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ACCESSORY PUBLICATION

Predicting livestock productivity and methane emissions in northern Australia: development of a bio-economic modelling approach

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Introduction

The model used in the paper (Charmley *et al*., 2008) is preliminary and designed to show the comparative impact of animal, pasture and management variables on methane emissions for typical northern Australian conditions. Model development is ongoing. This appendix summarizes the model inputs at the time of publication for the accompanying paper (Charmley *et al*., 2008).

A spreadsheet (Microsoft Excel) based model [the Northern Australia Beef Cattle Energetics and Methane Simulator (NABCEMS)] was developed to predict methane emissions from cattle under northern Australian conditions. The model encompasses three key components: (1) animal, (2) pasture, and (3) property/bioregional. The NABCEMS model also links with a separate, commercially available, economic herd model (Breedcow and Dymama herd budgeting software (Queensland Department of Primary Industries and Fisheries 2004)) to represent underlying herd dynamics and profit maximisation behaviour. This provides a flexible tool to evaluate, at property and regional levels, effects of management changes to animal and herd variables on methane emissions, live weight (LW) productivity and financial implications.

Currently, the model only applies to pasture-based systems, with the provision for molasses/urea supplementation.

The model is based on the metabolizable energy (ME) system, first devised for UK conditions (ARC 1980) but subsequently expanded upon in Feeding standards for Australian Livestock (SCA, 1990). Elements of both publications are used in the model. The model iterates on a weekly time step, calculating feed intake, productive performance and methane output over the lifetime of the animal. The primary driver for the model is diet quality (expressed as energy digestibility) which influences both dry matter intake (DMI) and efficiency of diet utilization for maintenance and production.

Estimating pasture quality

Pasture energy digestibility changes over the year according to a polynomial relationship (Figure 1) derived from published data (Ash and McIvor, 1988) and modified based upon personal communications with J.G. McIvor (pers. Comm.) and C. McDonald (pers. Comm.). The relationship can be described by the general equation:

$$Y = A + Bx - Bx^2 + Bx^3 \quad (1)$$

The year starts at the beginning of the wet season, which for the purposes of modelling is the 1st November. Digestibility of pasture is calculated over the year based on either of two seasonal patterns. For one pattern, digestibility declines quickly as the dry season advances; for the other, digestibility declines more slowly. For either of these patterns, a family of digestibility relationships with time can be generated which describes the change from high pasture quality in the wet season, to low quality at the end of the dry season. The model allows the user to select the most appropriate curve for the season and location.

Estimating energy requirements of cattle

The gross energy (GE) of the diet is calculated using the equation:

$$\text{GE (MJ/kg)} = 15.16+4.54(\text{GED}/100) \qquad (2)$$

where GED is the gross energy digestibility expressed as a percentage. Digestible energy (DE) is simply:

$$\text{DE (MJ/kg DM)} = \text{GE(GED)} \qquad (3)$$

where GED is calculated for a given week post-November 1st according to Figure 1. Metabolizable energy (ME) is given as:

$$\text{ME (MJ/kgDM)} = \text{DE}(0.77) \qquad (4)$$

Metabolizability (q) is then calculated for a diet as ME/GE.

Maintenance and activity

Energy requirements of cattle are calculated from the combined energy requirements for maintenance (fasting metabolism, activity and eating), growth, lactation and pregnancy. Fasting metabolism (F) is given in ARC (1980) as:

$$\text{F (MJ/d)} = \text{C1}\{0.53(\text{LW}/1.08)^{0.67}\} \qquad (5)$$

where C1 =1.15 and 1.0 for bulls and other cattle, respectively, of *Bos taurus* breeds and 1.05 and 0.8 for bulls and other cattle, respectively, of *Bos indicus* breeds. The lower fasting metabolism for *Bos indicus* cattle is based on data from Vercoe (1970) showing an approximate 20% lower fasting metabolism for Brahman versus British cattle. Activity allowance (ARC, 1980) is given as:

$$\text{Activity allowance (MJ/d)} = (\text{D x LW x 2})/1000 \qquad (6)$$

where D is the distance travelled in km/d. The eating allowance is taken from SCA (1990);

$$\text{Eating allowance (MJ/d)} = (0.006\text{DMI}) \times (0.9\text{GED}) \times \text{LW} \qquad (7)$$

The sum of equations 4, 5 and 6 comprise NE for maintenance. ME for maintenance is used with an efficiency (k_m) which is dependent upon q:

$$k_m = (0.35q) + 0.503 \qquad (8)$$

Similarly, efficiencies of utilization are also used for growth (k_f) and lactation (k_l):

$$k_{f} = (0.78q) + 0.006 \qquad (9)$$

$$k_{l} = (0.35q) + 0.42 \qquad (10)$$

Growth

A quadratic equation is used to predict energy value of weight gains (EV_g)

$$EV_g \text{ (MJ/kg)} = \frac{C2(4.1 + 0.0332LW - 0.000009LW^2)}{(1 - C3 \times 0.1475\Delta LW)} \qquad (11)$$

where C3 = 1 when plane of nutrition > 1 and C3 = 0 when plane of nutrition <1. C2 is a correction factor for the energy value of different breeds according Table 1. Daily energy retention is given by:

$$\text{Daily energy retention (MJ/d)} = \Delta LW \times EV_g \qquad (12)$$

Net energy for maintenance, activity and weight change is the sum of equations 4, 5, 6 and 10.

For cattle the dietary ME intake (MEI) is a function of the ME content of the diet (MJ/kg DM) and the diet dry matter intake (DMI):

$$\text{MEI (MJ/d)} = \text{DMI} \times \text{ME} \qquad (13)$$

For a given MEI intake a certain level of production (gain, pregnancy or lactation) can be attained once the requirements for maintenance have been accounted for.

For growing cattle, the ME required for maintenance and production can be estimated according to the general relationship in ARC (1980):

$$ME\ (MJ/d) = E/k. \qquad (14)$$

where E is the net energy of maintenance and production and k is the efficiency of utilization of ME. The model uses a variant of this relationship to account for differential efficiencies of utilization for maintenance and production and the effect of plane of nutrition:

$$MEmp\ (MJ/d) = (E_m/k) \times \ln\{B/(B-R-1)\} \qquad (15)$$

where E_m is the sum of fasting metabolism and activity,

$$B = k_m/(k_m-k_f), \qquad (16)$$

$$k = k_m \times \ln(k_m/k_f), \qquad (17$$

R is calculatede from :

$$E_f\ (MJ/d) = C4(EVg \times \Delta LW) \qquad (18)$$

where E_f is the net energy of gain, C4 = 1.15 for bulls and castrates and 1.10 for heifers, and then:

$$R = E_f/E_m \qquad (19)$$

Lactation and pregnancy

Net energy content of milk is based on a prediction of milk yield and composition over an entire lactation for *Bos indicus* x *Bos taurus* (Hunter and Magner, 1988) as shown in Figure 2. Selecting between 1 and 3 the user can input a specific milk energy content curve with peak milk production varying between 5 and 7 kg/d. ME requirement for milk production is given by

$$ME\ (MJ/kg) = NE_{milk} \times k_l \qquad (20)$$

where kl is defined in equation 10.

Net energy content of the foetus and adnexa (concepta) throughout pregnancy is based on the relationship used in ARC (1980) according to the equation:

$$NE_{pregnancy}\,(MJ/d) = 0.125e^{0.01978x} \qquad (21)$$

where x is days from conception. Efficiency of utilization of ME for concepta is assumed to be 0.133.

Total ME requirement for lactating cattle is the sum of requirements for maintenance, activity, growth, lactation and pregnancy. For both the growing and reproductive animal, weight change is dependent upon the ME available from the diet after accounting for maintenance, and in the case of reproductive cattle, lactation and pregnancy.

Estimating dr matter intake

Potential pasture intake can be calculated using three options. In the first the ARC (1980) equation can be used relating DMI to LW and diet quality:

$$DMI = \{(106.5q) + 24.1) \times LW^{0.75}\}/1000 \qquad (22)$$

Alternatively the SCA relationship can be used, which also related DMI to body weight and diet quality:

$$DMI\,(kg/d) = (0.025 \times LW \times (1.7\text{-}LW/MLW \times (1\text{-}(1.7*(0.64\text{-}GED) \qquad (23)$$

where MLW is mature LW.

Finally, in accordance with data for tropical diets (D.B. Coates, pers. comm.) the option exists to select DMI as 0.8 of the SCA estimate of DMI.

Having estimated potential DMI, actual DMI is calculated as a proportion of potential DMI according to the pasture DM yield. As yield declines, so too does the ability of the animal to reach its potential DMI based solely on forage quality. A range of relationships, depending upon pasture type, can be selected (Figure 3). These relationships have been taken from the literature (Coleman, 2005; based on Rayburn, 1986) and based on personal observations of J.O. Carter (pers. comm.).

Supplementation

The model simultaneously estimates performance and methane emissions without or with supplementation. Essentially, a minimum rate of LW gain can be entered on the inputs screen. If pasture cannot meet the ME requirements for this level of LW gain, the model calculates the amount of supplement required. A substitution effect is included which is positive (i.e. the supplement has a positive effect on pasture intake) below a digestibility of 50%, and negative above 50% digestibility (i.e. the supplement has a negative effect on pasture intake). The relationship is described by the equation:

$$\text{Substitution rate (kg/kg)} = -2.32 - 2.25/(1 - 0.038\text{GED}) \quad (24)$$

Estimating methane emissions

There are few data available for enteric emissions of methane from tropical forages. Thus, the model can utilize an equation based on diet quality of temperate forages using a relationship between digestibility and methane (Benchaar et al. 2001):

$$\text{Methane (g/kg DM intake)} = -1.689 \times \text{GED} + 137.3 \quad (25)$$

Alternatively, the model can predict methane from DMI, according to AGO guidelines using the original equation of Kurihara *et al*. (1999), but with the corrections reported by Hunter (2007):

$$\text{Methane (g/d)} = 34.9 * \text{DMI (kg/d)} - 30.8 \quad (26)$$

Finally a modification of the above relationship, which includes more recent results from cattle offered a poor quality tropical grass supplemented with urea can be used:

$$\text{Methane (g/d)} = 35.16 * \text{DMI (kg/d)} - 34.8 \quad (27)$$

Property and regional level dynamics

The property and regional component of the modelling approach incorporates animal LW gain and methane emissions into a herd structure based on typical trading enterprises. Economic and physical data from the annual ABARE farm surveys database (http://www.abareconomics.com/ame/mla/mla.asp) were used to describe a typical trading enterprise for each region based on the ABARE Australian broad acre zones and regions (Figure 4).

Data collected for specialist beef properties for each region are given in Table 2. The diet digestibility profile (Figure 1) was assigned to each bio-region based on annual live LW gain data from a recent industry survey (Bortolussi *et al*., 2005). Key modelling inputs used to characterise the representative properties and industry structure for each region are presented in Table 2.

Data on property herd sizes and variable costs for each region were incorporated in a herd economic budgeting model; Breedcow and Dynama herd budgeting software (Queensland Department of Primary Industries and Fisheries 2004). The calculation of property herd and regional methane emissions required a number of iterative steps between the NABCEMS and Breedcow models. First, the predicted live weight gains from the animal component of NABCEMS were used to derive animal sale prices by age class (i.e. weaners, steers, heifers and culled cows and bulls) using 5 year average saleyard prices from the MLA National Livestock Reporting Service (Table 3). The NABCEMS model calculates net saleyard prices after deducting transport, marketing commission and yarding costs. Second, net animal prices are manually entered into the herd economic model to maximize gross margin for a given marketing option (e.g. Japan Ox). The corresponding steady state herd outputs (i.e. animal age class cohorts) are then used as inputs in NABCEMS to calculate property LW gain and methane emissions. Regional level statistics were also generated based on the total number of properties within each region.

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Table 1. Correction factors (C2) for energy value of BW gains in different breeds

	Bulls	Castrates	Heifers
Early maturing	1	1.115	1.3
Medium maturing	0.85	1.0	1.15
Brahman cross	0.75	0.9	1.05
Brahman	0.7	0.85	1.0

Table 2. Key industry input parameters for the 8 bioregions included on the model

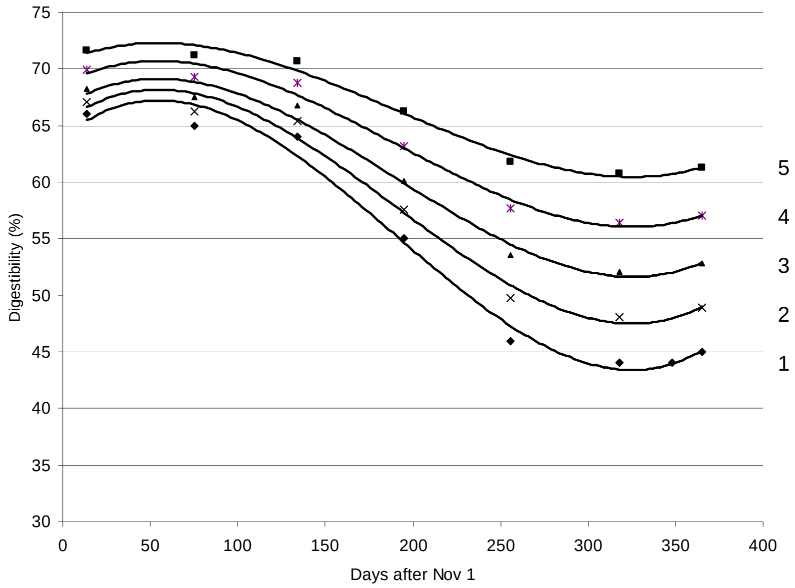
Input variables	Southern speargrass	Brigalow	Northern speargrass	Mitchell grass (W. Qld)	Mitchell grass (E. Qld)	Victoria River District	Barlky Tableland	Kimberley	Pilbara
Stocking rate (Ha/head)[A]	5	6	14	26	14	18	30	32	73
Digestibility profile (1-10)[B]	1.43	3	1.7	1.8	1.8	0.8	0.8	1.3	0.9
Biomass yield (kg/ha at end of wet season)[C]	1700	2000	1450	1100	1100	2000	1100	1500	500
Branding rate (%)[A]	67	71	59	62	76	61	62	60	59
Death rate – cows and steers (%)[A]	2	2	3	4	6	4	3	3	3
Number of properties [A]	2143	2059	482	188	432	64	28	51	101
Average herd size (AE) [A]	500	900	3000	6000		9500	17500	7500	3200
Distance to market (km)[B]	200	200	200	300	200	300	300	400	500
Key markets [B]	Domestic & export slaughter	Domestic & export slaughter	Domestic & export slaughter	Domestic & export stores	Domestic & export stores	Live export	Live export, domestic stores	Live export	Live export
Annual LWG (kg/year)[D]	132	183	141	145	145	110	111	127	114
Industry survey region and pasture type [D]	Speargrass	Brigalow	Speargrass	Mitchell grass	Mitchell grass	Ribbongrass	Mitchell grass	All spp.	Spinifex

[A]ABARE survey data, Beef specialists, 5 year average (2000-2005)
[B]Charmley et al., (2008)
[C]Hall et al (1988)
[D]Bortolussi et al. (2005)

Table 3. Weight for age specifications and saleyard prices (5 year averages)[A]

Weight for Age	LW (kg) min	LW (kg) max	Age (yrs) min	Age (yrs) max	Prices $/kg
Domestic feeder (heifer)	180	330	1.00	1.50	1.86
Domestic feeder (steer)	180	330	1.00	1.50	2.01
Stores/feeder (export)	300	480	1.00	2.50	1.92
EU export	430	620	1.50	2.50	1.80
Japanese Ox export	510	700	2.00	4.50	1.86
US manufacturing	330	800	2.50	5.00	1.61
Live export (light)	230	400	1.00	4.00	1.80
Live export (heavy)	400	500	1.00	5.00	1.65

[A]Derived from Meat and Livestock Australia (www.marketdata.mla.com); New South Wales Department of Agriculture (www.agric.nsw.gov.au/tools/cattle); Bortolussi *et al*. (2005c).



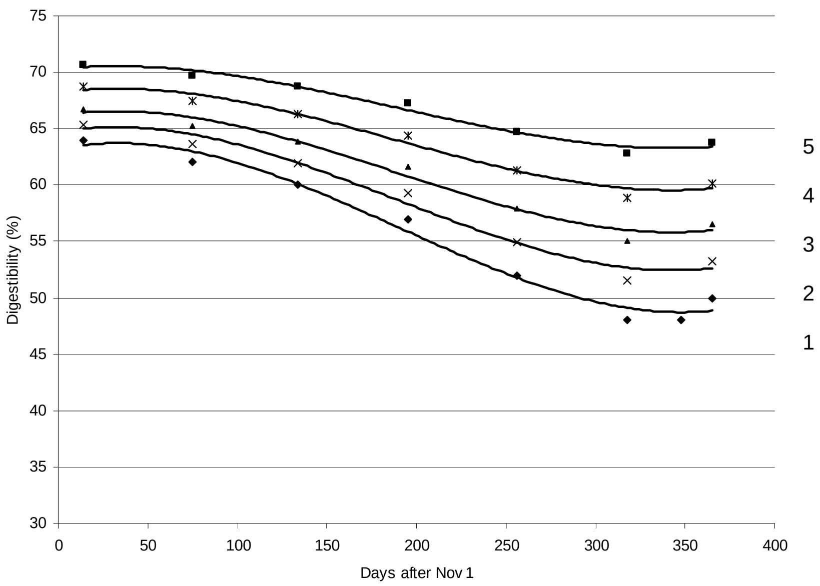


Fig. 1. Changes in gross energy digestibility over the season for high (top graph) and low (bottom graph) rates of decline in digestibility over time. Lines represent a gradation in overall forage quality from very low (quality index 1) to very high (quality index 5)**.**

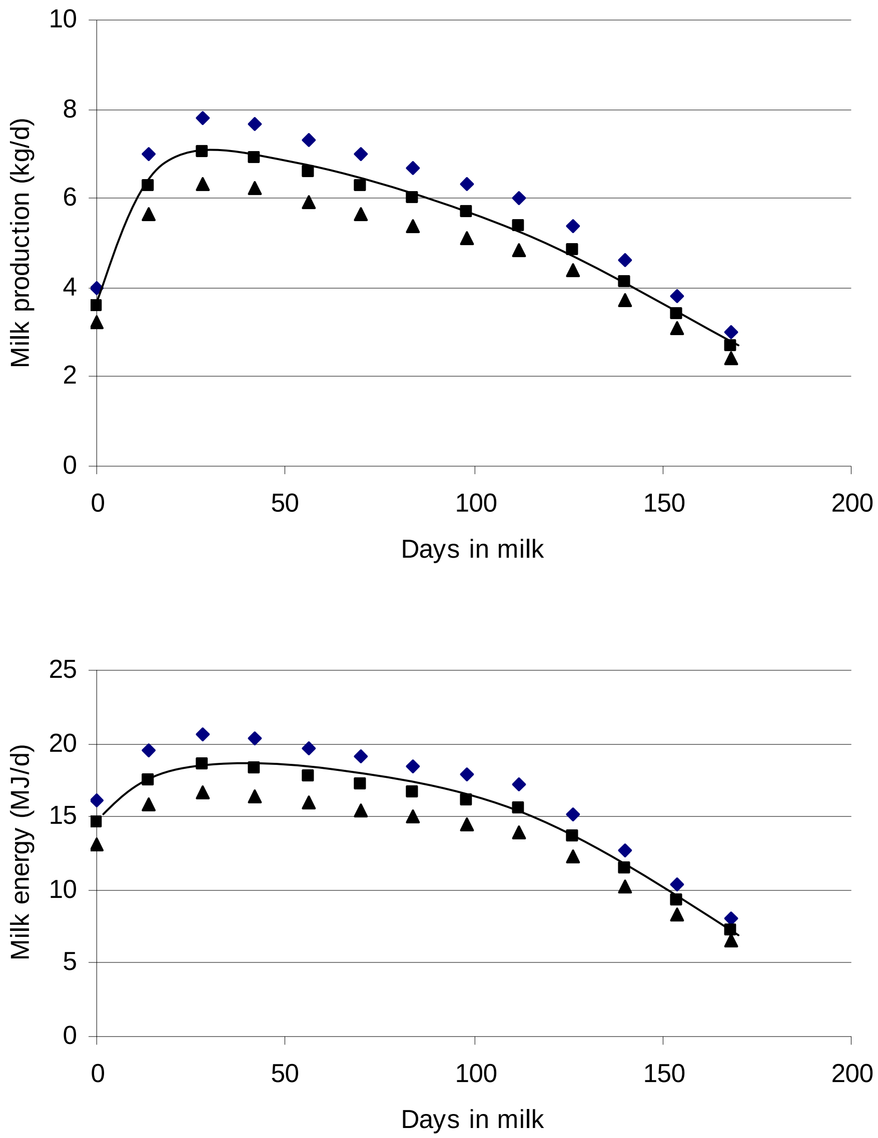


Fig. 2. Milk production and milk energy curves for three levels of milk production

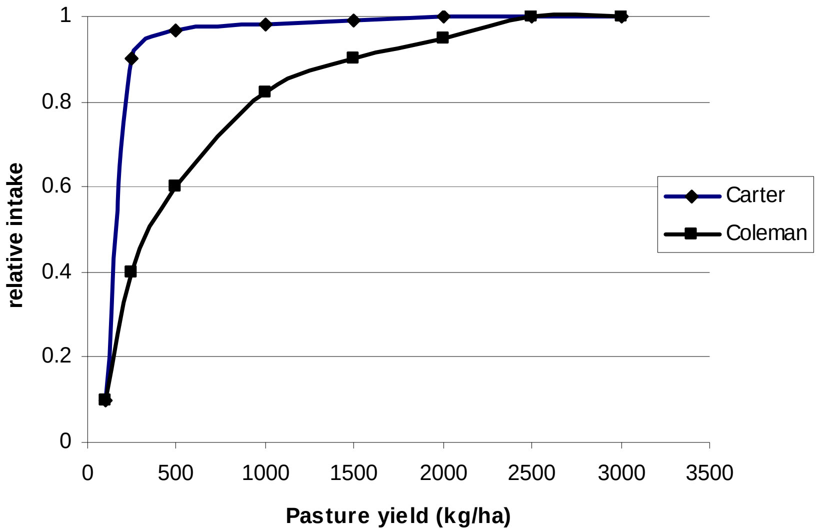
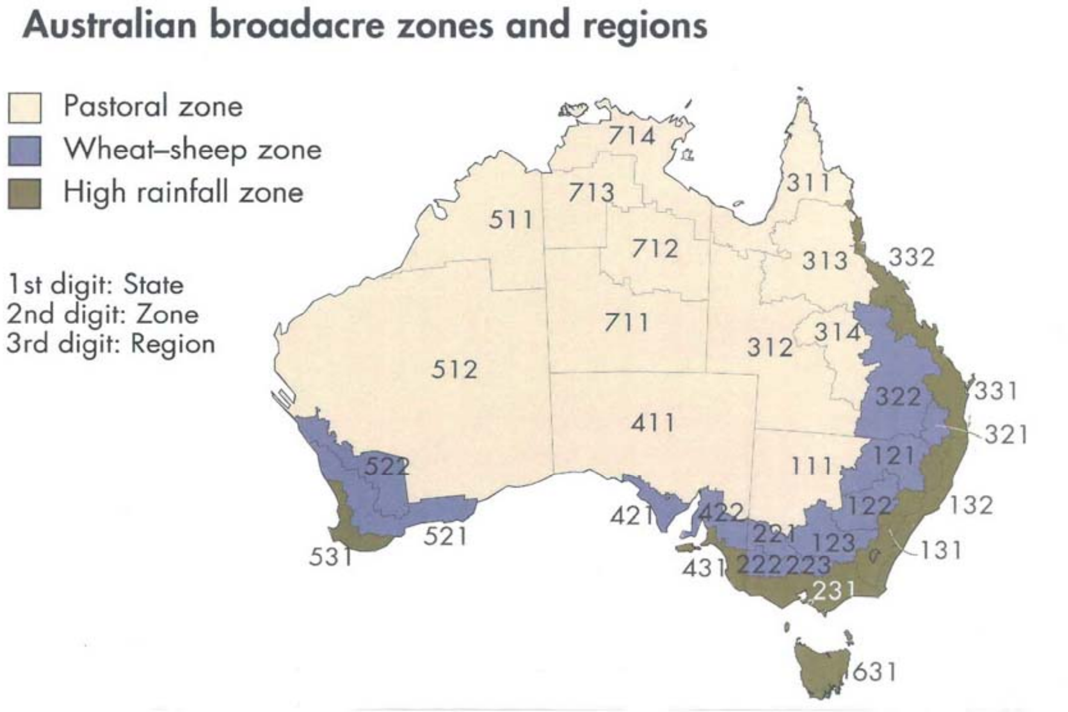


Fig. 3. Relationship between DM yield and potential intake for high (Coleman) and low (Carter, pers. comm.) relative availability



ABARE zone	Northern Australia beef industry bio-region	Geographic description
331	Southern speargrass	Southern Queensland coastal – Curtis to Moreton
322	Brigalow	Darling Downs and Central Highlands of Queensland
313	Northern speargrass	North Central Queensland
312	Mitchell grass (western)	Western and Southern Western Queensland
314	Mitchell grass (eastern)	Charleville-Longreach Queensland
713	Victoria River District	Katherine-Victoria River District
712	Barkly Tableland	Barkly Tablelands
511	Kimberley	The Kimberley
512	Pilbara	Pilbara and central pastoral Western Australia

Fig. 4. ABARE broadacre zones and regions