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Feedlot Mass Balance and Greenhouse Gas Emissions – A Literature Review

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Abstract

The use of mass-balance principles is a recommended methodology for estimating greenhouse gas (GHG) emissions (nitrous oxide and methane) from feedlot manure (Dong et al. 2006). This report reviews the current state of the mass balance approach for manure prediction, and capability to estimate methane (CH_4) and nitrous oxide (N_2O) from feedlot manure. BEEFBAL, a Microsoft Excel® model (QPIF 2004), estimates the TS, VS, FS, N, P, K and salt content of feedlot manure where the cattle are fed a ration of known composition and intake. At a foundational level, BEEFBAL utilises the Dry Matter Digestibility Approximation of Manure Production (DMDAMP) equations (van Sliedregt et al. 2000). An enhanced version of BEEFBAL, developed by FSA Consulting (Feedlot Simulation Model – FSA^2) was used to predict VS and nutrient content of manure, and subsequent losses from the various manure management stages for a sample Australian feedlot scenario. These stages included the feedpad, solid storage/composting, and liquid storage systems. There are limitations within the current version of BEEFBAL (BEEFBAL_v9.1_TI), since it was not developed as a whole-of-feedlot mass balance tool for nutrient and solid manure flows, FSA^2 attempts to overcome some of these deficiencies.

Estimates of CH_4, N_2O and NH_3 were obtained using a theoretical mass balance with FSA^2 for a sample feedlot. The availability of scientific data to validate these emissions from manure management sources within Australian feedlots is limited. There is a requirement for peer-reviewed data to validate estimations of CH_4 and N_2O emissions. The publication of such data (and use within mass balance methods) will enable the development of specific emission factors for Australian feedlots, a necessary component to develop a Tier 3 method for GHG estimation from manure (Dong et al. 2006). Estimates obtained using the theoretical mass balance of a sample feedlot indicate that the feedpad was the single largest GHG source (approximately 70%), followed by solid storage (approximately 20%), when determined as CO_2 equivalents (CO_2-e). Estimates are that N_2O emissions (CO_2-e) from the feedpad, (both direct and indirect) and direct N_20 emissions from the stockpile, represent the three largest sources of GHG from feedlot manure. Together, they equal approximately 80% of the total manure sourced GHG from the feedlot. Although the results within this report have limits to their application, these estimates are useful to identify high (and lower) priority requirements for research in GHG from feedlot manure.

Executive Summary

Enhanced scrutiny of greenhouse gas (GHG) emissions from animal agriculture within Australia is increasing the pressure on livestock industries to validate estimates of GHG emissions. As a component of the whole red meat industry, the feedlot sector is affected by the emission factors detailed for livestock and manure management arising from lot-feeding beef cattle. The greenhouse gases methane (CH_4) and nitrous oxide (N_2O) are produced directly and indirectly from animal production and manure management, and are reported to have 25 and 298 times the greenhouse potential of carbon dioxide (IPCC 2006). Carbon dioxide (CO_2) production is not estimated from animal production, since net CO_2 emissions are assumed to be zero.

The Intergovernmental Panel on Climate Change (IPCC) outline a 3 tiered system for estimating GHG emissions from animal agriculture (Dong et al. 2006). The IPCC three-tiered system for GHG estimation are summarised below.

Tier 1 Involves the simplistic use of IPCC default emission factors.

Tier 2 Follows the same calculation equation, but uses country-specific data for some or all of the variables. For example, the use of emission factors developed for Australian feedlots.

Tier 3 Is relevant where emissions are particularly important, and goes beyond industry defaults. This method of estimation requires a clearly described country-specific methodology, for example, a process-based mass balance approach (Dong et al. 2006).

In broad terms, the Department of Climate Change and Energy Efficiency (DCCEE) utilise the same methodology for the Tier 2 estimation as prescribed by the IPCC (Dong et al. 2006). The alternative for use of the prescribed DCCEE emission factors and estimates of N_2O are the implementation of a Tier 3 style system for emission estimation (Dong et al. 2006). Methodology for construction of a Tier 3 system for emission estimation is not prescribed by IPCC, however guidelines for such a methodology are described (Dong et al. 2006). Currently, the mass balance approach is the recommended method for development of country-specific (Tier 3) estimation procedures by the IPCC, particularly for N_2O emissions (Dong et al. 2006).

Prediction of manure production and nutrient composition is a critical component to estimating GHG production from livestock manure. Manure is composed of total solids (TS), which contain macro and micro nutrients, and water. Total solids fraction is composed of organic matter, measured as volatile solids (VS) and ash or fixed solids (FS). Estimation of VS is of two fold importance for GHG estimation sourced from manure; (i) the vast majority of N is within the VS fraction of manure, and (ii) estimated methane emissions is the product of VS x the ultimate methane potential (B_o) x the methane conversion factor (MCF).

The Digestibility Approximation of Manure Production (DAMP) technique, was proposed by Barth (1985a) to predict the organic content of excreted manure using animal performance data. 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 FS excreted by pigs. This method uses dry matter digestibility (DMD) instead of TDN values of individual ingredients to predict TS output.

BEEFBAL is a Microsoft Excel® model that can be used to determine the waste characteristics from a feedlot (QPIF 2004). It estimates the TS, VS, FS, N, P, K and salt in the manure from a feedlot, where the cattle are fed a ration of known composition and intake. The DMDAMP model (van Sliedregt et al. 2000), within BEEFBAL is used to calculate TS excreted and mass balance principles (Watts et al. 1994a), are used to determine the N, P, K, total salt and FS excreted. BEEFBAL was not developed as a total feedlot mass balance tool, rather for the prediction of (i) quantity and nutrient composition of manure produced, and (ii) land area required for application of manure produced. As such, 'gaps' exist in BEEFBAL as a mass balance tool of component (solids and nutrients) flows within a feedlot. To achieve realistic values of manure composition from the current version, (BEEFBAL_v9.1_TI), professional judgement, and knowledge of the composition of manure and effluent is required.

A theoretical mass balance has been developed using the FSA Consulting Feedlot Simulation Model (FSA^2) to estimate nitrogen flows (NH_3 and N_2O) and CH_4 emissions from feedlot manure management sources (i.e. feedpad, stockpiled/composted manure, and liquid storage systems). The BEEFBAL model and FSA^2 enables the estimation of excreted VS and N. Nitrogen is then traced through the feedlot system with a series of "back-calculated" partitioning and emission estimates. Volatile solids lost at each manure management stage are also estimated through "back-calculation" by inputting the VS to TS ratio of the manure at these manure stages.

Availability of usable scientific data within the literature, with which to validate VS and N losses from the various manure management sources is limited. For some manure management types, there is an absence of data to validate N_2O and CH_4 emissions from Australian feedlot manure. For these circumstances, DCCEE estimated emission factors, and/or "best judgement" values were used. The validation of a "Tier 3" method requires country-specific emission factors to be validated by peer reviewed publications (Dong et al. 2006). It is therefore a recommendation of this review that further Australian studies are supported to measure GHG emissions (N_2O and CH_4) from feedlot manure (feedpad, stockpiled/composed manure, and liquid storage systems), to validate emission factors for use by Australian feedlots. Future studies should provide understanding into the relative influence of climatic, seasonal and management conditions; to inform the necessity for regional based emission factors.

The following estimates are made from the theoretical mass balance using FSA^2:

- Approximately 86% of N fed to feedlot cattle is excreted and 14% is retained in liveweight gain and lost to mortalities.
- About 0.5% of intake N onto the pen surface is lost to the pond (approximately 0.4 kg/hd/yr).
- Approximately 62% of intake N is volatilised from the feedpad to the atmosphere as ammonia, N_2O and other N compounds.
- Total ammonia-N loss represents approximately 70% of intake N from the combined volatilisation of the feedpad, manure stockpile/compost, effluent and from application losses. Using an emission factor of 1% for N_2O from DCCEE for indirect N_2O from volatilised ammonia, this represents approximately 0.70% of intake N.
- Approximately 21 kg/hd/yr (23.6% of excreted N) is harvested from the pens in manure.

Estimated emissions from each manure management source are represented as a percentage of estimated GHG in CO_2 equivalents. Estimates provided indicate that N_20 emissions from the feedpad, (both direct and indirect) and direct N_20 emissions from the stockpile account for the three largest sources of GHG (in CO_2 equivalents) from feedlot manure management. Greenhouse gas produced from the feedpad is the largest source of GHG (in CO_2 equivalents) from feedlot manure, representing approximately 73% of total manure GHG. Conversely, GHG emissions from the pond are a small proportion of total GHG produced from feedlot manure, representing an estimated 1% of total manure GHG production (in CO_2 equivalents). Greenhouse gasses sourced from solid manure storage are intermediate, with approximately 19% of total GHG (in CO_2 equivalents) and manure/effluent application representing the remaining 7%.

These estimates are derived from a theoretical mass balance, which limits their application. However, these estimates of GHG produced from feedlot manure are useful to assist in prioritising research efforts in the area of GHG from feedlot manure sources.

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1 List of Abbreviations and Terms

1.1 Abbreviations

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

ASAE – American Society of Agricultural Engineers

B_o – Ultimate Methane Yield

BOD – Biological Oxygen Demand

B_u – Theoretical Methane Yield

C – Carbon

CO_2– Carbon Dioxide

CO_2-e – Greenhouse Gas Emission Calculated as Carbon Dioxide Equivalents

CH_4 – Methane

COD – Chemical Oxygen Demand

CP – Crude Protein

CRC – Cooperative Research Centre

DAMP – Digestibility Approximation of Manure Production

DCCEE – Department of Climate Change and Energy Efficiency

DEEDI – Department of Employment Economic Development and Innovation (Queensland) (formerly DPI or QDPI&F or QPIF)

DM – Dry Matter

DMD – Dry Matter Digestibility

DMDAMP – Dry Matter Digestibility Approximation of Manure Production

DMI – Dry Matter Intake

DOF – Days on Feed

FS – Fixed Solids

GHG – Greenhouse Gas

IPCC – Intergovernmental Panel on Climate Change

K – Potassium

LCA – Life Cycle Assessment

MCF – Methane Conversion Factor

MLA – Meat and Livestock Australia

N – Nitrogen

N_2 – Di-Nitrogen Gas

N_2O – Nitrous Oxide

NDF – Neutral Detergent Fibre

NGGI – National Greenhouse Gas Inventory

NH_3 – Ammonia

NH_4^+ - Ammonium

NO_2^- - Nitrite

NO_3^- - Nitrate

P – Phosphorous

QDPI&F – Queensland Department of Primary Industry and Fisheries (now DEEDI)

SCU – Standard Cattle Unit (regulatory standard in Queensland)

TDN – Total Digestible Nutrients

TS – Total Solids

VFA – Volatile Fatty Acids

VS – Volatile Solids

1.2 Definitions for Moisture / Solids Content and Volatile Solids

Throughout this report, various terms describing soil, manure and feed samples are used. This section provides some definitions.

Any sample (soil, manure, feed) consists of three sub-components – air, water and solids. Depending on the application, the solid component can be referred to as Dry Matter. The Dry Matter (or total solids (TS)) comprises organic and inorganic components. The relative proportions of organic and inorganic matter in a sample can be determined by combustion of the sample in an oven at 600°C. The organic component (volatile solids (VS)) is burnt off leaving the ash (fixed solids (FS)) component. Davis et al. (2010) gives more details about issues associated with the correct determination of VS for manure samples.

Each sub-component has a mass and volume within a sample as in Table 1.

TABLE 1 - SUB-COMPONENTS OF SOIL AND MANURE SAMPLES

Sample Sub-components	Mass	Volume	Density (g/cm^3)
Air	$m_a = 0$	V_a	0
Water	m_w	V_w	1.0
Volatile Solids	m_{vs}	V_{vs}	
Fixed Solids	m_{fs}	V_{fs}	2.65 for a soil

From this basic information, numerous parameters can be defined.

Total volume of sample, $V_t = V_a + V_w + V_{vs} + V_{fs}$
Volume of solids, $V_s = V_{vs} + V_{fs}$

Total mass of sample, $m_t = m_w + m_{vs} + m_{fs}$ - for a manure / compost
Total mass of sample, $m_t = m_w + m_s$ - for a soil (assuming no organic matter)
Total Solids, TS = VS + FS (Ash) = $m_{vs} + m_{fs} = m_s$ for a soil

Moisture Content

Confusion often exists on the definition of the moisture content of a sample. Typically, engineering soil laboratories implicitly use moisture content expressed on a “dry basis” while agricultural laboratories use moisture content expressed on a “wet basis” (see definitions below).

Very often, the exact basis on which moisture content is calculated is not explicitly stated. When the moisture content is low, there is little difference between "dry basis" and "wet basis" but this is not true for very wet samples.

Moisture content (% db – dry basis) = m_w / m_s
Moisture content (% wb – wet basis) = m_w / m_t

To convert (%wb) to (%db) %db = %wb /(100-%wb)

Moisture content (% v/v) = V_w / V_t

Convert (%db) to (%v/v) %v/v = %db x BD /1000 (where BD = kg/m^3)
Convert (%db) to (%v/v) %v/v = %db x BD (where BD = g/cm^3)

Bulk Density (BD) (wb) = m_t / V_t

Solids Density, AD = m_s / V_s range of 2.5 to 2.7 (say, 2.65)

Field / Dry Bulk Density, (BD) = m_s / V_t (usual definition of soil bulk density)

Dry Matter (DM) (%) = m_s / m_t

Total Solids (TS) (%) = m_s / m_t

Volatile Solids (VS) (%) = m_{vs} / m_s

Porosity, f = $V_a + V_w / V_t$
= 1 – BD/AD

2 Introduction

2.1 Background

Whole-of-system mass-balance models have been used for many years to predict waste production at cattle feedlots. The mass-balance approach has been adopted as it is the only rigorous methodology that can be used to account for the fate of all feedlot waste products.

The earliest example in Australia was Watts et al. (1992) – a mass-balance model for phosphorus at a cattle feedlot, known as P-BAL. This model was developed to address the potential environmental impact of feedlots on soils and watercourses. Since then, the mass-balance concept has expanded to included nitrogen balances and other parameters. Some years ago, it was made available to the public as the Department of Employment, Economic Development and Industry (DEEDI) BEEFBAL model.

Enhanced scrutiny of greenhouse gas (GHG) emissions from animal agriculture, from both within Australian and internationally, is increasing the pressure on livestock industries to scientifically validate their estimates of GHG emissions. This clearly includes the Australian beef feedlot sector. The Intergovernmental Panel on Climate Change (IPCC) outlines three options (a 3 tiered system) for estimating GHG emissions from animal agriculture (Dong et al. 2006). The tiered methodologies are defined for both carbon (methane (CH_4)) and nitrogen (nitrous oxide (N_2O)) sources of GHG from livestock and manure management. With the potential for future taxes on GHG emissions from agriculture, Meat and Livestock Australia (MLA) have raised concerns over generalisations, and a lack of a scientific foundation of prescribed emission factors for the Australian beef industry (as detailed by DCCEE (2010)).

Feedlot manure estimation models, such as BEEFBAL, have been used for estimating excreted volatile solids (VS) and nutrients (N, P, K) to assist in the design and regulation of Australian feedlots (QPIF 2004). More recently, the BEEFBAL model has also been used to provide input data for estimating manure GHG emissions by the Department of Climate Change and Energy Efficiency (DCCEE) as part of the estimation methodology (DCCEE 2010).

However, the model has not yet been developed to the level of a commercial product for general use by the public. It is currently provided by DEEDI free-of-charge to researchers and consultants on the understanding that it is provided on an "as-is" basis. Documentation of the science behind the model is poor, and several factors within the model rely on 'best-guess' input from the user. DEEDI advises that it is necessary to exercise both caution and professional judgement drawing conclusions from the model outputs. The BEEFBAL model has never been rigorously validated by experimental work.

Given the usage of the model by DCCEE, and the importance to industry of accurately estimating GHG emissions from feedlots, there is a need to review both the BEEFBAL model and the scientific literature to improve the rigour of the science and understanding behind manure estimation and mass-balance approach for feedlot systems. This is important both for advancing knowledge of feedlot nutrient management, feedlot GHG emissions and mitigation options, and for the use of these data in Life Cycle Assessment (LCA).

2.2 Project Objectives

The project involved a comprehensive literature review of mass-balance modelling and system components, including volatile solids (carbon), nitrogen (N), phosphorus (P) and potassium (K) flows of feedlots. The project reviewed the current BEEFBAL model provided by DEEDI. This report provides recommendations to address identified knowledge gaps in both the literature and the BEEFBAL model.

The specific objectives for the project were:

i. Complete and report a comprehensive literature review of mass-balance modelling, including volatile solids and nitrogen flows for feedlots.
ii. Collate the literature on emissions from feedlots into a theoretical mass balance to provide indications of the relative order of magnitude of emissions from various sources within the feedlot.
iii. Review the current BEEFBAL model and provide recommendations to address identified knowledge gaps in both the literature and the model.

In addition to these objectives, a brief review of the current methods for estimating GHG emissions from feedlots was undertaken. The ability of mass-balance models to assist in the prediction of GHG emissions is included.

3 Literature Review - Feedlot Mass Balance

3.1 Mass-Balance Modelling for Feedlots

In Australia in the late 1980s and early 1990s, there was a need to not only understand organic matter excretion at feedlots but also understand 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. 1994a, Watts et al. 1992).

These models applied a mass-balance approach to nutrients (N, P, K) and included a manure estimation model to predict 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 liveweights. These are all steady-state, annual time step, input-output models.

The concept behind mass-balance models for feedlots is that the fate of an entity entering the feedlot system can be determined by creating a mass-balance model for that entity and quantifying each sub-component.

Watts et al. (1992) prepared a schematic diagram of a feedlot system (Figure 1). This representation remains appropriate to modern feedlots. Figure 2 shows a revised version of the mass-balance schematic for a cattle feedlot. This diagram will be used throughout this report.

As an example, phosphorus is an element that can cause environmental harm if it reaches waterways or groundwater but is also an important resource as a fertiliser. Hence, the fate of phosphorus within the feedlot system needs to be understood. Phosphorus enters the feedlot system in the form of feed and live cattle. Some phosphorus leaves the feedlot system as finished cattle. The fate of the remaining phosphorus can be determined from a mass-balance of phosphorus throughout the feedlot system. To create the mass-balance model, a complete understanding of the flow path of phosphorus throughout the feedlot system is needed. In most feedlot mass-balance models, it is assumed that the system is steady-state and that there is no net accumulation of an element within the feedlot system. That is, the sum of all inputs equals to sum of all outputs.

Hence, in summary, phosphorus into the feedlot system (P_{in} – tP/yr) equals phosphorus out of the feedlot system (P_{out} – tP/yr). Phosphorous enters the feedlot within feed (P_{feed}) and live cattle (P_{LWTin}). By referring to Figure 1, it can be seen that P_{in} is portioned between phosphorus leaving the feedlot in live cattle (P_{LWTout}), phosphorus in carcasses and phosphorus in manure (P_{man}). P_{man} is portioned between phosphorus in runoff (P_{runoff}) and the phosphorus in harvested pen manure (P_{hm}). Hence, a simplified mass-balance formula for phosphorus (ignoring minor components) is:

$$P_{feed} + P_{LWTin} = P_{LWTout} + P_{runoff} + P_{hm} \qquad \textit{Equation (1)}$$

To undertake the mass balance, all of these factors except one must be quantified. The remaining factor can then be determined as the residual in the mass balance. In some cases, it is fairly easy to estimate the components. In most cases, the parameters above can be described as a mass times a concentration. For example,

P_{feed} = (Mass of feed fed to cattle) x (concentration of P in the feed)
P_{LWTin} = (Liveweight mass of cattle entering the feedlot) x (P concentration in each body)

Other parameters are more difficult to estimate as they require a detailed understanding of the chemical pathways of that nutrient. For example, the partitioning of phosphorus in manure between runoff and harvested pen manure is impossible to accurately predict. It is dependent, for example, on the intensity and quantity of rainfall on the feedpad, which will vary widely over time. Hence, in this instance, a representative ratio or percentage is used (say 5% of P in manure goes to runoff). Where possible, this ratio would be obtained from the scientific literature. When estimates such as this are used, it is essential that the mass-balance results are “ground-truthed” against typical values. In this instance, typical values exist for the quantity of runoff and manure harvested from feedlot pens, and the phosphorus concentration of the runoff and harvested manure. By multiplying quantity times concentration, a mass of phosphorus in runoff and harvested pen manure can be estimated. This should be compared to the prediction derived from the ratio partitioning. If the data does not compare favourably, a different partitioning ratio might be used.

Due to the incomplete understanding of all of the transfer mechanisms for nutrients in the feedlot system, this type of "ground-truthing" of results is common. Predictions should always be compared to typical measured values to ensure that sensible results are produced.

Notwithstanding the lack of precision in this approach, the mass-balance methodology always ensures that all of the nutrients entering a feedlot system are accounted for in some form of output.

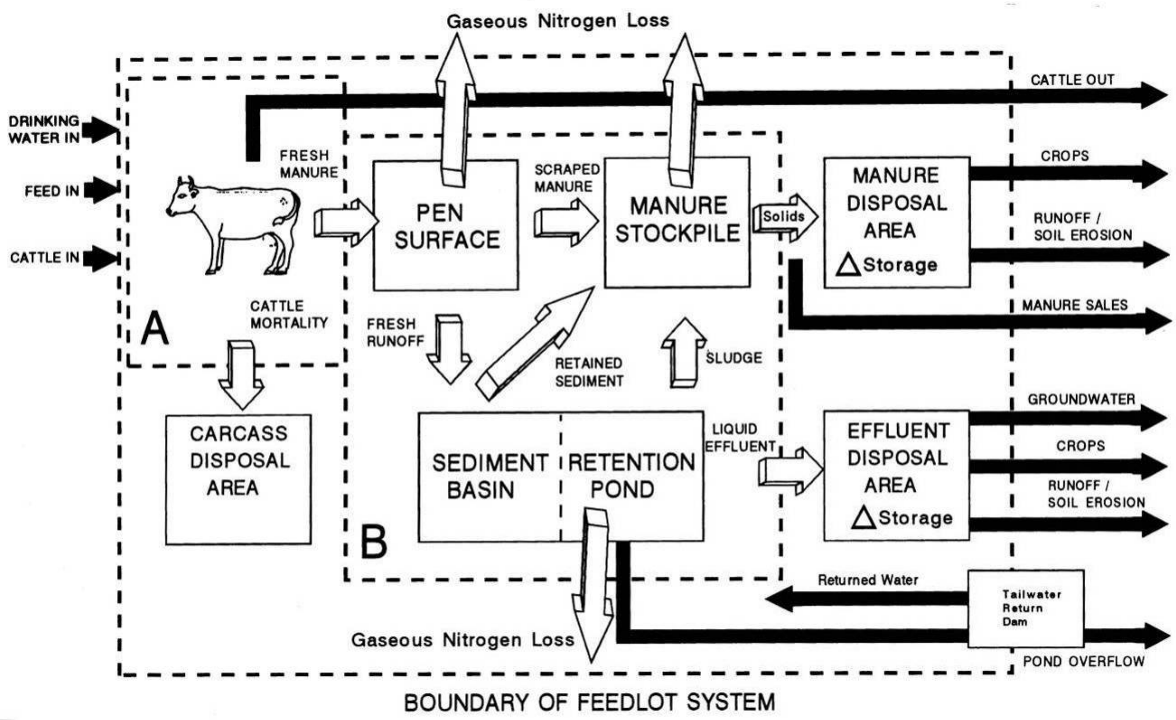


FIGURE 1 - SCHEMATIC DIAGRAM OF A FEEDLOT SYSTEM (WATTS ET AL. 1992)

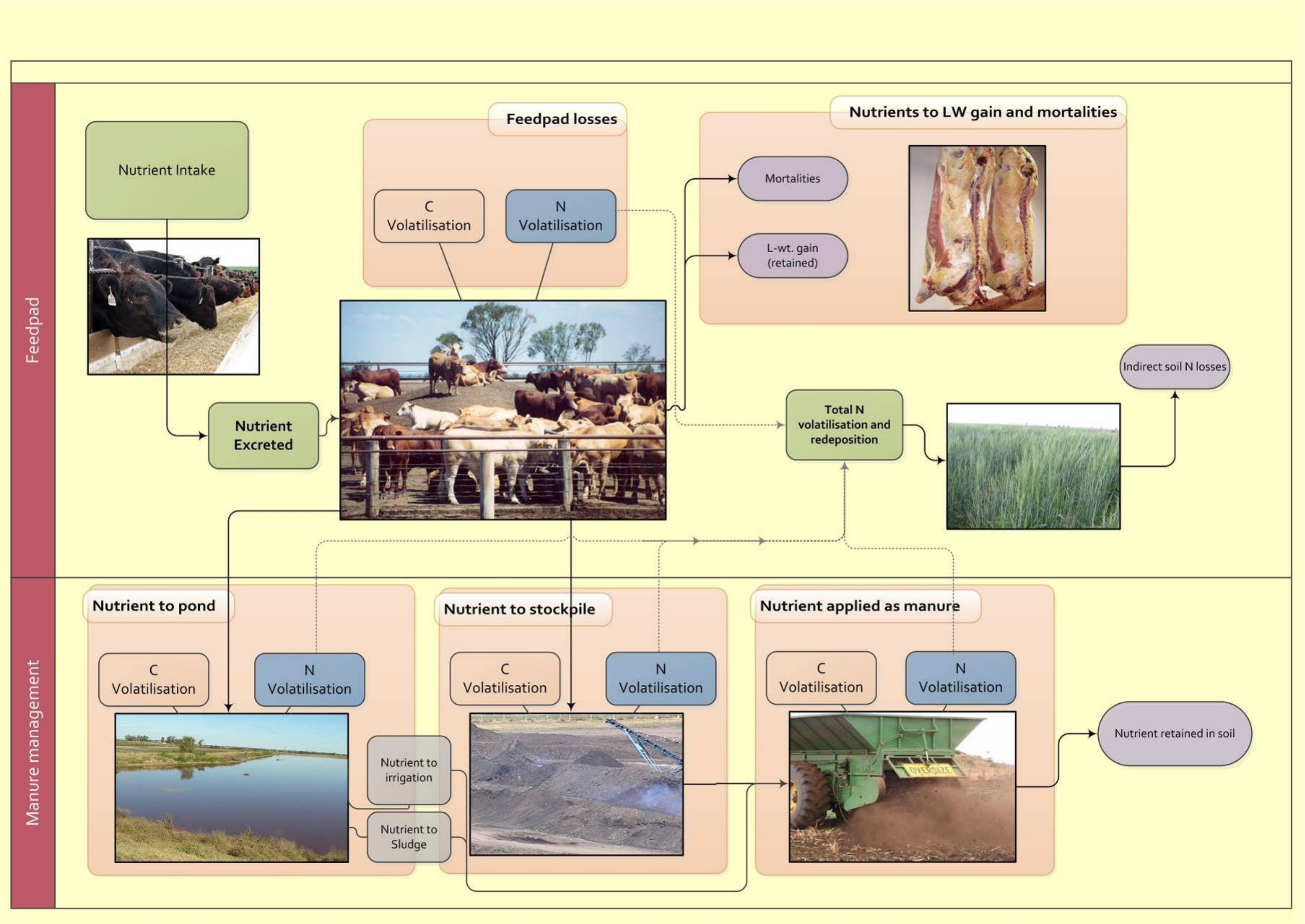


FIGURE 2 - MASS BALANCE SCHEMATIC FOR A CATTLE FEEDLOT SYSTEM

3.2 Feedlot Whole-of-System Overview

A cattle feedlot is a facility where beef cattle are housed in open pens and fed a prepared ration until they reach a specified weight. Only weaned cattle enter the feedlot and no breeding of cattle occurs at the feedlot. Different aspects of the feedlot system will be discussed below.

3.2.1 Livestock

In Australian feedlots, cattle are fed for different market specifications. Within a typical feedlot, there could be several different market types being fed at any one time. The parameters that specify the herd component of the feedlot system include:

- Entry weight (kg) – the liveweight of individual incoming cattle. This typically ranges from 250 kg to 450 kg depending on market type.
- Exit weight (kg) – the liveweight of individual cattle leaving the feedlot. This typically ranges from 400 kg to 700 kg depending on market type.
- Days on feed (DOF) – the number of days that cattle of each market type are fed. This typically ranges from 60 days to 300 days depending on market type.
- Average daily gain (ADG) (kg/day) – the average daily liveweight gain from entry to exit
- Liveweight gain (kg) – Exit weight, minus entry weight
- Mortality rate (%) – the percentage of incoming cattle that die during their time at the feedlot (typically 0.5% to 1.5%).
- Cattle on hand – the mean number of cattle in the feedlot at any one time.
- Occupancy (%) – cattle on hand as a percentage of pen capacity.

Table 2 gives typical herd data for different market types in Australia. Appendix A provides a more detailed analysis of this information based on the major lot feeding regions of Australia.

TABLE 2 - TYPICAL AUSTRALIAN FEEDLOT PARAMETERS

Market type	Domestic	Short Fed		Mid Fed	Long Fed
Days on feed (range)	60	100-140	150-180	220-240	300+
Entry Weight (kg)	335	412	408	380	415
Exit Weight (kg)	455	640	705	705	735
Net Gain (kg)	120	228	297	325	320
Dressing Percent	55%	56%	57%	57%	57%
Dressed Carcase Wt (HSCW)	250	355	400	405	420
ADG (kg gain/head/day)	1.6	1.9	1.7	1.3	1.0
DMI (kg DM/hd/day)	9.3	10.3	10.9	11.0	9.9
FCE[a] (kg DM/kg gain)	5.8	5.4	6.6	8.5	9.9
Mortality Rate (No in/No Out)	2.0%	2.0%	2.0%	2.0%	2.0%

Source: EconSearch Pty Ltd (2009).

In the past, mortalities were typically buried somewhere on-site but in most modern feedlots, cattle carcasses are composted and combined with manure. Hence, the nutrients they contain become a component of the manure for disposal.

PHOTOGRAPH 1 - TYPICAL VIEW OF CATTLE IN AN AUSTRALIAN FEEDLOT

3.2.2 Nutrient Composition of Livestock Carcasses

A basic component of a feedlot mass-balance model is to understand the nutrients contained within the liveweight (carcass) of cattle. Several studies were reviewed that investigated the body composition of cattle by carcass dissection and chemical analysis, regression equations, slaughter balance or retention per kilogram of liveweight gain. A summary is presented in Table 3.

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

	N (%)	P (%)	K (%)	Salt (%)	FS (%)
Starter/Intermediate Cattle	2.7	0.67	0.17	0.14	5.0
Grower/Finisher Cattle	2.4	0.70	0.18	0.15	4.0
Source	a	b,c	b,c	b,c	b,c,d

Starter / intermediate cattle are those cattle new to the feedlot. Grower / finisher cattle are older and have been in the feedlot for some time. There are no exact weight or age definitions for these cattle classes.

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.

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 N = 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)

Koelsch and Lesoing (1999) used a similar approach from the literature, where:

$N = (0.235 \times \text{empty body weight} – (0.00013 \times (\text{empty body weight})^2 - 2.418)/6.25$, or
$N = 2.40$ to 2.80% of bodyweight

and

$P = .47$ to $.56\%$ of bodyweight

3.2.3 Housing System

In Australian cattle feedlots, cattle are housed in open pens at a stocking density ranging from 10 m^2 to 20 m^2 of pen area per head. In some cases, shade is provided. The base of the pens (the feedpad) is typically compacted earth or gravel with a small percentage adjacent to feed and water troughs being concrete. An open feed bunk (trough) typically runs along the high side of each pen with 200 mm to 400 mm of feed bunk length provided per head (Photograph 2). Pens are sloped away from the feed bunk to allow for drainage following storm events.

3.2.4 Feed (rations)

Cattle are fed a total mixed ration (TMR) that typically contains 70-80% grain plus roughage, protein source and supplements. The feed ingredients are determined to match cattle market types and available feed ingredients, and typically vary during the period when the cattle are in the feedlot. For example, cattle which are new to the feedlot typically receive a “starter” ration, which is higher in roughage. Hence, several different ration types would be prepared at a feedlot on any one day. Rations are processed (e.g. steam flaking) to maximise digestibility and to increase daily weight gain. The parameters that specify the feed component of the feedlot system include:

- Dry matter content (DM) (%) – the dry matter content of the TMR. This is typically 60% to 80%.
- Dry matter intake (DMI) (kg DM/hd/day) – the daily feed intake of each market type on a dry matter basis.
- Feed conversion ratio (FCR) – the ratio of DM feed intake (kg/day) to average daily gain (kg/day). This typically ranges from 5 to 9 depending on the market type.

PHOTOGRAPH 2 - DELIVERING A PREPARED RATION TO A FEED BUNK

3.2.5 Typical Feedlot Ration Analyses

Feedlot rations can be comprised of a wide range of different ingredients. Feedlot nutritionists formulate these rations by combining available ingredients to achieve a target energy level at least cost per tonne of ration while providing minimum nutrient levels. This often means that some nutrients are provided in excess of minimum requirements. Table 4 shows typical ingredients for feedlot rations in SE Queensland. Appendix A provides more details for other regions across Australia.

TABLE 4 - TYPICAL FEEDLOT RATION INGREDIENTS FOR SE QLD

Parameter	Type	Units	Market Type			
		(DM)	Domestic	Short Fed	Mid-Fed	Long-Fed
Grain	Summer	%	32	32	32	32
	Winter	%	43	43	43	43
Protein	Cottonseed	%	10	10	10	10
	Canola	%	0	0	0	0
	Lupins	%	0	0	0	0
	Other	%	0	0	0	0
Roughage	Straw/Hay	%	3.5	3.5	3.5	3.5
	Silage	%	5	5	5	5
Liquids		%	1.5	1.5	1.5	1.5
Supplements		%	5	5	5	5

Exact proportions vary according to Region and Season. Source: (EconSearch Pty Ltd et al. 2009).

From a mass-balance perspective, it is necessary to know the N, P and K content of a complete ration. Table 5 provides a range of nutrient contents as determined from the typical rations given in Appendix A. However, there can be a wide range of nutrient contents depending on the availability of ration ingredients at the time.

TABLE 5 - TYPICAL RATION ANALYSIS OF FEEDLOTS FROM 9 REGIONS IN AUSTRALIA

Ration component (% as-fed)	Average	Minimum	Maximum
N	1.54	1.39	1.69
Protein (6.25 x N)	9.63	8.69	10.60
P	0.29	0.28	0.32
K	0.46	0.44	0.49
Fixed solids (ash)	4.44	4.30	4.73

(As modelled by BEEFBAL. Typical diet compositions from Appendix A.)

For example, the phosphorus requirements of cattle vary according to liveweight and performance level. The NRC's recommendations for minimum P intakes are given in grams per day for cattle of differing liveweights and performance levels (National Research Council 1984). Assuming average dry matter intakes, Watts and Tucker (1993) calculated that the recommended P content of a ration should be 0.26% for "local-trade" cattle and 0.18% for "Jap-ox" cattle. ("Local-trade" and "Jap-ox" were typical market types at that time). These recommended P requirements are shown on Figure 3. Watts and Tucker (1993) analysed sixteen samples of feedlot rations from different sources. All rations were found to exceed the minimum NRC requirements for "Jap-ox" cattle and all but two exceeded the minimum requirement for "local-trade" cattle. In some cases, there may have been over twice the NRC recommendations for P in some rations (Figure 3). Almost certainly, the same situation exists for N and K. For example, in some areas in the USA, cheap distiller's grain by-products are fed to cattle at high percentages in the ration. These least-cost rations can be very high in nitrogen. This would lead to excessive nitrogen excretion with corresponding higher nitrogen losses to the environment.

From a waste management perspective, excess nutrients fed to cattle appear as excess nutrient in manure and this increases the environmental burden from the feedlot. This aspect will be considered later in this report.

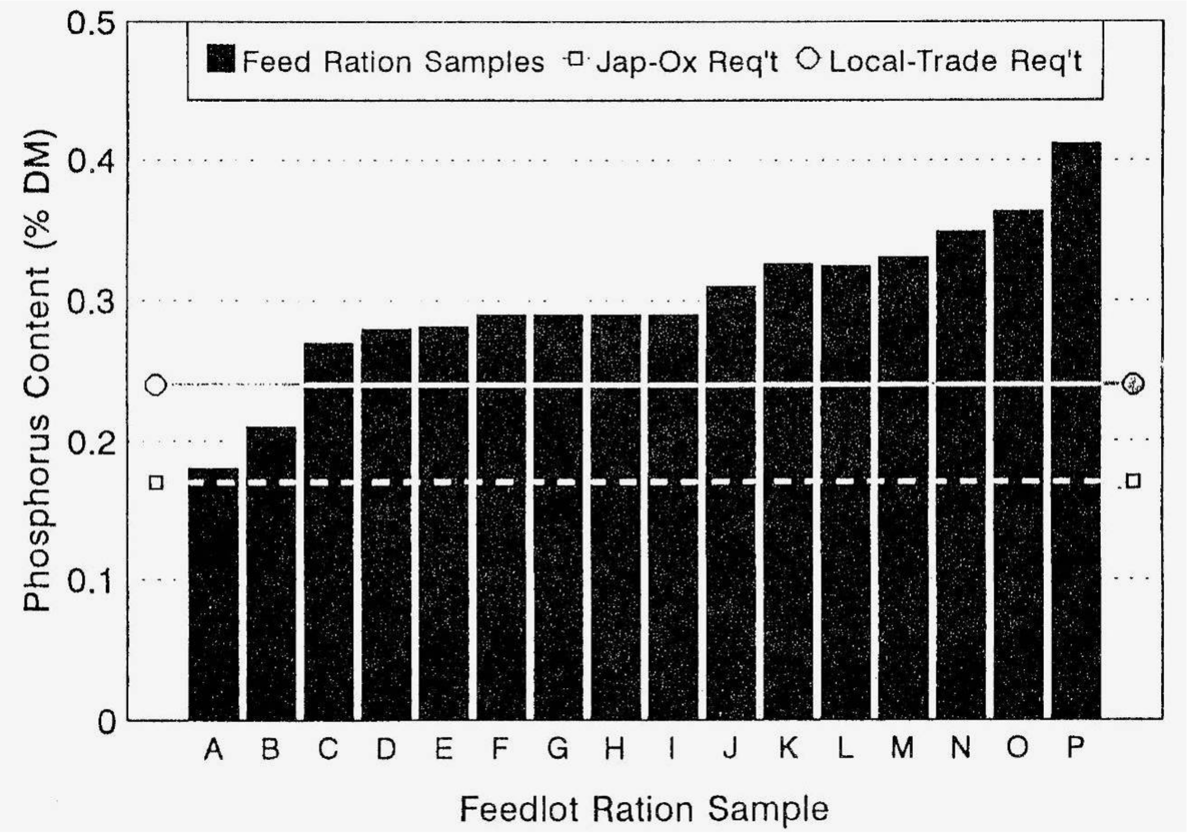


FIGURE 3 - VARIATION IN P CONTENT OF FEEDLOT RATIONS

3.3 Manure Excretion Estimation Models

3.3.1 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 (Dong et al. 2006). Manure is composed of total solids (dry matter), which contains macro and micro nutrients, and water. The TS fraction is composed of organic matter (measured as VS) and ash or fixed solids (FS). The TS fraction is determined by drying manure in an oven to remove the moisture until a stable weight is achieved. The method to measure VS in the laboratory is to burn dried manure (TS) 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 ash or fixed solids (FS) remains. The VS fractions are determined by mass balance (i.e. TS mass – FS mass).

Fixed solids (ash component) represents the mineral component of the manure. This includes, amongst other elements, phosphorus, potassium and calcium.

3.3.2 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 Biological Oxygen Demand (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 (1985).

There was wide variation in reported values from the literature on how much TS, VS, N and P a feedlot animal excretes. Table 6 shows the TS, VS, N and P production for a 600 kg liveweight beef/feedlot animal from four different sources.

TABLE 6 - 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.(1994b)
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.

3.3.3 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 component of animal manure based on known diet and digestibility data. This technique applied 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 fixed solids available in the organic and mineral component of the diet of each feed component offered.

Barth (1985a) found that 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 (2005) and MWPS (1985) 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, N-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 CH_4 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.

3.3.4 DMDAMP Model

Over time, it became apparent that the DAMP model required 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. Sinclair (1997) reported 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 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 20 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.

3.3.4.1 Digestibility Model (DMDAMP) for Predicting Solids Excretion

As with the DAMP model proposed by Barth (1985a), the DMDAMP model requires, as input data, 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 ($FS_{fed} - FS_{retained} = FS_{excreted}$), not one of two fixed values depending on whether it is an organic or inorganic component of the feed.

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.

$$TS\ excreted = DMI \times (1 - DMD\ fraction\ of\ the\ ration) \qquad \text{Equation (2)}$$

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 liveweight gain. Volatile solids is simply calculated as TS minus the FS.

The modification of DAMP to DMDAMP was 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 3). 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.

$$DMD = (Feed\ DM - Faeces\ DM) / Feed\ DM \qquad \text{Equation (3)}$$

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.

3.3.4.2 Feed Intake Data used in DMDAMP

Data collected by the Cattle and Beef Industry CRC for cattle of the three most common feedlot market types (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. Figure 4 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).

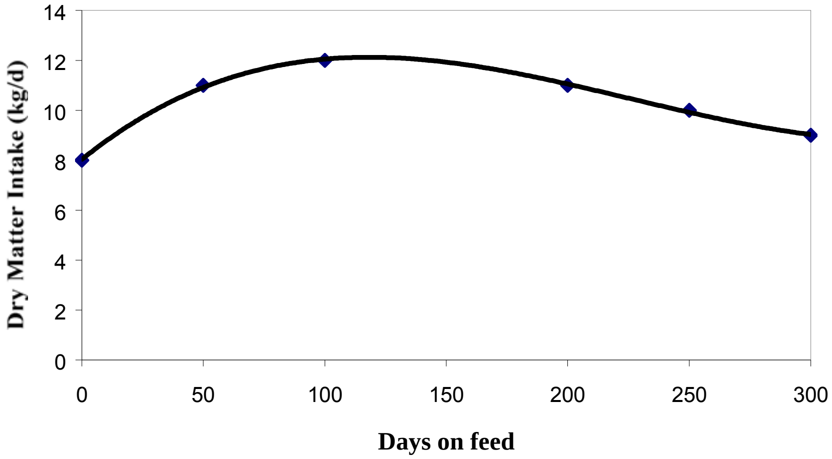


FIGURE 4 - RELATIONSHIP BETWEEN DMI (KG/DAY) AND DAYS ON FEED

3.3.4.3 Digestibility of Rations used in DMDAMP

Feedlot animals are typically fed a number of rations, including starter; intermediate; grower and finisher. The roughage to concentrate ratios change from approximately of 40:60 for starter rations, through to 10:90 for finisher rations 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, 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 neutral detergent fibre (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.

3.3.4.4 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 5. The majority of values fall below the 1:1 line, which indicates DMDAMP slightly underestimates DMD and consequently overestimates manure production. The only Australian 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%.

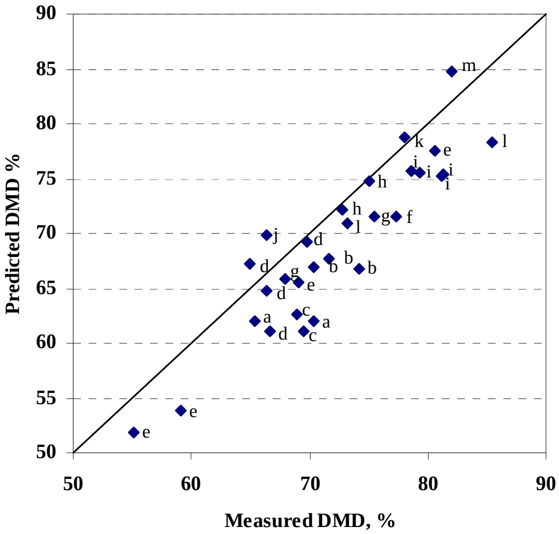


FIGURE 5 - REPORTED VERSUS PREDICTED RATION DRY MATTER DIGESTIBILITY (DMD)

Source data for Figure 5:

a. Glenn et al. (1989)
b. Mir and Mir (1994)
c. Wiedmeier 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)

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 of 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%.

3.3.5 Predicting Waste Output of Different Classes of Feedlot Cattle

The DMDAMP model was used to predict waste production from six market types 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 7). 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 4. 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 8.

The predicted excretion of TS, VS, N and P in kg/yr for each class of animal is shown in Table 9 for the sorghum and barley rations.

TABLE 7 - RATION FORMULATION USED TO ESTIMATE MANURE OUTPUT FROM DMDAMP MODEL

	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 8 - ASSUMPTIONS USED TO PREDICT WASTE FOR DIFFERENT MARKET TYPES

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 9 - PREDICTION OF FEEDLOT WASTE FOR THE DIFFERENT MARKET TYPES AND 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 11.9%. 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 ration is within the range suggested by Barth et al. (1999) and Watts et al. (1994b) in Table 6, for a 600 kg beef animal. Predicted TS and VS by Barth et al. (1999) and Watts et al. (1994b) are lower than those predicted by (ASAE 1988) and (MWPS 1985). The predicted VS of the barley ration are slightly lower than any values mentioned in Table 6. 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/hd/year for sorghum rations and 65.0 to 76.5 kg/hd/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/hd/year suggested in Table 6, by ASAE (1988), MWPS (1985) and Watts et al. (1994b). The P levels excreted ranged between 10.4 and 13.0 kg/hd/year for the sorghum ration and 9.1 to 11.3 kg/hd/year for barley ration again across all classes of cattle from the 70-day domestic to 300-day Jap-ox. While the references in Table 6 quoted an average 20 kg/hd/year of phosphorous, Gardner et al. (1994) estimated P excretion between 2.3 and 5.1 kg/hd/year for local trade cattle and between 8.3 to 14.9 kg/hd/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. Sinclair (1997) reported total P excretion rates to range between 17.3 g and 26 g/hd/day, which equates to between 6.3 and 9.5 kg/hd/year for the liveweight range 250-350 kg.

3.3.6 ASABE Methods

Although Clanton et al. (1988) recognised the value of mass-balance models for nutrient estimation, it has only been 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 (ASAE 2005). The new ASABE standard has also improved the digestibility model to improve VS excretion predictions. This model determines "as-excreted" manure and does not include a component for wasted feed or bedding material. This is consistent with DMDAMP.

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), N, P, K, Ca, total manure and moisture per kg/finished animal. Table 10 presents the estimated typical manure as excreted.

TABLE 10 - ESTIMATED TYPICAL MANURE (URINE AND FAECES) AS-EXCRETED (ASAE 2005)

Animal Type and Production Grouping	TS	VS	N	P	Ca	Calculated VS/TS ratio
			kg/finished animal (f.a.)			
Beef – finishing cattle	360	290	25.0	3.3	7.7	0.81

The assumptions used to provide these estimates in Table 10 are:

- Liveweight range = 338 – 554 kg
- Average daily gain = 1.42 kg/hd/day
- Days on feed = 153 days
- Dry matter intake = 2% of body weight
- Dry matter digestibility (DMD) = 80%

- Organic matter digestibility = 20%
- Crude protein intake = 1200 g/day
- Phosphorus intake = 28 g/day
- Calcium intake = 62 g/day
- Ash = 4%

Alternatively, equations are provided to calculate excretion of TS, VS, N, P and Ca. (VS is called organic matter (OM)). Equation 4 and 5 (ASAE 2005) predict OM (i.e. VS) excretion:

$$OM_{E} = [DMI*(1-ASH/100]*(1-OMD) + 17*(0.06*BW_{AVG}) \qquad \text{Equation (4)}$$

$$OM_{E-T} = n^{n}{}_{x=1}\ [DMI_{x} * DOF_{x} *(1-ASH_{x}/100)]*(1-OMD_{x}/100) + n^{n}{}_{x=1}\ DOF_{x}*17*(0.06* BW_{AVG}) \qquad \text{Equation (5)}$$

Where:

OM_E = OM (or VS) excretion per animal per day (g of OM / day / animal)
DMI = the dry matter intake (g DM / day)
ASH = ash concentration of total ration (% of DMI)
OMD = organic matter digestibility of total ration (% of OMI)
BW_{AVG} = average live body weight for the feeding period (kg)
OM_{E-T} = total organic matter (or VS) excretion per finished animal (g of organic matter / finished animal)
DOF = days on feed for individual ration (days)
X = ration number
N = total number of rations fed

Equation 6 predicts N excretion (ASAE 2005).

$$N_{E-T} = n^{n}{}_{x=1}\ (DMI_{x} *C_{cp-x} *DOF_{x} */ 6.25) - [41.2*(BW_{F} - BW_{I})] + [0.243*DOF_{Tt} * [(BW_{F} + BW_{I}) /2]^{0.75} * (SRW/(BW_{F} *0.96))^{0.75} *[BW_{F} - BW_{I})/DOF_{T}]^{1.097}] \qquad \text{Equation (6)}$$

Where:
DMI = the dry matter intake (g DM / day)
C_{cp} = concentration of crude protein of total ration
DOF = days on feed for individual ration (days)
BW_F = live body weight at finish of feeding period (market wt)^2 (kg)
BW_I = live body weight at start of feeding period (market wt)^2 (kg)
OM_{E-T} = total organic matter (or VS) excretion per finished animal (g of organic matter / finished animal)
X = ration number
N = total number of rations fed

3.3.7 Nitrogen Excretion

3.3.7.1 Experimental Determination of Nitrogen Excretion

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

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

Sinclair (1997) is an example of a study where N excretion was determined by directly measuring urine and faeces and subsequently determining the N content of the manure.

Erickson et al. (2002), Farran (2004), Luebbe et al. (2008) and Luebbe et al. (2009) all use the same mass balance approach to determine N 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 N intake and N retention.

Figure 6 shows the N excretion of cattle (expressed as a % of N intake) from several studies. Figure 7 shows the same N excretion data but expressed as g of N 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 N that is fed is excreted, with a range of 80 to 90%.

3.3.8 Phosphorus Excretion

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

$$\text{Total P excretion (g/d)} = 8.23 + 0.433 \times \text{P Intake} \qquad \text{Equation (7)}$$

Phosphorus excretion can also be estimated by the following equation (ASAE 2005).

$$P_{E-T} = \Sigma^{n}_{x=1} (DMI_x * C_{P-x} * DOF_x) - [10.0 * (BW_F - BW_I)] + \{5.92 * 10^{-2} * DOF_T * [(BW_F + BW_I)/2]^{0.75} * [(BW_F - BW_I)/DOF_T]^{1.097}\} \qquad \text{Equation (8)}$$

Where:

n = total number of rations fed
x = ration number
BW_F = Live body weight at finish of feeding period (market weight)^2 (kg).
BW_I = Live body weight at start of feeding period (purchase weight)^2 (kg).
DMI = Dry matter intake (g dry feed/day).

However, in BEEFBAL, P excretion is determined by mass-balance as in Table 9.

TABLE 11 - 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
Phosphorus						
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
Nitrogen						
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
	kg 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)

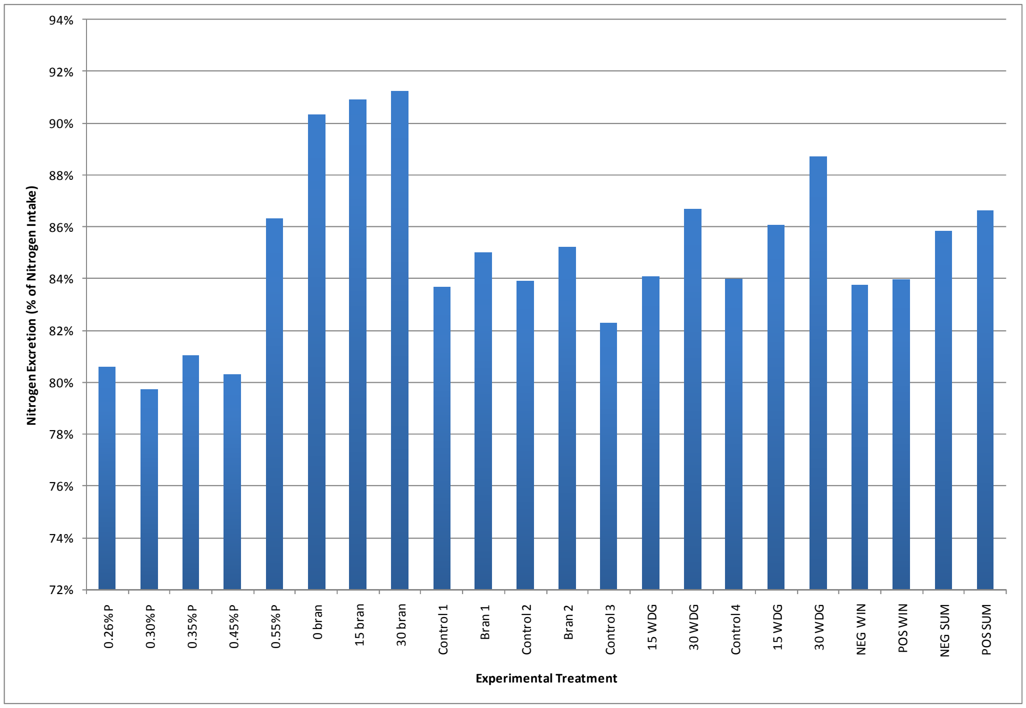


FIGURE 6 - NITROGEN EXCRETION OF CATTLE (% OF INTAKE) – NUMEROUS STUDIES

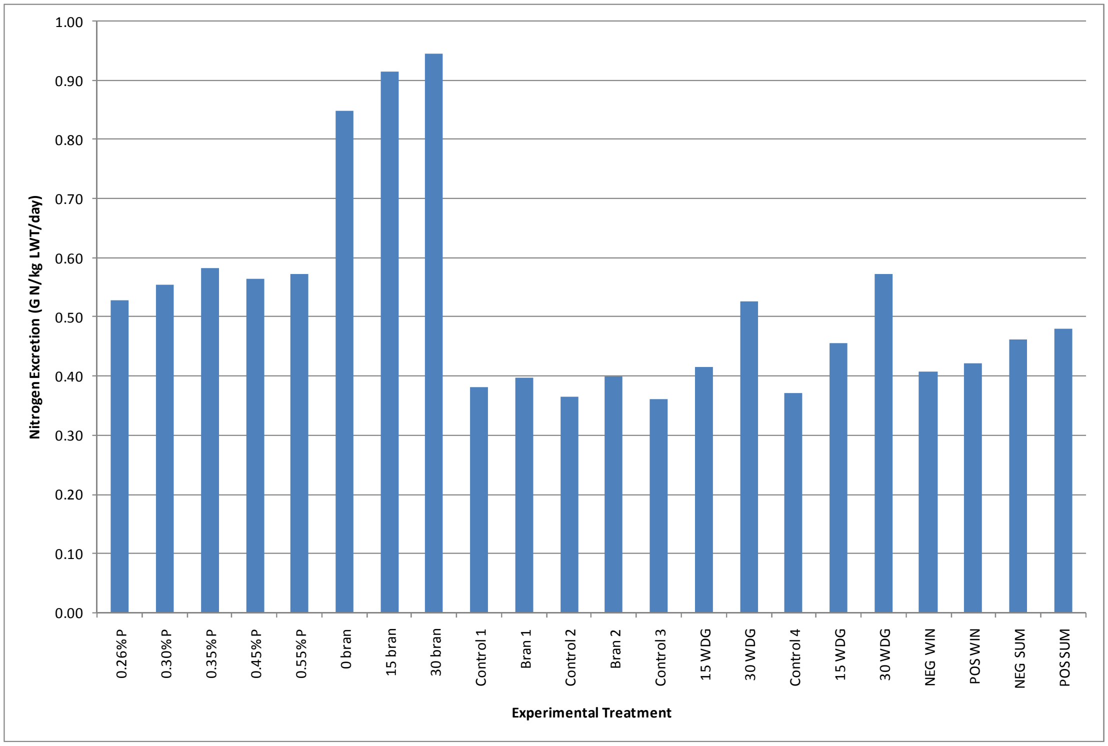


FIGURE 7 - NITROGEN EXCRETION OF CATTLE (G N /KG LWT/DAY) – NUMEROUS STUDIES

3.3.9 IPCC Manure Estimation Method

The previous sections have described manure estimation methods 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 GHG emissions from intensive livestock facilities.

The IPCC provide methods to estimate emissions as direct and indirect fraction of manure management. Three tiered options are provided for estimating both CH_4 and N_2O emissions (Dong et al. 2006), with CH_4 emissions driven by VS excretion and N_2O emissions driven by N excretion. In brief, the three-tiered options are:

Tier 1 Involves the simplistic use of IPCC default emission factors.

Tier 2 Follows the same calculation equation, but uses country-specific data for some or all of the variables, for example, the use of emission factors developed for Australian feedlots. In essence, DCCEE (2010) estimates fit into Tier 2 methodology.

Tier 3 Is relevant where emissions are particularly important, and goes beyond industry defaults. This method of estimation requires a clearly described country-specific methodology, for example, a process-based mass balance approach (Dong et al. 2006).

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 7.

$$VS = [GE * (1 – (DE\% / 100) + (UE * GE)] * [(1-ASH) / 18.45] \qquad \text{Equation (9)}$$

Where:

VS = VS 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 = 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 GHG 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%.

The DCCEE (2010) only defines a single emission source of CH_4 and N_2O and NH_3 from feedlots (i.e. it doesn’t provide separate emission values for the feedpad and the manure stockpile/compost). There are no emissions provided for the runoff collection and treatment system, presumably with the assumption is that they are minor sources of GHG within the feedlot.

Details of the default method for estimating manure emissions from feedlot cattle is provided by the DCCEE (2010). This method is summarised in the following sections for the two emission sources, manure CH_4 and N_2O.

3.3.10 DCCEE Manure Excretion and GHG Emissions Estimation Method

3.3.10.1 Volatile Solids and Total Solids

The DCCEE (2010) method of estimating emissions from manure is as follows, beginning with estimation of VS (VS kg/head/day):

$$VS = I \times (1 - DMD) \times (1- A) \qquad \text{Equation (10)}$$

Where:

I = Dry matter intake.

DMD = digestibility expressed as a fraction (assumed to be 80%).

A = ash content expressed as a fraction (assumed to be 8% of faecal DM).

Volatile solids are calculated using standard figures for dry matter intake and ration digestibility and have been developed using BEEFBAL (QPIF 2004).

Table 12 presents the estimated VS and TS production for three feedlot cattle classes using the DCCEE (2010) methodology and assumptions (1996+).

TABLE 12 - ESTIMATED VS AND TS PRODUCTION (KG/HD/YR) USING DCCEE (1996+) METHODOLOGY

Animal Class Type	Domestic (75 days)	Export (140 days)	Jap. ox (250 days)
VS (kg/head/yr)	658	786	739
TS (kg/head/yr)	715	854	803

3.3.10.2 Nitrogen

The majority of N consumed by feedlot cattle as protein in the diet is excreted in manure and urine. Excreted N is rapidly lost to the atmosphere through a number of pathways, of these direct N_2O emissions contribute to the GHG profile of the feedlot. Additionally, emissions of NH_3 contribute to indirect GHG emissions when NH_3 is deposited to surrounding land and re-emitted as N_2O. Hence, both direct N_2O emissions and NH_3 emissions are important for the estimation of total GHG.

Estimation of N emissions begins with calculation of the total mass of N excreted from the cattle. Excretion is determined by difference from estimating crude protein intake and storage within the animal. The following algorithms are used to calculate crude protein input (CPI) and storage (NR).

$$CPI\ (kg/head/day) = NI \times 6.25 \qquad \text{Equation (11)}$$

Where:

NI = nitrogen intake (kg/day)
6.25 = factor for converting N into crude protein

NI is calculated from the N concentration of different dietary components and the proportion of these components in the ration. This is detailed in Eqn 12.

$$NI = (I \times P_{grain} \times N_{grain}) + (I \times P_{conc} \times N_{conc}) + (I \times P_{grass} \times N_{grass}) + (I \times P_{legume} \times N_{legume}) \quad \text{Equation (12)}$$

Where:

N_{grain} = nitrogen content of grain
N_{conc} = nitrogen content of other concentrates portion of the diet
N_{grass} = nitrogen content of grasses portion of the diet
N_{legume} = nitrogen content of legumes portion of the diet

The methodology for estimating N excretion in manure, F (kg/head/day) is based on the indigestible fraction of the undegraded protein from solid feed and the microbial crude protein, plus the endogenous faecal protein. This methodology takes a mass balance approach where N output = N input - N storage. The total-N output is then split into urinary and faecal components.

The N excreted in faeces (F kg/head/day) is calculated as:

$$F = \{0.3(CPI \times (1-[(DMD+10)/100])) + 0.105(ME \times I \times 0.008) + 0.0152 \times I\} / 6.25 \quad \text{Equation (13)}$$

Where:

DMD = digestibility expressed as a percentage (assumed to be 80%)
I = feed intake (kg/day)

ME = metabolisable energy (MJ/kg DM) is calculated:

$$ME = 0.1604 \times DMD - 1.037 \quad \text{Equation (14)}$$

The amount of N that is retained by the body, NR (kg/head/day) is calculated as the amount of N retained as body tissue such that:

$$NR = \{[0.212-0.008(L - 2) - \{(0.140-0.008(L - 2)) / (1+\exp(-6(Z - 0.4)))\}] \times (LWG \times 0.92)\}/6.25 \quad \text{Equation (15)}$$

Where:

L = Relative intake, which is feed intake divided by the intake require for maintenance.
Z = Relative size (liveweight/standard reference weight).
LWG = Liveweight gain.

Nitrogen excreted in urine (U kg/head/day) is calculated by subtracting NR, F and dermal protein loss from the N intake such that:

$$U = (CPI / 6.25) - NR - F - [(1.1 \times 10^{-4} \times W^{0.75})/6.25] \quad \text{Equation (16)}$$

Where:

W = Liveweight

The total annual faecal (AF) and urinary (AU) N excreted is then calculated by:

$AF = (N \times F \times 365) \times 10^{-6}$ *Equation (17)*

$AU = (N \times U \times 365) \times 10^{-6}$ *Equation (18)*

Where:

F = Equation 11
N = the annual equivalent number of feedlot cattle.
U= Equation 14

Once excreted N has been estimated, losses of N_2O and NH_3 can be calculated using emission factors provided.

Table 13 presents the estimated N intake and excretion for three feedlot cattle classes using DCCEE (2010) methodology and assumptions (1996+).

TABLE 13 - ESTIMATED N INTAKE AND EXCRETION (KG/HD/YR) USING DCCEE (1996+) METHODOLOGY

Animal Class Type	Domestic (75 days)	Export (140 days)	Jap. Ox (250 days)
N Intake (kg/head/yr)	66.0	78.5	73.9
N Excretion (kg/head/yr)	55.1	70.7	67.9
Percentage N Excreted (%)	83.4	90.1	91.9

3.3.10.3 Manure Methane Emissions

The rate of CH_4 emission depends upon the VS content of the manure and the manure management system. The estimation of methane emissions from manure is based on an estimate of the VS content of manure, taking into consideration the production (or emissions) potential and the yield for a given manure management system (expressed as the Manure Conversion Factor - MCF). The ultimate methane yield of an anaerobically digested material is known as B_o.

The MCF provides an estimate of the portion of the methane-producing potential of waste that is achieved (IPCC 1997). Different waste management systems and climatic conditions affect the methane-producing potential of waste. Manure managed as a liquid under hot conditions has higher CH_4 formation and emissions and hence a high MCF value. Manure managed as a dry material in cold climates does not readily produce CH_4 and consequently has a lower MCF.

Following VS estimation, CH_4 production from faeces, M (kg/head/day) is calculated in DCCEE (2010) as:

$M = VS \times B_o \times MCF \times \rho$ *Equation (19)*

Where:

B_o = emissions potential ($0.17 m^3$ CH_4/kg VS)
MCF = methane conversion factor (Drylot MCF values for 'warm' regions such as Queensland and the Northern Territory =5%, MCF values for 'temperate' regions (for all other States) = 1.5%.
ρ = density of CH_4 ($0.662 kg/m^3$)

The DCCEE (2010) simplify manure management at feedlots into a single manure management system (drylot) and therefore consider only point of emission (presumably the feedpad). Hence, any losses occurring from the effluent pond, sedimentation basin or effluent irrigation are not considered in the DCCEE (2010) scenario.

3.3.10.4 Manure Nitrous Oxide and Ammonia Emissions

The DCCEE (2010) identify one aggregated direct source of N_2O emission from the feedlot only. This is designated 'drylot and solid storage' and is calculated as follows:

$$Faecal_{MMS} = (AF \times MMS \times EF_{(MMS)} \times 44/28) \qquad \text{Equation (20)}$$

$$Urine_{MMS} = (AU \times MMS \times EF_{(MMS)} \times 44/28) \qquad \text{Equation (21)}$$

$$Total_{MMS} = (Faecal_{MMS} + Urine_{MMS}) \qquad \text{Equation (22)}$$

Where:

AF = Annual faecal N excreted
AU = Annual urinary N excreted
MMS = the fraction of the annual N excreted (AU + AF) that is managed in the different manure management systems. It is assumed that with feedlot cattle all manure is dry packed (MMS = 4), which equals an emission rate of 2% of excreted N.
$EF_{(MMS)}$ = emission factor (N_2O-N kg/ N excreted) for the different manure management systems.
44/28 = factor to convert elemental mass of N_2O to molecular mass.

Emissions of NH_3 from the feedpad are calculated as 30% of excreted N. No other NH_3 emission sources (i.e. ponds, manure stockpiles) are provided for beef cattle in feedlots.

3.3.10.5 Manure Application Emissions

The DCCEE (2010) estimates that further losses of N_2O occur following application of solid manure. Emission estimation relies on an estimate of applied N, which is estimated as excreted N, less losses of N_2O-N and NH_3-N as calculated above.

Once the mass of N available for land application is determined, emissions are calculated as 1% of applied N.

Losses from effluent application are not identified by the DCCEE (2010) methodology.

3.3.10.6 Indirect Nitrous Oxide Emissions

The DCCEE (2010) identify further N_2O emissions associated with feedlots via the volatilisation and deposition of NH_3-N from the feedlot. This N is subsequently available for re-volatilisation as N_2O. Ammonia-N losses are estimated at 30% of excreted N. Of this, 1% is re-volatilised as N_2O. No further losses are identified.

3.3.11 Summary – Manure Excretion Estimation Methods

There are number of models with which to estimate the volume of excreted manure. These methods are summarised below.

- **Pond organic loading rate models**; initial estimates based on a fixed amount (kg VS/head/day) or as a percentage of liveweight.

- **DAMP model**; aimed to predict organic content of excreted manure using animal performance data. Total digestible nutrient (TDN) of each dietary component was the central element of the model.
- **DMDAMP model**; utilises dry matter digestibility (DMD) instead of TDN of individual ration ingredients to predict TS excreted. Volatile (VS) component was calculated using mass balance principles on the FS component of the feed, minus the FS retention of the animal.
- Current **ASABE models** estimate "as-excreted" manure based on a typical diet, and are consistent with DMDAMP estimation techniques. Predictions are based on animal performance, dietary feed and nutrient intake according to life stage of the animal.
- **IPCC** methodology is based on energy intake, digestibility and ash content.
- **DCCEE** methodology based on DMD (as per BEEFBAL) with standard assumption for DMD of feedlot diets and ash content of manure.

3.3.12 Knowledge Gaps and Recommendations – Manure Estimation Models

Limitations exist in the current manure estimation techniques, mostly regarding the digestibility of the ration components when included in a TMR. There are limitations in the estimates of the associative effects of ration components on the DMD of an individual TMR (Section 3.3.4.4), which stem from the high cost and difficulty associated with measuring DMD of all possible rations under different circumstances. Further to this, the variability of ingredients and method of grain processing adds complexity to the estimation of DMD. Digestibility studies, while relatively simple in concept, have a large labour and laboratory analysis cost.

The solution may be to refine the DMD with strategic testing of different rations that are representative of key rations utilised within the industry.

3.4 Feedlot Manure Management Systems

3.4.1 Manure Management Overview

Cattle excrete fresh manure (urine plus faeces) onto the pen surface (known as the feedpad) where it immediately begins to breakdown. Ammonia and other volatile components are rapidly lost from the manure. After a period of time, machinery removes the dry manure from the pens (Photograph 3). The manure is typically held in a manure stockpile area where it may be composted prior to sale off-site or spreading as an organic fertiliser on agricultural land. Some manure is removed from pens by runoff during heavy rainfall events. Dry matter (mainly carbohydrates) is lost from manure to the atmosphere as CO_2 and CH_4 in all phases of manure handling and storage.

Manure management is site-specific, since it depends on feedlot design, management, labour, climate and seasonality. In Australian feedlots, the components of manure management are:

- Pen cleaning and manure harvesting.
- Manure stockpiling and/or composting.
- Manure utilisation as fertiliser.

Manure is a valuable organic fertiliser. It is also the source of most odour emitted from a feedlot. Hence, there has been considerable research undertaken over the years into the characteristics of feedlot pen manure. This information can be used as a ground-truth against predictions of manure quantity and quality made in the mass-balance modelling.

The following sections review the current literature available in this area.

PHOTOGRAPH 3 - BOX SCRAPER USED TO CLEAN FEEDLOT PENS

3.4.2 Quantity of Harvested Feedlot Pen Manure

While there are many studies that report the characteristics (quality) of feedlot pen manure, surprisingly few studies have quantified the manure removed from feedlot pens. Recently, Kissinger et al. (2006b) and several others measured manure removal from a number of feedlot pens. Kissinger et al. (2007) reviewed available literature on the characteristics and quantity of manure removed from feedlot pens in the USA. Table 14 is a summary of his review. When using this data in Australia, care should be taken in interpreting the results as there are significant variations in:

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

Sweeten et al. (1985) analysed manure harvested from several different feedlots in the USA in 1979 and 1980. Samples were analysed for ash content, moisture content, total-N, 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 15 shows Sweeten's results from one site. Average manure depth is stated to be 115 mm 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 4 shows a US feedlot where 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 volumes with manure during pen cleaning. Photograph 5 shows pen mounding, another common activity in US feedlots. Earth mounds are constructed in the middle of feedlot pens to provide a dry refugee for cattle during wet conditions. These are very clearly shown in Photograph 5. Under these circumstances, when manure is removed, particularly under wet conditions, considerable soil can be taken with the manure.

In the second part of the Sweeten 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 14 - 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/hd/day unless otherwise indicated				
			Excreted Manure					
(Gilbertson et al. 1974)	420-kg feeder, Eastern NE	High energy		1.76	1.65			
(NRCS 1992)	420-kg feeder	High forage	88	2.84	2.53	0.13	0.046	0.1
	420-kg feeder	High 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	3.4	3.4	0.28	0.042	0.14
	340-kg feeder	High forage	92	2.4	2.4	0.19	0.028	0.094
	204-kg calf		92	1.3	1.3	0.063	0.020	0.041
			Harvested Manure					
(NRCS 1992)	454-kg feeder	Open lot	45					
		Surfaced – high forage	53					
		Surfaced – high energy	52					
(ASAE 2005)	446-kg feeder	High energy	33					
(Gilbertson et al. 1974)	420-kg feeder	Roofed – high energy	78					
	408-kg feeder	Eastern NE open lot – High energy	55					
(Gilbertson et al. 1971)	18.5 m^2/hd Eastern NE	Eastern NE open lot	54					
(Kissinger 2005)	Summer – 467 kg (132 pens) Winter – 465 kg (112 pens)	Eastern NE open lot	[a] 30±15 39±21	[b] 4.7±4.4 8.8±8.6	[b] 1.1±1.0 2.2±1.5	[b] 0.06±0.06 0.10±0.07		
(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 17-20 m^2/hd	Eastern CO open lots – 152 day feeding period	[a] 48±19% 38±26%		[c] 65±24% 37±35%	[c] 2.6±0.5%		
(Sweeten et al. 1985)		Eastern CO open lots – 152 day feeding period	[a] 52±10%		[c] 62±11%	[c] 2.7±0.4%	[c] 1.5±0.6%	

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

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. (In US studies, "feedlot soil" refers to the combination of soil and manure harvested from pens.) 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.

TABLE 15 - 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)

Kissinger et al. (2006a) 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 TS 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 TS 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. (2006a) 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.

In summary, in the last 25 years, the main good quality US 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 (1.7 to 3.2 t DM/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. None of these studies provide any data on the amount of soil or gravel that is replaced into pens to restore the level of the original pen surface.

There is an important point to note when using this data for “ground-truthing” feedlot mass-balance model results. When data is presented on the concentration of nutrients in feedlot manure (following section), this is determined on pen manure samples that may contain soil from the pen surface. This would tend to produce nutrient concentration levels that are lower than would be measured from a “pure” pen manure sample.

By contrast to US feedlots, 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 so as not to disrupt the compacted pen surface (Photograph 3). Hence, in most Australian feedlots, the amount of soil removed during pen cleaning should be minimal.

This should be reflected in a higher VS content in Australian harvested pen manure than in US or Canadian feedlots.

In Australia, for many years, the “standard” amount of manure removed from feedlot pens was quoted to be 1 t DM/hd/yr (2.74 kg DM/hd/day). In recent years, some lot feeders have indicated that their manure harvesting records indicate the real number could be half of this (0.5 t DM/hd/yr or 1.37 kg DM/hd/day). It is reasonable to suggest that improved diet formulation and feed processing methods have improved diet digestibility so that less manure is excreted per head.

PHOTOGRAPH 4 - A US FEEDLOT WITH PEN SURFACE OF UNCOMPACTED SOIL

PHOTOGRAPH 5 - FEEDLOT PEN WITH EARTH MOUNDS

In order to determine whether manure harvested from Australian feedlot pens contains less soil than US pen manure, Davis et al. (2010) undertook a study aimed at measuring the quantity and quality of manure removed from Australian feedlot pens and comparing that data with BEEFBAL predictions.

Six feedlots across Australia, which are representative of climatic zones, feeding regimes and manure management processes were selected as study sites for this project. A methodology to measure manure accumulation rates 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 using electromagnetic (EM) induction mapping. 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 (two feedlots dropped out of the study) were collected several times between pen cleaning events over a 12-month period. For each batch of cattle, records of cattle numbers and liveweights, ration types and feed consumption were collected. Feedlot managers were asked to completely clean pens at the start of the study and then clean them back down to exactly the same level at the end of the study so that there would be no net accumulation or reduction in manure in the feedpad.

The results showed that 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 feedpad compacts very tightly under dry conditions. Further, it is likely that some manure is removed from the pen as dust under these conditions but it was impossible to quantify this loss.

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. The wetter the pen surface, the greater the variation across the pen. Greater 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 regularly. 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 CH_4 or CO_2. 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.

Harvested manure data was obtained from four feedlots. The wet mass of manure from pens was weighed and representative samples taken to determine moisture content. From this data, TS and VS excreted was estimated and compared with BEEFBAL predicted values (Figure 8). Estimated data was comparable to predicted data at only one feedlot. At this feedlot, manure excretion ranged between 800 and 1200 kg DM/SCU/year. Dry conditions and maintenance of a manure interface layer ensured that the material harvested was manure only, thus resulting in comparable data. At this site, the data suggests that little soil was harvested.

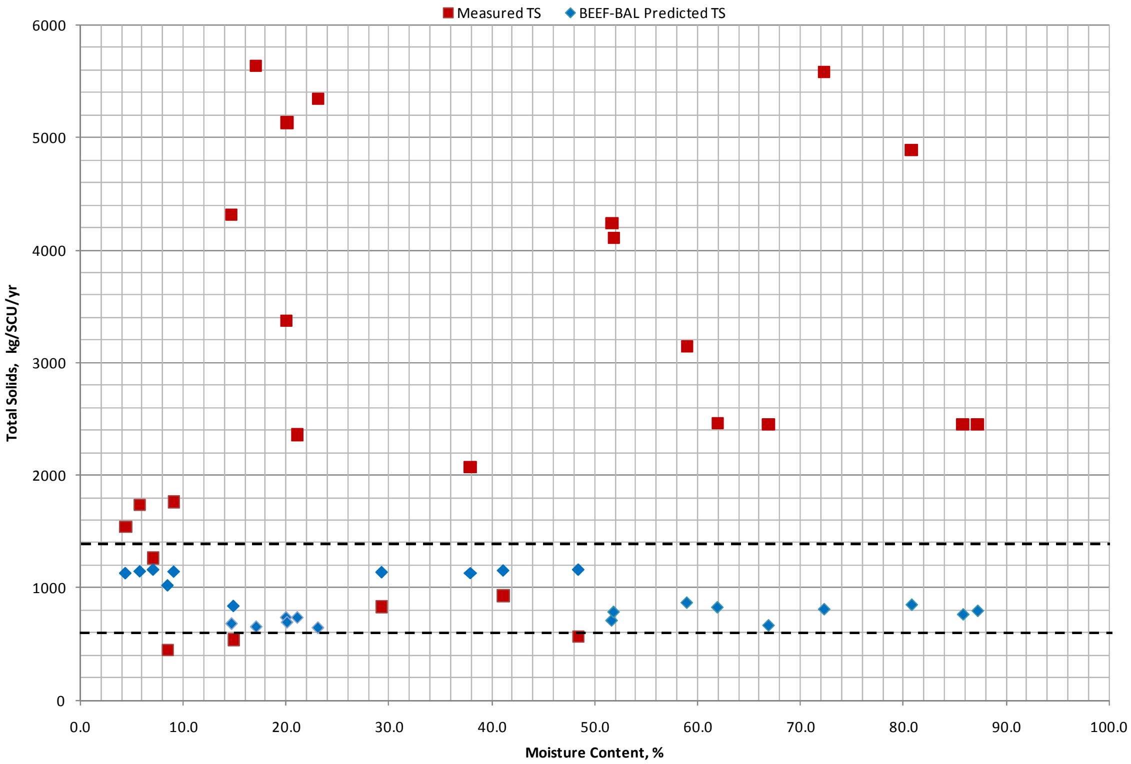


FIGURE 8 - COMPARISON OF MEASURED VERSUS PREDICTED MANURE (TS) REMOVED FROM PENS

At feedlots which cleaned their pens back to the gravel base, the measured TS was up to five times higher than the predicted value using DMDAMP in BEEFBAL. 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 lowering the organic content. This is consistent with US feedlots where “feedlot soil” is harvested.

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.

The data of Davis et al. (2010) suggests that, when only manure is removed from pens, the annual manure harvesting is about 1 t DM/hd/yr as previously quoted. However, as with US experience, if soil is removed with the manure, the annual harvested tonnage is much higher.

Hence, when using nutrient concentration data for feedlot pen manure for ground-truthing mass-balance modelling, the effect of harvesting soil with pen manure should be taken into account.

3.4.3 Quality (characteristics) of Feedlot Manure

The economic value of feedlot manure is largely determined by the composition (quality) of the manure (Table 16). Table 17 and Table 18 show 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 with a range of values to emphasise the inherent variation. This occurs due to wide variations in design, management, diets and climatic conditions between feedlots.

TABLE 16 - CHARACTERISTICS OF AUSTRALIAN FEEDLOT MANURE (1990S DATA)

Component	Units	Average*	Range
Dry matter	% wb	73.0	53.7 - 92
Volatile solids	% db	67.6	55 - 75.9
Ash	% db	32.4	24.1 - 45
pH		6.95	5.6 - 9.2
Total-N	% db	2.18	1.0 – 3.0
Ammonium-N	% db	0.038	0.04 – 0.17
Total-P	% db	0.8	0.4 – 1.3
Potassium	% db	2.32	1.5 – 4.0
Sodium	% db	0.61	0.3 – 1.3
Chloride	% db	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 variation in moisture, total N and P concentrations between fresh feedpad samples and stockpiled samples from southern Queensland lots is shown in Table 17. 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.

TABLE 17 - COMPARISON OF FEEDPAD AND STOCKPILED MANURE FROM SOUTHERN QUEENSLAND FEEDLOTS

(adapted from Lott 1995)

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

TABLE 18 - ANALYSIS OF FEEDPAD AND STOCKPILED MANURE FROM 6 AUSTRALIAN FEEDLOTS (2000 – 2010)

	Feedpad manure				Stockpiled manure			
	Sample count	Avg	Std Error	Range	Sample count	Avg	Std Error	Range
Moisture (%)	34	31.2	±3.9	5.6 - 82.1	9	29.63	±3.17	13.2 - 44.6
Electrical Conductivity (1:5)	12	15.3	±0.7	9.1 - 18.8	5	9.38	±2.98	2.64 - 16.2
Organic Matter (% d.b)	3	59.4	±7.6	39.6 - 82.6	4	59.40	±9.88	30 - 72.3
Organic Carbon (% d.b)	3	41.3	±4.3	34.1 - 49.1				
Total-N (% d.b)	14	2.8	±0.6	1.6 - 10.5	10	2.49	±0.18	1.5 - 3.3
Ammonia-N (mg/kg)	14	1378	±250.8	450 - 3300	9	3556	±1577	130.1 – 12000
Nitrate-N mg/kg	5	173	±1145	47 - 630				
Organic-N (mg/kg)	5	26 5	±6131	15120 – 103000				
Total solids (%)	14	68.7	±3.6	17.9 - 94.4	2	71.95	±4.85	67.1 - 76.8
Ash (% d.b)	3	39.5	±3.7	32.6 - 45.2				
Volatile solids (% d.b)	37	60.8	±2.1	37.8 - 83.4	2	67.45	±1.25	66.2 - 68.7

Davis et al. (2010) also measured the nitrogen content of manure during their study. Manure samples from four feedlots were analysed for total-N and its forms at three sampling events throughout the duration of the study. Manure samples were taken from Pen A at each feedlot at the initial pen cleaning, at the final pen cleaning and in between. The fresh manure samples represent faeces, as it was difficult to obtain the urine component (of manure) directly from unconfined animals in the field.

Table 19 to Table 22 summarise the harvested manure data for Feedlots A, D, E and F respectively. In these tables, the parameters are:

- S1 – Initial Pen Cleaning (start of batch of cattle)
- S2 – Midpoint Sample (midpoint of batch of cattle)
- S3 – End of the Batch

At Feedlot A (Table 19), samples were taken from Pen A during Batch 2. 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. 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. 2006a).

TABLE 19 - MANURE TOTAL-N - FEEDLOT A (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	1.9	18600	97.9	18206	0.04	7	2.0	387	59.2	19.2	80.8
S2	2.3	22600	94.9	21462	0.26	59	4.8	1080	83.4	20.2	87.9
S3	2.5	24500	86.4	21158	1.4	353	12.2	2990	86.2	19.6	80.4
Feedpad Manure											
S1	1.9	18700	85.4	15972	0.06	11	14.5	2717	52.3	36.4	63.6
S2	1.2	12200	83.1	10139	0.17	21	16.7	2040	36.6	57.7	42.3
S3	1.4	14400	82.7	11912	0.47	68	16.8	2420	41.9	44.4	55.6
Stockpile Manure											
S1	2	20000	82.1	16424	0.07	14	17.8	3562	50.3	37.2	62.8
S2	1.9	18900	85.6	16171	0.15	29	14.3	2700	44.6	48.3	51.7
S3	1.7	17000	89.2	15146	0.55	94	10.3	1760	46.9	42.1	57.9
Composted Manure											
S1	0.8	8000	85.3	6832	2.2	172	12.5	996	18.3	78.6	21.4
S2	1.0	9720	80.6	7830	8.0	780	11.4	1110	20.9	82.6	17.4
S3	1.0	9500	87.3	8294	0.48	46	12.2	1160	28.5	51.5	48.5

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%.

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 but also indicates that the urine component has not been included.

Table 20 shows the analysis results of manure samples taken from Feedlot D (Pen A) during Batch 2. The total-N content of fresh manure measured ranged from 3.3 to 3.8%, higher total-N contents than that measured for Feedlot A. Differences in the higher total-N content of fresh manure are 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 nitrogen 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-N 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 %.

Table 20 - Manure total-N - Feedlot D (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	3.8	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
						Feedpad 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

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

Generally, total-N content for Feedlot E (Table 21) 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.

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%.

Fresh faeces ammonia-N was found to range from 5.9 to 9.9% of total-N. 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.

These data provide further data points where mass-balance estimates of nitrogen throughout the feedlot system can be ground-truthed.

Table 21 - Manure total-N - 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
Feedpad 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

Table 22 - Manure total-N - Feedlot F (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	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
Feedpad 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

3.5 Runoff (Effluent) Production and Management

Heavy or persistent rainfall can cause runoff from the open pens. This runoff is contaminated by the manure in the pens and could cause environmental damage if not controlled. Hence, most feedlots have a holding pond (retention pond) at the lower end of the feedlot which captures and stores runoff prior to disposal by evaporation and/or irrigation (Photograph 6). Typically, there is a solids removal system (sediment basin) between the feedlot pens and the holding pond which removes a proportion of the entrained manure before it enters the holding pond (Photograph 7).

PHOTOGRAPH 6 - TYPICAL FEEDLOT RUNOFF HOLDING POND

PHOTOGRAPH 7 - TYPICAL SEDIMENTATION BASIN AT A FEEDLOT

3.5.1 Quantity of Feedlot Effluent

The quantity of runoff (effluent) generated by a feedlot is dependent on several factors including:

- rainfall (amount and intensity)
- cattle stocking density and occupancy
- feedlot design (pen slopes, pen surface design)
- feedlot management (pen cleaning frequency).

Assuming that manure is 90% water, it has been calculated that heavy cattle stocked at 10 m^2/head can add up to 900 mm/year of additional "rainfall" to the feedpad surface. Hence, a feedlot pen would be expected to generate considerably more runoff than adjacent fields.

A number of computer simulation models have been developed to estimate feedlot runoff. Two daily-time-step models are MEDLI (Atzeni et al. 2001) and FSIM (Lott 1997). As a rule-of-thumb, the runoff from the feedlot should be in the range of 25% to 40% of annual rainfall and the catchment area of the feedlot should be 2-3 times the pen area. Total pen area is feedlot capacity (head) times stocking density (m^2/head).

3.5.2 Quality of Feedlot Effluent

The measured characteristics of feedlot effluent have been collated from a number of sources. The "Designing Better Feedlots" data was collected in the early 1990's, with some more recent data collected by the DEEDI (formerly DPI&F Queensland) from 11 feedlots in southern Queensland (Table 23). These results show a wide variation in the data.

Recently, Tucker et al. (2011) collated feedlot holding pond data from a number of sources including on-going environmental monitoring data (taken for regulatory compliance) and specific samples taken for various research projects. In total, 239 samples were obtained. Some of these were discarded as non-representative as they were taken from feedlots that were either not occupied or not fully developed, so that much of the catchment was not pen surface. Other samples were discarded due to unexplained anomalies in the data. This left 194 samples for analysis. Table 24 shows the N, P and K data for Australian feedlot holding ponds (Tucker et al. 2011). There is a wide range for all parameters.

It should also be noted that the volume of effluent available for irrigation is influenced by the evaporation losses from the holding pond and rainfall collected on the holding pond surface. Nutrient concentrations in feedlot holding ponds will also be influenced by evaporation (leading to an increase in nutrient concentration), solids settling (leading to a decrease in nutrient concentration) and volatilisation (leading to a decrease in nitrogen concentration).

Thus "typical or average" pond supernatant (irrigation water) concentrations of nutrients and salts cannot be specified. These factors are site specific and driven by design, management, diets and climatic factors. In order to calculate the amount of nutrients entering the pond, the BEEFBAL model needs both the volume of runoff (based on rainfall and runoff coefficients) and the average or typical concentration of the captured effluent. A sensitivity analysis could be conducted to examine the influence of different assumptions of feedlot pond nutrient concentrations on BEEFBAL nutrient balances but this is a small component of the overall nutrient mass balance.

TABLE 23 - CHARACTERISTICS OF AUSTRALIAN FEEDLOT POND EFFLUENT (1990’S)

		Designing Better Feedlots[1]	DPI&F Qld (2001) – Unpublished data[2]
Dry matter	% wb	1.57 (1.2 – 2.6)	
Volatile solids	% db	48.56 (39 – 62)	
Ash	% db	51.44 (38 – 60)	
pH		7.43 (6.9 – 8.1)	8.0 (7.2 – 9.1)
COD	mg/L	9579.2 (4862 – 16806)	
Total-N	mg/L	720.55 (286 – 1155)	
TKN			188 (46 – 333)
Ammonium-N	mg/L		139 (37 – 277)
Total-P	mg/L	103.76 (26 – 440)	65 (22 – 114)
Ortho-P	mg/L		20 (7 – 45)
Potassium	mg/L		784 (307 – 2800)
Sulphate	mg/L		59 (1 –317)
Boron	mg/L		
Kjeldahl Copper	mg/L		0.100 (0.03 – 0.19)
Dissolved Iron	mg/L		1.45 (0.4 – 4.8)
Manganese	mg/L		0.18 (0.1 – 0.5)
Zinc	mg/L		0.40 (0.1 – 1.0)
Calcium	mg/L		65 (25 – 118)
Magnesium	mg/L		158 (59 –441)
Sodium	mg/L		473 (102 – 933)
Chloride	mg/L	420 (333 – 674)	1256 (370 – 2660)
Conductivity	dS/m	13.19 (3.88 – 37.8)	6.8 (2.2 – 11.4)
SAR			7.15 (2.2 – 14.5)

[1]. Designing Better Feedlots (Watts & Tucker 1994) - Data from ASAE, Powell and DPI
[2]. DPI&F Qld 2001 – 11 Feedlots on the Darling Downs

TABLE 24 - N, P AND K DATA FOR FEEDLOT POND EFFLUENT

Parameter	Units	No. of Samples	Mean	Median	Max.	Min.	Std Dev.	Std Error
Total-N	mg/L	175	219.8	165.0	1095.0	25.0	193.5	14.6
TKN	mg/L	173	217.6	153.0	1095.0	23.0	194.4	14.8
Ammonia	mg/L	99	114.7	68.7	861.4	0.1	133.8	13.4
Ammonia-N	mg/L	99	89.1	53.3	670.0	0.1	104.0	10.5
Nitrate	mg/L	101	10.1	1.0	305.0	0.1	33.9	3.4
Nitrate-N	mg/L	96	2.3	0.2	68.8	0.0	7.7	0.8
Nitrite	mg/L	19	1.7	1.0	16.8	0.0	3.7	0.8
Nitrite-N	mg/L	20	0.5	0.3	5.1	0.0	1.1	0.2
Total-P	mg/L	171	70.6	56.0	387.0	1.8	52.5	4.0
Phosphate-P	mg/L	102	16.8	10.1	132.7	0.0	18.8	1.9
Phosphate	mg/L	93	51.7	30.0	407.1	1.0	59.6	6.2
Phosphate P/Total-P	%	94	31	26	91	2	23	2
Potassium	mg/L	122	1091.5	796.0	6390.0	20.5	990.3	89.7

Source: Tucker et al. (2011)

3.6 Nitrogen Loss Pathways at a Feedlot

3.6.1 Overview of Nitrogen Loss Pathways

A comprehensive mass-balance of N within a feedlot system is complex, as N is present within the feedlot system in numerous chemical forms, including. protein-N, urea-N, ammonia-N, nitrogen oxides-N, N_2O-N and ammonium-N. Each form has different properties that influence the balance of N loss from the separate pathways. Climatic and environmental conditions (both on the macro and micro level) influence the partitioning of N loss between different pathways. Further, N losses from feedlot manure occur at the three major manure management stages:

- the feedpad
- the effluent treatment and holding, and
- from stockpile and/or composting.

At each of manure management stage, volatilisation of N occurs in the form of N_2O and NH_3. This is presented diagrammatically in Figure 9. Nitrous oxide is also produced from the deposition of volatilised NH_3 (from all sources) to the soil surrounding the feedlot, and therefore must be considered within GHG emission estimates from feedlots.

In addition to N losses as NH_3 and N_2O, N is lost from the feedlot system in other nitrogenous compounds. The form of these is likely to include:

- Nitrogen oxides (NO_x)
    - Nitrate (NO_3^-)
    - Nitrite (NO_2^-)
    - Nitric oxide (NO)
- Ammonium (NH_4)
- Dinitrogen (N_2)
- Nitrogen within dust particles

Nitrogen flows out of the feedlot in these forms have not been quantified scientifically. Therefore a gap exists in the total feedlot N balance. Within the theoretical mass balance, it is assumed that losses from the feedlot in these forms are minimal.

The factors that influence the production of N_2O within manure from the pen surface are discussed in Section 3.6.2.5. It is recognised that the same factors are relevant to the discussion of N_2O produced from stockpiled and composting manure, and also from the application of manure and effluent to soils. Table 25 details reported values of N loss (NH_3 and N_2O), as a percentage of N excreted.

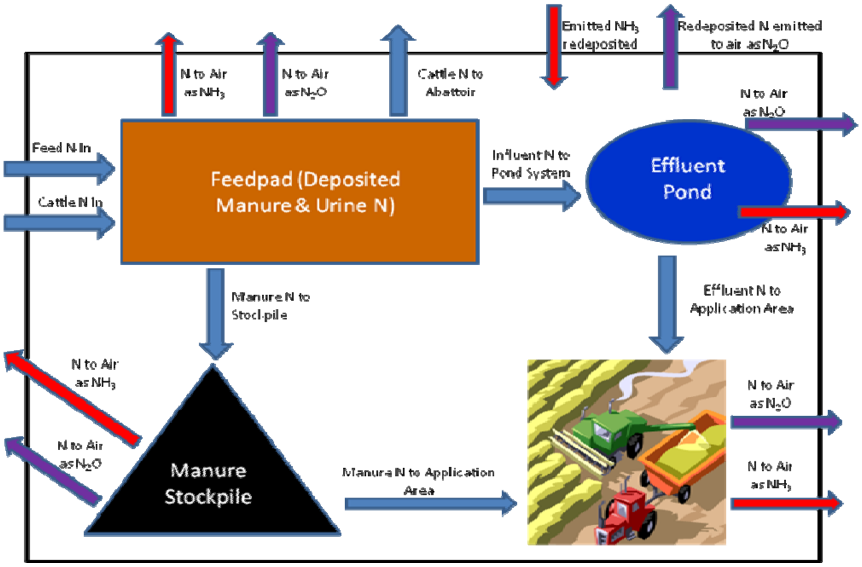


FIGURE 9 - THEORETICAL MASS FLOW FOR EXCRETED N IN AUSTRALIAN FEEDLOTS

TABLE 25 - REPORTED VALUES OF N LOSS (NH_3-N AND N_2O-N), AS A PERCENT OF N EXCRETED

(Sourced from IPCC and DCCEE, and reviewed literature)

Emission source	N loss (% of N excreted) Value	Range	min	max	Comments	Reference
NH_3-N (% of N excreted)		50.0 - 55.0	50.0	55.0		Flesch et al. (2007)
	0.59				IHF measurement (Vic and Qld, Australia)	Denmead et al. (2008)
		57.0 - 67.0	57.0	67.0	6 to 12 months cleaning intervals	Bierman et al. (1999)
		47.0 - 69.0	47.0	69.0	18 harvesting experiments	Kissinger et al. (2006a)
		25.2 - 47.9	25.2	47.9	Bran supplemented treatments	Farran et al. (2004)
		55.5 - 78.4	55.5	74.4	Varying pen cleaning frequency	Wilson et al. (2004)
		62.0 - 64.0	62.0	64.0	10 week study - Texas, USA	Todd et al. (2006)
		63.0 - 65.0	63.0	65.0	2 month study - Texas, USA	Flesch et al. (2007)
	80				Review of literature for NPI review	FSA Consulting (2006)
	30				Suggested values	IPCC (2006)
	30	20.0 - 50.0	20.0	50.0	Suggested values	DCC (2007)
	70				*Based on literature and measured harvested manure N values*	*Estimate derived from BEEFBAL*
Range values		**20.0 - 74.4**	**20.0**	**74.4**		
N_2O-N (% of N excreted)		†	†	0.06	Based on measured value. Percent of total excreted N estimated from BEEFBAL	Boadi et al. (2004)
	2.0	1.0 - 4.0	1.0	4.0	Suggested values	IPCC (2006)
	2.0				Suggested values	DCC (2007)
Range values		**1 - 4**	**1.0**	**4.0**		

† values from Boadi et al. (2004) are excluded from reported ranges, since excreted N values are estimated (by **extrapolation**) from BEEFBAL using N intake data.

3.6.2 Nitrogen Losses from the Feedpad

The N excreted onto a feedpad 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.

3.6.2.1 Ammonia-N Volatilisation

The greatest NH_3 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 NH_3 (Flesch et al. 2007). Bierman et al. (1999) reported that 57 to 67% of the total-N excreted is volatilised by the time that feedlot pens are cleaned, which is typically every 6 to 12 months.

Faecal N is 50% organic-N and 50% NH_3 (Mackie et al. 1998). However, urine contains up to 97% urea-N, which is readily converted by microbial urease to NH_3 following excretion from cattle (Mobley & Hausinger 1989). As NH_3 is potentially highly volatile, there is scope for large N losses from the pen surface. The volatilisation loss is dependent on a range of parameters including:

- manure and air temperature
- manure moisture content
- manure pH
- C to N 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. (2006a) summarised the data from 18 separate manure harvesting experiments in Nebraska. Since Nebraska generally has cold, relatively dry winters and warm, wet summers, the data was summarised into summer and winter experiments. In each experiment, the N excreted onto the pen surface was determined as the residual between N fed and N retained in the cattle. They measured N in runoff and the N in harvested manure. From this data, they calculated the N lost by volatilisation (expressed as a % of the N excreted) as the residual.

Kissinger et al. (2006a) found that, on average, 69% of the excreted N was lost by volatilisation during summer. This dropped to 47.2% lost in the winter trials. This difference was primarily attributed to different ambient temperatures (Kissinger et al. 2006a).

3.6.2.2 Effect of Carbon to Nitrogen Ratio

Erickson et al. (2002) undertook three experiments to evaluate digestibility effects of rations on N 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 to N ratio of the manure. Adding carbon to manure decreases N loss by lowering pH when manure is stored anaerobically or by microbial immobilisation when stored aerobically (Erickson et al. 2002).

Put simply, N 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 N 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. Adams et al. (2004) observed 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 N 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. Adams et al. (2004) concluded that the increase in volatilisation due to temperature increase dominated the N balance. Regardless, the addition of carbon to the pen surface, either through the ration or the addition of bedding, has the potential to reduce N volatilisation from pen surfaces.

3.6.2.3 Effect of Manure Management

Farran et al. (2004) undertook a study to investigate the effect of pen cleaning frequency on N losses from a pen surface. Their hypothesis was as follows: if N 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 (VS) excretion to the pens. The hypothesis behind the diet treatments was that a higher C:N ratio in the manure would decrease N losses.

When N loss from the pen surface is expressed as a percentage of N 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 in the manure. 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 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 N loss from pens. Their methodology is similar to Farran et al. (2004). In a 2001 study, Wilson et al. (2004), observed monthly pen cleaning to result in 63.6% N loss. This 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 (Wilson et al. 2004).

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

3.6.2.4 Effect of Ration Additives

Sherwood et al. (2005) undertook a N 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 NH_3 on the feedlot pen surface thus reducing NH_3 losses and increasing the N content of the manure. They found that a 1.2% inclusion of clinoptilolite in the feedlot ration did not affect the N balance of the feedlot pen (Sherwood et al. 2005).

Summary

Using theoretical mass balance estimates, NH_3 volatilisation from the feed pad are the single largest form of N loss from the feedlot, and are likely to be in the order of 75% of excreted N (64% of total-N intake).

3.6.2.5 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.

3.6.2.6 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. The solid manure fraction was stored at heated temperature to simulate heat production during long-term stockpiling. The solid manure fraction was kept at 41°C, reducing by 2°C each week of the experiment.

The formation of a persistent crust on the liquid manure samples (Külling et al. 2003) was acknowledged as a contributor to higher N_2O emissions, when compared to previous studies in manure storage. Others suggest that covering of slurry manure storage with organic material (straw) may increase 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 as a fertiliser are in the form of N_2O.

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) are probably not applicable to Australia. 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.

3.6.2.7 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, there is a need to evaluate the emission factors used to estimate N_2O emissions from Australian feedlots. Understanding the drivers 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 and a soil profile.

Cole et al. (2009) comprehensively investigated the chemical characteristics of the manure and soil layers within three feedlots in Texas (USA) over four 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.

Based on the range of values (1 to 4% of N excreted) reported in IPCC (IPCC 2006), a theoretical mass balance estimates that approximately 1.7% of excreted N is volatilised as N_2O (Figure 17). In the same theoretical mass balance, N_2O emissions from the feedpad are estimated to comprise approximately 3.7% of total feed intake (Figure 16).

3.6.2.8 Ratio of N_2O to N_2 production

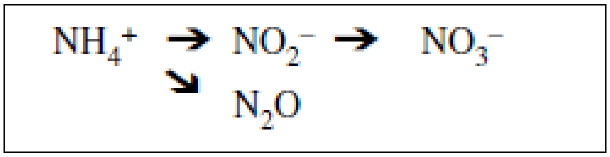
Observed differences in the production ratios of N_2O to N_2 have been observed between different frequency of cattle traffic and deposition of excreta for intensively housed cattle in Europe. An over wintering area (pastures where high densities of cattle are located for relatively long periods during 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 occurred during early spring at relatively low temperatures (Hynst et al. 2007).

These observations appear 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 TS/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).

3.6.2.9 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 seen diagram below. Nitrous oxide is a by-product of this process (Kebreab et al. 2006, Stevens et al. 1998).



$$\begin{tikzcd} NH_4^+ \arrow[r] \arrow[dr] & NO_2^- \arrow[r] & NO_3^- \\ & N_2O & \end{tikzcd}$$

3.6.2.10 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). It is well established that denitrification occurs under anaerobic conditions (Hao et al. 2001). This process is can be altered by several conditions (as listed above).

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

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; WFPS) is a significant determining factor in the N_2O to N_2 ratio (Figure 6), although other factors mentioned previously are also important.

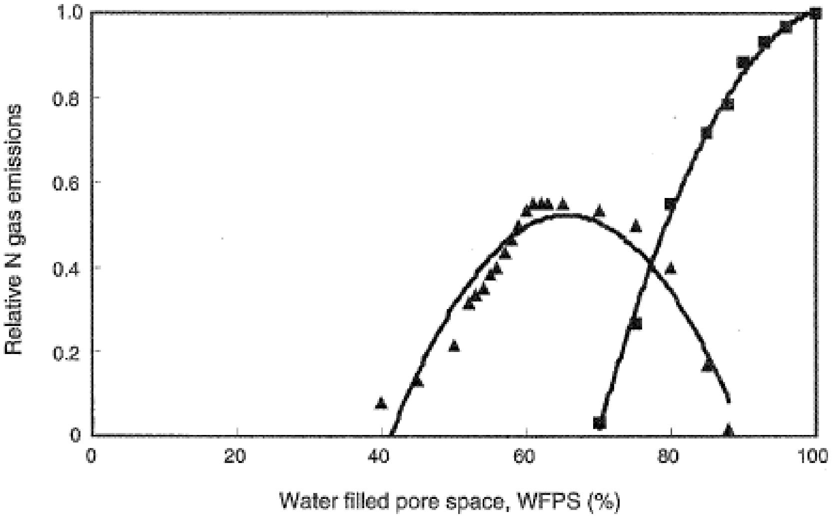


FIGURE 10 - GENERALISED RELATIONSHIP BETWEEN WATER-FILLED PORE SPACE OF SOILS AND RELATIVE FLUXES OF N_2O (▲) AND N_2 (■) FROM NITRIFICATION AND DENITRIFICATION

Taken from (Dalal et al. 2003)

3.6.2.11 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 (see Table 42). 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 increasing 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). Straw incorporation 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 (Table 42). It is not likely that findings of studies in Northern Hemisphere climates will be directly 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.

3.6.2.12 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 N balance of a pen.

Erickson (2002), Farran et al. (2004), Luebbe et al. (2008, 2009) all use the same approach to determine N loss in runoff. In their experimental work, N 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 11 shows the N lost in runoff in these studies (expressed as a percentage of excreted N). It ranges from almost 0% to almost 5%. Kissinger et al. (2006a) 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 N excretion in pen runoff while winter pens averaged 1.8% N loss.

Bierman et al. (1999) calculated the N 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 N 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 N content of the runoff was 400 mg N/L, 117 kg of N would be lost from the pen surface. If the cattle excrete 80 kg of N 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 N concentration of the runoff would be higher, as would the percentage loss, say 2%.

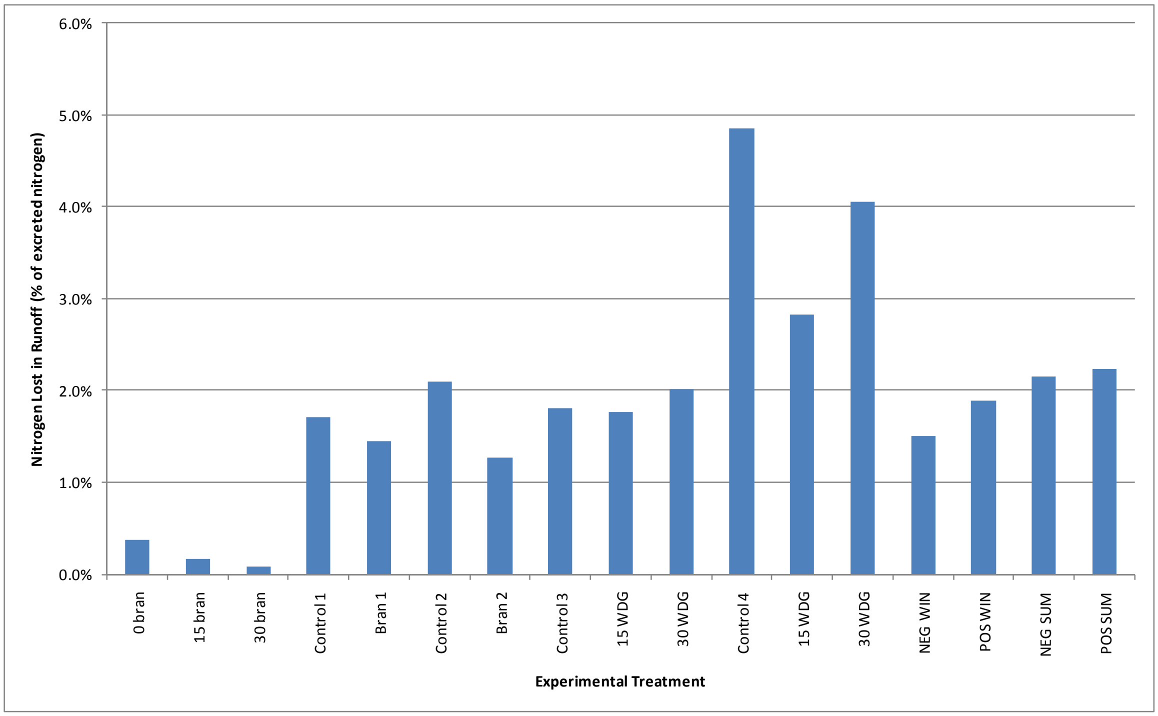


FIGURE 11 - PEN N LOST IN RUNOFF (% OF EXCRETED N) – NUMEROUS STUDIES

3.6.3 Nitrogen Losses from the Feedlot Pond

3.6.3.1 Gaseous Nitrogen Losses

Atzeni et al. (2001) highlighted the rate of N volatilisation as an area requiring further research. There is little experimental data on the volatilisation rates of NH_3 from Australian feedlot ponds. The reported range of values for runoff quality in holding ponds is both broad and variable within and between feedlots and difficult to predict. In the absence of published Australian data, the greatest challenge remains the prediction of runoff quality.

Sweeten and Wolfe (1994) found that well maintained settling ponds produced a total-N removal efficiency of 14 to 24%. Culley and Phillips (1989) observed that liquid storages can lose approximately 33% of the N by volatilisation. Madden & Dornbush (1971) estimated potential N reductions of around 35%.

Available research data regarding NH_3-N volatilisation from feedlot effluent ponds is limited. As such, IPCC and DCCEE estimated values of N loss (N_2O and NH_4) from liquid manure storage are used within the theoretical mass balance Table 26.

TABLE 26 - REPORTED VALUES OF N LOSS (NH_3-N AND N_2O-N), AS A PERCENT OF N TO POND

(Sourced from IPCC and DCCEE, and reviewed literature)

	N loss (% of N to pond)					
Emission source	Value	Range	min	max	Comments	Reference
NH_3-N emissions from N entering pond	35.0	20.0 - 80.0	20.0	80.0	Values from dairy ponds, as no data from beef feedlots	IPCC (2006)
	30.0				Value from dairy ponds, as no data from beef feedlots	DCC (2007)
	35.0				Review of literature for NPI Review	FSA Consulting (2006)
Range values		**20 - 80**	**20.0**	**80.0**		
	0.0				Assumes no $N_2$0 emissions from anaerobic ponds	IPCC (2006)
N_2O-N emissions from N entering pond	**0.1**				Value for uncovered anaerobic ponds	DCC (2007)

Using a theoretical mass-balance, NH_3-N volatilisation from feedlot effluent ponds is estimated that to be in the order of 35% of total-N to pond (0.5 kg/SCU/yr) (Figure 17).

3.6.4 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 C:N 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).

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 27. 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.

Nitrogen 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.

TABLE 27 - REPORTED 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 (% of N Stored)					
Emission source	Value	Range	min	max	Comments	Reference
NH_3-N (% of N Stored)	45†	10.0 - 65.0	10.0	65.0	Source: Table 10.22 of IPCC 2006	IPCC (2006)
	30				From dairy; no beef cattle value provided	DCC (2007)
	25	15.0 - 40.0	15.0	40.0	Review of literature for NPI Review	FSA Consulting (2006)
	25					*BEEFBAL*
Range values		**10.0 – 65.0**	**10.0**	**65.0**		
N_2O-N (% of N Stored)		0.62 - 1.07	0.62	1.07	Passive storage vs. turning	Hao et al. (2001)
		0.39 - .68	0.39	0.68	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)
	10.0	5.0 - 20.0	5.00	20.0	Intensive composting (frequent turning)	IPCC (2006)
	0.60	0.3 - 1.2	0.30	1.20	Static piles with forced aeration	IPCC (2006)
	1.00	0.5 - 2.0	0.5	2.0	Passive windrow - infrequent turning	IPCC (2006)
	0.50	0.25	0.27	1.00	Solid storage	IPCC (2006)
Range values		**0.27 - 20**	**0.27**	**20.0**		

† High N_2O-N (as percentage of total-N to stockpile), since freshly excreted manure was used within simulated storage experiments. See Table 36 for further comments regarding Kulling et al. (2003).

3.6.5 Nitrogen Losses from Land Application of Manure and Effluent

Fresh, stockpiled manure or composted manure is typically spread on cropped or pastured land. Numerous methods are used to apply and incorporate manure and N loss varies widely depending on the method used. The most common method is broadcast spreading.

Rotz (2004) suggests that solid cattle manure loses some 20% (8–60%) of the initial total-N applied through NH_3 volatilisation, 1–25% as NO_3 and <1–4% as N_2O. N can be lost through surface runoff but this is generally quite low (<3% up to 10%). Surface spreading of manure without soil incorporation often ensures the loss of all remaining inorganic N (typically 20-40% of remaining N). Rapid incorporation decreases this loss by at least 50% (Rotz 2004) and by up to 98% (Svensson (1994)).

Research suggests a loss rate in the order of 20% would be applicable for manure application under Australian conditions.

Most N losses during irrigation are due to NH_3 volatilisation. The type of irrigation system affects the volatilisation rate. An irrigation system producing small droplets may produce higher volatilisation rates, because of the greater total surface area of the droplets. However, Chastain and Montes (2004) conducted an assessment of NH_3 volatilisation losses during sprinkler irrigation. Data in literature included losses from travelling gun, centre pivot and impact sprinkler irrigation for dairy, swine, and beef effluent. Total ammonia-N (TAN) (NH_3–N + NH_4–N) collected on the ground did not differ from that collected from irrigated wastewater. Furthermore Chastain & Montes (2004) concluded evaporation and drift were not major factors in TAN loss.

N losses during irrigation also vary with pH. Henderson et al. (1955) showed that at a neutral pH (piggery effluent) N losses ranged from about 8-10%.

Volatilisation of N may be decreased by acidifying slurry (Frost et al. 1990, Pain et al. 1990), injection into the soil, or the use of NH_3 inhibitors. Studies in Northern Ireland have indicated that the injection of animal slurries into the soil offers improved nutrient management over surface application, by reducing losses of gaseous N (Long & Gracey 1990, Thompson & Pain 1987) and reducing coating and scorching of herbage by slurry (Long & Gracey 1990, Prins & Snijders 1987). Long & Gracey (1990) concluded that mid-season injection of slurry increased herbage dry matter production and consequent N use. However, two studies illustrate that denitrification with injection is greater than denitrification with surface application of manure (Comfort et al. 1990, Thompson & Pain 1987). The suggested explanation is that the injected manure is concentrated in a smaller volume of soil with a corresponding increase in microbial activity and hence increased potential for nitrification-denitrification. The effectiveness of injected liquid manure has been improved by maintaining the NH_4-N form by adding nitrification inhibitors. Pain et al. (1990) found that the amount of N lost through denitrification was reduced by over 70% using the nitrification inhibitor 'dicyandiamide.' As well as being an effective method of utilising slurry N, injection also offers environmental benefits by reducing odour and the risk or surface runoff (Dam Koeford 1981, Hall 1986, Long & Gracey 1990). Soil type, soil plasticity, slope and stoniness, however, limit the application of slurry injection.

Ammonia emission is reported to increase by 5% of ammonium-N for each 1% increase in slurry DM content between 1% and 9% DM (Chambers et al. 1999). In a literature summary of NH_3 volatilisation losses during irrigation, Chastain and Montes (2004) found NH_3 loss ranged from 2.5% to 13% with an overall mean of 4% of the TAN applied.

Other studies (Safley Jr. et al. 1992, Westerman et al. 1995), have reported volatilisation losses of 10 to 18% during irrigation of liquid swine manure. However, Welsh (1973) concluded volatilisation losses during irrigation of dairy slurry, liquid swine manure and effluent from an oxidation ditch were insignificant. Chastain and Montes (2004) reported on three studies (Montes 2002, Safley Jr. et al. 1992, Welsh 1973) that quantified NH_3 losses and conclusions were inconclusive.

Similarly, Smith et al. (2001) reported NH_3 losses from a range of overseas research. These losses ranged from 14-38% for piggery effluent reuse. The research by Smith et al. (2001) using piggery effluent on a winter and summer crop rotation in south-eastern Australia showed that about 12% of the total-N was lost by NH_3 volatilisation and represented a less significant loss pathway than previously thought. This research studied a centre-pivot irrigator applying 18 mm of effluent every three days. The irrigator operated 24 hours a day. When these losses were split into daytime and night-time losses, they corresponded to 21% and 3% respectively. Night-time effluent irrigation is not regularly practiced for intensive animal operations in Australia, being discouraged from an odour dispersion perspective. Smith et al. (2001) also states that the average 12% loss ignores losses from the boom, which account for approximately 7% loss. Smith & Snow (2001) also studied the loss of N from an overland flow system. They found that at least 48% of the N from the piggery effluent applied was lost by either volatilisation or denitrification.

The NH_4-N losses associated with land application occur over a 1 to 4 day period following application (Meisinger & Jokelo 2000, Montes 2002). The percentage of NH_3 in the TAN form depends on pH. About 8–10 % of TAN is in the NH_3 form hence only a small fraction of the TAN has the potential to be lost during land application.

The literature identifies that volatilisation losses during irrigation typically range from 8-20%. Hence, it is assumed that a reasonable estimate is that 15% of the N in effluent is lost during irrigation.

TABLE 28 - VALUES OF N LOSS (NH_3-N AND N_2O-N), AS A PERCENT OF TOTAL-N APPLIED IN MANURE

(Sourced from IPCC and DCCEE, and reviewed literature)

	N loss (% of N Applied)					
Emission source	Value	Range	Min.	Max.	Comments	Reference
NH_3-N (% of N Applied)	20.0	8.0 - 60.0	8.0	60.0	Solid cattle manure application	Rotz (2004)
		10.0 - 30.0	10.0	30.0	Review of literature for NPI review	FSA Consulting (2006)
	10.7					Gac et al. (2007)
Range values		**8 - 60**	**8.0**	**60.0**		
N_2O-N (% of N Applied)		1.0 - 4.0	1.0	4.0	Solid cattle manure application	Rotz (2004)
	0.3	0.2 - 0.4	0.2	0.4	4 studies from Canada applying 173 - 510 kg N/ha/yr	Lessard et al. (1996)
		2.0 - 3.4	2.0	3.4	Canadian study, 1 year	Chang et al. (1998)
	0.16				Farmyard manure, surface applied	Thorman et al. (2007)
		0.09 - 0.12	0.09	0.12	Farmyard manure, incorporated	Thorman et al. (2007)
		0.025 - 0.85	0.025	0.85	6 day study, 180, 450 and 900 kg N/ha	Paul et al. (1993)
	0.085				7 months, autumn, winter experiments. 570 kg N/ha	Wantanabe et al. (1997)
Range values		**0.025 – 4.0**	**0.03**	**4.0**		

3.6.6 Indirect Nitrous Oxide Emissions

The DCCEE (2010) and IPCC (2006) identify further N_2O emissions associated with feedlots via the volatilisation and deposition of NH_3-N from the feedlot. These NH_3-N losses are associated with the feedpad, manure stockpile/compost, effluent pond and from application losses. These need to be added to give a total NH_3-N loss available for deposition and re-volatilisation as N_2O. DCCEE (2010) and IPCC (2006) assume 1% of the deposited NH_3-N is re-volatilised as N_2O.

The literature suggests that indirect N_2O losses from the deposition of NH_3 are 1% of deposited NH_3-N.

3.6.7 Knowledge Gaps and Recommendations – Nitrogen Balance

As discussed in Section 3.6.1, it is difficult to fully quantify a nitrogen balance within a feedlot considering the many forms of N, and the many potential loss pathways. It is not surprising then, that a full mass-balance of N within feedlots has not been completed in Australia. This is the primary limitation regarding N mass flows within feedlots. In addition to this, differences between Australian and climatic conditions and feedlot construction in the Northern Hemisphere mean that values reported in the US literature may not be generally useful for Australian conditions. Seasonality and climatic conditions have a significant effect on nutrient loss pathways

A further limitation regarding N in feedlots is the assumption that N losses in the forms of NOx (nitrate, nitrite and nitric oxide) are minimal from the feedlot system. These loss pathways have not been measured and quantities of N loss in these forms (while likely to be small) are not measured. The loss of nutrients (not only N) from the feedlot in the form of dust may be considerable in Australian feedlots, especially during prolonged drought conditions. It is likely that nutrient loss via dust removed from manure management systems may, under certain conditions, may be large. Quantifying the N losses from the feedlot in response to these factors remains a challenge.

3.7 Phosphorus Pathways in a Feedlot

The pathways of phosphorus movement are considerably more simple than for N, since P is not volatilised. After excretion, phosphorus movement from the feedpad occurs in sediment transported in runoff from the feedpad to the holding pond (Eigenberg et al. 1998) or occurs when manure is harvested from the pens and stockpiled or composted. Within a mass-balance context, the partitioning of excreted P between the holding pond and solid manure are based on typical P concentrations in effluent and manure as there is no fundamental understanding of the factors that partition P between runoff and manure.

3.8 Potassium Pathways in a Feedlot

Potassium pathways are similar to phosphorus pathways. Potassium is not volatilised, but unlike P, K is highly soluble. This causes a concentrating effect of K within feedlot effluent compared to K content within feed. Based on analysis included in this report (Table 23 and Table 24), the ratio of P:K within the effluent is between 1:12 and 1:16 (mean data). However, the P:K ratio in the diet (Table 5) is only 1:1.6. This highlights that a larger proportion of the fed and subsequently excreted K is removed from the feedlot pad in runoff compared to P.

3.9 Carbon Loss Pathways

3.9.1 Overview of Carbon Loss Pathways

A significant proportion of the excreted manure carbon is lost from the feedpad as a result of bacterial oxidation, predominantly in the forms of CO_2 and CH_4. The carbon loss pathways within a feedlot are presented diagrammatically in Figure 12. The percentage that is lost will be dependent on the pad conditions (pH, moisture content, temperature) and the frequency between manure harvesting events. There is currently little reported data on VS loss from the feedpad. However, there is measured data on the VS:TS ratio of fresh and harvested manure. Assuming all excreted FS is harvested, it can be estimated that VS loss from fresh manure is about 50% before manure harvesting (pen cleaning).

Carbon dioxide GHG emissions from livestock are assumed to be zero; i.e. the CO_2 photosynthesised by plants is returned to the atmosphere as respired CO_2 (Dong et al. 2006). Methane is produced under anaerobic conditions by methanogens (Metcalf & Eddy Inc. 2003), while CO_2 is produced under aerobic conditions. Therefore, manure management systems that involve anaerobic digestion will produce significantly greater proportions of CH_4 (Dong et al. 2006) than systems that are aerobic. Other factors that influence the CH_4 production from manure are discussed within this section.

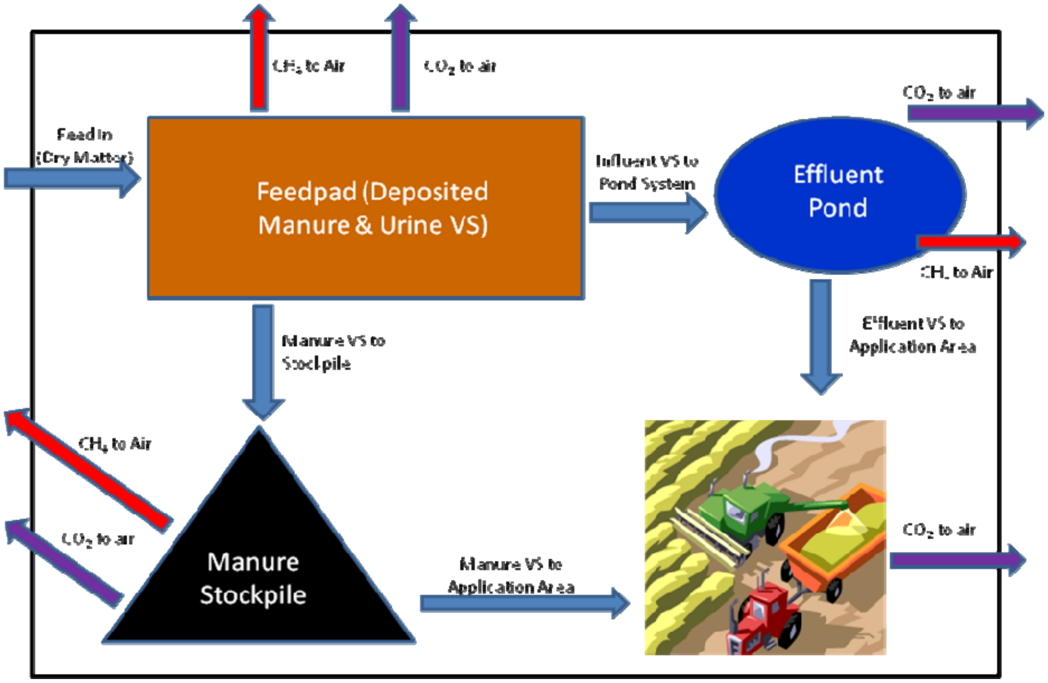


FIGURE 12 - THEORETICAL MASS FLOW FOR CARBON (VS) IN AUSTRALIAN FEEDLOTS

3.9.2 Methane Carbon Losses from the Feedlot Pen

3.9.2.1 Methane Emission Estimation

The VS component of manure is used for CH_4 estimation, since the B_o and MCF are applied to the estimated VS. To determine the CH_4 production from manure, it is necessary to convert VS content to CH_4 generation. This is done by applying the B_o factor and the MCF factor (see Equation 19, Section 3.3.10.3).

3.9.2.2 B_o Factor

The B_o is the maximum CH_4-producing capacity for manure produced by an animal and has the units of m^3 CH_4/kg VS (IPCC 2006). The B_o production 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 29 shows IPCC values for B_o for pigs, dairy cattle and beef cattle in Australia (Oceania).

TABLE 29 - MAXIMUM METHANE-PRODUCING CAPACITY OF 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 CH_4 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 B_o will always be lower than the Bu yield because a fraction of the substrate is used to synthesize 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 NH_3 and volatile fatty acids (VFA) is another factor contributing to the actual CH_4 yield being lower than the potential yield which would be obtained if inhibition was not present. It has been observed that both the B_o and the volumetric CH_4 production (L CH_4/ m^3 manure) of manure from different origins can vary considerably. Moller et al. (2004) notes that the B_o (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. (2005) 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. (2005) suggests that B_o takes into account housing and feeding systems. This has clear implications for actual CH_4 yield predictions from a manure treatment system depending on the MCF applied.

The B_o is determined by anaerobically digesting a sample of manure and measuring the CH_4 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. Variances 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 CH_4 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, with variable data (Table 30).

Currently, there is no Australian-specific value of B_o. This information would be essential to provide more accurate estimation of CH_4 production for feedlots under Australian conditions. Instead, international published data is used.

Table 31 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 CH_4 yield. The higher the feeding intensity and the milk yield, the greater was the reduction in CH_4 yield through an increase in lignin content.

Moller et al. (2004) determined both B_u and B_o for pigs and dairy cattle. The theoretical CH_4 productivity is higher in grower pigs (0.516 m^3 CH_4/kg VS) and sows (0.530 m^3 CH_4/kg VS) manure than in dairy cattle manure (0.469 m^3 CH_4/kg VS), while the B_o in terms of VS is considerably higher in grower pigs (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 32 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 CH_4 yield from manure.

TABLE 30 - MAXIMUM CH_4-PRODUCING CAPACITY FOR US 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 (1999)

TABLE 31 - MEASURED MAXIMUM METHANE-PRODUCING CAPACITY OF MANURE (BO)

Slurry	Bo	
	Min	Max
Swine	0.244	0.343
Dairy cattle	0.204	0.296

Source: Vedrenne et al. (2008)

TABLE 32 - REPORTED RANGE OF B_o 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

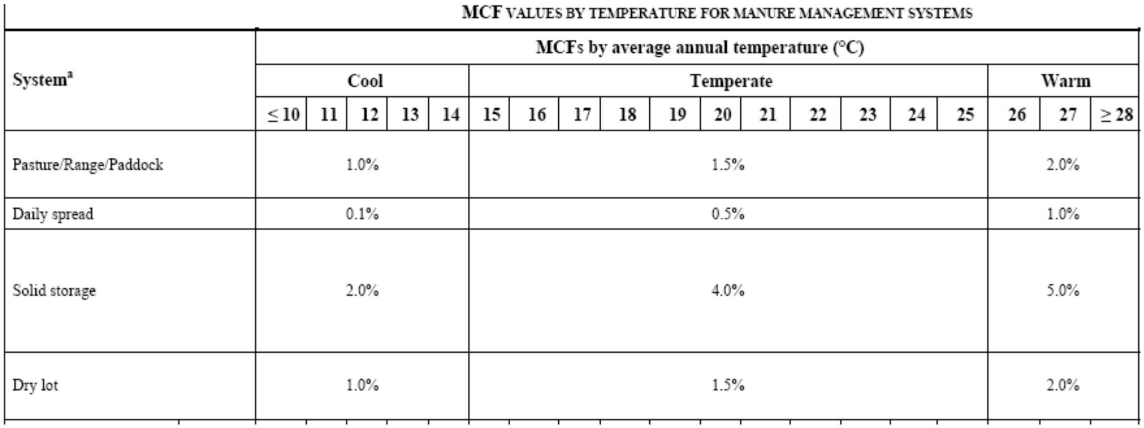
3.9.2.3 MCF Factor

Methane conversion factor (**MCF**) reflects the portion of B_o that is converted to CH_4 (IPCC 2006). The MCF for a manure management system varies with the manner in which the manure is managed and climate. Theoretically, it can 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 CH_4 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 CH_4, and consequently has an MCF of about 1%.

DCCEE (2010) assumes that the only source of CH_4 emissions from a feedlot is “solid storage and dry lot”. It is assumed that there are no CH_4 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 are 5%, and MCF values for ‘temperate’ regions for all other States are 1.5%. However, IPCC (2006) estimate CH_4 loss at separate manure management sites within the feedlot (Table 33). 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 (IPCC 2006).

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 CH_4 emissions from manure pads in a grazing context and from feedlot surfaces. The experimental methodology of Lodman et al. (1993) would now be regarded as inadequate and, hence, some of their absolute numbers on CH_4 emissions are questionable. However, Lodman et al. (1993) did draw relevant conclusions on relative CH_4 emissions rates from feedlot surfaces under differing conditions. They found that the variables that contributed most to differences in CH_4 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 (Lodman et al. 1993).

TABLE 33 - SELECTED MCF FACTORS FOR MANURE MANAGEMENT SYSTEMS



MCF VALUES BY TEMPERATURE FOR MANURE MANAGEMENT SYSTEMS

System^a	MCFs by average annual temperature (°C)																		
	Cool					Temperate											Warm		
	≤ 10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	≥ 28
Pasture/Range/Paddock	1.0%					1.5%											2.0%		
Daily spread	0.1%					0.5%											1.0%		
Solid storage	2.0%					4.0%											5.0%		
Dry lot	1.0%					1.5%											2.0%		

Source: IPCC (2006)

The 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 & Casey 1998).

For beef cattle feedlots, VS are estimated with Equation 8 using dry matter intake, digestibility and ash content. Table 34 gives the feed intakes for feedlot cattle that are assumed from NGGI calculations.

$$VS = I \times (I - DMD) \times (1 - A) \qquad \text{Equation (23)}$$

where:

I = dry matter intake (Table 34), 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 34 - DCC 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 Australian 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) to 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) to 2% (warm regions). This is equivalent to 0.84 – 1.69 kg CH_4 / hd / yr (assuming an excretion of 750 kg VS annually).

3.9.3 Carbon Losses from the Feedlot Pad in Runoff

Solids (including VS) lost from pens in runoff is typically a small component of the carbon balance of a pen. Kissinger et al. (2006a) 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. In summer experiments, an average of 6.2% of excreted VS solids is lost from the pens in runoff. In winter experiments, the excreted VS loss in runoff averaged 1.9%.

There are no studies available in Australia that has measured VS loss from pens in runoff.

Based on typical runoff concentrations of VS from feedlots and modelled runoff volumes, it is estimated the VS transported to the effluent treatment and holding system is in the order of 2% of excreted VS. This is equivalent to 15 kg of VS / SCU / yr (assuming an SCU excretes 750 kg VS annually).

3.9.4 Methane Losses from the Feedlot Pond

Liquid manure storage systems used in feedlots are predominantly anaerobic, and can be visualised as having three zones. The heavier particles and the fixed solids such as ash will settle and accumulate in the sludge zone which forms a layer over the base of the pond and is largely inert. A lighter active sludge layer containing a high concentration of VS forms above the inert sludge layer. Above that, a supernatant layer forms which is relatively low in suspended solids.

Chemical and biological reactions occur predominantly in the lighter sludge accumulation layer (Kruger et al. 1995). Organic material is broken down by a range of microbes to form VFA's, including acetic acid and under the correct conditions the digestion process continues to form carbon dioxide and CH_4 gas. The carbon dioxide formed either escapes from the pond surface as a gas or is converted to alkaline bicarbonate which helps balance the acid produced to maintain a pond pH between 6.4 and 7.2 (Kruger et al. 1995). Each species of microbes has an optimum environment which includes preferred temperature, pH, salinity, dissolved oxygen levels and light.

The lower layers of the pond are lacking in oxygen and the anaerobic process dominates. Closer to the surface of the pond, oxygen from the air can diffuse into the surface liquid and support colonies of aerobic microbes. The facultative zone between contains microbes that can exist in both an aerobic and anaerobic environment.

Figure 13 provides a general overview of the biological activity occurring in the anaerobic pond.

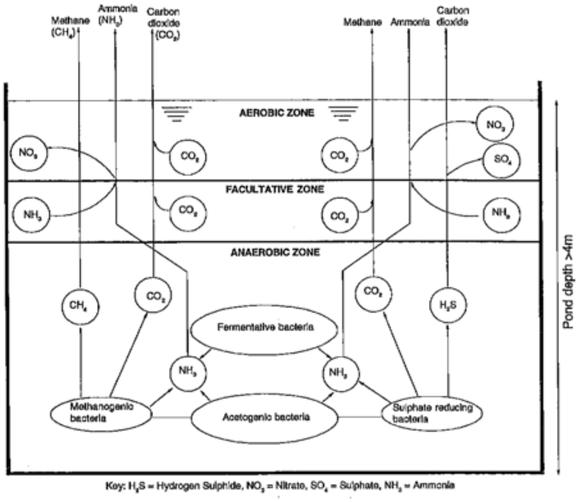


FIGURE 13 - ANAEROBIC POND GENERAL OVERVIEW

SOURCE: KRUGER ET AL. (1995)

DCCEE (2010) do not provide an estimate of CH_4 emissions from liquid storage, since all manure management for feedlots is attributed to MMS = 4, (solid storage and drylot). Limited information exists in the literature to indicate possible CH_4 emissions. However, it does provide CH_4 emissions from anaerobic ponds of 90% for dairy cattle and piggeries.

With only 2% VS excreted likely to be entering the pond system (Section 3.9.4), and using a B_o = 0.17 kg CH_4 / kg VS, a CH_4 density of 0.662 m^3/kg and MCF of 90%, this is equivalent to 1.52 kg CH_4 / SCU / yr (assuming 15 kg of VS /SCU enters the pond annually).

3.9.5 Carbon Losses from Manure Stockpiling and Composting

Methane losses from stockpiled and composting manure from feedlots has been researched in North America and Europe. However, data from Australian feedlots is limited. Summarised data of CH_4 loss from stockpiling and composting of feedlot manure is presented in Table 35. Comments regarding experimental procedures and interpretation of these data are presented in Table 36.

Where possible, the values provided in Table 35 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 Table 37. 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%.

The IPCC (2006) provides MCF factors for static pile composting of 0.5%, active composting ranges from 0.5 – 1.5% (cool to warm climates respectively) and stockpiling 4%. The DCCEE (2010) provides MCF factors for solid storage of 1.5 % (southern Australia) and 5% (Queensland and Northern Territory). Methane emission rates for numerous studies are reported in Table 37.

TABLE 35 - 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		600.0	-	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				357.0	± 12.0	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 <40°C	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	Consecutive summers (beef following dairy)	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		

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TABLE 36 - COMMENTS RELATING TO PUBLISHED EMISSION VALUES IN TABLE 35

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. Measured emissions for chambers include data from 12 chambers.
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).

TABLE 37 - 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

3.9.6 Knowledge Gaps and Recommendations – Carbon Losses

All studies included in Table 37 were conducted in the Northern Hemisphere. Temperature affects VS losses and with lower temperatures experienced in the Northern Hemisphere 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 when converted to like terms range from 0.11 to 26.8 kg CH_4/hd/yr, with the majority below reported values by IPCC (2006) and DCCEE (2010).

Of the studies that have been completed in Australia regarding methane emissions from feedlots (Loh et al. 2008, McGinn et al. 2008), measured methane emissions are unable to be related back to feed intake, since intake data was not recorded.

As discussed in previous sections, the following deficiencies in knowledge on carbon losses from Australian feedlots are noted below.

- There are currently no studies in Australia that have measured VS loss via runoff from feedlots (Section 3.9.3)
- To Australian data is available on the CH_4 emissions from the feedpad (Section 3.9.2.3)
- There is no Australian-specific value of B_0, which is essential to provide more accurate estimation of CH_4 emissions from Australian conditions.

3.10 The DEEDI BEEFBAL Model

3.10.1 Overview

BEEFBAL is a Microsoft Excel® worksheet model that can be used to determine the waste characteristics from a feedlot (QPIF 2004). It estimates the TS, VS, FS, N, P, K and salt (as sodium chloride) in the manure from a feedlot, where the cattle are fed a ration of known composition and intake. The DMDAMP model (van Sliedregt et al. 2000), within BEEFBAL, is used to calculate TS excreted and mass balance principles (Watts et al. 1994a), are used to determine the N, P, K, total salt and FS excreted. This model was first developed in the mid 1990's and has been modified and refined since, according to various case studies and consulting needs.

BEEFBAL 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. BEEFBAL is used extensively to provide waste estimates for new and expanding feedlot applications throughout Australia.

BEEFBAL 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). 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 DM/hd/day) 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, BEEFBAL predicts the amount of solids and nutrients left for land utilisation. This information is used to calculate the size of appropriate application areas for effluent and solids. BEEFBAL accounts for 'associative' effects that occur in ruminants that affect the digestibility of consumed feed. Factors accounted for include characteristics and composition of individual ingredients, as well as the digestive processes that occur when feeds are mixed.

BEEFBAL has not yet been developed to a commercial standard for general public use. It is provided by DEEDI 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. Considering the objectives for which BEEFBAL was originally constructed, the current version contains limitations for use as a whole of feedlot mass-balance tool. These limitations are discussed below.

3.10.2 BEEFBAL Model Inputs

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

- System input parameter modules
- Feedlot design
- Market type and herd production
- Rations and ingredients
- Feed intake
- Assumptions for mineral content of animals, feedlot runoff concentrations, runoff coefficients and manure decomposition (feedpad, stockpile and composting)

3.10.2.1 Feedlot Design

In some states in Australia, feedlot capacity is defined in terms of "standard cattle units" (SCU) rather than number of head. Table 38 provides data to convert cattle liveweight to SCU.

TABLE 38 - STANDARD CATTLE UNITS (SCU) CONVERSION TABLE (ARMCANZ 1997)

Liveweight 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

BEEFBAL requires input data on various feedlot design parameters including:

- Maximum capacity in SCU (Table 38)
- 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.

3.10.2.2 Market Type and Herd Production

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

- Entry weight (kg)
- Average Daily Gain (ADG) (kg/hd/day)
- 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)

For this input data, the model calculates:

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

3.10.2.3 Rations and Ingredients

BEEFBAL 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)

3.10.2.4 Feed Intake

BEEFBAL 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.

3.10.3 BEEFBAL Model Outputs

BEEFBAL model output modules include:

- Manure production
- Animal, pen and feedlot nutrient balance
- Manure harvesting, stockpiling and composting
- Runoff collection, storage and irrigation

The primary purpose for the development of the BEEFBAL 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 BEEFBAL (V9.1_TI) uses the DMDAMP methodology as described in Section 3.3.4 to estimate TS excretion and mass balance principles (Intake – Uptake in liveweight gain) to predict FS, N, P and K excretion. Volatile solids 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 inputting VS:TS ratios at 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 user inputting a total loss percentage of N during these stages. No guidance is provided to the user on the appropriate values of these inputs.

3.10.4 Partitioning of Manure and Nutrients to Liquid Fraction

The amount of nutrients (N, P and K) removed from the feedlot pad to the effluent treatment and holding system is estimated by the user inputting various parameters:

- Nutrient content of effluent pond water
- Pen area mean annual runoff coefficient
- Soft balance area mean annual runoff coefficient
- Hard balance area mean annual runoff coefficient
- Mean annual rainfall
- Pan-to-pond conversion factor.

Total runoff is calculated by adding the amount of runoff from each separate area with runoff for each area calculated as by:

Runoff = Area (m2) x Rainfall (m) x Runoff coefficient *Equation (24)*

The mass of nutrients exported from the pad is calculated backwards by inputting the nutrient concentration of the effluent pond water.

No guidance is provided to the user on runoff coefficients or typical nutrient concentrations of effluent.

BEEFBAL estimates the amount of VS lost at each stage of the feedlot manure management system (feedpad and stockpile/compost) by inputting the VS:TS ratio of the manure at these stages to "back-calculate" a VS loss. No guidance is provided to the user of the form of this VS loss. The problem is that data on the amount of manure available and its corresponding VS:TS ratio is poor.

3.10.5 Limitations of BEEFBAL as a Tool for Feedlot Mass Balance

3.10.5.1 Gaps in Mass-Balance Estimation with BEEFBAL

BEEFBAL was not designed and developed as a total feedlot mass balance tool, since the concept was for the prediction of (**i**) quantity and nutrient composition of manure produced, and (**ii**) land area required for application of manure produced. As such, 'gaps' exist in the program as a mass balance tool of component (solids and nutrients) flows within a feedlot. These limitations are discussed below.

- The user must estimate the VS: TS ratio of the manure at manure management stages to calculate the VS decomposition (i.e. fresh, scraped and stockpile) to calculate a dry matter (total solids loss).
- Similarly, total-N losses are estimated by inputting the % N loss at manure management stages (% loss of N from the feedpad and stockpile/composting).
- Other losses from the feedpad are likely to represent significant losses of total-N and VS fractions. For example, other losses are likely to include dust, nitrogen oxides (NO_x), and feed wastage.

This effectively means that the mass flow of nutrients and solids is "back-calculated" by a reliance on the user to have both:

- reliable data on manure and effluent composition, and
- a good knowledge of manure production and composition to obtain any sort of reliable answer.

User inputs required to estimate manure losses at the feedpad, pond and stockpile and functionality of BEEFBAL are presented in Figure 14. For the current version, (BEEFBAL_v9.1_TI) the user must use their professional judgement, and knowledge of the composition of manure and effluent (e.g. Table 16 and Table 23) to achieve realistic values of manure composition.

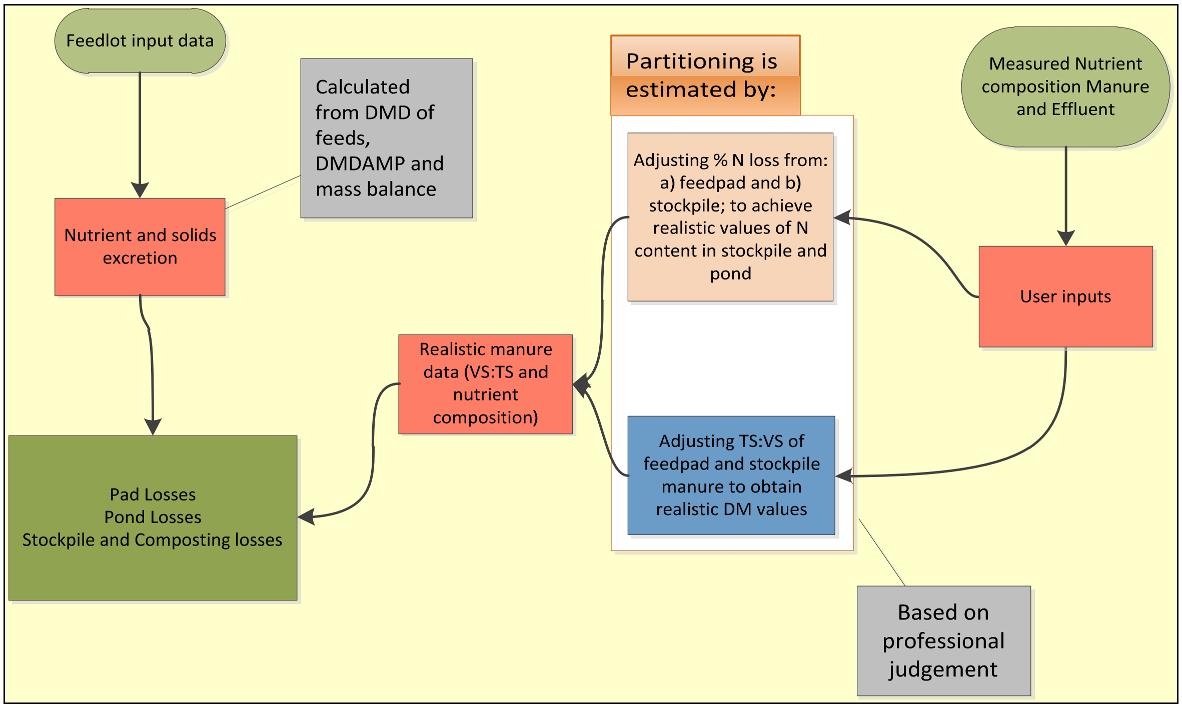

FIGURE 14 - REQUIRED USER INPUTS AND FUNCTIONALITY OF BEEFBAL_V9.1_TI

3.10.5.2 Mass-Balance Error in BEEFBAL

The current version of BEEFBAL (BEEFBAL_V9.1_TI) has a mass balance error that affects the prediction of FS, N, P and K. On the "DAMP Analysis" page, the concentration of ingredient components of the diet (kg / 100 kg) fed calculates the concentration of TS, VS, FS, N, P, K and salt of the total diet in kg / 100 kg fed (as-is basis). The error occurs where FS, N, P and K are calculated. These concentrations should be determined by multiplying the amount fed of each ingredient by the as-is concentration and then adding this up for the entire diet. The problem with the current version of BEEFBAL is that these individual ingredient values are also multiplied by their dry matter concentration, thus underestimating the amount of these ingredients fed and subsequently excreted. This will cause the amount of excreted TS predicted to remain the same, FS excreted will increase, and subsequently reducing VS excreted estimates. All nutrient (N, P and K) excretion estimation will increase by varying amounts depending on their uptake by the animal.

Thus, the current version of BEEFBAL produces potentially significant errors in the estimation of FS, N, P and K. Using the "standard" diet provided in BEEFBAL V9.1_TI, FS is underestimated by approximately 22%. This however, means that VS is over estimated by approximately 9%. A larger error occurs with the underestimation of nutrients, with N excretion underestimated by 16%, phosphorus underestimated by 21% and potassium underestimated by 17%.

The error could be corrected by either:

- modifying the equations in the DMDAMP analysis page, or
- inputting the feed usage data on the Diet Analysis page as dry matter intakes.

4 Methodology – Development and Use of a Mass Balance Model

4.1 Development of an Enhanced Mass-Balance Feedlot Model – FSA^2

The DEEDI BEEFBAL model (BEEFBAL_V9.1_TI) is a Microsoft Excel© based program which was developed by the Queensland DPI (McGahan et al. 2002, QPIF 2004) to estimate the waste produced by cattle feedlots and to assess the environmental sustainability of associated land application practices. This model has been further enhanced by FSA Consulting.

As with the DEEDI BEEFBAL model, the enhanced model (Feedlot System Assessment model or FSA^2) can simulate different herd capacities; several market classes (i.e. domestic, mid-fed, long-fed), specific rations for each market, different average daily gains (ADG), liveweight, occupancy and mortalities. In addition, FSA^2 predicts a number of physical inputs and outputs from a feedlot such as water usage and traffic generation. However, it is not an economic model. FSA^2 can provide an estimate of feed inputs (broken down by each commodity), water and energy requirements, incoming cattle, numbers on feed and cattle trucks, etc. Model outputs include an estimate of the numbers turned off per year, commodity usage, staff required.

As with BEEFBAL, FSA^2 performs a mass balance on the nitrogen, phosphorus, potassium and salt entering the feedlot system (in the forms of incoming cattle, feed and drinking water) to determine the masses of nutrients and salt in the manure and liquid effluent produced by the feedlot. The model uses much of the information contained in the preceding literature review. The model includes the DMDAMP methodology to determine the "as excreted" manure constituents, based on a wide range of possible ration ingredients and up to five market classes (e.g. domestic, mid-fed and long-fed).

In addition to the waste estimation component, FSA^2 includes the DCCEE and IPCC manure production and GHG emission estimation algorithms to determine the various manure production and GHG emissions for a given scenario.

The model output has been cross-checked against actual feedlot production data that were obtained in the MLA project FLOT.328, which collected feedlot specific data for the red meat life cycle analysis project COMP.094.

4.1 Application of the Enhanced BEEFBAL Model – FSA^2

The functional elements of the DEEDI BEEFBAL (BEEFBAL_V9.1_TI) model and FSA^2 are reviewed in previous sections (Section 3.10 and Section 4.1). The purpose here is to state the values that were used as inputs to generate a manure production estimation for Australian feedlots.

In order to assess the feedlot mass-balance model, it was decided to test the model using a typical feedlot. There are many possibilities for a “typical” feedlot (see Appendix A). It was decided to use data collected at a feedlot in southern Queensland as part of an energy and water auditing project - MLA project FLOT.328. The feedlot is currently operational and input data to the mass-balance model reflect the operational inputs of that feedlot. This was to ensure that the model predictions were in line with industry in the current operational climate. Table 39 summarises the input data used to test the mass-balance modelling.

TABLE 39 - SAMPLE INPUT DATA FOR STANDARD RUN OF FSA[2]

Input category	Value	Units
Production data		
Feedlot capacity	1508	hd
	1240	SCU
Total cattle in	6880	hd
Total cattle out	6790	hd
Mortalities	1.3	% of cattle in
Occupancy	80	%
Average DOF	64	days
DMI	10.2	kg DM/hd/day
Entry LW	360	kg
Exit LW	462	kg
Total growth	102	kg
ADG	1.6	kg/hd/day
Ration component		
Ration processing	Tempering	
TS (DM)	79.5	%
N	2.59	%DM
P	0.47	%DM
K	0.90	%DM
Calculated feed DMD	83.7	%
Carcass composition assumptions		
N content cattle in	29.4[a]	g/kg liveweight
N content cattle out	27.6a	g/kg liveweight
P content cattle in	6.7	g/kg liveweight
P content cattle out	7.0	g/kg liveweight
K content cattle in	1.7	g/kg liveweight
K content cattle out	1.8	g/kg liveweight
Ash content cattle in	50.0	g/kg liveweight
Ash content cattle out	40.0	g/kg liveweight
VS content manure		
Fresh manure	83	%
Scraped manure	70	%
Stockpiled manure	65	%
Runoff estimates (to pond)		
TS	2	%
VS	2	%
N	2	%
P	2	%
K	15	%
Pond losses		
Ammonia volatilisation	35	%
VS degradation	50	%

a - actual calculated value from National Research Council (1996) – Standard BEEFBAL value = 27 g/kg
b - actual calculated value from National Research Council (1996) – Standard BEEFBAL value = 24 g/kg

4.2 Sensitivity Analysis

A sensitivity analysis was conducted by modifying a number of key input parameters that are most likely to impact on estimated manure production parameters. These parameters included:

- Diet composition – four additional diets using diet composition data from the MLA Project FLOT.132 (EconSearch Pty Ltd et al. 2009).
- Feed dry matter digestibility (DMD)

Additionally, a sensitivity analysis was conducted on the VS content of harvested manure to assess manure production rates at harvest.

TABLE 40 - SENSITIVITY ANALYSIS PARAMETERS

Input category	**Values**
Diet composition	
Southern Qld diet – Appendix A	NA
Southern NSW diet – Appendix A	NA
Victoria / Tasmania diet – Appendix A	NA
Southern WA diet – Appendix A	NA
Feed digestibility	
5% higher than estimated by FSA^2 (%)	88.7
5% lower than estimated by FSA^2 (%)	78.7

5 Results of Mass-Balance Modelling

5.1 Manure Excretion Predictions for FSA^2 and BEEFBAL_V9.1_T1

Table 41 shows a comparison of daily feed intake per head, daily manure production per head and annual manure per head between FSA^2 and the DEEDI BEEFBAL (BEEFBAL_V9.1_T1). Both models used the sample input data from the southern Queensland feedlot described in Section 4.1.

TABLE 41 - COMPARISON OF MANURE PRODUCTION BETWEEN FSA^2 AND BEEFBAL_V9.1_T1

Parameter	Units	FSA^2	BEEFBAL_V9.1_TI	% Difference
Feed Intake				
DM	kg/hd/day	10.2	10.2	0.0
N	g/hd/day	240	250	-4.2
P	g/hd/day	44	46	-4.5
K	g/hd/day	89	87	2.2
Daily manure excreted				
TS (DM)	kg/hd/day	1.66	1.88	-13.3
VS	kg/hd/day	0.90	1.35	-51.7
VS:TS Ratio		0.54	0.72	-33.3
N	g/hd/day	206	157	23.8
P	g/hd/day	31	26	16.9
K	g/hd/day	86	67	22.1
Annual manure excreted				
TS (DM)	kg/hd/yr	607	685	-12.9
VS	kg/hd/yr	329	494	-50.2
N	kg/hd/yr	75.2	57.2	23.9
P	kg/hd/yr	11.4	9.5	16.7
K	kg/hd/yr	31.4	24.5	22.0

5.2 Nitrogen Mass-Balance of Sample Feedlot

Further partitioning of nitrogen from the FSA^2 model is summarised in Figure 16, and Figure 17. (This portioning cannot be done within DEEDI BEEFBAL). These outputs further describe the fate of nitrogen post excretion using the sample feedlot inputs described in Section 4.1. Values are obtained from a theoretical mass balance, using published values within literature. Nitrogen loss from manure management within the feedlot, (N_2O and NH_3) as a percentage of N intake is represented in Figure 16. Figure 17 also represents a theoretical N mass balance of feedlot manure, with percentages representing proportion of N flows to the individual manure management sites (i.e. feedpad (excreted N), effluent ponds, solid manure stockpile, and subsequent solid manure application).

The following estimates are made from the theoretical mass balance:

- Approximately 86% of N fed to feedlot cattle is excreted and 14% is taken up as liveweight gain or removed in mortalities.
- About 0.5% of N fed to feedlot cattle is lost to the pond (approximately 0.5 kg/ SCU; Figure 17).
- Approximately 62% of N fed to feedlot cattle is volatilised to the atmosphere from the feedlot pad as NH_3, N_2O and other N compounds.
- The remaining 25% of N fed to feedlot cattle is harvested from the pens in manure.

Figure 15 shows the partitioning of nitrogen intake from the FSA^2 into excretion, liveweight gain and mortalities.

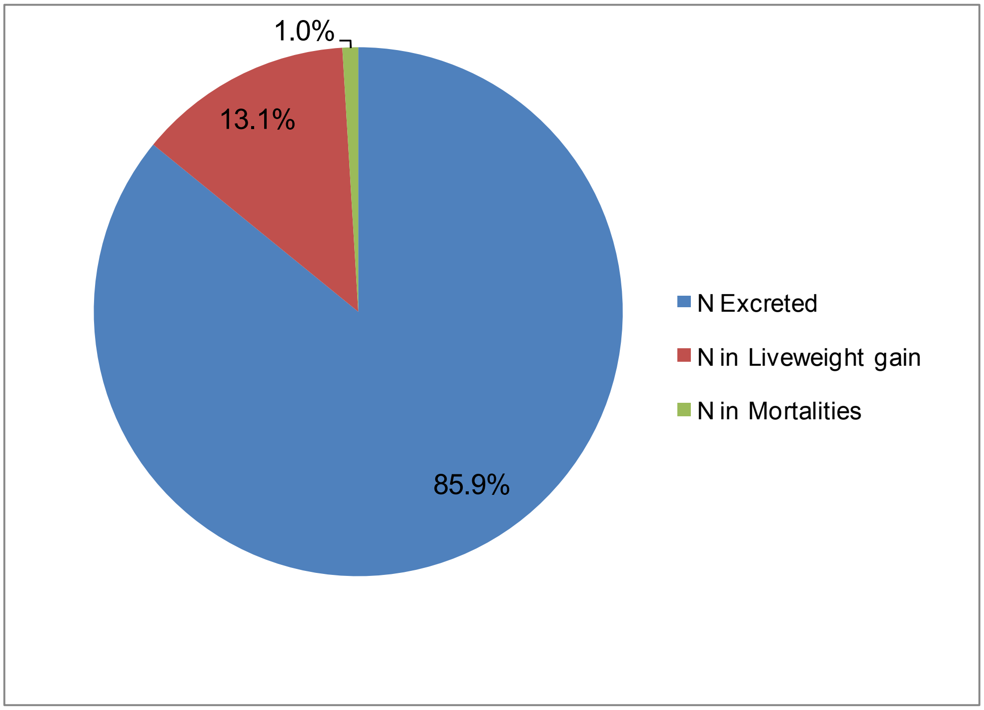

FIGURE 15 - FATE OF N FED TO FEEDLOT CATTLE (PERCENTAGE OF N INTAKE)

Figure 16 shows the portioning of the total-N intake for the sample feedlot. Manure N loss as volatilised NH_3-N from the feedpad is the primary N loss vector (60.1% of intake N). Conversely, N flows to the feedlot pond represent only 0.5% of intake N.

From Figure 17, total NH_3-N loss represents 70.5% of intake N from the combined volatilisation from the feedpad, manure stockpile/compost, effluent and from application losses. This NH_3-N loss becomes available for deposition and re-volatilisation as N_2O. Using an emission factor of 1% for N_2O, this represents approximately 0.70% of intake N; equal to 0.62 kg/hd/yr.

5.1 Phosphorus Mass-Balance of a Feedlot

Figure 20 and Figure 18 shows the fate of P, as a percentage of P fed for the sample feedlot. This shows that approximately 70% of the P fed remains for land application in manure and pond effluent/solids.

5.2 Potassium Mass-Balance of a Feedlot

Figure 19 and Figure 21 shows the fate of K, as a percentage of K fed for the sample feedlot. This shows that over 80% of the K fed remains for land application in manure and pond effluent/solids.

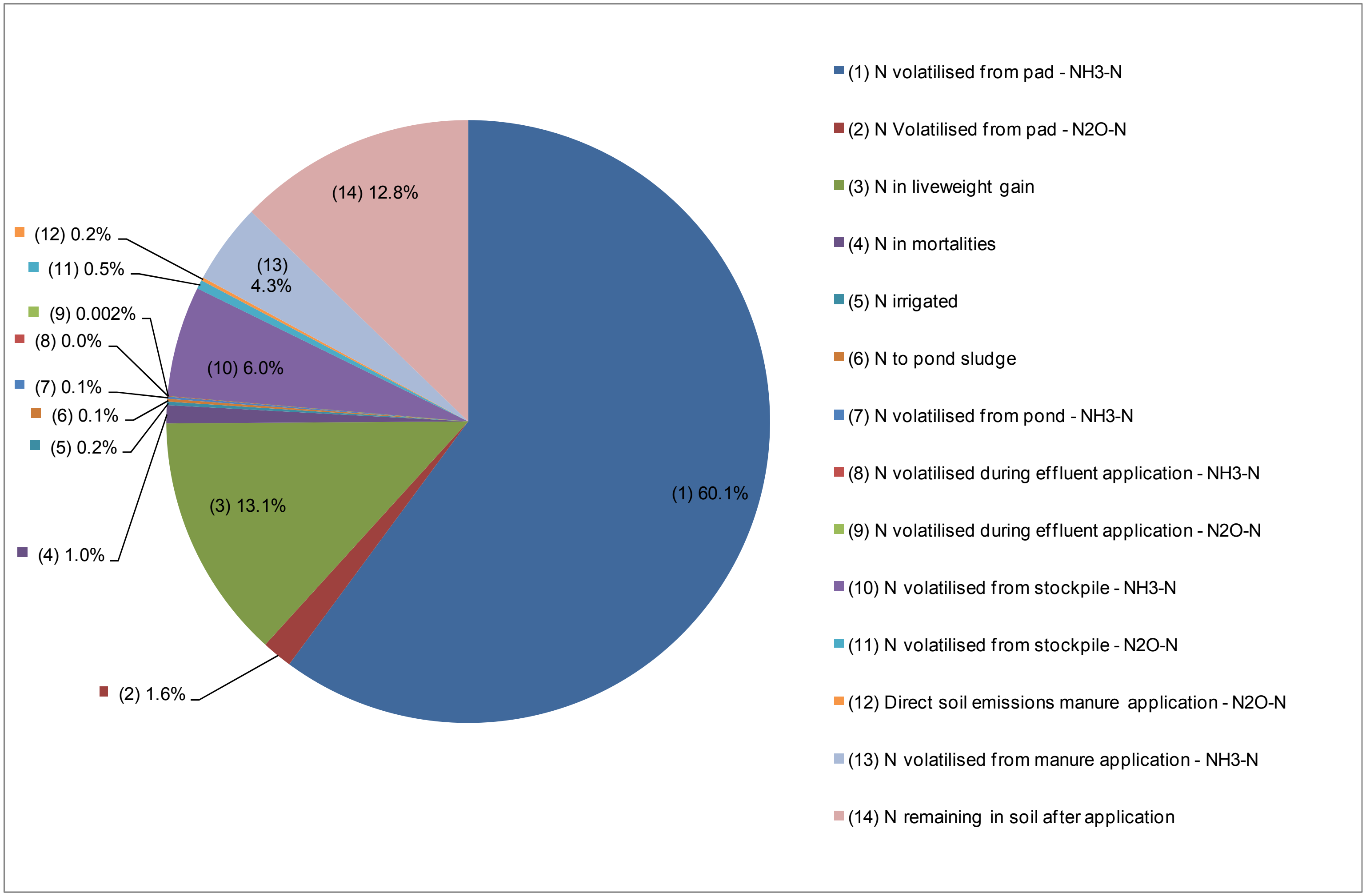

FIGURE 16 - FATE OF N FOR SAMPLE FEEDLOT (PERCENTAGE OF N INTAKE)

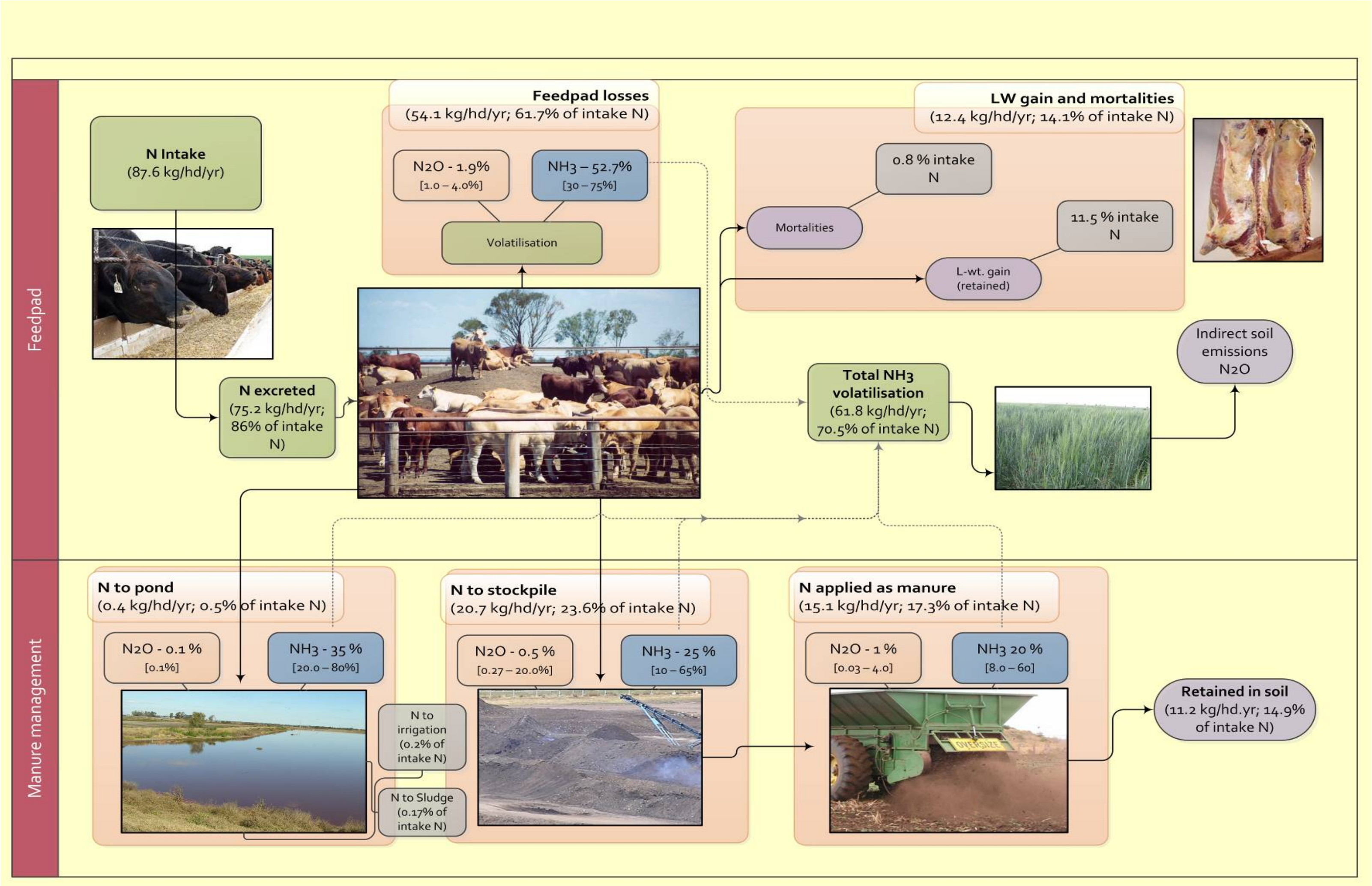

FIGURE 17 - NITROGEN FLOWS FOR A FEEDLOT ANIMAL DERIVED FROM A THEORETICAL MASS BALANCE SHOWING TOTAL-N FLOWS AND RANGES OF REPORTED VALUES IN PARENTHESES

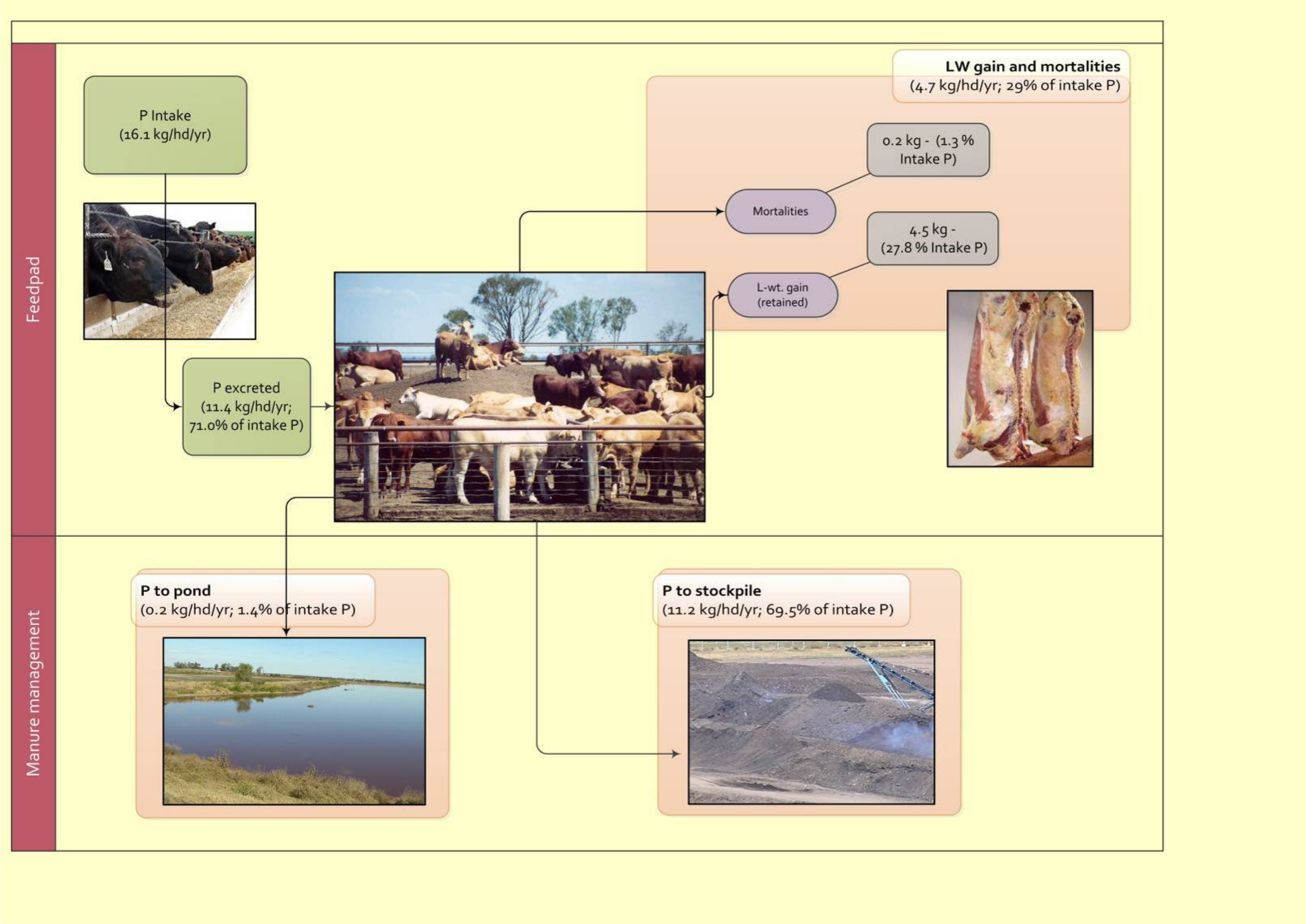

FIGURE 18 - PHOSPHORUS FLOWS FOR A FEEDLOT ANIMAL DERIVED FROM A THEORETICAL MASS BALANCE SHOWING TOTAL-P FLOWS

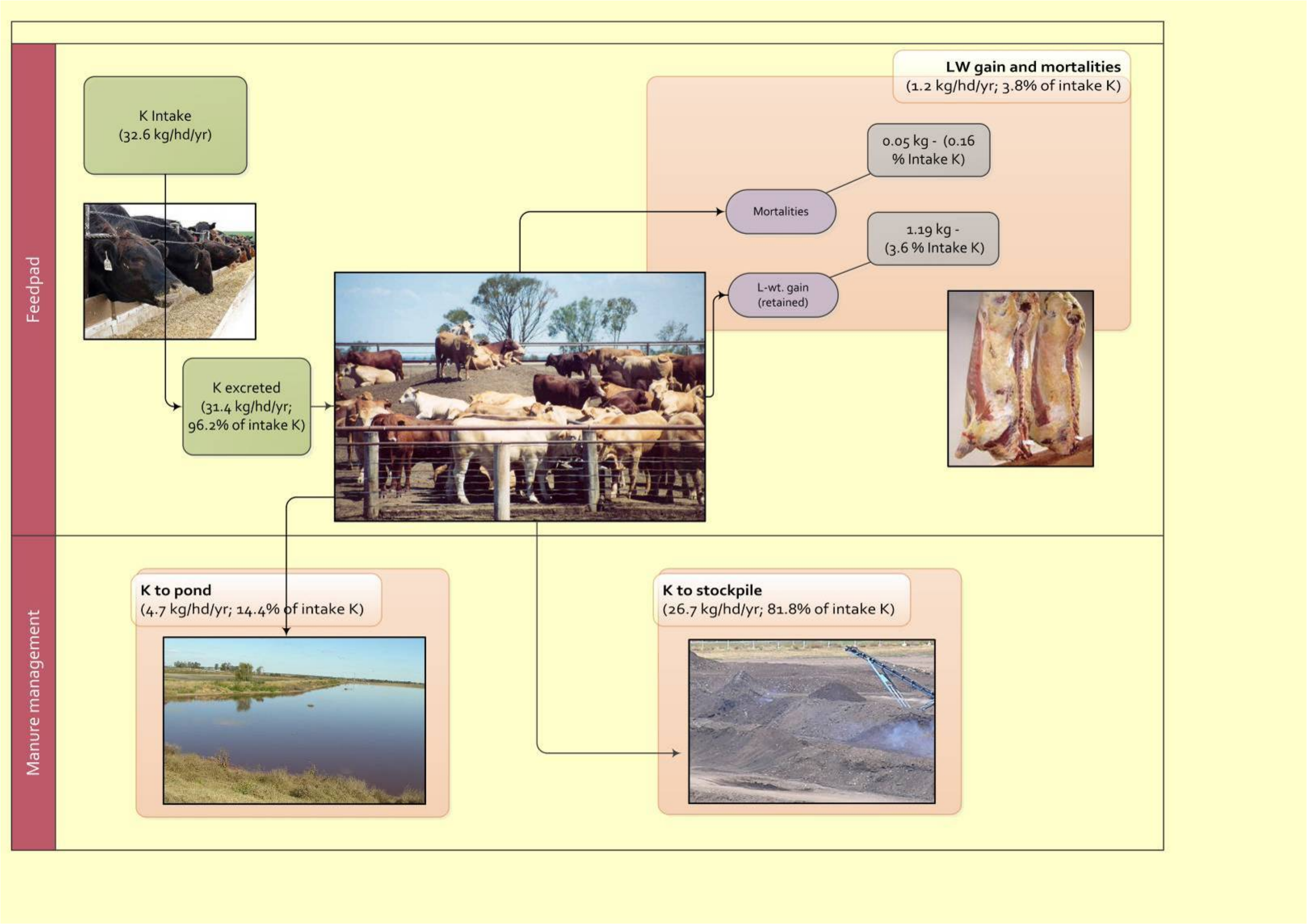

FIGURE 19 - POTASSIUM FLOWS FOR A FEEDLOT ANIMAL DERIVED FROM A THEORETICAL MASS BALANCE SHOWING TOTAL-K FLOWS

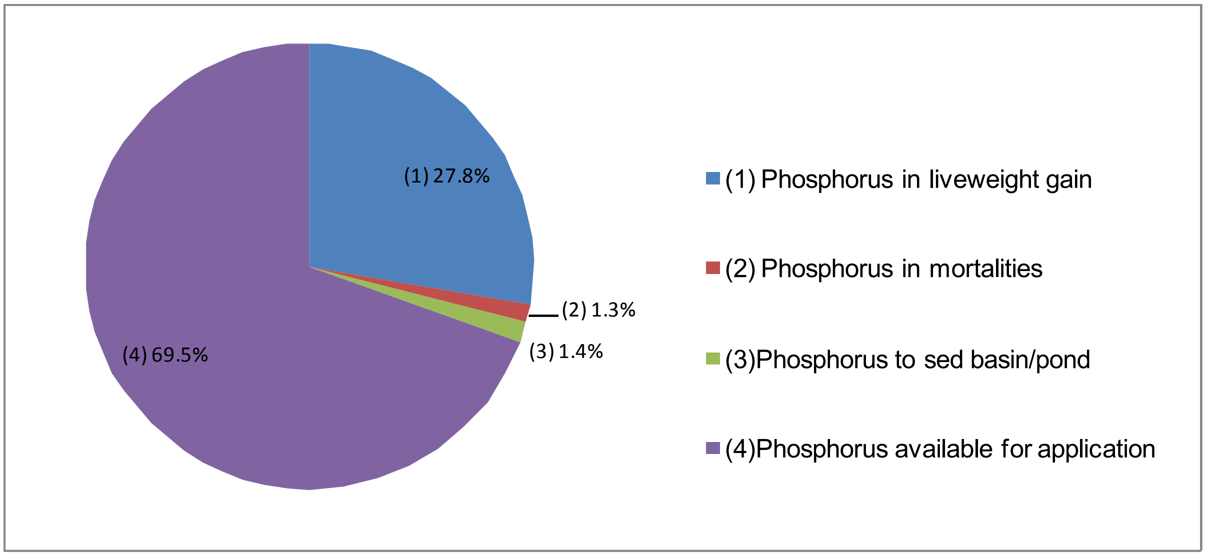

FIGURE 20 - FATE OF P FOR SAMPLE FEEDLOT (PERCENTAGE OF P INTAKE)

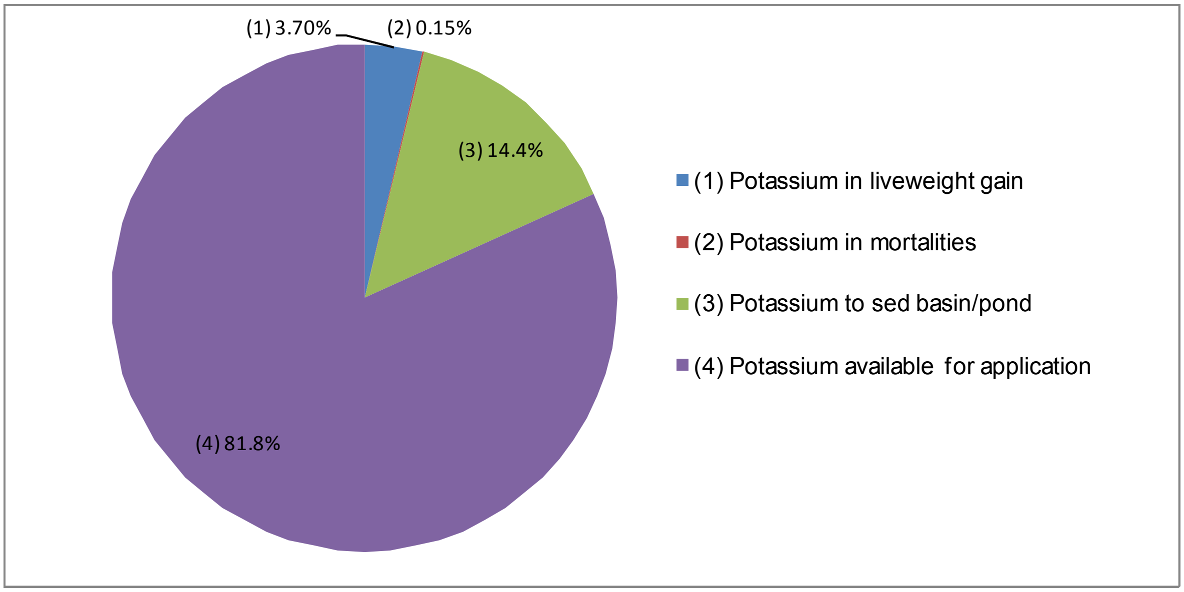

FIGURE 21 - FATE OF K FOR SAMPLE FEEDLOT (PERCENTAGE OF K INTAKE)

5.3 Sensitivity Analysis

Sensitivity analysis was performed on FSA[2] with a number of key input parameters, including:

- Ration formulation
- Whole of ration DMD.

Figure 22 to Figure 26 shows the variation in TS, VS, N, P and K production in kg/hd/yr for five diets. These diets include:

- Sample diet from southern Queensland feedlot used in previous MLA project (MLA project FLOT.328) investigating water and energy use.
- Southern Western Australian diet – see Table A1.
- Southern Queensland diet - see Table A6.
- Southern New South Wales diet - see Table A8.
- Victorian / Tasmanian diet - see Table A9.

Figure 27 shows the effect of varying the DMD of the Sample Feedlot scenario diet by ±5%.

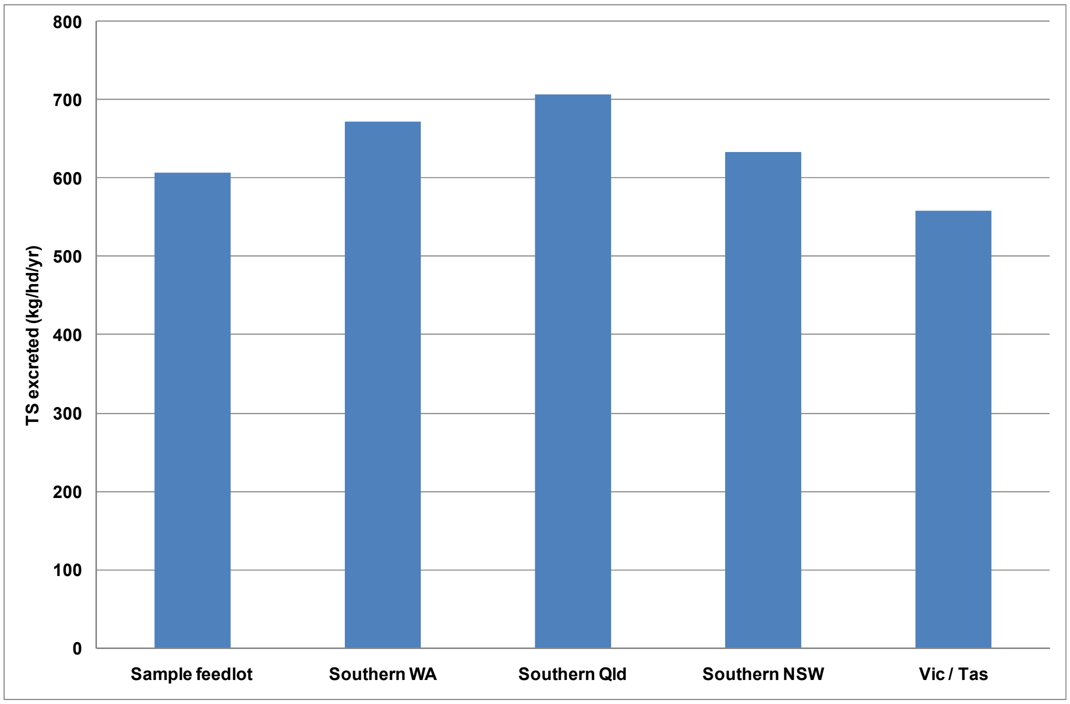

FIGURE 22 - ESTIMATED TS EXCRETION (KG/HD/YR) FOR FIVE DIETS

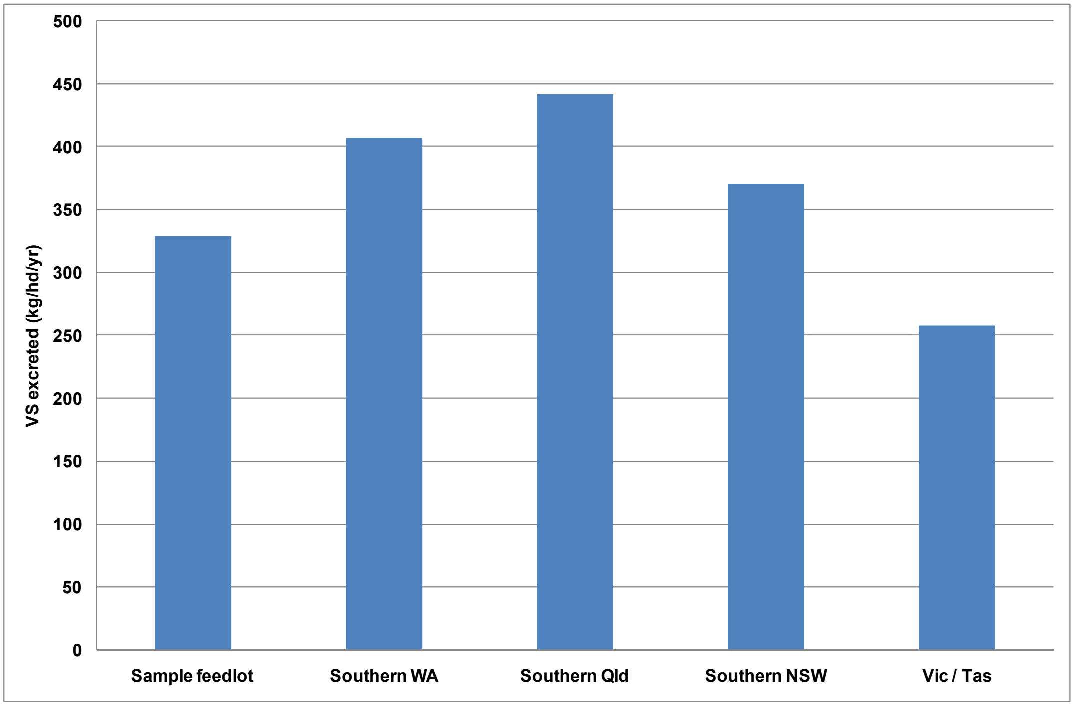

FIGURE 23 - ESTIMATED VS EXCRETION (KG/HD/YR) FOR FIVE DIETS

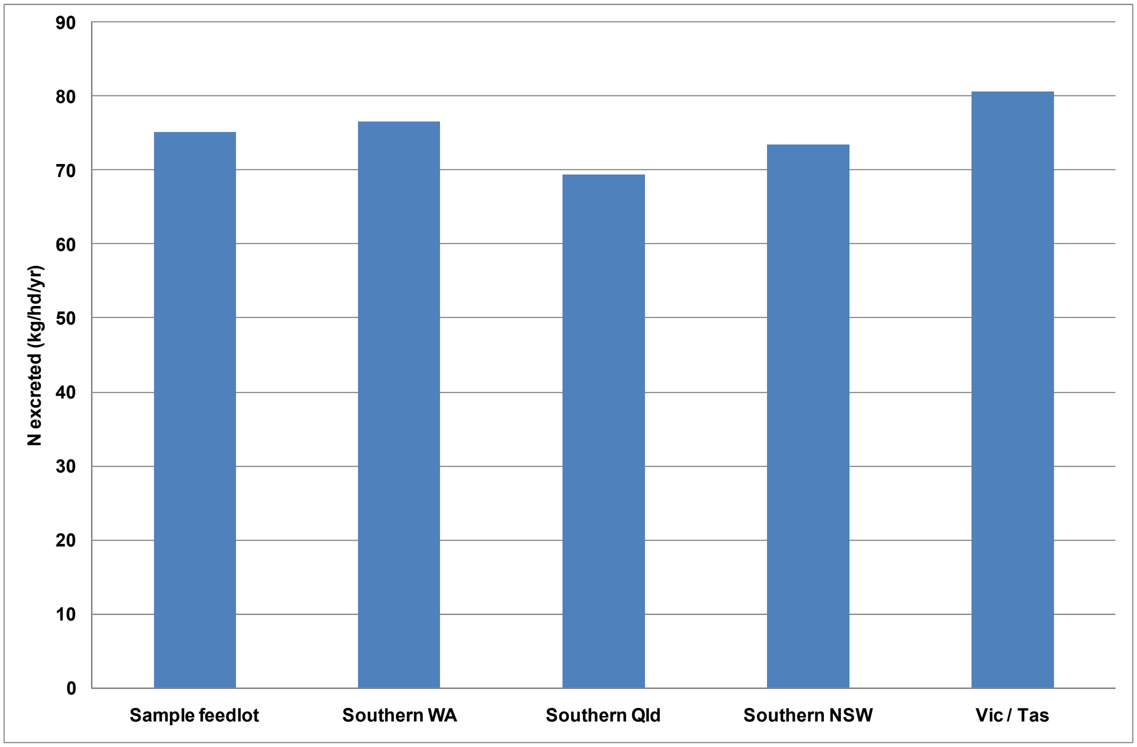

FIGURE 24 - ESTIMATED N EXCRETION (KG/HD/YR) FOR FIVE DIETS

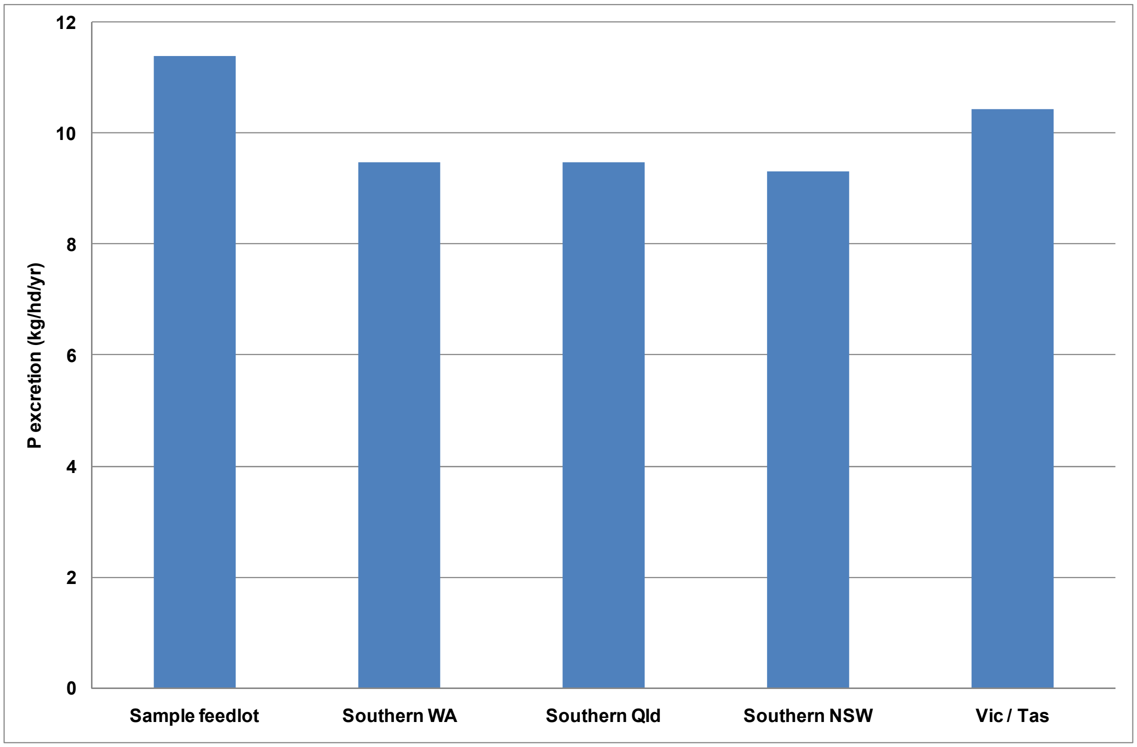

FIGURE 25 - ESTIMATED P EXCRETION (KG/HD/YR) FOR FIVE DIETS

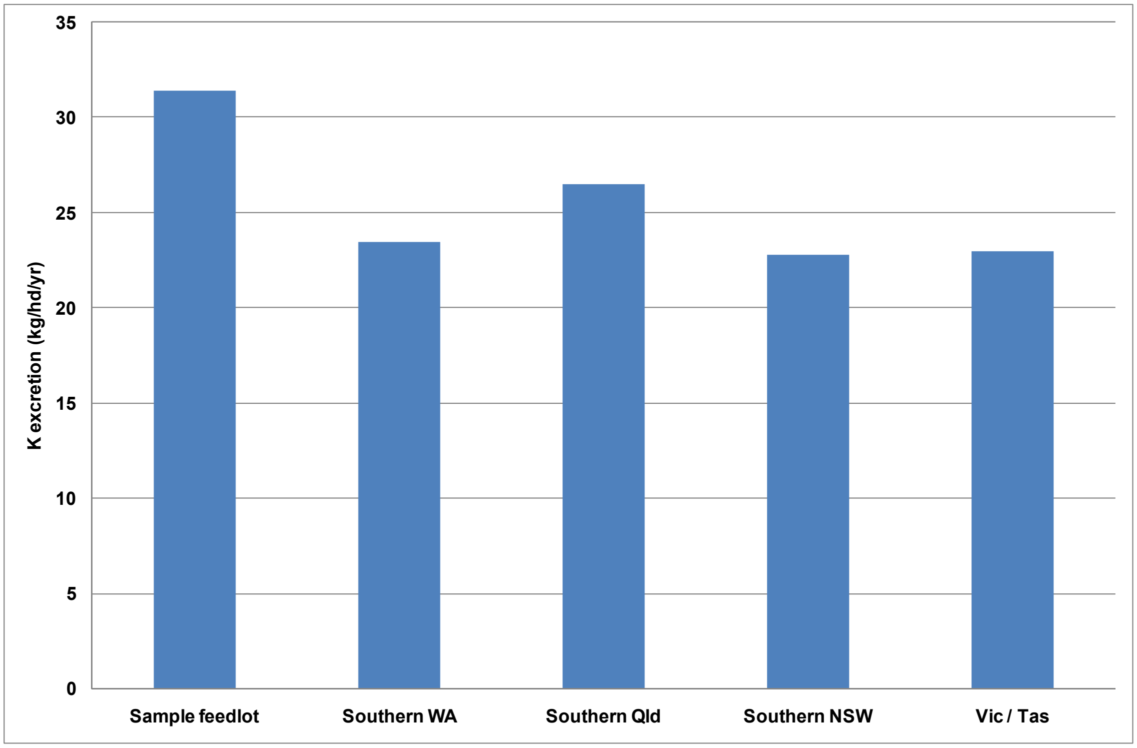

FIGURE 26 - ESTIMATED K EXCRETION (KG/HD/YR) FOR FIVE DIETS

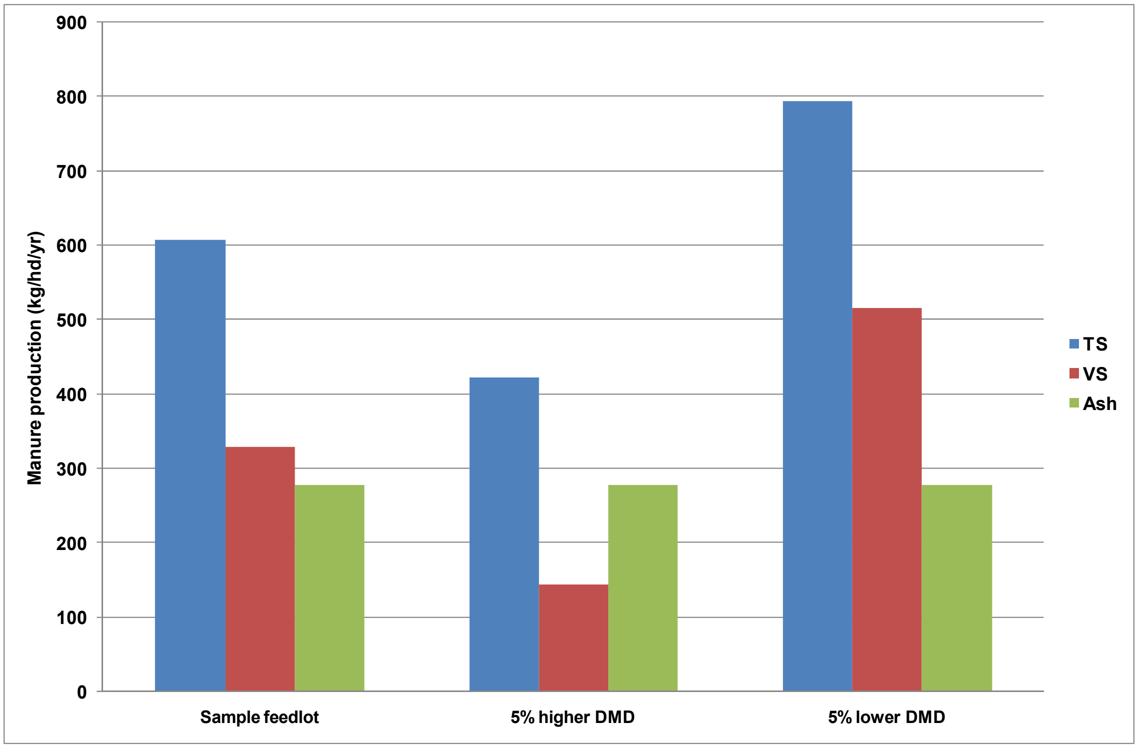

FIGURE 27 - ESTIMATED TS, VS AND ASH EXCRETION (KG/HD/YR) BY VARYING DMD BY ±5%

5.4 Estimated Greenhouse Gas Losses from Australian Feedlot Manure Management

FSA[2] was used to estimate the N_20-N and CH_4-C losses from manure management for the Sample Feedlot. To estimate the GHG potential of N_20 and CH_4 emissions, it is necessary to convert these emissions to CO_2 equivalence. The IPCC (2006) report the GHG potential (in CO_2 equivalents) of N_20 and CH_4 as 298 and 25 respectively, which were multiplied by the estimated N_20-N and CH_4-C losses. The estimated losses of N_20-N and CH_4-C were converted to whole mass values to give the estimated mass of N_20 and CH_4.

Estimated emissions from each manure management source are represented as a percentage of estimated GHG in CO_2 equivalents, as shown in Figure 28. Figure 29 shows estimates of GHG in CO_2 equivalents from the manure sources in the feedlot.

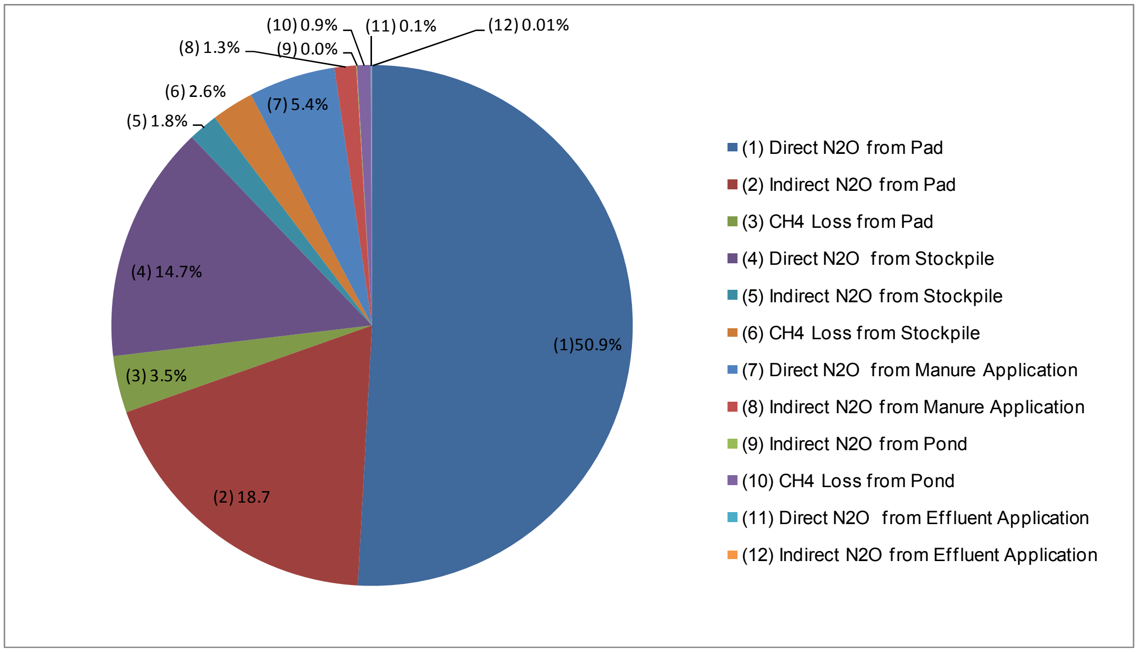

FIGURE 28 - PERCENT OF MANURE GHG EMISSIONS (CO_2-E) BY SOURCE

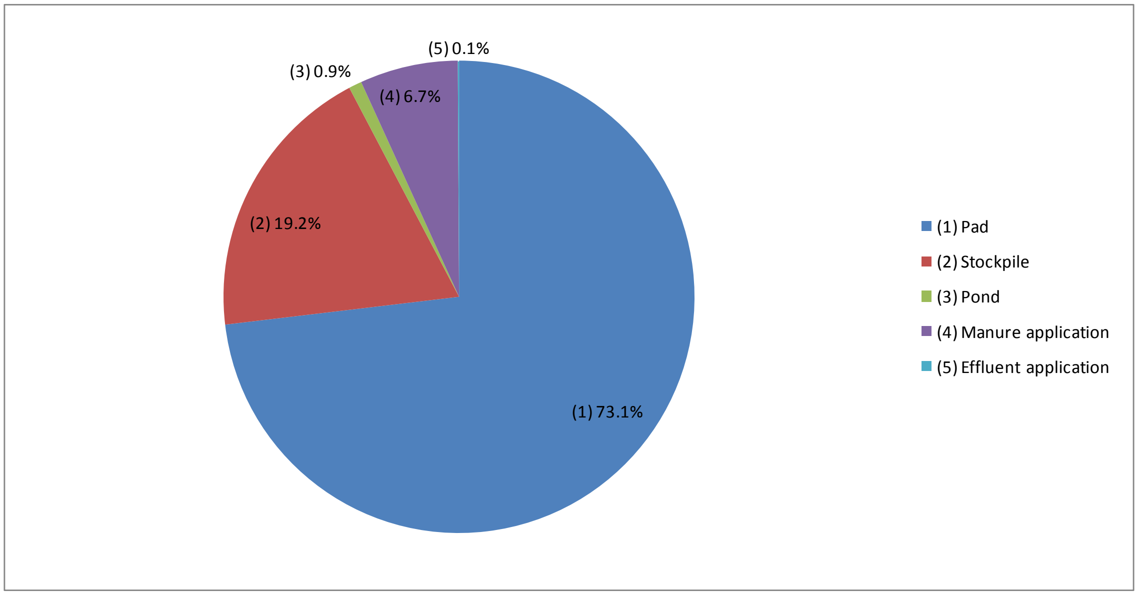

FIGURE 29 - PERCENT OF MANURE GHG EMISSIONS (CO_2-E) BY STAGE OF MANURE MANAGEMENT

6 Discussion

6.1 Ground-Truthing of Mass-Balance Models

A comparison was made between the FSA Consulting Feedlot System Assessment model (FSA^2) and the latest version of BEEFBAL (BEEFBAL_V9.1_T1) using a sample feedlot with collected input data from a previous MLA project MLA FLOT.328). FSA^2 under estimated TS and VS by approximately 13 and 50% respectively compared to the BEEFBAL model. However, it overestimated N, P and K by approximately 20%. These differences are likely due to a number of factors. It is believed that the BEEFBAL model under-estimates the concentration of ash, N, P and K in the diet due to a calculation error. BEEFBAL also appears to calculate total nutrient and feed intake by assuming 100% feedlot occupancy, but then factors in occupancy to calculate feed intake per head. BEEFBAL also has a fixed value (user input) for N carcass composition.

Both models appear to underestimate the VS:TS ratio of excreted manure (0.54 for FSA^2 and 0.72 for BEEFBAL). These values are both considerably less than recently measured data reported by Davis et al. (2010) of 0.83. This is likely due to two possibilities. Firstly, the ash retention in the carcass is too low and thus excretion of ash is high, resulting in a lower VS excretion. Secondly, the predicted DMD of the diet is too high, resulting in the TS excreted being underestimated. Both possibilities could be influencing the results.

FSA^2 (329 kg/hd/yr) and BEEFBAL (494 kg/hd/yr) both predict a lower amount of VS production for a short fed animal (60 – 70 DOF) than that estimated by the DCCEE methodology (658 kg/hd/yr). FSA^2 (607 kg/hd/yr) and BEEFBAL (685 kg/hd/yr) also both predict a lower amount of TS production than estimated by the DCCEE methodology (715 kg/hd/yr). FSA^2 (72 kg/hd/yr) and BEEFBAL (57 kg/hd/yr) both predict a higher amount of N production than estimated by the DCCEE methodology (55 kg/hd/yr). These factors mean that the DCCEE methodology may be incorrectly predicting manure GHG emissions for feedlots in Australia.

The FSA^2 assessment of the Sample Feedlot shows that >85% of fed N is excreted and of this excreted N, 82% is lost via NH_3 volatilisation from the feedpad, manure stockpile/compost, effluent and application of effluent and manure. This NH_3-N loss then becomes available for deposition and re-volatilisation as N_2O. Using an emission factor of 1% for N_2O, this represents approximately 0.8% of N excreted. Additionally >70% the P fed remains for land application in manure and pond effluent/solids and over 96% of the K fed remains for land application in manure and pond effluent/solids.

6.2 Sensitivity Analysis

FSA^2 was tested with five different diets representative of Australian feedlot production areas. The results showed large variations in TS, VS, N, P and K manure production for the five diets. This highlights the effect that different diet ingredients can have on manure component output. The use of 'standard textbook' values is likely to provide significant errors in estimated manure production.

The sensitivity analysis of the FSA^2 showed that varying feed digestibility by ±5% from the predicted DMD of the Sample Feedlot (83.7%) had a large effect on predicted TS and VS output. A 5% increase in feed DMD (88.7%) decreased TS and VS production by 30% and 55% respectively and resulted in an estimated VS:TS ratio of manure of 34%. This result is inconsistent with known data for feedlot manure. Conversely a 5% decrease in feed DMD (78.7%) increased TS and VS production by 30% and 55% respectively and resulted in an estimated VS:TS ratio of manure of 65%. This indicates that predicted feed DMD values generated by DMDAMP may be too high and may be underestimating manure production rates in terms of TS and VS.

6.3 Greenhouse Gas Losses from Manure Management

The theoretical mass balance has estimated N_20-N and CH_4-C losses for the Sample Feedlot. These estimates indicate that N_20 emissions from the feedpad, (both direct and indirect) and direct N_20 emissions from the stockpile are the three largest sources of GHG (in CO_2 equivalents) from feedlot manure management. Greenhouse gas produced (in CO_2 equivalents) from the feedpad is the largest source of GHG (in CO_2 equivalents) from feedlot manure, representing an estimated 73% of total manure GHG. Conversely, GHG emissions from the pond are a small proportion of total GHG produced from feedlot manure, representing an estimated 1% of total manure GHG production. Greenhouse gasses sourced from solid manure storage are intermediate, with an estimated 20%.

The reader is reminded that these estimates are derived from a theoretical mass balance from one simulated feedlot, and consequently have inherent limitations. However, these estimates of GHG produced from feedlot manure are useful to assist in prioritising research efforts in the area of GHG from feedlot manure sources.

7 Conclusions

7.1 Current State of Mass Balance Methodology of Manure from Australian Feedlots

BEEFBAL is a tool for estimating manure quantity and nutrient composition. However, the current version contains limitations and mathematical errors, and does not provide a complete mass balance of feedlot nutrient flows. Currently, there is not a publically available complete mass-balance tool available to estimate CH_4 and N_2O emissions from manure management from Australian feedlots. BEEFBAL (V9.1_TI) has limitations in estimating nutrient and VS composition of separate manure management components. BEEFBAL (V9.1_TI) effectively "back-calculates" the mass flow of nutrients and solids based on the professional judgement of the user. For accurate data, the BEEFBAL user must have reliable data on manure and effluent composition and a good knowledge of manure production and composition. The current form of BEEFBAL also includes potential mass balance errors. These errors involve the calculation of nutrient and FS intake of the whole diet (dry matter basis), when using the nutrient content of ingredients (as-fed basis), as well as inconsistent use of herd occupancy in calculating nutrient feed intake.

To enable a theoretical mass flow of nutrients in order to estimate the GHG emissions from various stages of manure management at feedlots, FSA Consulting has developed the Feedlot System Assessment model (FSA^2). Both the BEEFBAL and FSA^2 models appear to under-estimate the VS:TS ratio of fresh manure. This is likely due to an overestimation of the feed DMD and/or an under-estimation of ash retention in liveweight gain.

7.1 Current Unknowns in Greenhouse Gas Emissions from Australian Feedlots

Available published data regarding GHG emissions from feedlots from international literature is limited, and there is a deficit of Australian literature for feedlots. As such, current estimates of GHG emissions (or a relative order of magnitude) from manure from Australian beef feedlots are based on a theoretical mass balance. Presently, the nutrient loss (N and VS) within dust and NO_x are assumed to be minimal. Similarly, the influence of feed wastage losses (e.g. rain damaged feed within the feed bunk) are also not considered

Specific knowledge gaps are listed below.

1. N_2O emissions from the different manure management system (within Australia), remains unknown including:
    a. the feedpad
    b. solid manure stockpiles/composting
    c. liquid storage process and ponds
    d. application of manure to soils.
2. The effect of varied environmental conditions on the pathways of N_2O emissions on separate feedlot manure management stages is not well understood. This is relevant for understanding N_2O emissions from different climates. Climate factors include:
    a. temperature
    b. solar radiation

   c. rainfall.

3. The effect of altered physical manure management within the feedlot on the biochemical pathways of N_2O emissions at the feedpad is unknown. For example the following factors are likely to influence N_2O emissions:
   a. provision of shade during summer; influences behaviour and deposition of manure on the feedpad
   b. manure residence on the feedpad; frequency of pen cleaning operations
   c. use of mounds within the pen
   d. design and construction of the feedlot; compaction during construction, slope of the feed pad, drainage
   e. integration of these factors (i.e. the most important factors are unknown).

There is also a lack of published data regarding measured CH_4 emissions from manure management in Australian feedlots. In the 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 based on gross energy intake, digestibility, urinary energy and ash content. Currently, there is a deficiency of CH_4 emission data, including an Australian-specific value of B_o from feedlot manure management. DCCEE (2010) estimates of CH_4 emissions from feedlot manure include a single figure to cover manure management from excretion through to application of manure to soil. Thus, DCCEE (2010) do not differentiate between losses from manure management sources (feedpad, solid storage and composting) within the feedlot. In addition, DCCEE (2010) do not include liquid manure storage as a source of CH_4 emissions, and therefore assume CH_4 emissions from liquid manure storage to be zero. Methane emission potential from feedlot manure is the essential limiting component to the formation of Tier 3 methodology for estimating GHG emissions from Australian feedlots.

Further to this, there are limitations in the current estimation of VS composition of manure at the various stages of manure management within Australian feedlots. The effects of climate, seasonality and management of manure are significant factors affecting the loss of VS from feedlot manure, at the various types of management. Data is required to support mass flow estimates of VS losses.

8 Recommendations

The use of Tier 3 (country-specific) methodology for estimating GHG emissions requires the validation of measurements in peer-reviewed publications. This process allows the development of country-specific emission factors (Dong et al. 2006). The use of the mass balance method is the recommended methodology for estimating GHG emissions from livestock, particularly for N emissions from manure (Dong et al. 2006). As such, recommendations from this review can be grouped under two major headings, with the aim of estimating GHG emissions from Australian feedlots, using emission factors relevant for Australian feedlots.

1. Further research to measure GHG emissions from Australian feedlots, by:
   a. Quantifying N_2O and NH_3 from different manure management options in Australian feedlots, relative to N intake and N content of manure inflows.
   b. Quantifying VS loss at different manure management options in Australian feedlots, relative to VS content of manure inflows.
   c. Providing an order of magnitude of loss of N and VS in other forms that are currently unquantified, for example dust, and NO_x.
   d. Publishing data in peer-reviewed journals.

   e. Research to establish the relative effects of climate (regional influence), seasonality and management systems on CH_4 and N_2O emissions from manure management in Australian feedlots.

2. A revision of BEEFBAL is required to provide a complete mass balance of N and VS flows within feedlots. Nitrogen and VS are used to calculate the likely manure GHG emissions (N_20 and CH_4) is recommended to involve:

   a. Additions to predict manure partitioning between the various manure management types within Australian feedlots.
   b. Incorporation of current values of emission factors, as supplied by research (from point 1 above). This will then facilitate a more comprehensive mass balance, which can then be used by the feedlot industry to estimate GHG emissions.

9 References

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Appendix A – Typical Feedlot System Parameters by Region

EconSearch Pty Ltd, IQ Agribusiness, FSA Consulting and Warwick Yates and Associates Pty Ltd (2009) undertook a study of the future of lot feeding in Australia. In that study, Australia was divided into nine lot feeding regions (Figure A1). For each region, typical ration ingredients were developed in consultation with industry representatives. Tables A1 to A9 provide the operating parameters for each region.

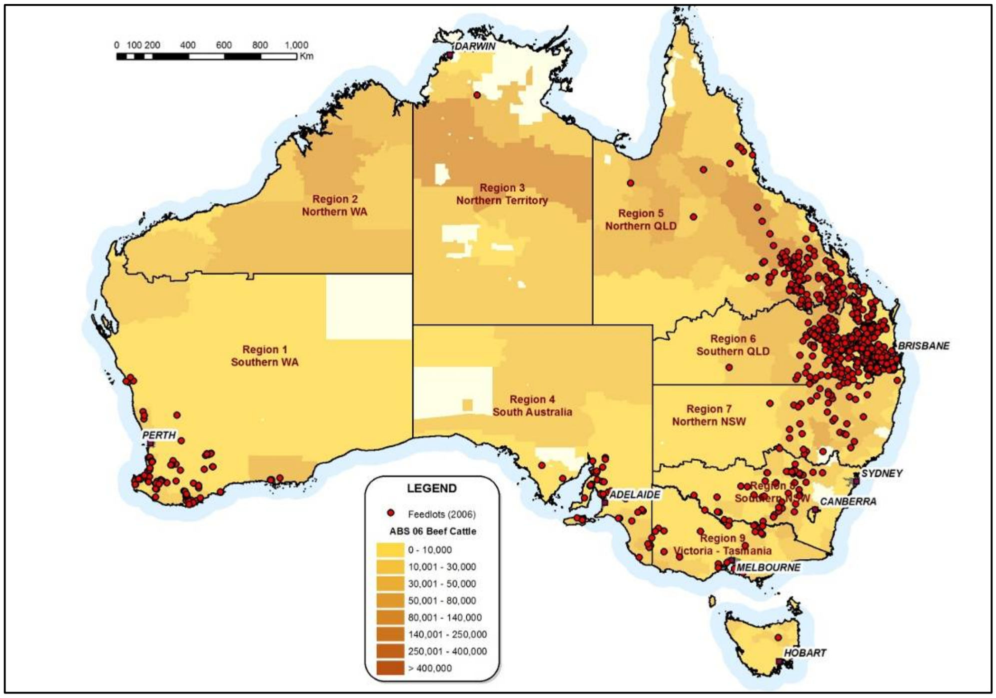

FIGURE A1 - LOT FEEDING REGIONS IN AUSTRALIA

TABLE A1 - REGION 1 (SOUTHERN WESTERN AUSTRALIA) RATION COMPOSITION PARAMETERS

Parameter	Type	Units	Market Type			
		(DM)	Domestic	Short Fed	Mid-Fed	Long-Fed
Grain	Summer	%	0	0		
	Winter	%	75	75		
Protein	Cottonseed	%	0	0		
	Canola	%	5	5		
	Lupins	%	5	5		
	Other	%	0	0		
Roughage	Straw/Hay	%	9.5	9.5		
	Silage	%	0	0		
Liquids		%	0.5	0.5		
Supplements		%	5	5		

TABLE A2 - REGION 2 (NORTHERN WESTERN AUSTRALIA) RATION COMPOSITION PARAMETERS

Parameter	Type	Units	Market Type			
		(DM)	Domestic	Short Fed	Mid-Fed	Long-Fed
Grain	Summer	%	75	75		
	Winter	%	0	0		
Protein	Cottonseed	%	5	5		
	Canola	%	0	0		
	Lupins	%	0	0		
	Other	%	5	5		
Roughage	Straw/Hay	%	2	2		
	Silage	%	4	4		
Liquids		%	4	4		
Supplements		%	5	5		

TABLE A3 - REGION 3 (NORTHERN TERRITORY) RATION COMPOSITION PARAMETERS

Parameter	Type	Units	Market Type			
		(DM)	Domestic	Short Fed	Mid-Fed	Long-Fed
Grain	Summer	%	75	75		
	Winter	%	0	0		
Protein	Cottonseed	%	5	5		
	Canola	%	0	0		
	Lupins	%	0	0		
	Other	%	5	5		
Roughage	Straw/Hay	%	2	2		
	Silage	%	4	4		
Liquids		%	4	4		
Supplements		%	5	5		

TABLE A4 - REGION 4 (SOUTH AUSTRALIA) RATION COMPOSITION PARAMETERS

Parameter	Type	Units	Market Type			
		(DM)	Domestic	Short Fed	Mid-Fed	Long-Fed
Grain	Summer	%	0	0	0	0
	Winter	%	75	75	75	75
Protein	Cottonseed	%	0	0	0	0
	Canola	%	5	5	5	5
	Lupins	%	4	4	4	4
	Other	%	0	0	0	0
Roughage	Straw/Hay	%	9.5	9.5	9.5	9.5
	Silage	%	9	9	9	9
Liquids		%	1.5	1.5	1.5	1.5
Supplements		%	5	5	5	5

TABLE A5 - REGION 5 (NORTHERN QUEENSLAND) RATION COMPOSITION PARAMETERS

Parameter	Type	Units	Market Type			
		(DM)	Domestic	Short Fed	Mid-Fed	Long-Fed
Grain	Summer	%	50	50	50	50
	Winter	%	25	25	25	25
Protein	Cottonseed	%	10	10	10	10
	Canola	%	0	0	0	0
	Lupins	%	0	0	0	0
	Other	%	0	0	0	0
Roughage	Straw/Hay	%	2	2	2	2
	Silage	%	4	4	4	4
Liquids		%	4	4	4	4
Supplements		%	5	5	5	5

TABLE A6 - REGION 6 (SOUTHERN QUEENSLAND) RATION COMPOSITION PARAMETERS

Parameter	Type	Units	Market Type			
		(DM)	Domestic	Short Fed	Mid-Fed	Long-Fed
Grain	Summer	%	32	32	32	32
	Winter	%	43	43	43	43
Protein	Cottonseed	%	10	10	10	10
	Canola	%	0	0	0	0
	Lupins	%	0	0	0	0
	Other	%	0	0	0	0
Roughage	Straw/Hay	%	3.5	3.5	3.5	3.5
	Silage	%	5	5	5	5
Liquids		%	1.5	1.5	1.5	1.5
Supplements		%	5	5	5	5

TABLE A7 - REGION 7 (NORTHERN NEW SOUTH WALES) RATION COMPOSITION PARAMETERS

Parameter	Type	Units	Market Type			
		(DM)	Domestic	Short Fed	Mid-Fed	Long-Fed
Grain	Summer	%	25	25	25	20
	Winter	%	50	50	50	37
Protein	Cottonseed	%	10	10	10	0
	Canola	%	0	0	0	0
	Lupins	%	0	0	0	0
	Other	%	0	0	0	8
Roughage	Straw/Hay	%	3.5	3.5	3.5	5
	Silage	%	5	5	5	15
Liquids		%	1.5	1.5	1.5	10
Supplements		%	5	5	5	5

TABLE A8 - REGION 8 (SOUTHERN NEW SOUTH WALES) RATION COMPOSITION PARAMETERS

Parameter	Type	Units	Market Type				
		(DM)	Domestic	Short Fed	Mid-Fed		Long-Fed
Grain	Summer	%	0	0	0	0	0
	Winter	%	75	75	75	75	65
Protein	Cottonseed	%	10	10	10	10	0
	Canola	%	0	0	0	0	4
	Lupins	%	0	0	0	0	3
	Other	%	0	0	0	0	0
Roughage	Straw/Hay	%	3.5	3.5	3.5	3.5	8
	Silage	%	5	5	5	5	10
Liquids		%	1.5	1.5	1.5	1.5	5
Supplements		%	5	5	5	5	5

TABLE A9 - REGION 9 (VIC/TAS) RATION COMPOSITION PARAMETERS

Parameter	Type	Units	Market Type				
		(DM)	Domestic	Short Fed	Mid-Fed		Long-Fed
Grain	Summer	%	0	0	0	0	
	Winter	%	75	75	75	75	
Protein	Cottonseed	%	0	0	0	0	
	Canola	%	6	6	6	6	
	Lupins	%	4	4	4	4	
	Other	%	0	0	0	0	
Roughage	Straw/Hay	%	3.5	3.5	3.5	3.5	
	Silage	%	5	5	5	5	
Liquids		%	1.5	1.5	1.5	1.5	
Supplements		%	5	5	5	5	

TABLE 42 - SUMMARY OF STUDIES MEASURING NITROUS OXIDE EMISSIONS FROM MANURE MANAGEMENT WITH FEEDLOTS

Source of emissions	Country	Method	Study period	Temperature	Treatments	DMI (kg/hd/d)	Intake N (CP%)	Estimated† N excretion (g/h) d^{-1}	Estimated‡ N2O-N as % of excreted N	Recorded value		SE	Units	Observation period	Reference
										CO_2-eq. (IPCC)	Absol. values				
Beef feedlot (feedpad)	Canada	Chamber	02 Oct 2001 (Start)	Manure on feedpad 4.3° C	low forage	11.7	13.2	261	0.065%	50.5	0.17		g N_2O-N (hd.d)$^{-1}$	126 d, periodic measures	Boadi et al. (2004)
								+ 50	*0.05%*						
								- 50	*0.08%*						
					high forage	10.0	12.0	261	0.059%	46.0	0.15		g N_2O-N (hd.d)$^{-1}$		
								+ 50	*0.05%*						
								- 50	*0.08%*						
Dairy stand-off pad	New Zealand	Chamber	May to Aug 2005	NR	no treatment						0.01		N_2O-N % of total N	10 weeks	Luo and Saggar (2008)
Dairy manure (liquid, solids)	Switzerland	Chamber	unknown	Ambient 20°C	Grass low protein; liquid manure						0.79	± 13.28	N_2O-N % (of total N)		Kulling et al. (2003)
										267	*0.57*	*± 0.67*	*g N_2O-N (hd.5 week)$^{-1}$*	Series 1 (low grass protein): storage for 5 weeks	
				Water bath; 41° C decreasing by 2°/ wk	Grass low protein; solid manure						12.3	± 13.28	N_2O-N % (of total N)		
										1775	*3.79*	*± 0.67*	*g N_2O-N (hd.5 week)$^{-1}$*		
				Ambient 20°C	Grass high protein; liquid manure						1.45	± 0.72	N_2O-N % (of total N)		
										1494	*3.19*	*± 0.33*	*g N_2O-N (hd.7 week)$^{-1}$*	Series 2 (high grass protein): storage for 7 weeks	
				Water bath; 41° C decreasing by 2°/ wk	Grass high protein; solid manure						7.12	± 0.72	N_2O-N % (of total N)		
										1770	*3.78*	*± 0.33*	*g N_2O-N (hd.7 week)$^{-1}$*		
Composting of feedlot manure	Canada	Chamber	May, 1997	mean daily ambient; 10 to 25°C; Passive max 62°C, decreasing to <40°C	Passive (no turning)						0.62	-	N_2O-N % (of total N)	99 days	Hao et al. (2001)
										52	*0.11*	-	*Kg N_2O-N (t manure)$^{-1}$*		
					Active (6 turns)						1.07	-	N_2O-N % (of total N)		
										89	*0.19*	-	*Kg N_2O-N (t manure)$^{-1}$*		
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						0.39	-	N_2O-N % (of total N)	99 days	Hao et al. (2004)
										36	*0.0771*	-	*Kg N_2O-N (t manure)-1*		
					Wood-chip based bedding material						0.68	-	N_2O-N % (of total N)		
										39	*0.0842*	-	*Kg N_2O-N (t manure)-1*		
Beef cattle manure	Canada	Chamber	Consecutive summers (beef following dairy)	NR	Slurry (anaerobic)					5	0.017		g N_2O-N kg^{-1} DM	3 months	Pattey et al. (2005)
					Stockpile (mixed)					10.1	0.034		g N_2O-N kg^{-1} DM		
					Composted (aerobic)					48	0.162		g N_2O-N kg^{-1} DM		

SE Standard Error

NR Not Reported

† N excretion estimated using BEEFBAL, for steer on feed for 100 days

‡ N2O-N as percent of Total excreted N; = (measured N2O-N/ estimated total excreted N)