot A the same ration was fed to cattle in Pen A, Pen B and Pen C. The analysis data was compared with the BEEF-BAL predicted data to assess the variation in each predicted parameter. These data are shown in Table 52. This process allows the development of a better understanding of the prediction process.

The predicted dry matter of the ration ranged from 82.2 to 82.5%. This compared with an actual dry matter level of 69.7 to 71.3%. From these data, BEEF-BAL over predicted the dry matter level by approximately 10%. This result can be explained by the inherent variability in the actual moisture content of the ration components which are unknown. The moisture content of each component will vary from standard values depending on quality, growing conditions etc. In BEEF-BAL, the user inputs the composition analysis of individual ingredients. Whilst, feedlots frequently analyse ration samples (e.g. protein, ash, energy etc) the individual ingredients are not analysed. Therefore, in lieu of actual individual ingredient analyses standard values are used. Typically, the composition analysis of individual ingredients are taken from NRC values for beef cattle (NRC, 2000).

The predicted ash level of the ration ranged from 5.1 to 7.9%. This compared with an actual ash level of 5 to 7.4%. From these data the feed ash level predicted by BEEF-BAL was comparable with the actual level of ash measured in a ration sample. Less variation in ash levels between standard tabulated values and actual levels for each ingredient when compared with moisture content variation is a plausible explanation of this.

TABLE 52 – ESTIMATES OF RATION DRY MATTER AND ASH LEVELS VERSUS MEASURED FOR FEEDLOT A

	Pen A/Pen B/Pen C		
	B1	B2	B3
Dry Matter – Measured %	70.5	71.3	69.7
Dry Matter – Predicted %	82.2	82.5	82.4
Feed Ash – Measured %	7.4	5.2	5.3
Feed Ash – Predicted %	7.9	5.1	5.1

Fresh manure was collected from the feedlot for analysis. Fresh manure was only collected from Pen A as the cattle type and ration was similar across the 3 trial pens. The fresh manure was analysed for TS and VS. Table 53 shows the measured data and the BEEF-BAL predicted data for Feedlot A.

TABLE 53 – ESTIMATES OF FRESH MANURE TOTAL SOLIDS, VOLATILE SOLIDS AND ASH LEVELS VERSUS MEASURED FOR FEEDLOT A

Fresh Manure	Pen A/Pen B/Pen C		
	B1	B2	B3
Total Solids – Measured %	15.6	15.5	19.6
Total Solids – Predicted %	14.9	15.8	15.9
Volatile Solids – Measured %	84.7	83.7	83.5
Volatile Solids – Predicted %	71.1	70.9	71.1
Ash – Measured %	15.4	16.5	16.6
Ash – Predicted %	29.9	29.1	29.9

Table 53 shows that the BEEF-BAL predicted levels of TS ranged from 14.9 to 15.9%. The measured TS in fresh manure samples were found to be similar to the BEEF-BAL predicted values. The percentage of VS measured in fresh manure samples ranged from 83.5 to 84.7%. The percentage of VS in fresh manure predicted by BEEF-BAL was found to range from 69.9 to 71.1%. In all batches, BEEF-BAL underpredicted VS by about 13%.

The percentage of ash measured in fresh manure samples ranged from 15.4 to 16.6%. The percentage of ash in fresh manure predicted by BEEF-BAL was found to range from 29.1 to 29.9%. In all batches, BEEF-BAL overpredicted the ash content of fresh manure by a factor of two. The overprediction of ash by BEEF-BAL translates into a reduction in the prediction of VS.

Table 54, Table 55 and Table 56 show the comparison between measured and predicted TS and VS for Pen A, Pen B and Pen C at Feedlot A respectively. These data have been corrected to account for the contribution of urine.

These tables show significantly higher measured values when compared to BEEF-BAL predicted quantities. These data suggest that the material harvested contains material other than manure. At Feedlot A, the wet conditions experienced over winter combined with not retaining a manure interface layer (very difficult to maintain under wet conditions) it is likely that the material harvested contains pen base material (rocks or soil). The pen cleaning operation is uncontrolled and it is difficult to remove only manure from holes and undulations that form across the pen surface. Typically, manure is removed from holes to allow refilling with gravel during pen base repairs. The measured TS was over 5 times predicted values. TS of up to 5,000 kg/SCU/year were measured which is obviously cannot be realistic for manure only. The VS/TS ratio of measured manure also confirms that the material has a lower organic content than manure.

Table 54 – Estimates of VS and TS production versus measured output for Feedlot A – Pen A

Parameter	Units	Pen A					
		B1	B1	B2	B2	B3	B3
		Measured	Predicted	Measured	Predicted	Measured	Predicted
Volatile Solids	kg/day	**385**	163	**806**	193	**908**	240
Total Solids	kg/day	**845**	229	**1727**	274	**1,962**	339
Volatile Solids	kg/year	**140,524**	59,540	**294,145**	70,618	**331,549**	87,624
Total Solids	kg/year	**308,515**	83,579	**630,196**	99,875	**715,997**	91,262
Volatile Solids	kg/SCU/year	**1,115**	472	**2,334**	561	**2,584**	572
Total Solids	kg/SCU/year	**2,449**	663	**5,002**	793	**5,581**	807
VS/TS Ratio	-	**0.46**	0.71	**0.46**	0.71	**0.46**	0.71

Table 55 – Estimates of VS and TS production versus measured output for Feedlot A – Pen B

Parameter	Units	Pen B					
		B1	B1	B2	B2	B3	B3
		Measured	Predicted	Measured	Predicted	Measured	Predicted
Volatile Solids	kg/day	**474**	228	**728**	197	**588**	231
Total Solids	kg/day	**1,042**	323	**1,600**	273	**1,269**	325
Volatile Solids	kg/year	**173,184**	83,104	**265,787**	72,042	**214,469**	84,140
Total Solids	kg/year	**380,219**	117,940	**584,134**	99,699	**463,158**	118,777
Volatile Solids	kg/SCU/year	**1,117**	536.2	**1,930**	511	**1,455**	611
Total Solids	kg/SCU/year	**2,453**	761	**4,241**	707	**3,142**	866
VS/TS Ratio	-	**0.46**	0.7	**0.46**	0.72	**0.46**	0.71

Table 56 – Estimates of VS and TS production versus measured output for Feedlot A – Pen C

Parameter	Units	Pen C					
		B1	B1	B2	B2	B3	B3
		Measured	Predicted	Measured	Predicted	Measured	Predicted
Volatile Solids	kg/day	**1,248**	373	**1,414**	364	**737**	364
Total Solids	kg/day	**2,723**	519	**3,105**	515	**1,543**	517
Volatile Solids	kg/year	**455,665**	136,213	**516,172**	132,847	**268,861**	132,829
Total Solids	kg/year	**993,958**	189,452	**1,133,233**	187,853	**563,202**	188,736
Volatile Solids	kg/SCU/year	**1,883**	563	**2,228**	599	**1,174**	580
Total Solids	kg/SCU/year	**4,107**	783	**4,891**	847	**2,459**	824
VS/TS Ratio	-	**0.46**	0.72	**0.46**	0.71	**0.48**	0.7

Feedlot D

Feed analysis data was obtained from the feedlot for a prepared ration, where possible. In the case of Feedlot D the same ration was fed to cattle in Pen A and Pen B. Pen C contained long fed cattle and were therefore fed a different ration to cattle in Pen A and Pen B. The analysis data was compared with the BEEF-BAL predicted data to assess the variation in each predicted parameter. These data are shown in Table 57. This process allows the development of a better understanding of the prediction process.

The predicted dry matter of the ration fed to Pen A and Pen B ranged from 78.7 to 80.1%. This compared with an actual dry matter level of 70.1 to 72.2%. The ration fed to Pen C cattle recorded a slightly higher actual dry matter of 74.7% when compared to Pen A and Pen B ration. The BEEF-BAL predicted dry matter of the ration (76.8%) fed to Pen C was comparable with the actual dry matter measured (74.7%).

For Pen A and Pen B data, BEEF-BAL over predicted the dry matter level by approximately 8%. The higher predicted values can be explained by the inherent variability in the actual moisture content of the ration components which are unknown. Further, this is most likely due to variation in grain moisture as the ration fed to Pen A and Pen B contains a higher percentage of grain than the ration fed to Pen C. The moisture content of each component will vary from standard values depending on quality, growing conditions etc.

The predicted and actual ash level of the ration fed to Pen A and Pen B was found to be similar with an average of about 5%. It is plausible to suggest that there would be less variation in ash levels between standard tabulated values and actual levels for each ingredient when compared with moisture content variation. Hence, BEEF-BAL is able to more closely predict the actual ash level.

TABLE 57 – ESTIMATES OF RATION DRY MATTER AND ASH LEVELS VERSUS MEASURED FOR FEEDLOT D

	Pen A/Pen B			Pen C
	B1	B2	B3	B1
Dry Matter – Measured %	71.5	70.1	72.2	74.7
Dry Matter – Predicted %	80.1	78.7	78.7	76.8
Feed Ash – Measured %	5.0	5.1	4.7	9
Feed Ash – Predicted %	5.1	5.1	5.1	5.5

Fresh manure was collected from the feedlot for analysis. Fresh manure was only collected from Pen A and Pen C as the cattle type and ration was similar across Pen A and Pen B. The fresh manure was analysed for TS and VS. Table 58 shows the measured data and the BEEF-BAL predicted data for Feedlot D.

TABLE 58 – ESTIMATES OF FRESH MANURE TOTAL SOLIDS, VOLATILE SOLIDS AND ASH LEVELS VERSUS MEASURED FOR FEEDLOT D

Fresh Manure	Pen A/Pen B			Pen C		
	B1	B2	B3	B1	B2	B3
Total Solids – Measured %	19.8	21.4	21.2	21	21.2	24.9
Total Solids – Predicted %	22.9	22.2	22.4	19.4	19.9	19.9
Volatile Solids – Measured %	80.0	81.5	80.0	79.0	82.5	72.3
Volatile Solids – Predicted %	79.3	79.5	79.8	71.7	72.8	72.7
Ash – Measured %	20.0	18.5	20.0	21.0	17.5	27.7
Ash – Predicted %	20.7	20.5	20.2	28.3	27.2	27.3

Table 58 shows that the BEEF-BAL predicted levels of TS ranged from 22.2 to 22.9% in Pen A and Pen B. These data were slightly higher than the measured TS of 19.8 to 21.4% respectively. Pen C fresh manure recorded a slightly lower TS (19.9%) when compared to Pen A and Pen B manure. The BEEF-BAL predicted TS of Pen C fresh manure (21-24.9%) was comparable in batches 1 and 2 and slightly lower in batch 3 samples.

In Pen A and Pen B, the percentage of ash in fresh manure predicted by BEEF-BAL was found to range from 20.2 to 20.7%. Batch 1 and Batch 2 samples from Pen C recorded ash levels of 17.5 % and 21% respectively. These are similar to Pen A and Pen B levels. A higher level of ash was measured in Batch 3 of Pen C (27.7%) when compared to Batch 1 and Batch 2. In all batches, BEEF-BAL predictions of ash were comparable to the measured ash content of fresh manure.

The percentage of VS measured in fresh manure samples ranged from 80.0 to 81.5% in Pen A and Pen B. In Pen C, the percentage of VS measured in fresh manure samples ranged from 72.3 to 82.5%. In all batches, BEEF-BAL predictions of ash were comparable to the measured ash content of fresh manure.

Table 59, Table 60 and Table 61 show the comparison between measured and predicted TS and VS of excreted manure for Pen A, Pen B and Pen C at Feedlot D respectively. These data have been corrected to account for the contribution of urine.

These tables show comparable results between measured and BEEF-BAL predicted quantities. These data suggest that excretion ranges between about 800 and 1100 kg/SCU/year. Feedlot D experienced dry conditions throughout the study period and retains a manure interface layer in the pens. Therefore, the material harvested is manure only and not contaminated with foreign material such as rocks or soil. It is plausible that TS were lost as dust and this has resulted in lower measured values. The VS/TS ratio of measured manure is about 15% lower than predicted values.

Table 59 – Estimates of VS and TS production versus measured output for Feedlot D – Pen A

Parameter	Units	Pen A					
		B1	B1	B2	B2	B3	B3
		Measured	Predicted	Measured	Predicted	Measured	Predicted
Volatile Solids	kg/day	**238**	398	**307**	237	**348**	309
Total Solids	kg/day	**366**	502	**452**	298	**528**	387
Volatile Solids	kg/year	**86,935**	145,328	**112,099**	86,395	**126,992**	112,668
Total Solids	kg/year	**133,636**	183,217	**165,008**	108,817	**192,772**	141,160
Volatile Solids	kg/SCU/year	**540**	903	**1,180**	909	**1,016**	901
Total Solids	kg/SCU/year	**830**	1,138	**1,737**	1,145	**1,542**	1,129
VS/TS Ratio	-	**0.65**	0.79	**0.68**	0.79	**0.66**	0.80

Table 60 – Estimates of VS and TS production versus measured output for Feedlot D – Pen B

Parameter	Units	Pen B					
		B1	B1	B2	B2	B3	B3
		Measured	Predicted	Measured	Predicted	Measured	Predicted
Volatile Solids	kg/day	**292**	429	**281**	306	**447**	344
Total Solids	kg/day	**435**	540	**419**	385	**667**	432
Volatile Solids	kg/year	**106,607**	156,713	**102,692**	111,816	**163,297**	125,691
Total Solids	kg/year	**158,850**	197,169	**153,016**	141,483	**243,320**	157,730
Volatile Solids	kg/SCU/year	**623**	916	**849**	924	**1,183**	911
Total Solids	kg/SCU/year	**929**	1,153	**1,265**	1,161	**1,763**	1,143
VS/TS Ratio	-	**0.67**	0.79	**0.67**	0.8	**0.67**	0.8

Table 61 – Estimates of VS and TS production versus measured output for Feedlot D – Pen C

Parameter	Units	Pen C					
		B1	B1	B2	B2	B3	B3
		Measured	Predicted	Measured	Predicted	Measured	Predicted
Volatile Solids	kg/day	**100**	249	**94**	260	**123**	232
Total Solids	kg/day	**168**	347	**157**	357	**207**	319
Volatile Solids	kg/year	**36,500**	90,885	**34,310**	94,900	**44,895**	84,680
Total Solids	kg/year	**61,320**	126,655	**57,305**	130,305	**75,555**	116,435
Volatile Solids	kg/SCU/year	**334**	833	**267**	740	**321**	605
Total Solids	kg/SCU/year	**562**	1161	**449**	1019	**540**	833
VS/TS Ratio	-	**0.6**	0.72	**0.6**	0.73	**0.6**	0.73

Feedlot E

Feed analysis data was obtained from the feedlot for the finisher ration fed to Pen C cattle. The analysis data was compared with the BEEF-BAL predicted data to assess the variation in each predicted parameter. These data are shown in Table 62. This process allows the development of a better understanding of the prediction process.

The predicted dry matter of the ration was 82.9% and compared with an actual dry matter level of 74.5%. From these data, BEEF-BAL over predicted the dry matter level by approximately 7%. This result can be explained by the inherent variability in the actual moisture content of the ration components which are unknown. The moisture content of each component will vary from standard values depending on quality, growing conditions etc. BEEF-BAL predictions can be refined by using actual ingredient analyses as input data.

The BEEF-BAL predicted ash level of the ration was 4.7% and was comparable to the measured ash level of 5.3%. Less variation in ash levels between standard tabulated values and actual levels for each ingredient when compared with moisture content variation is a plausible explanation of this.

TABLE 62 – ESTIMATES OF RATION DRY MATTER AND ASH LEVELS VERSUS MEASURED FOR FEEDLOT E

	Pen C
	B1
Dry Matter – Measured %	74.5
Dry Matter – Predicted %	82.9
Feed Ash – Actual %	5.3
Feed Ash – Predicted %	4.7

Fresh manure was collected from the feedlot for analysis. Fresh manure was only collected from Pen C as the cattle type and ration was similar across the 3 trial pens. The fresh manure was analysed for TS and VS. Table 63 shows the measured data and the BEEF-BAL predicted data for Feedlot E.

TABLE 63 – ESTIMATES OF FRESH MANURE TOTAL SOLIDS, VOLATILE SOLIDS AND ASH LEVELS VERSUS MEASURED FOR FEEDLOT E

Fresh Manure	Pen C
	B1
Total Solids –Measured %	24.1
Total Solids – Predicted %	20.6
Volatile Solids – Measured %	84.3
Volatile Solids – Predicted %	80.0
Ash – Measured %	15.7
Ash – Predicted %	20.0

Table 63 shows that the BEEF-BAL predicted TS was 20.6 %. This compared with a measured TS in fresh manure of 24.1 %. The percentage of VS measured in fresh manure samples was 84.3%. The percentage of VS in fresh manure predicted by BEEF-BAL was found to be 80.0%. BEEF-BAL underpredicted TS by 4% and overpredicted VS by a similar margin.

The percentage of ash measured in fresh manure was 15.7%. The percentage of ash in fresh manure predicted by BEEF-BAL was found to be 20.0%. The overprediction of ash by BEEF-BAL translates into a reduction in the prediction of VS when compared with measured values.

Table 64 shows the comparison between measured and predicted TS and VS of excreted manure for Pen C at Feedlot E. These data have been corrected to account for the contribution of urine. Table 64 shows a significantly higher measured value of TS when compared to BEEF-BAL predicted quantities. These data suggest that the material harvested contains material other than manure. At Feedlot C, a manure interface layer is not retained. Thus, it is likely that the material harvested contains pen base material (rocks or soil). Photograph 37 shows the harvested manure stockpile in the centre of Pen C prior to removal from the pen. This shows that significant quantities of pen base material (large rocks/gravel) included in the material scraped from the pen. It is practically impossible to exclude this foreign material when scraping manure from the pen base.

The measured TS was double the predicted value. The VS/TS ratio of measured manure (0.46) also confirms that the material has a lower organic content than manure.

Table 64 – Estimates of VS and TS production versus measured output for Feedlot E – Pen C

Parameter	Units	Pen C					
		B1	B1	B2	B2	B3	B3
		Measured	Predicted	Measured	Predicted	Measured	Predicted
Volatile Solids	kg/day	**765**	732	**-**	-	**-**	-
Total Solids	kg/day	**1,679**	914	**-**	-	**-**	-
Volatile Solids	kg/year	**279,142**	267,237	**-**	-	**-**	-
Total Solids	kg/year	**612,944**	333,453	**-**	-	**-**	-
Volatile Solids	kg/SCU/year	**943**	903	**-**	-	**-**	-
Total Solids	kg/SCU/year	**2,071**	1,127	**-**	-	**-**	-
VS/TS Ratio	-	**0.46**	0.80	**-**	-	**-**	-

PHOTOGRAPH 37 – HARVESTED MANURE AT FEEDLOT E

Feedlot F

Feed analysis data was obtained from the feedlot for a prepared ration, where possible. In the case of Feedlot F the same ration was fed to cattle in Pen A, Pen B and Pen C. The analysis data was compared with the BEEF-BAL predicted data to assess the variation in each predicted parameter. These data are shown in Table 65.

The predicted dry matter of the ration ranged from 80.5 to 81.3%. This compared with a measured dry matter level of 76.7 to 78.3%. BEEF-BAL over predicted the dry matter level by approximately 4%. The higher predicted values can be explained by the inherent variability in the actual moisture content of the ration components which are unknown. The moisture content of each component will vary from standard values depending on quality, growing conditions etc.

The predicted (4.9%/5.2%) and measured (5.9%/5.3%) ash levels of the ration fed were found to be similar with a difference of around 0.5 % between batches. It is plausible to suggest that there would be less variation in ash levels between standard tabulated values and actual levels for each ingredient when compared with moisture content

TABLE 65 – ESTIMATES OF RATION DRY MATTER AND ASH LEVELS VERSUS MEASURED FOR FEEDLOT F

	Pen A/Pen B/Pen C	
	B1	B2
Dry Matter – Measured %	76.7	78.3
Dry Matter – Predicted %	80.5	81.3
Feed Ash – Measured %	5.9	5.3
Feed Ash – Predicted %	5.2	4.9

Fresh manure was collected from the feedlot for analysis. Fresh manure was only collected from Pen A as the cattle type and ration were identical across all pens. The fresh manure was analysed for TS and VS. Table 66 shows the measured data and the BEEF-BAL predicted data for Feedlot F.

TABLE 66 – ESTIMATES OF FRESH MANURE TOTAL SOLIDS, VOLATILE SOLIDS AND ASH LEVELS VERSUS MEASURED FOR FEEDLOT F

Fresh Manure	Pen A/Pen B/Pen C	
	B1	B2
Total Solids – Measured %	19.9	19.0
Total Solids – Predicted %	13.8	15.3
Volatile Solids – Measured %	83.1	81.3
Volatile Solids – Predicted %	63.3	65.0
Ash – Measured %	16.9	18.7
Ash – Predicted %	36.7	35.0

Table 66 shows BEEF-BAL predicted levels of TS ranging from 13.8 to 15.3% in Batch 1 and Batch 2 respectively. Predicted data were lower than the measured TS of 19.0 and 19.9% respectively. The percentage of VS measured in fresh manure samples ranged from 81.3 to 83.1%. The percentage of VS in fresh manure predicted by BEEF-BAL was found to range from 63.3 to 65.0%. In all batches, BEEF-BAL underpredicted volatile solids by about 17%.

The percentage of ash measured in fresh manure samples ranged from 16.9 to 18.7%. The percentage of ash in fresh manure predicted by BEEF-BAL was found to range from 35.0 to 36.7%. In both batches, BEEF-BAL overpredicted the ash content of fresh manure by a factor of two. The overprediction of ash by BEEF-BAL translates into a reduction in the prediction of VS. This result is similar to that found in Feedlot A.

Table 67, Table 68 and Table 69 show the comparison between measured and predicted TS and VS for excreted manure Pen A, Pen B and Pen C at Feedlot E respectively. These data have been corrected to account for the contribution of urine.

These tables show a significantly higher measured value of TS when compared to BEEF-BAL predicted quantities. These data are similar to Feedlot A and Feedlot E results. The measured TS was over 5 times that of the predicted value. The VS/TS ratio of measured manure (0.37) compared with predicted value in the order of 0.65 confirms that the material has a lower organic content than manure. These data suggest that the material harvested contains material other than manure. At Feedlot F, a manure interface layer is not retained. Hence, the material harvested is likely to contain pen base material (rocks and/or soil). This additional material influences the results by increasing quantity of material harvested and lowers the organic content.

Table 67 – Estimates of VS and TS production versus measured output for Feedlot F – Pen A

Parameter	Units	Pen A					
		B1	B1	B2	B2	B3	B3
		Measured	Predicted	Measured	Predicted	Measured	Predicted
Volatile Solids	kg/day	**913**	179	**451**	172	-	-
Total Solids	kg/day	**2,445**	295	**1,218**	265	-	-
Volatile Solids	kg/year	**333,245**	65,335	**164,615**	62,780	-	-
Total Solids	kg/year	**892,425**	107,675	**445,788**	96,725	-	-
Volatile Solids	kg/SCU/year	**1,994**	392	**1,247**	477	-	-
Total Solids	kg/SCU/year	**5,343**	644	**3,369**	733	-	-
VS/TS Ratio	-	**0.37**	0.61	**0.37**	0.65	-	-

Table 68 – Estimates of VS and TS production versus measured output for Feedlot F – Pen B

Parameter	Units	Pen B					
		B1	B1	B2	B2	B3	B3
		Measured	Predicted	Measured	Predicted	Measured	Predicted
Volatile Solids	kg/day	**943**	180	**753**	200	-	-
Total Solids	kg/day	**2,518**	291	**2,044**	322	-	-
Volatile Solids	kg/year	**344,195**	65,700	**274,845**	73,000	-	-
Total Solids	kg/year	**919,070**	106,215	**746,060**	117,530	-	-
Volatile Solids	kg/SCU/year	**2,111**	403	**1,588**	421	-	-
Total Solids	kg/SCU/year	**5,638**	652	**4,313**	679	-	-
VS/TS Ratio	-	**0.37**	0.62	**0.37**	0.62	-	-

Table 69 – Estimates of VS and TS production versus measured output for Feedlot F – Pen C

Parameter	Units	Pen C					
		B1	B1	B2	B2	B3	B3
		Measured	Predicted	Measured	Predicted	Measured	Predicted
Volatile Solids	kg/day	**874**	212	**495**	282	-	-
Total Solids	kg/day	**2,334**	314	**1,337**	415	-	-
Volatile Solids	kg/year	**319,010**	77,380	**180,675**	102,930	-	-
Total Solids	kg/year	**851,910**	114,610	**488,005**	151,475	-	-
Volatile Solids	kg/SCU/year	**1,922**	466	**872**	497	-	-
Total Solids	kg/SCU/year	**5,132**	691	**2,357**	732	-	-
VS/TS Ratio	-	**0.37**	0.67	**0.37**	0.68	-	-

Figure 48 shows the estimated TS versus the BEEF-BAL predicted values for each completed experiment. These data illustrate that the BEEF-BAL predicted values ranged from 600 to 1200 kg/SCU/year. Measured data from Feedlot D fell within this range of predicted values. However data from Feedlots A, E and F is clearly shown to be well above the maximum predicted level. These data are clearly incorrect as a typical beast consuming 11 kg/day of dry matter could theoretically only excrete less than 4000 kg of total solids per year.

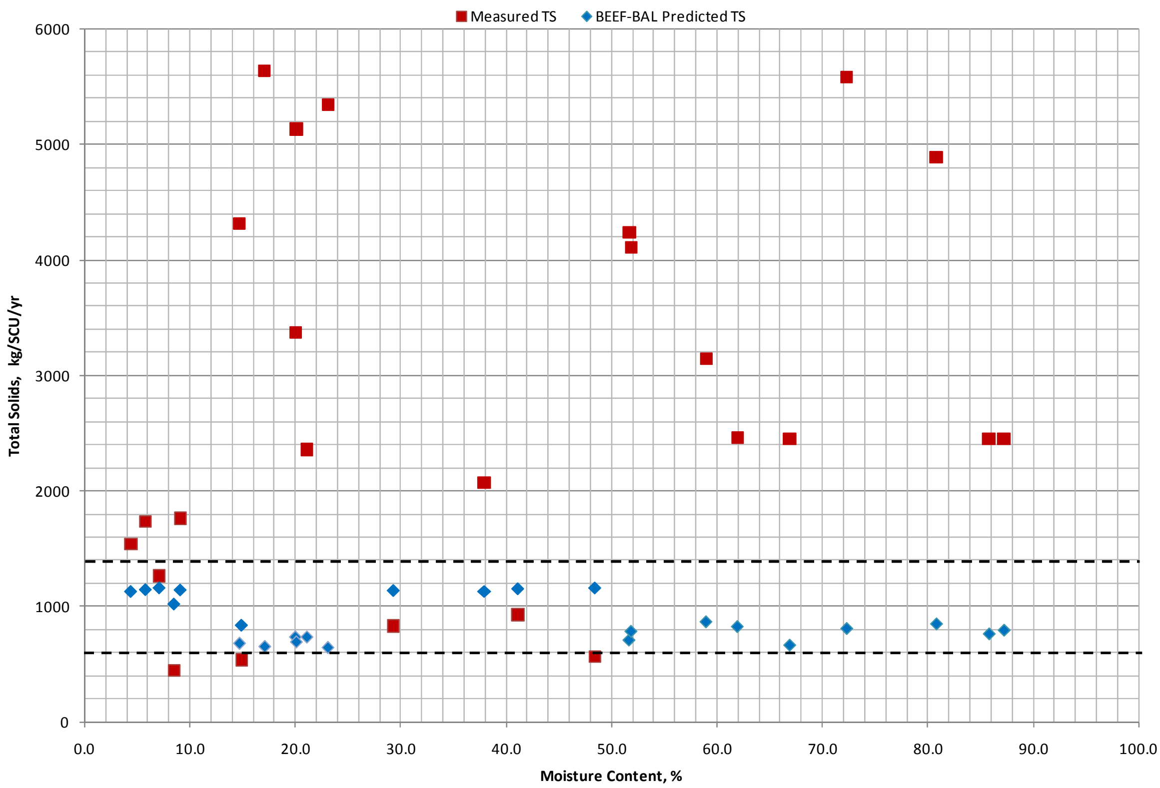

FIGURE 48 – COMPARISON OF MEASURED VERSUS PREDICTED TOTAL SOLIDS

Figure 49 shows the VS/TS ratio of BEEF-BAL predicted and measured compared to the VS/TS ratio of fresh manure. The measured values are back-calculated from harvested manure data. Fresh manure VS/TS ratio was obtained from fresh faeces samples and adjusted for urine. Figure 49 shows that BEEF-BAL predicted values more closely compares with fresh manure measurements rather than estimated from manure harvest data. The contamination of harvested manure with material of lower organic content than manure is clearly shown in the low VS/TS ratio.

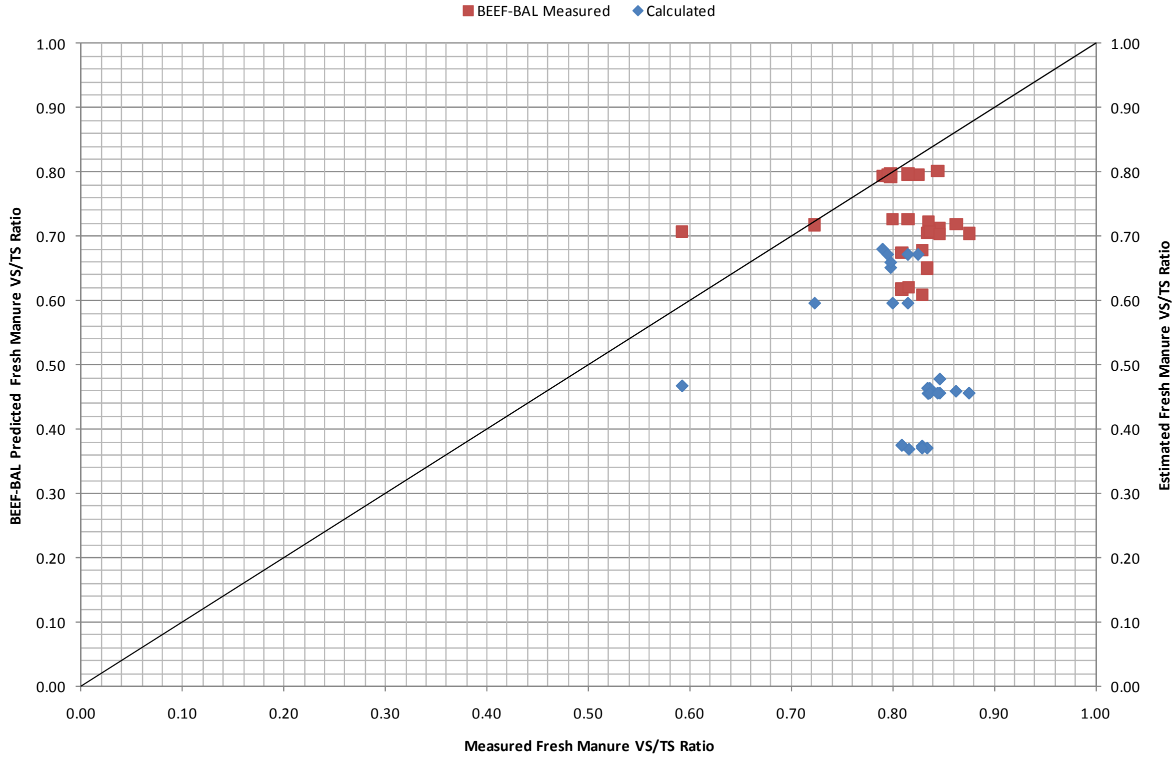

FIGURE 49 – BEEF-BAL PREDICTED AND ESTIMATED VERSUS MEASURED VS/TS RATIO OF FRESH MANURE

Conclusions

Six feedlots across Australia which are representative of climatic zones, feeding regimes and manure management processes were selected as study sites for this project. An undertaking from the management of all six feedlots to participate fully and provide the data required was obtained. However, over the course of study, access to one study feedlot was unable to be obtained to collect manure accumulation and manure deterioration samples and the site was abandoned. At another feedlot, whilst manure accumulation and manure deterioration samples were collected over a 12 month period, cattle and feed intake data for each respective batch and pen were unable to be obtained. Hence, comparison with BEEF-BAL could not be made.

A methodology was developed based on grid sampling pattern to provide a feedlot 'manure budget'. The grid sampling pattern allowed representative sub samples to be collected from across the pen. The appropriateness of the grid pattern for obtaining representative samples was assessed with electromagnetic (EM) induction. The EM survey data reinforced that the grid sampling pattern would provide representative samples being taken from these pens.

Manure accumulation rates and manure decomposition data from four feedlots were collected a number of times between pen cleaning over a 12 month period.

Manure depth was quite variable across the pen due to deposition rates and moisture content at the time of measurement. Under dry conditions, on average across the pen about 20 mm of manure had accumulated after about 25 days. Manure accumulated gradually to about 30 mm after 75 days. With continued dry conditions the manure pack gradually increases to around 35 mm after a further 100 days. These data indicate that the manure pack compacts very tightly under dry conditions. Further it is likely that some manure is removed from the pen as dust under these conditions.

Conversely, under wet conditions, on average across the pen a manure depth of 30 mm was measured after about 25 days. After 75 days a manure depth of 50 mm on average was measured. When the compact manure pack is moistened due to rainfall it can increase the dry compacted depth two-fold as shown. The wetter the pen surface, the greater the variation across the pen. Higher depth measurements indicate areas of higher manure deposition and pugging of the manure due to cattle concentration.

The VS content of the manure on the pen surface was measured. Samples were obtained directly after pen cleaning, prior to harvest and in between. Over time, the VS in the manure breaks down and is released to the atmosphere as methane or carbon dioxide. The loss of VS from the pen surface was calculated. The following can be concluded from the manure decomposition stage of the study.

- After 20 days a reduction of between 60 and 70% in VS in the pad manure compared to fresh manure was measured.
- After 35 days a reduction of 70% in VS in the pad manure compared to fresh manure was measured.
- After 80-100 days a reduction of 75% in VS in the pad manure compared to fresh manure was measured.

From a manure methane harvesting perspective the rapid decline of VS after excretion will impact on the economic feasibility of capturing this potential energy source. The data collected in this study suggests that the manure needs to be harvested within days of excretion. Typically cleaning and removal of manure from one average size pen (150 head) takes half a day. Hence, there are significant practical implications of implementing a pen cleaning rotation per pen of less than a week across a large feedlot. To achieve this pen cleaning frequency, equipment (multiple loaders, trucks etc) and labour resources significantly greater than those which currently exist would be required.

BEEF-BAL over predicted the dry matter % of the ration by approximately 10%. This result can be explained by the inherent variability in the actual moisture content of the ration components which are unknown. In BEEF-BAL, the user inputs the composition analysis of individual ingredients. Whilst, feedlots frequently analyse ration samples (e.g. protein, ash, energy etc) the individual ingredients are not analysed. Therefore, in lieu of actual individual ingredient analyses standard values from literature are used. This is a source of error.

BEEF-BAL predicted ash level of the ration was comparable with actual ash level % from ration analysis. Less variation in ash levels between standard tabulated values and actual levels for each ingredient when compared with moisture content variation may explain this.

BEEF-BAL predicted TS% of fresh manure was comparable to measured values. However, the ash content of fresh manure was overpredicted by a factor of two. The overprediction of ash% by BEEF-BAL translates into a reduction in the prediction of VS% by mass balance. The percentage of volatile solids in fresh manure predicted by BEEF-BAL was found to be about 13% lower than that measured in actual manure. However, it is noted that the VS of fresh manure was not measured rather the VS of faeces was measured and corrected for the VS contribution of urine.

It is concluded that the BEEF-BAL model can provide a good estimate of ration dry matter %, ash%, and TS% of excreted manure where “real data” can be input on production details, diet ingredients fed and amount of feed used.

Harvested manure data was obtained from four feedlots. TS and VS excreted was estimated from harvested manure data and compared with BEEF-BAL predicted values. Estimated data was comparable to predicted data at only one feedlot. At this feedlot, manure excretion ranged between 800 and 1200 kg/SCU/year. Dry conditions and maintaining a manure interface layer ensured that the material harvested is manure only thus resulting in comparable data.

At feedlots which cleaned their pens back to the gravel base, the measured TS was over 5 times that of the predicted value. In addition, the VS/TS ratio of the excreted manure was about half that of fresh manure. Data from these feedlots suggest that the material harvested contains material other than manure. This additional material (e.g. rocks and/or soil) influences the results by increasing quantity of material harvested and lowers the organic content.

The practicalities of obtaining actual manure excretion data form field conditions were highlighted. Difficulties encountered included removal of manure from pens due to storm events prior to manure harvest and ensuring the pen is cleaned back to the same condition as at the start of the experiment. The key issue with harvested manure was that it was contaminated with foreign material from the base of the pen. This significantly affected the results.

From this study, BEEF-BAL could not provide comparable data on manure excretion where the manure harvested was contaminated with soil and/or pen foundation gravel. Ensuring that only manure is removed from the pen is difficult to achieve in practice. The uneven conditions of the pen surface (e.g. depressions, holes etc) along with operator controlled height control on mobile plant translates into variability in cleaning performance and the inevitable contamination of harvested manure.

It is recommended that future work on validating the BEEF-BAL model and DMDAMP should be conducted under controlled conditions (e.g. metabolic crate) or in small research type feedlots where conditions can be better controlled.

The following can be concluded from the nitrogen losses during breakdown from fresh to composted manure.

- The measured total N content of fresh manure (faeces adjusted for urine) ranged from 5.0% to 8.5%. BEEF-BAL predicted total N excretion was typically about 2% less than measured values.
- Sources of error within measured and BEEF-BAL input data can explain the differences found between measured and predicted values of total N excretion. Firstly, the actual total N of excreted manure is not directly measured. Rather fresh faeces is sampled and an adjustment based on data from literature is made. Secondly, errors are introduced through the ingredient analysis for N content as standard values are used rather than actual values. These errors are a plausible explanation for the differences found between the measured and predicted values.

- The total N excreted as a percentage on nitrogen intake across all feedlots was found to range from 89.4% (Feedlot F) to 97.3% at Feedlot E. These data compare favourably with the literature which suggests about 90% of the nitrogen intake excreted.

- The greatest loss of total N was measured on the pen surface. Between 64 and 71% of the total N fed to feedlot cattle was lost to the atmosphere.

- Across all study feedlots, the ammonia-N level in fresh faeces was typically less than 10%. This compares with typical values from the literature of about 50% ammonia-N for faeces. This indicates that ammonia-N is rapidly lost from faeces after deposition.

Implications

Whilst, the lot feeding industry is a large potential source of manure the key issue will be whether economical quantities of methane will be readily available from this source.

This study has demonstrated that VS declines rapidly after excretion. Hence, a significant quantity of methane is lost on the pen surface and this will impact on the economic feasibility of harvesting this energy source.

From a practical and economic perspective, implementing a frequent pen cleaning regime to harvest manure prior to it losing VS to the atmosphere will be a challenging.

Recommendations

From this study the following recommendations can be made:

1. From a manure methane harvesting perspective the rapid decline of VS after excretion will impact on the economic feasibility of harvesting this energy source. Hence, further detailed work on VS decomposition should be undertaken and the impact on manure management regimes (e.g. impact of contamination with rocks/or soil, implementing a manure interface layer) assessed.

2. Review the current version of BEEF-BAL (V9.1_TI) and the potential mass balance error. This error is involved in the calculation of nutrient and FS intake of the whole diet (dry matter basis), when using the nutrient content of ingredients (as-fed basis).

3. Ensure that BEEF-BAL is kept up-to-date with the latest digestibility and nutrient content of feed ingredients. It would also be useful to investigate the updating of this model with energy balance predictive methods, as this information is more readily available in the Australian literature compared with dry matter digestibility values for individual feed ingredients.

4. It is recommended that future work on validating the BEEF-BAL model and DMDAMP should be conducted under controlled conditions (e.g. metabolic crate) or in small research type feedlots where conditions can be better controlled.

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