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Prepared by: Dr Stuart R McLennan & Dr Dennis Poppi
Department of Primary Industries & Fisheries
University of Queensland

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Improved prediction of the performance of cattle in the tropics

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Abstract

A study was carried out to improve the prediction of performance of cattle in northern Australia. Existing data sets were used to evaluate the current feeding standards, or the decision support systems developed from them, for use with cattle grazing tropical pastures. The models tested were GrazFeed, developed in Australia, and the Cornell Net Carbohydrate and Protein System (CNCPS) from the USA. Our findings were that the underlying equations used in the feeding standards and models were sound and provide a basis for future development of decision support systems for northern cattlemen. The CNCPS and the equations used in GrazFeed predicted liveweight gain well when intake was known but not when intake had to be predicted from diet composition. By the reverse process, intake could be predicted from the models when liveweight gain was known, either by direct measurement or from historical records. The predicted intake can be used to determine appropriate stocking rates, for instance. Neither GrazFeed nor the CNCPS are currently suited for use under northern rangeland conditions as they require relatively detailed inputs on the pasture/diet, but modifications have been suggested to accommodate the simpler inputs available from faecal NIRS analysis.

Executive summary

For cattle producers, being able to predict the performance of their animals in the short to medium term would provide added flexibility of management especially in terms of meeting target markets. Nutritionists use the feeding standards to predict animal performance from diet attributes. A study was carried out with three main objectives: to determine the applicability of the current feeding standards to tropical breeds of cattle on tropical forage systems; to determine how well existing decision support systems (DSSs) based on the feeding standards predict the performance of cattle on these systems; and to make recommendations on how the feeding standards and DSSs could be changed to improve predictions of grazing cattle performance. Past experience suggested that the DSSs predicted performance poorly under rangeland conditions in northern Australia. The other aim was to provide the link between the information currently provided by faecal near-infrared reflectance spectroscopy (NIRS) methodology on diet quality of grazing cattle, and ways of using this information to predict animal performance or devise feeding strategies to improve performance.

Two DSSs were chosen to address these objectives on the basis that they were quite different in their underlying approach, were well supported by research groups and were commercially available. There were GrazFeed, developed by CSIRO Canberra, and the Cornell Net Carbohydrate and Protein System (CNCPS) developed at Cornell University, NY State, USA. The basic equations from the Australian feeding standards (SCA), which are incorporated in GrazFeed, were also evaluated. We used an extensive data set from experiments with *Bos indicus* steers carried out in previous MLA-supported studies for our investigations.

The major findings were:

- The established principles of energy use for growth by cattle do apply with tropical diets in the same way they do with temperate diets, as evidenced by the close linear relationship between (metabolisable) energy intake and cattle growth rate. This finding endorses the future application of the feeding standards to tropical grazing systems.
- The CNCPS and SCA gave good predictions of liveweight gain (LWG) when the diet composition was described in detail and intake was known. GrazFeed, by contrast, did not predict LWG well.
- The different DSSs use different equations and approaches for determining aspects of energy utilisation but the finding that LWG was well predicted by SCA and the CNCPS suggests that the equations underpinning these DSSs were robust and sound.
- Improvements in growth rate predictions were achieved with the SCA by changing components of the equation predicting the maintenance requirements of animals, in particular the breed effect and effect of metabolisable energy intake. Several changes have been recommended.
- GrazFeed uses essentially the same equations as SCA and based on the good LWG predictions with SCA, these equations are sound.
- The under-prediction of LWG with GrazFeed was related to the fact that when this model predicts a deficiency of rumen degradable protein (RDP) in the diet, it reduces intake and thus the estimate of LWG. At times, GrazFeed used a lower intake than was actually measured.
- Estimated microbial crude protein (MCP) production is the major contributor to metabolisable protein supply for cattle on tropical forage diets and, whilst CNCPS predicted MCP production well, GrazFeed under-predicted it.

- Based on the good predictions of LWG from known intake, both the CNCPS and SCA equations could be used to back-calculate intake from a measured or historical estimate of LWG, given limited description of the diet (e.g., from NIRS) and of the animals.
- A spreadsheet intake calculator, “QuikIntake”, was developed to calculate intake from basic inputs describing the animal and with known digestibility of the diet from NIRS. This spreadsheet is available now for producers to use, for instance to determine appropriate stocking rates.
- Neither GrazFeed nor the CNCPS provided an accurate prediction of intake when only diet and animal descriptors were used due to the generally poor relationships between intake and diet composition parameters.
- Based on the poor predictions of intake, the models would not give good predictions of LWG when intake is not known.
- In their present form, both GrazFeed and the CNCPS require complex inputs on the pasture or diet parameters in order to predict animal performance.

Conclusions:

- The equations underpinning the feeding standards and DSSs are robust and applicable for tropical diets and provide confidence that reliable DSSs can be developed for northern Australia in the future.
- If LWG is known, either measured or as a historical estimate, the CNCPS and SCA equations can be used to estimate intake of grazing animals with some information on the animal and diet.
- Neither GrazFeed or the CNCPS is suitable in its current form for predicting cattle performance in northern Australia, a major problem being that the amount or type of information they require on the pasture or diet is not readily available under rangeland grazing conditions.
- Poor prediction of intake from diet composition alone is the major limitation to developing DSSs which can be used to predict the performance of grazing animals.

Recommendations:

- Existing DSSs need to be modified to accept more limited but accurate input data available from faecal NIRS.
- The findings of this study for growing cattle, especially as they relate to the prediction of intake from known LWG, need to be extended to grazing cows. This will be hampered by the limited information available on reproductive females but the current experience with the growing cattle suggests the feeding standards will be sound.
- Research is required to provide a clear definition of when herbage mass / pasture structure limits intake of cattle grazing tropical pastures, rather than pasture quality upon which intake / diet characteristic relationships are currently based.
- In view of the problems associated with the current intake / diet composition relationships, two strategies should be explored, viz., (i) investigate and validate other such relationships perhaps involving a multi-component description of diet quality; and (ii) compare the error of prediction of intake from an intake / faecal NIRS relationship with that of existing conventional relationships for intake determination.

Contents

1 Background

Cattle producers in northern Australia have identified the need for strategies to increase growth rate of their cattle and for improving their ability to make decisions on supplementation, as key issues affecting their management. One of the major limitations confronting producers is their inability to estimate current performance (e.g., growth rate) of their animals on which to base decisions for ensuing nutritional management. There are nutritional models, which are based on the feeding standards, available but these have been developed on temperate forage systems and usually with *Bos taurus* cattle and are generally poor in predicting the performance of cattle grazing tropical forages. It appears that some of the basic equations included in these models are not appropriate for the cattle genotypes predominating in our tropical environment or for the diets encountered. All these models aim to predict metabolisable energy (ME) and metabolisable protein (MP) intake and to use these in turn to predict animal performance.

There is some evidence that there are significant errors with the models in the prediction of both ME and MP intakes with tropical forages. Intake is usually predicted from an estimate of the digestibility of the diet, or some other dietary descriptor, but with tropical forages the models do not appear to predict intake well from a digestibility estimate, i.e., the intake/digestibility equation which forms the basis of all predictive equations is not appropriate.

Microbial protein, i.e., the protein contributed by the microbes residing in the rumen, is the main contributor to MP intake in grazing animals and a second likely source of error within the models is the prediction of microbial protein production. Microbial protein production is predicted by using an estimate of ME intake, which as indicated above may be flawed, combined with the application of a fixed value for the amount of microbial protein produced per unit of ME intake or fermentable ME intake, i.e., using a constant efficiency of microbial protein production (EMCP) value. We have shown in our previous studies that the efficiency of microbial protein production for cattle consuming tropical forages is often considerably lower (e.g., by half) than predicted by the feeding standards.

Another potential source of error is the relationship, included in the feeding standards, between energy intake and energy utilisation by the animal, which is fundamental to describing the link between intake and animal performance. It is unlikely that this general relationship is flawed but it needs to be tested using data from tropical forages and cattle.

In this study we addressed these issues by utilising a large data set from our own research group derived from the feeding of tropical forages and various supplements to tropical breed cattle, where intake, *in vivo* digestibility, microbial protein production and liveweight change have been measured. Using data sets where intake, *in vivo* digestibility and liveweight gain were known allowed intake determination to be separated from the utilisation of energy and for relevant equations to be assessed. We evaluated the equations and principles of two widely-used decision support models, (DSMs) viz. the Cornell Net Protein and Carbohydrate System (CNCPS) from North America and GrazFeed from Australia, in relation to energy utilisation by cattle. Our aim was not to compare the models. Rather we sought to examine their prediction of liveweight gain and energy utilisation. As the models use different equations and concepts, it was thought that this approach could identify the strengths and weaknesses of the different approaches. Neither of the DSMs was developed primarily for tropical feeding systems although some modifications have been put in place in the DSS to account for this. Recent developments in faecal near-infrared reflectance spectroscopy (NIRS) methodology has resulted in accurate predictions of the digestibility and crude protein (CP) content of forage alone and mixed diets (where supplements are used), with accuracy far in excess of any previous methodology used in the tropics. It is logical to link any predictions of animal performance to the outputs from the faecal NIRS outputs of diet quality in terms of CP content and digestibility. The two models provide an avenue for using this information.

2 Project objectives

For cattle grazing tropical and sub-tropical pastures:

1. Determine the reasons for the current poor predictions by the principal feeding standards and decision support models (DSMs) of animal growth.
2. Identify the essential dietary parameters required to accurately predict animal growth in such feeding standards and DSMs.
3. Recommend changes to the principal feeding standards to improve predictions of animal growth and communicate these recommendations to the owners of the DSMs.

3 Methodology

3.1 Purpose and use of models

There are several potential uses of nutritional models for grazing animals in the tropics some of which differ from the more traditional ration formulation exercise employed with housed animals. Some potential uses include:

- prediction of intake from animal performance;
- prediction of liveweight change from pasture and/or diet characteristics;
- prediction of responses to supplements;
- identification of limiting nutrients.

These predictions, coupled with the information provided from faecal NIRS analysis, have the potential to provide a valuable management tool for use with grazing cattle in the northern tropics of Australia and in other tropical ruminant production systems. However, to date, the general experience in northern Australia has been that the output of most interest, LW change, is often predicted with values that are unrealistic, suggesting a lack of precision in the estimation of ME intake and/or its utilisation. Models are consequently infrequently used. Nevertheless, the greater emphasis now on targeting specific cattle markets with narrow specifications for carcass age, weight and composition, and the need to determine appropriate stocking rates for responsible pasture and land utilisation, have increased the scope for these predictive tools.

3.2 Description of the database

The database used was drawn from a series of experiments carried out by our research group using Bos indicus crossbred steers and low quality tropical forages, with and without supplement (McLennan 1997, 2004; Bolam 1998; Marsetyo 2003). This included six pen feeding experiments (240 steers) carried out over 63 to 70 d in which intake and liveweight gain were measured, and six associated metabolism studies using the same diets to determine in vivo digestibility and microbial protein production by the purine derivative method (Chen and Gomes 1995). The various studies were conducted in a sub-tropical environment, mainly in Autumn or Spring, and thus avoided extremes of temperature or humidity. Steers were individually fed. They were aged between 12 and 15 months and weighed between 156 and 243 kg at the start of feeding (205 kg average liveweight (W) during experiments). Low quality tropical grass hays, six in total from the grasses Chloris gayana (Rhodes grass) and Panicum maximum (green panic grass), containing (DM basis) 4.8 to 7.7% crude protein (CP) and 67.0 to 71.9% neutral detergent fibre (NDF), and with organic matter digestibility (OMD) of 52.9 to 57.5%, were fed ad libitum to all steers. Dry matter intake of hay for unsupplemented steers ranged from 1.80 to 2.35%W/d. Supplements were fed in increasing amounts up to 2%W/d to allow response curves to be developed, with treatments arranged in a randomised block design. Total DM intakes were increased up to 3.4%W/day. There were 3-6 steers per treatment in the pen feeding studies. Supplements included sorghum grain (dry rolled and expanded), barley (dry rolled), molasses, cottonseed meal, copra meal and various combinations of these. In most cases urea and some minerals were included in the grain and molasses supplements to balance the rumen for rumen degradable nitrogen (RDN) to fermentable energy and to avoid specific mineral deficiencies in these energy supplements. The database pooled 62 treatments for intake and growth rate. Liveweight change for the unsupplemented steers ranged from -0.10 to 0.25 kg/day and peaked at 1.20 kg/day for supplemented steers.

By its nature the database exhibited several desirable features, notably the inclusion of tropical hays, a wide range of diet combinations and growth rates ranging from maintenance to in excess of 1 kg/d. There was also some uniformity in the type of animals used in the experiments. On the negative side, all of the hays were of low quality and the increases in energy intake by steers within an experiment were achieved by changing the proportion of supplement to hay in the diet and thus the energy density of the diet (M/D), not by increasing intake of a diet of fixed quality. Nevertheless, the data mimic real commercial feeding scenarios towards which model application should be aimed.

3.3 Description of the models

The GrazFeed DSS is based on the Australian feeding standards for ruminants, as compiled by the Standing Committee on Agriculture (SCA 1990), with some later modifications (see Freer et al. 2004). However, GrazFeed has integrated the nutritional principles of SCA (1990) into a decision support tool for use with grazing animals to predict animal performance and assess supplement requirements to meet various production goals. It does this by assessing the nutritive value of the pasture being grazed and predicting the quality of the diet selected. GrazFeed version 4.1.10 was used in this study.

The CNCPS is a mathematical model that estimates cattle requirements and nutrient supply according to information provided on the animal, environment and feed composition. Feed energy values, e.g., M/D and net energy (NE) intake are based on total digestible nutrient (TDN) content of the diet. The model incorporates a level 1 and level 2 solution whereby either a tabular value for TDN is used (level 1) or TDN is predicted mechanistically from pool sizes of carbohydrate and protein fractions and their digestion and passage rates (level 2). Version 5.0.34 of the CNCPS was used.

3.4 Model inputs

GrazFeed. In applying GrazFeed, the animals were, except where otherwise indicated, described as British x Brahman steers, 12-15 months of age with a SRW of 550 kg for females, equivalent to 660 kg for castrates. Weather effects were ignored throughout. Actual composition of the hay and supplements was used except where some aspects of composition were not known, e.g., rumen degradable protein (RDP) content, in which case values from the GrazFeed feed library were used.

CNCPS. In using the CNCPS, the animals were described as Brahman x Shorthorn crossbred "Growing/Finishing" steers, aged 12-15 months, with a body fat end-point of 22% (devoid of marbling) at 480 kg shrunk body weight (mature shrunk body weight; MSBW). A body condition score of 5 (beef scale 1-9) was used. The environment described was a "confinement barn" and benign climatic conditions (25oC and 40% relative humidity) likely to have minimal effect on energy utilisation were chosen, in keeping with the conditions encountered during the studies. Where determined, actual compositions of the forages and supplements were used; otherwise values from the CNCPS feed libraries were used. For instance, actual composition for CP, NDF and ADF composition of the feed components were used but because the various feed sources had not been analysed for pool sizes and degradation and passage rates of the various carbohydrate and protein fractions required to run CNCPS level 2, values for these characteristics were taken from feed sources in the Tropical Feed Library with similar chemical composition, e.g., CP and NDF. The level 2 solution in the CNCPS was applied except where otherwise indicated.

In all cases data were entered as group averages, not as individual steer values.

3.5 Approach

As indicated earlier there are two potential major errors in predicting the performance of grazing animals using DSSs. The first relates to the prediction of intake from available information on diet composition and animal characteristic; the second is the precision with which the models or the feeding standards upon which they are based translate known nutrient intake into animal performance. This review examined the second aspect by entering measured intakes and diet composition into the models and evaluating the extent to which liveweight gain was predicted accurately. In some cases the model sets an upper limit on intake given certain nutritional constraints (e.g., GrazFeed) and these values had to be used. This is discussed later.

3.6 Statistical analyses

Simulated values from the models were compared with observed values from the database. Data were compared using regression analysis with the main parameters used for determining prediction efficiency being the coefficient of determination (R2), the slope of the regression, the residual standard deviation (rsd), the standard error of prediction (sep) from the bisector (Y=X) and the bias%. A positive bias indicates the Y values are greater than the X values. Where the intercept of the regression line was not significantly different from zero, the bias was calculated as the slope of the regression line through zero minus one. Otherwise, bias (%) was calculated by dividing the mean of the Y-variate (the observed or measured value) minus the mean of the X-variate (predicted value) by the mean of the X-variate, expressed as a percentage. The statistical significance of the difference in residual mean square between the fitted line (Y= a + bX) and the bisector (Y=X) was tested by analysis of variance.

4 Results and discussion

4.1 Utilisation of energy

ME intake (MEI) is determined by multiplying the intake of the animals by the energy density of the diet (M/D, i.e., MJ ME/kg DM). In our simulations, equations 31 and 32 from Freer *et al.* (2004), shown below as equations 1 and 2, were used to calculate the MEI for steers receiving hay alone or a mixed diet, respectively. The equations are:

Forage: $MEI_f = (17.2\ DMD_f - 1.47)\ I_f$ (1)
Supplement: $MEI_s = (13.3\ DMD_s + 23.4\ EE_s + 1.32)\ I_s$; (2)

where MEI_f and MEI_s are ME intake (MJ/d), DMD_f and DMD_s are DM digestibility (fractional), I_f and I_s represent DM intake (DMI; kg/d), of the forage and supplement, respectively, and EE_s is the ether extract content (g/g) of the supplement. With the mixed forage/supplement diets, the intake and DMD of the total diet were substituted for I_s and DMD_s, respectively, in equation 2 (M. Freer, pers. comm.). In each equation, the M/D of the diet is represented by the segment in brackets. For our calculations, the DMD of the diets were *in vivo* values determined with a 7 d measurement of intake and faecal output of the same steers.

The relationships between estimated MEI and the recorded liveweight change (LWC) are shown for an individual experiment and for all experiments pooled, in Figure 1. In addition, energy retention (ER) was calculated from this liveweight change using equations 1.31 and 1.32A from SCA (see equations 3 and 4, respectively, below), viz.:

$ER = LWG / (0.92\ EVG)$ (3)
$EVG = (6.7 + R) + (20.3 - R)/[1 + e^{-6(P-0.4)}]$ (4)
$R = [EBC/(4\ SRW^{0.75})] - 1$
$P = \text{current } W/SRW$;

where ER is energy retention (MJ/d), LWG is liveweight gain (kg/d), EVG is energy value of empty weight gain (MJ/kg), R is the adjustment for rate of gain or loss (no dimensions), EBC is empty body (kg; = 0.92 liveweight change (LWC; kg)), SRW is standard reference weight of the animal being the liveweight achieved by the animals of that breed and sex when skeletal development is complete and empty body contains 25% fat (kg; SCA 1990), and P is the ratio of current liveweight (W) to SRW.

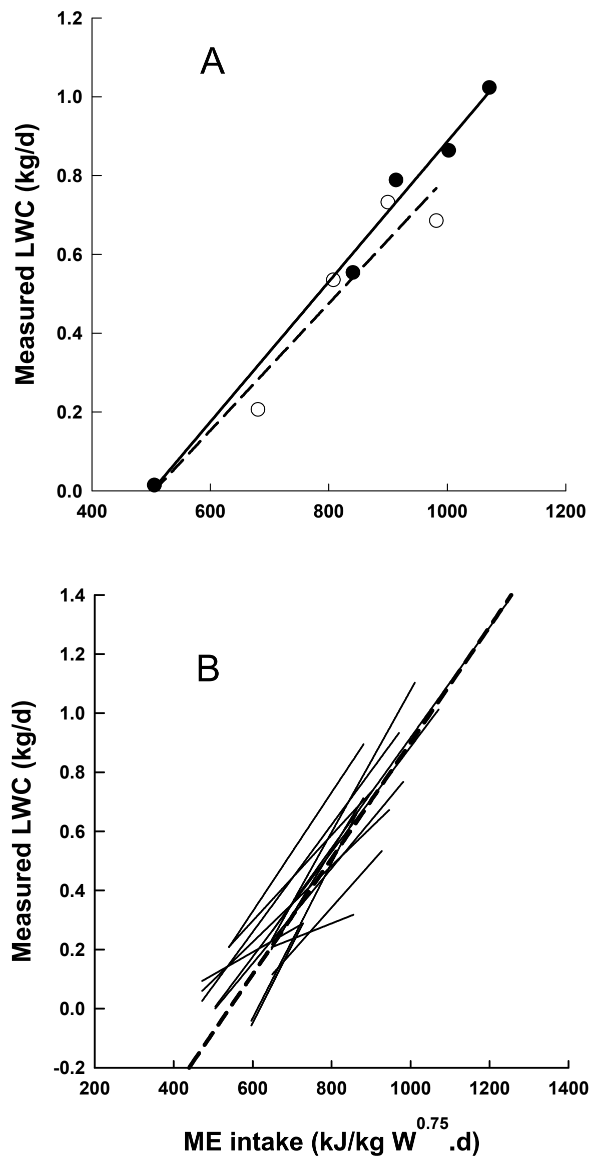

Figure 1. Relationship between estimated ME intake and measured liveweight change (LWC) for (A) a single experiment with steers receiving barley (○) or barley/cottonseed meal/copra meal (2:1:1; ●), where symbols represent group means, and (B) all treatments (solid lines) from all experiments in the database, including the overall mean for all data (dashed line). This equation representing the pooled data is:

$Y = -1.062 + 0.0020 X$, ($R^2 = 0.95$; rsd = 0.144).

The relationship between ER (kJ/kg $W^{0.75}$.d) and MEI (kJ/kg $W^{0.75}$.d) for the pooled data was: ER = 0.493 MEI – 270.48, (R^2 = 0.95; rsd = 35.79).

These various relationships between MEI and either liveweight change or ER, either for individual treatments or pooled data, are typical of those described in the various feeding standards which have been derived primarily from temperate diets, and support the earlier contention of Poppi and McLennan (1995) that there is no sound reason to discard the feeding standards when tropical diets are involved. Based on the pooled data the maintenance requirements (ME_m), as denoted by zero LWG or zero ER, were 530.8 and 548.3 kJ/kg $W^{0.75}$.d, respectively. The range in values for individual treatments was 271.8 to 629.7 kJ/kg $W^{0.75}$.d although most values (excluding two molasses treatments) were in the range 383.9 to 629.7 kJ/kg $W^{0.75}$.d. The overall average values fell within the range expected from the feeding standards. For instance, estimations of ME_m using equations 1.22 and 1.23 from SCA (1990; see equations 5 and 6 below) range from 503 to 569 kJ/kg $W^{0.75}$.d for a steer of liveweight 205 kg (average LW from our database) and consuming 1.5 to 2.4%W/d of DM of forages ranging in DMD from 50 to 80%. From the relationship between MEI and ER it can be deduced that the efficiency of utilisation of ME for growth (k_g) across all diets was about 0.49. However, this value is indicative only as within this database increases in MEI were brought about not only by increases in DM intake but also by marked changes in the M/D of the diet according to the type of supplement fed and its proportion in the total diet. Changes in M/D affect ME_m, the efficiency of use of ME for maintenance (k_m) and k_g (see SCA 1990, for instance). Nevertheless, the linear nature of the relationship suggests that the general principles of energy utilisation are valid notwithstanding the highly variable nature of the diets included.

This is further supported by the within experiment data evaluations illustrated in Figure 1. For each experiment the relationships of LWC with MEI were highly linear with R^2 generally in excess of 0.96 (all except one; R^2 = 0.89) and rsd averaging 0.077 kJ/kg $W^{0.75}$.d. There was large variation between experiments reflecting, as expected, variation in k_m, ME_m and k_g associated with different combinations of diet components.

The equations used were:

$$ME_m = K.S.M\,(0.26\,W^{0.75}\,e^{(-0.03\,A)})\,/k_m + 0.09\,MEI + EGRAZE + ECOLD \qquad (5)$$

$$k_m = 0.02\,M/D + 0.5 \qquad (6)$$

where ME_m and MEI are in MJ/d, M/D is in MJ/kg DM and is calculated using equations 1 and 2 above, W is liveweight in kg, A is age in years; K = 1.2 for *B. indicus* and 1.3 for *B. indicus* crosses, S = 1.0 for castrates and M = 1 for non-suckled animals. The terms EGRAZE and ECOLD represent the additional energy expenditure of grazing or of cold stress.

4.2 Validation of energy use principles

Growth rates were predicted using the DSS and compared with measured growth rates. In applying GrazFeed, the pasture selection option was suppressed and the actual composition of the hay and supplements, and their relative proportions in the total diet, were entered in the “Supp” window with intake of the total diet entered in the “Feeding” window. In addition, the “bail feeding” option was chosen to indicate that the supplements were fed prior to grazing. The CNCPS predicts both an ME-allowable and metabolisable protein (MP)-allowable gain and the lowest of these was used as the predicted gain in the comparisons with measured liveweight gain. The level 2 solution of CNCPS was used here.

The comparison of growth rates predicted using GrazFeed and the CNCPS against measured values are shown in Figure 2. In view of the results of these comparisons, a third alternative was evaluated using equations from SCA (1990) (hereafter SCA where referring to the simulations) to predict LWC. The respective SCA (1990) equations were used to calculate ME_m (equation 5), k_m (equation 6), k_g (equation 7, see below) and thence ER (equations 3 and 4), and LWC was determined by back-calculation from ER using equations 3 and 4. The EGRAZE component of equation 5 was not relevant for these pen fed steers and ECOLD was also not relevant under the conditions of the experiment. GrazFeed uses the same equations to estimate LWC except for the determination of M/D of the diet, where GrazFeed uses equations 1 and 2 above which differ from those of SCA (1990), mainly in the inclusion of the ether extract content of the supplement with GrazFeed. In our study, we also used equations 1 and 2 to determine M/D for the SCA simulations, for consistency. However, one change was made in applying the SCA (1990) equations. For the SCA simulations, we used a lower "K" value of 1.2 (pure *B. indicus*) in equation 5 for estimating ME_m, rather than the 1.3 used by GrazFeed and suggested in SCA (1990) for application to *B. indicus* first-cross steers. The predicted versus measured LWC using the modified SCA equations is also shown in Figure 2.

$$k_g = 0.043 \text{ M/D} \qquad (7)$$

The equations describing the linear relationships between measured LWC and that predicted using GrazFeed, CNCPS (Level 2) and SCA are also shown in Figure 2. For all predictions the R^2 values were quite high but there was considerable variability in the data and rsd values varied from 0.14 and 0.19 kg/d. GrazFeed grossly under-predicted growth rate with a mean bias of 104.6%. Furthermore, there was a trend for this under-prediction to increase with increasing growth rate and thus increasing supplement intake. The intercept was different from zero ($P<0.05$) and the slope was different from one ($P<0.05$). These under-predictions are consistent with anecdotal evidence from researchers and extension workers in northern Australia, where unsupplemented cattle often gain weight despite GrazFeed predictions to the contrary (e.g., McLennan 1997).

By contrast, the SCA simulations provided a better prediction of growth rate with the under-prediction reduced to 9.6%. The intercept of the trend line was not significantly different from zero ($P>0.05$), indicating good predictions at low growth rate and thus at low or zero supplement intake. Once again the trend was for increased under-prediction of growth rate at high supplement intake as indicated by a slope greater than one ($P<0.05$). CNCPS also under-predicted growth rate (bias = 17.0%) but in contrast to GrazFeed and SCA the slope of the trend line was not different to one ($P>0.05$) indicating a constant over-prediction across the full range of diets. The intercept was different to zero ($P<0.05$).

Of major interest in these simulations is firstly the precision with which the models predict when animals have only low or zero growth, that is when low quality forage is the main or only component of their diet, and secondly the effect of increasing the supplement intake. Using the different models had a variable effect on both aspects, as indicated by the different intercepts and slopes of the regressions. There are various factors which could contribute to these differences, the main ones being: (i) the description of the diet; (ii) the description of the animal; (iii) the prediction of ME_m; (iv) the prediction of k_g; and (v) the prediction of the energy value of gain. These aspects are considered in detail below.

However, there is one other major factor affecting differences between using the three models. All predict LWC based on an estimate of ER, as determined by various attributes associated mainly with the diet and the animal. However, GrazFeed and the CNCPS also determine the availability of metabolisable protein (MP) and evaluate its effect on eventual animal performance. GrazFeed first determines whether MP will allow the growth rate otherwise predicted from energy available for growth, and if not, reduces ER accordingly. A major determinant of MP supply is the predicted MCP production so this is obviously an important parameter in determining eventual ER. Thus the growth rates shown in Figure 2 are ME-allowable gains for SCA, with no consideration of MP availability, whilst those for GrazFeed are either ME- or MP-allowable gains. This is an important difference between GrazFeed and SCA predictions which are otherwise based on similar equations and principles.

The CNCPS employs a similar approach to this but presents both an ME- and MP-allowable gain, with the obvious expectation that the lower of the two values is chosen by the operator. Protein availability is particularly important in these simulations given the low protein content of the basal forages, and of many of the supplemented diets included in our database, and is heavily influenced by predictions of microbial crude protein (MCP) production. Accordingly, except where protein meals were fed at relatively high levels (>0.5%W/d) in our experiments, the CNCPS predicted that growth rate was first restricted by MP availability, not ME. This is illustrated in Figure 3 where ME-allowable gains generally exceeded MP-allowable gains. This had a pronounced effect. For instance, if MP availability was ignored and ME-allowable gains only were used, the relationship between growth rate predicted and measured would become: Measured LWC (kg/d) = 0.020 + 0.862 Predicted LWC (kg/d), (R^2 = 0.93; rsd = 0.168; bias = -12.1%), where the intercept was not different from zero (P>0.05).

GrazFeed has another feature which makes it difficult to apply easily to this study. Our objective was to input a measured DMD and hence M/D together with a measured DMI. GrazFeed will use the measured DMD, and hence M/D, and estimate a DMI for a defined class of animal. In a number of cases this was less than the measured intake and it is not possible to over-ride this practice and force the model to accept the measured intake if it is greater than the predicted value. Similarly, the CNCPS has a feature which restricts the use of the measured DMD as it calculates this independently from other diet characteristics. This is discussed further below.

In view of the effects discussed above, and in keeping with our main objective of evaluating whether the general principles of energy use apply with our diets, the major emphasis below is given to the SCA simulations rather than GrazFeed. The effects of MP availability are discussed further below.

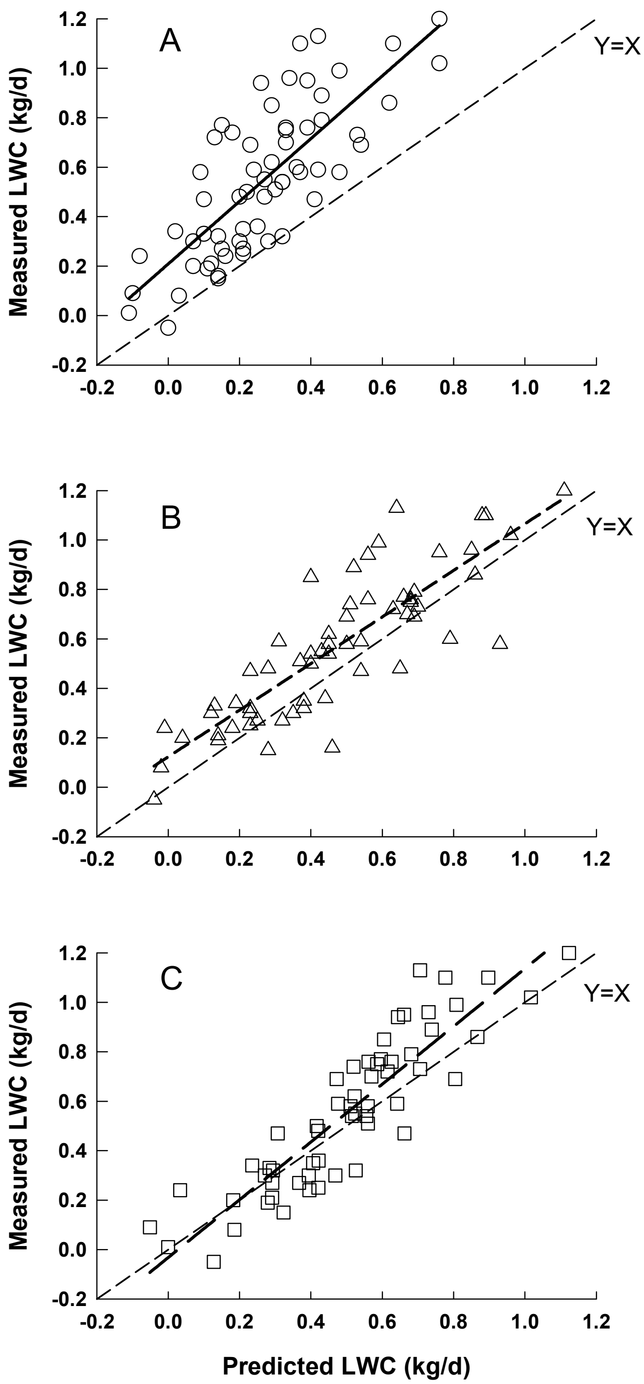

Figure 2. Relationship between measured liveweight change (LWC) and that predicted using (A) GrazFeed (SRW = 550 kg), (B) CNCPS (Level 2 solution) or (C) SCA (1990). Within figures, symbols represent group mean values. These relationship equations are as follows:
GrazFeed: Y = 0.209 + 1.267 X, (R^2 = 0.91; rsd = 0.194; bias = 104.6%);
CNCPS: Y = 0.123 + 0.942 X, (R^2 = 0.94; rsd = 0.159; bias = 17.0%);
SCA: Y = -0.031 + 1.171 X, (R^2 = 0.95; rsd = 0.142; bias = 9.6%).

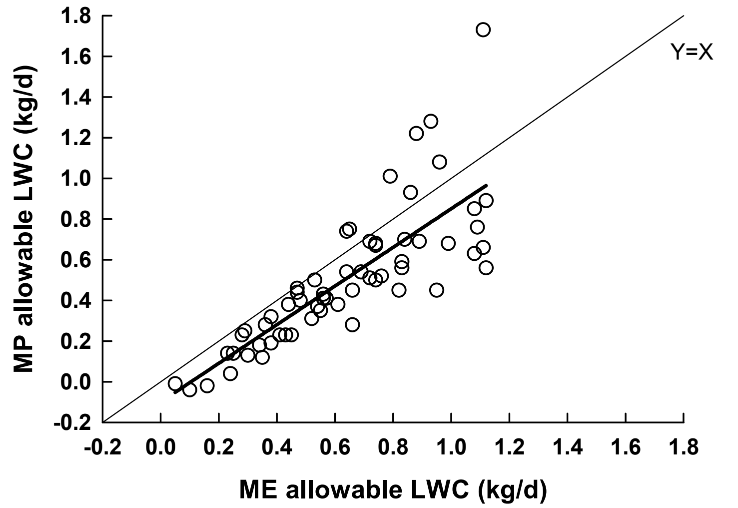

Figure 3. Relationship between metabolisable energy (ME)-allowable and metabolisable protein (MP)-allowable liveweight change (LWC) predicted using the CNCPS (level 2 solution). The relationship equation is as follows:
$Y = -0.100 + 0.950 X$; ($R^2 = 0.89$; rsd = 0.199; bias = -20.7%).

4.2.1 Diet description

Diet composition is used to estimate M/D of the diet which is in turn an integral component in the estimation of k_m, ME_m and k_g and thus ER. Hence predictions of growth rate will depend heavily on achieving an accurate description of diet composition. With the SCA (1990) equations, the two contributing factors in the estimation of M/D were the DMD of the total diet, as determined in the metabolism experiments, and EE content. *In vivo* DMD was measured in our experiments but the models use different ways to estimate M/D. In the case of GrazFeed and CNCPS, actual compositions of the forages and supplements were used where they had been determined; otherwise values from the respective feed libraries were used. For instance, in CNCPS actual composition of CP, NDF and ADF content in the diets were used. However, because the various feed sources had not been analysed for pool sizes and degradation and passage rates of the various carbohydrate and protein fractions required to run CNCPS level 2, values were taken from the tropical feed library for feed sources of similar description (e.g., C4 grass) and similar CP and NDF content. Similarly, with GrazFeed, values for digestibility and protein degradability in the rumen of various supplement components were not determined in our studies and feed library values were used. The use of these surrogate values for feed compositions in both DSS provides avenues for error in predictions, but represent essentially the same decisions field users of the models will need to make to use the models under practical feeding conditions.

The CNCPS requires a much more detailed description of the diet than GrazFeed and various other models but does provide the option of using a simpler level 1 solution. As detailed earlier, level 1 uses tabular values for TDN rather than predicting these from the pool sizes and digestion and passage rates of the various carbohydrate and protein fractions. In both cases, this TDN value is used to estimate the M/D of the diet. We were thus unable to enter our measured *in vivo* DMD of the diet in using the CNCPS model. Within the CNCPS model there is no option to enter the DMD of the diet, as might be obtained from a faecal NIRS screening of grazing animals, or to use this to directly estimate M/D. Methods to achieve this end are discussed further in the Applications section. Faecal

NIRS screening provides one option for describing the diet under such conditions but is limited in its output to CP, DMD and perhaps ADF and NDF (D. Coates, pers. comm.).

Figure 4 shows the comparison of M/D values calculated using equations 1 and 2 and measured DMD, as used in the SCA simulations, and that determined with the CNCPS level 1 and 2 and GrazFeed. The GrazFeed comparison is limited by the fact that only whole numbers for M/D are shown in the model output, although a more precise value is used in the model. Despite the fact that GrazFeed used the same equations as those applied in the SCA simulations to calculate M/D, the GrazFeed values were slightly lower than for SCA simulations. This could be due to the rounding effect in GrazFeed or perhaps a lower estimated DMD for the total diet in GrazFeed compared to measured DMD. Errors in describing the DMD of individual feed components for inclusion in GrazFeed may have contributed to this. Values for individual supplement DMD were estimated from our experiments. The CNCPS showed considerable variability in relation to SCA values with a tendency for higher estimates than SCA in the low range and lower estimates in the high range of M/D values. Differences between level 2 and level 1 solutions in the CNCPS were not large but the slope of the level 2 regression was closer to one than for level 1 (0.63 versus 0.43) indicating closer agreement with SCA values. The main finding though is that there is considerable variation between models in the estimation of M/D which could contribute to errors in prediction of LW gain.

When the level 1 solution was used in CNCPS the relationship between predicted and measured LWC (kg/d) was: Measured LWC = 0.149 + 0.888 Predicted LWC, (R^2 = 0.95; rsd = 0.148; bias = 22.0%). Thus there was very little difference between the precision of the level 2 (Figure 2) or level 1 solutions, with similar R^2, rsd and bias estimates. This is an important practical finding in that it suggests that for workers in the field with limited information about the composition of the diets of grazing animals, or with limited experience in using the CNCPS, the simpler level 1 approach can be used without major sacrifice in precision of the predictions.

4.2.2 Animal description

Both the CNCPS and GrazFeed require some description of the mature animal in terms of its expected body composition. With SCA (1990), and thus GrazFeed, this involves the assignment of a SRW which defines the weight of a mature non-pregnant, non-lactating female in medium body condition, with adjustments for castrates (multiply by 1.2) or entire males (multiply by 1.4). In the initial simulations reported in Figure 2, a SRW for females of 550 kg (or 660 kg for castrates), as offered in SCA (1990) for Brahman crossbreds, was used. However, there are suggestions that this SRW is too high for Brahman crossbred cows in the northern Australian environment (G. Fordyce, pers. comm.) and the lower SRW of 450 kg for females, or 540 kg for castrates, was also evaluated. When the lighter SRW was used in the SCA simulations, the regression equation was: Measured LWC = -0.030 + 1.331 Predicted LWC, (R^2 = 0.95; rsd = 0.144; bias = 24.9%). Thus reducing the SRW did not change the intercept, which in both cases was not different from zero, or the R^2, but did change the slope from 1.17 to 1.33, reflecting increased under-prediction of growth rate as supplement intake increased, and also increased the bias from 9.6 to 24.9%. Thus in this study the higher SRW seemed to provide a better prediction of growth rate.

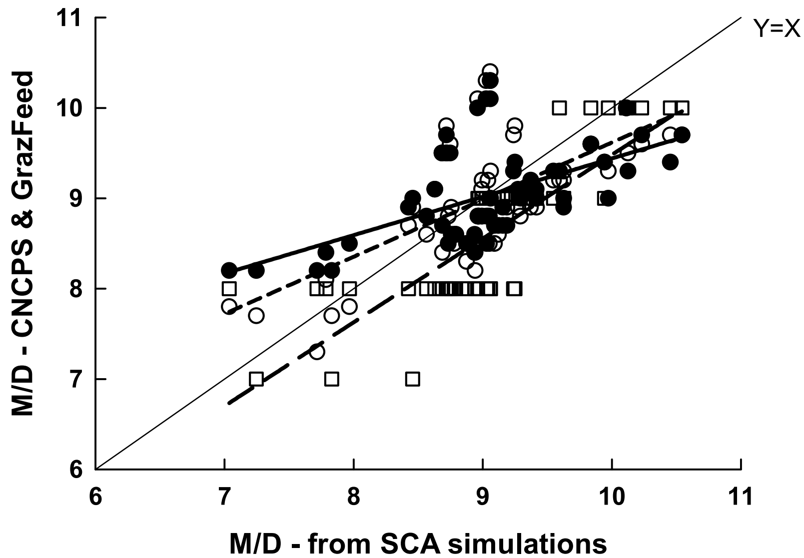

Figure 4. Relationship between metabolisable energy density of the diet (M/D; MJ/kg DM) estimated in the SCA simulations using* in vivo *DM digestibility with that determined using the CNCPS level 2 (O; short-dash) and level 1 (●; solid line) and GrazFeed (□; long-dash). The relationship equations are as follows:
CNCPS level 2: Y = 3.296 + 0.632 X; (R^2 = 1.00; rsd = 0.522; bias = 0.0%);
CNCPS level 1: Y = 3.296 + 0.632 X; (R^2 = 1.00; rsd = 0.426; bias = 0.0%);
GrazFeed: Y = 3.296 + 0.632 X; (R^2 = 1.00; rsd = 0.522; bias = -4.9%).

Changing the SRW in GrazFeed from 660 (see Figure 2) to 540 kg for steers also had a marked effect on the growth rate predictions. The regression equation for the lighter SRW was: Measured LWC = 0.322 + 1.110 Predicted LWC, (R^2 = 0.87; rsd = 0.231; bias = 162.8%). Thus compared with a SRW of 660 kg for steers (see Figure 2), the lower SRW was associated with a reduced R^2 value and increased rsd and bias estimates. There are two principal reasons for these differences with the different SRWs. The first mirrors the effect described above for SCA (1990) predictions. It relates to the effect of reducing SRW on increasing the stage of maturity of a steer of fixed liveweight with consequences for the proportions of different types of tissue being deposited and thus for the energy value of the gain. In general, increasing stage of maturity will be associated with increased fat to protein deposition, higher energy value of gain and thus lower growth rate per unit energy retention. This is consistent with the lower predicted growth rate of the steers when SRW was 540 kg versus 660 kg.

The second effect relates to the fact that GrazFeed predicts DM intake and, if the predicted is less than actual intake, it uses this predicted DM intake to estimate MEI and consequently growth rate. In GrazFeed, intake is predicted as the product of the potential intake of the diet when limited by neither quantity nor quality (i.e., DMD of 80% or more), and the relative intake, expressed as a proportion of the potential intake, that the animal can acquire from the food supply (Freer *et al.* 2004). Potential, but not relative, intake is a function of SRW so reducing the SRW puts a lower threshold on the intake of the animals. With our data set, there were a number of instances where predicted intake was less than actual intake for both SRWs, but the number of such instances was considerably greater for the lower SRW. Thus the reduction in SRW exacerbated the under-prediction of growth rate. This was particularly so for unsupplemented treatments as evidenced by the greater intercept with the lower SRW. It was noteworthy that when only those data for which predicted intake was equal to measured intake were plotted, the predictions of LW gain were similar for the two SRWs. The relevant linear relationships under these conditions for the 660 and 540 kg SRWs, respectively, were as follows: Measured LWC = 0.139 + 1.367 Predicted LWC, (R^2 = 0.93, rsd = 0.160, bias = 90.2); and Measured LWC = 0.116 + 1.386 Predicted LWC, (R^2 = 0.94, rsd = 0.133, bias = 94.5).

In our simulations, a further contributing factor to these low predicted intakes with GrazFeed relates to the procedure we used of entering all components of the diet as elements of the "supplement". GrazFeed treats the supplement as a temperate (C3) feed source and applies the associated linear relationship between DMD and relative ingestibility of the diet, which is a component of relative intake. However, within the GrazFeed structure, application of the alternative tropical (C4) relationship, as appropriate for the hay component of our diets, results in higher relative intake at the same DMD. Although this is an important limitation for the current exercise, under grazing conditions the user can nominate whether the pasture is tropical or temperate, and the appropriate intake/DMD relationship is applied.

The CNCPS also uses a size scaling system based on the ratio of current weight to mature weight to predict the composition of gain. This system adjusts the shrunk body weight (SBW) of the animal to a weight equivalent to a standard reference animal at the same stage of growth, i.e., equivalent shrunk body weight (EqSBW; Tylutki *et al.* 1994; NRC 1996). The EqSBW = SBW x (SRW/MSBW) where SRW is the mature BW of the standard reference animal and MSBW is the expected mature finished weight at target body fat content in growing and finishing steers. The SRW is 400, 435, 462 and 478 kg for steers marketed at 22, 25, 27 or 28% body fat, respectively. In our simulations a MSBW of 480 kg and body fat end-point of 22% were used (D. Fox, pers. comm.). Tedeschi *et al.* (2002a) reported values of between 365 and 456 kg empty body weight (EBW) at 22% empty body fat (EBF) for the expected finished weight of Nellore (*Bos indicus*) steers and bulls fed high-forage diets, equivalent to 410 to 510 kg SBW, respectively. Thus although the MSBW we used was within this range, it was at the higher end typical of values for bulls in the study of Tedeschi *et al.* (2002a). Reducing the MSBW to 410 kg at 22% EBF with our data set resulted in the following regression equation when the level 2 solution was applied: Measured LWC = 0.101 + 1.027 Predicted LWC, (R^2 = 0.94; rsd = 0.155; bias = 21.3%). Thus compared with the regression established in Figure 2 using the higher final weight (480 kg), there were only minor changes to the intercept and slope of the regression line and a slightly higher bias (21.3 versus 17.0%). Changing the final body weight had some effect on the predicted ME-allowable gain, but negligible effect on predicted MP-allowable gain, and as indicated above, in most feeding situations encountered in our experiments MP, and not ME, was the primary limiting nutrient within the CNCPS model. Thus changing the final body weight only affected predicted gain when the steers were fed diets containing high amounts of protein meals and thus when ME became first limiting. We observed similar negligible changes in the relationship between measured and predicted LWG when the final EBF was changed from 22 to 25% but MSBW was not changed (480 kg), for the same reasons. The relationship for the 25% fat end-point was: Measured LWC = 0.109 + 0.990 Predicted LWC, (R^2 = 0.94; rsd = 0.157; bias = 19.1%). Despite the limited effect of changing the final composition of the mature animal in this case with low quality basal diets, it is obvious that for both models the user requires an adequate knowledge of the final weight and composition of the animals under consideration if accurate predictions of growth rate are to be made.

4.2.3 Prediction of ME_m

Errors in the estimation of maintenance requirements of the experimental animals could explain the divergence of the regressions comparing predicted and measured LW gain from the bisector (Figure 2). With CNCPS, the slope of the regression was equal to one suggesting that the model may have slightly and uniformly over-predicted ME_m across the full range of diets leading to slight under-prediction of growth rate. By contrast, with both the GrazFeed and SCA simulations, the divergence of the regressions increased as the proportion of supplement in the total diet increased, perhaps suggesting increased over-estimation of ME_m as supplement intake increased. The zero intercept with the SCA simulations indicated accurate determination of ME_m when the steers were sustained predominantly on low quality forage. Thus one of the main difference between the SCA and GrazFeed simulations lies in the magnitude of the intercept (Figure 2).

Figure 5 shows the estimated ME_m requirements of the steers, as determined with the different systems, in relation to the MEI. Whereas maintenance requirements declined with increasing energy intake in the CNCPS, the opposite occurred with GrazFeed and SCA largely in response to the ‘0.09MEI’ factor in equation 5. The SCA (1990) system incorporates a positive correction to the maintenance requirements with increases in MEI to account for the higher maintenance requirements of productive animals (above those of fasting metabolism only), in lieu of making adjustments for energy intake with k_g. The increasing disparity between predicted and measured growth rate with increasing MEI (Figure 2) might suggest that this is an over-correction for energy intake. Removal of the “0.09 MEI” factor altogether from the ME_m calculation slightly over-corrects, as indicated by the modified regression: Measured LWC = -0.102 + 1.066 Predicted LWC, (R^2 = 0.95; rsd = 0.141; bias = -11.0%). By contrast, there is no adjustment for energy intake in the determination of maintenance requirements in the CNCPS. In this model a net energy for maintenance (NE_m) is calculated, this being a function of metabolic body size with adjustments for breed, physiological state, activity, urea excretion, acclimatisation and heat or cold stress. In the current simulations, effects of temperature stress were minimal and the only variable between treatments was the weight of the steers. Thus, when expressed as a function of liveweight (kJ/kg $W^{0.75}$.d), NE_m was constant as MEI increased whilst ME_m decreased, in response to increases in k_m (results not shown).

GrazFeed and SCA estimates of ME_m effectively increased in parallel as MEI increased, but with different intercepts (Figure 5). As indicated earlier, the SCA simulations used the lower breed multiplier (K value) of 1.2 in equation 5 instead of the 1.3 used in GrazFeed, and consequently resulted in reduced estimates of maintenance requirements. To further demonstrate this effect, changing the K value back to 1.3 in the SCA simulations resulted in the following relationship: ME_m (kJ/kg $W^{0.75}$.d) = 522.4 + 0.045 MEI (kJ/kg $W^{0.75}$.d), (R^2 = 1.00; rsd = 7.57); which is very similar to the GrazFeed equation shown in Figure 5. Furthermore, when the higher K value was used in SCA, it did increase the extent of under-prediction of growth rate compared with use of the lower value, but not to the extent of the GrazFeed predictions. The corresponding growth rate relationship for the modified SCA simulation was: Measured LWC = 0.043 + 1.175 Predicted LWC, (R^2 = 0.95; rsd = 0.140; bias = 27.4%). Thus compared with the equation present for SCA in Figure 2, the main difference was in the intercept (0.043 *vs* -0.031 kg/d), although neither intercept was different from zero, and in the bias (27.4 vs 9.6%). It appears therefore, that differences in ME_m only explain part of the difference in growth rate predictions between GrazFeed and SCA simulations.

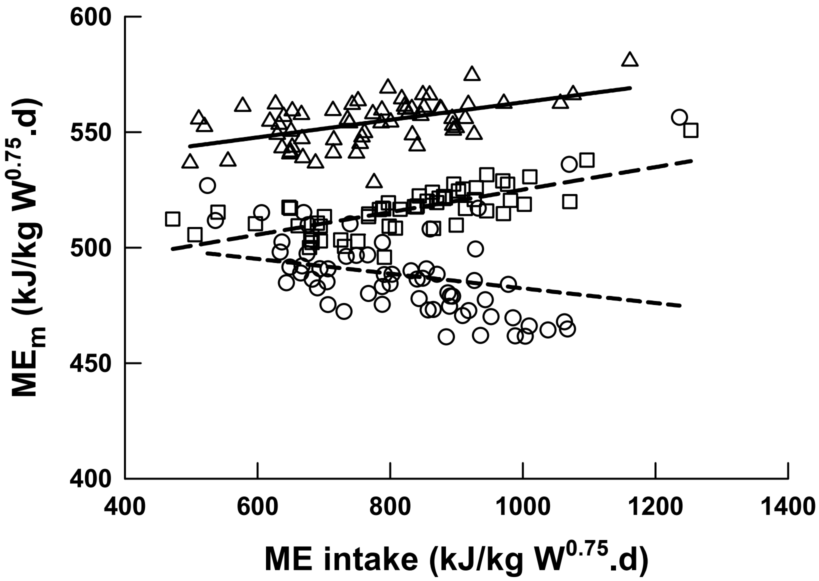

Figure 5. Relationship between estimated ME maintenance (ME_m) requirements as determined using CNCPS (○), GrazFeed (Δ) and SCA (1990; □) and ME intake (MEI). The regression equations are as follows:

CNCPS:	ME_m	$= 505.6 - 0.022$ MEI,	($R^2 = 1.00$; rsd = 19.26);
GrazFeed:	ME_m	$= 520.1 + 0.042$ MEI,	($R^2 = 1.00$; rsd = 8.12);
SCA:	ME_m	$= 476.4 + 0.049$ MEI,	($R^2 = 1.00$; rsd = 6.91).

4.2.4 Prediction of k_g

Disparity between models in the prediction of LWC could also arise through differences in estimation of the efficiency of use of ME for weight gain. GrazFeed applies equation 1.39 from SCA (1990) to calculate k_g (equation 7 below) for components of the 'supplement', which included the total diet in our simulations. With the CNCPS, k_g is not derived by equation. Our values were determined by dividing the amount of NE available for growth (NE_g) by the calculated ME for growth. The effect of increasing MEI, and by association M?D of the mixed diet, on the estimations of k_g for SCA (using equation 7) and the CNCPS are shown in Figure 6. Values for k_g were, on average, lower for the CNCPS than for SCA, and hence also GrazFeed (difference in intercept = 0.07), but the regressions tended to increase in parallel over the full range of energy intakes (see Figure 6). Differences in k_g are thus unlikely to explain much of the difference in the LWG prediction trends between SCA and GrazFeed, and the CNCPS, as growth rate increased (see Figure 2).

$$k_g = 0.043 \text{ M/D} \qquad (7)$$

Where cattle are grazing and the 'pasture' options are used in the model, GrazFeed applies a modified equation for calculating k_g which takes into account the poorer utilisation of ME of tropical versus temperate forage and also accounts for seasonal effects (early- vs late-growth). The equation is a modification of equation 1.42 from SCA (1990) and is presented in Freer *et al.* (2004) as equations 38-40. The equation, ignoring the legume component, is:

$$k_g = 0.9\,(0.043 \text{ M/D} + 0.01(15.4 - \text{M/D})\,(\lambda/40 \sin(2\pi \text{DOY}/365) - 1.0)) \qquad (8)$$

where M/D is expressed in MJ/kg DM, λ is latitude (no dimension; here -25) and DOY is day of year.

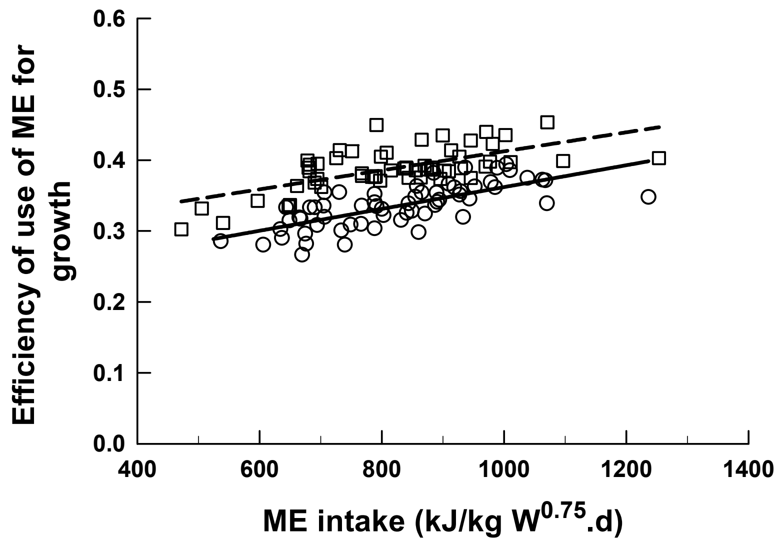

Figure 6. Relationship between ME intake (MEI) and the efficiency of use of ME for growth (k_g), as determined using CNCPS (○, solid line) and SCA (1990; □, dashed line). The regression equations are as follows:
CNCPS: Y = 0.208 + 0.0002 X, (R^2 = 1.00; rsd = 0.022);
SCA: Y= 0.279 + 0.0001 X, (R^2 = 1.00; rsd = 0.022).

For this investigation, we tested the effects of applying equation (8) in the SCA simulations using day 90 and day 270 of the year, where these days tend to represent the low and high extremes for k_g in line with seasonal effects on pasture quality. Applying this more complex equation had the effect of reducing k_g values when compared with the SCA simulation (Figure 6), as shown by the regression equations: day 90, k_g = 0.156 + 0.0002 MEI, (R^2 = 0.99; rsd = 0.022); and day 270, k_g = 0.209 + 0.0001 MEI, (R^2 = 1.00; rsd = 0.020), where the slopes were similar but the intercepts lower than for SCA. The effect of these reduced k_g values is a reduction in predicted LWC at the same MEI so that applying equation (8) increased the extent of under-prediction of LWC compared with the simple equation (7) from SCA. Although these simulations were carried out with mixed diets rather than forage alone, they do question the need for this increased complexity when tropical diets are involved.

4.2.5 Prediction of energy value of gain

The CNCPS and SCA (1990) use different equations to calculate liveweight gain from the estimated ER, based on their determinations of the energy value of the gain (EVG). However, as indicated earlier, both systems scale the weight of an animal to that of a standard reference animal of known body composition. Figure 7 shows the estimated EVG of steers for the different systems, where, in order to use model output data directly, EVG (MJ/kg empty body gain) was determined by dividing the ER by the predicted empty body weight gain. In the case of the CNCPS, the ME-allowable gains were used as the ER given by the model is uncorrected for MP availability. Given the description of the standard reference animals used here, SCA clearly predicts a higher EVG than the CNCPS. Thus for the same predicted ER, SCA would predict a lower LWC than the CNCPS. In fact, at low growth rates the opposite occurs albeit that differences are small (Figure 2) and it suggests some compensating effect, presumably in the conversion between MEI and ER.

A further observation from Figure 7 is the variation around the regression line for each model. This arises because the weight of the animals varied between experiments (range 156-243 kg at beginning) and this affects the EVG at any particular LWC due to stage of maturity effects. In Figure 8 theoretical calculations have been carried out based on the equations used in both models and using the same parameters to describe the animals, e.g., SRW, as have been used in the foregoing simulations. This figure illustrates the higher EVG across the full spectrum of LWC for SCA compared with the CNCPS calculations.

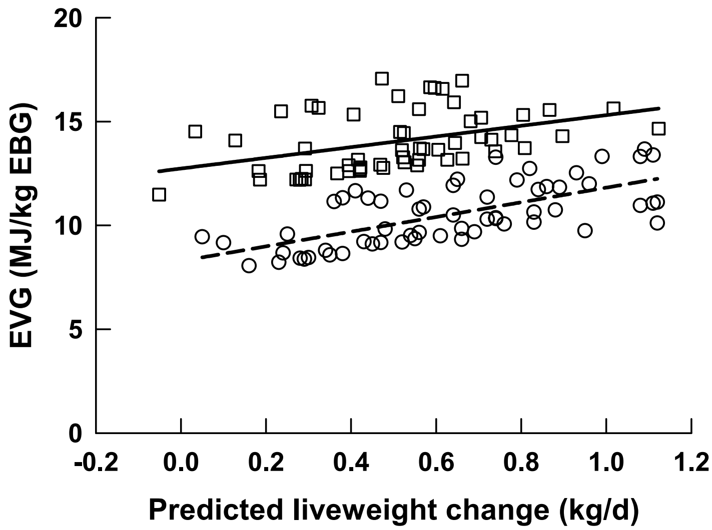

Figure 7. Relationship between the predicted liveweight change and the estimated energy value of the gain (EVG) on an empty body gain (EBG) basis, as determined using CNCPS (○, dashed line) and SCA (1990; □, solid line). For CNCPS, the data refer to the ME-allowable gain. The regression equations are as follows:
CNCPS: $Y = 8.28 + 3.535\ X$, ($R^2 = 0.99$; rsd = 1.105);
SCA: $Y = 12.74 + 2.572\ X$, ($R^2 = 0.99$; rsd = 1.323).

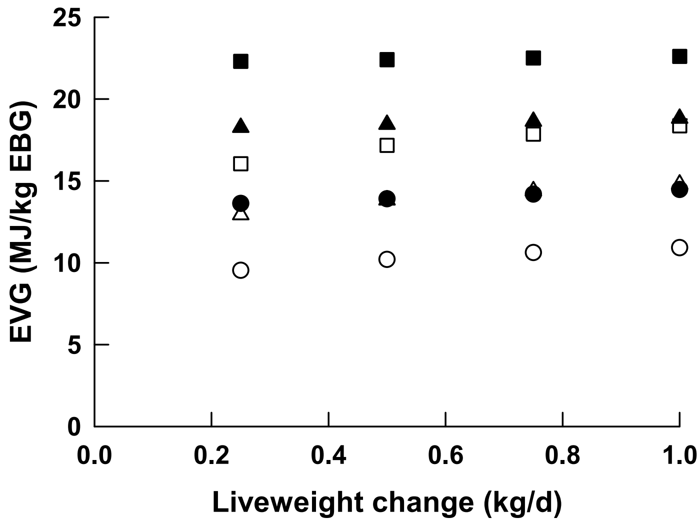

Figure 8. Theoretical relationship between liveweight change and the energy value of the gain (EVG), on an empty body gain (EBG) basis, for steers of liveweight 200 (circle), 300 (triangle) and 400 (square) kg, as determined using CNCPS (open symbols) and SCA (closed symbols) equations.

5 Applications

5.1 Conclusions on energy use

The foregoing discussion has supported our earlier contention that the well established principles of energy utilisation, as detailed in the feeding standards and incorporated in various DSS, do apply to tropical diets. Liveweight gain was closely aligned to MEI within treatment groups, and in general across all treatments despite the highly variable nature of the diets (Figure 1). The variability that exists across treatments is typical of biological data of this nature, and also likely associated with some inadequacies in diet or animal characterisation.

The comparative evaluation of GrazFeed and the CNCPS, and the equations from SCA (1990) upon which GrazFeed was based, illustrated considerable differences in the prediction of growth rate of the experimental animals (see Figure 2). In balance, the CNCPS and SCA provided reasonably good predictions of growth rate (9.6-17.0% bias) but the predictions of GrazFeed were poor (104.6% bias). Accordingly, some confidence could be placed in the use of the CNCPS or the general equations of the SCA for predicting growth of cattle on tropical diets. However, with all three systems there was substantial variability about the trend lines (rsd 0.14-0.19 kg/d) indicating considerable errors in prediction, with extremes of up to about ±0.4 kg/d (±2 rsd). The user would need to assess whether this level of error could be accepted and the ramifications of such. Whether the errors can be reduced, for instance by more accurate assessment of the diet or animals, is questionable.

Attempts to identify reasons for the disparity between predicted and measured growth rate revealed marked differences between the models in estimations of ME_m, k_g and the EVG, all of which impact significantly on the predicted growth rate. The fact that there were differences in all three factors makes it difficult to implicate a single one and the final outcome is the result of counteracting effects between all three factors. The comparison of GrazFeed with the feeding standards from which it was derived, SCA (1990), provided an opportunity to differentiate between the direct application of the energy use equations, and their application within a whole system DSS. Our simulations indicated that, even when the same equations were used for SCA (including for $ME_{m)}$ as are incorporated in GrazFeed, the predictions of growth rate were much better with SCA. Nevertheless, the good predictions with SCA also demonstrate that the underlying equations in GrazFeed for determination of energy utilisation are sound. A likely reason for the difference between the two systems is the limiting effect of MP supply, of which RDP is in turn a limiting factor, on intake and thus LWC in GrazFeed. Where intake of RDP (RDPI) is less than requirements (RDPR), GrazFeed reduces the potential intake by the factor RDPI/RDPR. The model then undertakes several steps to re-estimate ER, on the basis of energy and protein availability, and thence re-calculates LWC which is effectively the lowest of MP-and ME-allowable gain. SCA, by contrast, determined only an ME-allowable LWC. With 24 of the 62 diets tested in our study, GrazFeed predicted a deficit of RDP.

The closer prediction of LWC with SCA than GrazFeed suggests that the estimate of MP deficit may have been excessive perhaps through overestimation of RDPR, underestimation of RDPI, or both. In Figure 9, estimated MCP production was plotted against that determined experimentally using the purine derivative-excretion method and shows that GrazFeed has predicted MCP production well at low or nil supplement intakes (intercept not different from zero; $P<0.05$) but increasingly underestimated it as supplement intakes increased (slope not equal to one; $P>0.05$). However, interpretation of these results is influenced by the effect of MP supply on intake, and *vice versa*, as detailed above. Nevertheless, the indication is that the model has under-predicted MCP supply. By contrast, with the CNCPS the bias was less (9.2 *v.* -18.0%) and indicative of a slight over-prediction of MCP production, but the intercept was not different from zero and the slope not different from one ($P>0.05$). Thus the generally lower MP-allowable than ME-allowable growth rates with the CNCPS do not appear related to errors in prediction of MCP production. With both models there was considerable variability (rsd 84-90 g/d) but errors in estimation of MCP production using the purine method may have also contributed to this. Notwithstanding the above factors, our results indicate that both the CNCPS and SCA could be used directly, and GrazFeed after some modifications, by researchers, cattle producers and their advisors to predict grazing animal performance. Some practical applications of the models are discussed below.

5.2 Prediction of intake from known liveweight gain

The prediction of intake by grazing cattle would be of considerable benefit to research workers studying utilisation of nutrients or whole property nutrient management. Cattle producers and their advisors also require an estimate of intake for feed budgeting and stocking rate allocations. The latter has particular relevance in the seasonally-dry tropics where accumulated pasture resources at the end of the wet season usually represent the total feed reserves for the whole dry season, and over-grazing has implications for sustainable use of pasture and land. If the equations describing the utilisation of energy by animals are sound, as has been shown in general terms above, then just as it is possible to use those equations to predict animal growth rate from known intake it should also be possible to predict intake when liveweight change is known, by the reverse process. This liveweight change could be a measured change or alternatively a historical value for a given paddock, site or region. Cattle producers often know, from past records, approximate growth rates of a class of animal over a period at a particular time of year, for instance the dry season, albeit this can vary quite markedly with the length and severity of the season. Nevertheless, regular adjustments to predictions of intake can be made as seasonal and pasture conditions change.

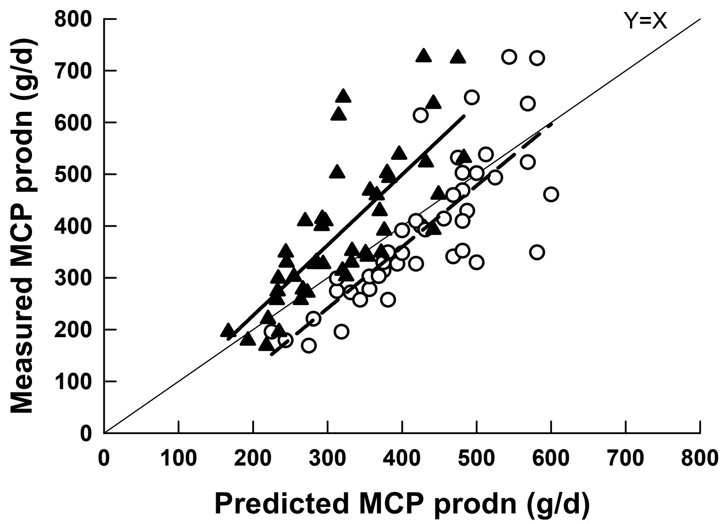

Figure 9. Relationship between the measured microbial crude protein(MCP) production (prodn) and that predicted using the CNCPS (○, dashed line) and GrazFeed (▲, solid line). The regression equations are as follows:
CNCPS: Y = -114.7 + 1.185 X, (R^2 = 0.96; rsd = 84.02; bias = 9.2);
GrazFeed: Y = -45.44 + 1.361 X, (R^2 = 0.96; rsd = 89.58; bias = -18.0).

This approach to intake prediction is not new, and previous workers have applied a similar method using various feeding standards (Minson and McDonald 1987; Baker 1982, 2004). Minson and McDonald (1987) used the energy requirement tables from ARC (1980) and assumed a linear relationship between growth rate of cattle and DMD of the pasture eaten to established a multiple regression equation for estimating intake from animal liveweight and growth rate. When tested, intake was predicted with a coefficient of variation of 8.7%. Baker (1982) and (2004) used the MAFF (1975) and AFRC (1993) feeding standards, respectively, to back-calculate intake. Our approach is similar except that we have first validated the models using tropical diets and supplements and thus established some confidence in their application to the tropical grazing situation. Some estimate of energy content of the diet is required and this can be a DMD provided by faecal NIRS, as described earlier.

5.2.1 SCA

The application of SCA equations is relatively straight forward. With a description of the breed and sex of the cattle, to establish the SRW, and the LW and estimated LWC of the cattle and the DMD of the diet, intake can be predicted. We have developed a Microsoft Excel spreadsheet calculator, "QuikIntake" using the equations evaluated in the SCA simulations above. What is more complex is determining the additional energy expenditure of a grazing compared with a housed animal, e.g., "EGRAZE" in the SCA (1990) publication (equation 5 above). The difficulty here is that the equation for EGRAZE (equation 1.24; SCA 1990) requires an estimate of DM intake. These equations have been modified slightly and simplified for inclusion in GrazFeed and the modified equations, as presented in Freer *et al.* (2004), are shown below (equations 9 and 10). Thus there are two components: the first describes the additional NE expenditure (MJ) on eating during grazing, and the second (EMOVE; MJ) describes the NE expenditure on walking.

$$\text{EGRAZE} = 0.0025 \times W \times \text{DMI}\,(0.9 - \text{DMD}) + \text{EMOVE}; \qquad (9)$$

EMOVE = 0.0026 x D x W x S; (10)

where W is LW in kg, DMD is expressed as a decimal, D is distance walked (km) and S is slope of the landscape on a scale from 1 (flat) to 2 (steep). EMOVE has been modified from the equation given in Freer *et al.* (2004) so that estimated distance walked is used rather than one calculated on the basis of green and dead content of the pasture and stocking rate which are less relevant under extensive grazing conditions. These NE values are converted to ME by dividing by k_m. The contribution of the grazing term in equation 9, and as a component of total ME_m, is small. For example, for an 18 month old, 300 kg *B. indicus* steer consuming a diet of 50% DMD with an intake of 1.5%W/d (nil grazing), the ME required is equivalent to 0.1% of total ME_m. The equivalent value for the same steer consuming 2.5%W/d of a 60% DMD diet is still only 0.1% of ME_m, so errors in this term make an insignificant difference in the prediction of DMI. A provisional estimate of DMI could be made for the above calculation of ME_m, as we have done in QuikIntake, by estimating potential and relative intake in the manner described by Freer *et al.* (2004) and as used in GrazFeed. By contrast, the EMOVE component could be considerably larger especially under extensive grazing conditions where adult cattle in large paddocks might walk 10 km or more a day for grazing and access to water. Thus for the same steer as above walking 6 km on undulating ground (slope factor 1.5), the contribution of EMOVE to total ME_m would be 11 MJ/d or 26% of total. An alternative approach to estimating EGRAZE is to nominate a proportional increase in maintenance requirements, say between 5 and 30%, and arbitrarily vary this according to grazing conditions (M. Freer, pers. comm.). It would appear simpler and more appropriate to insert an estimate of the km walked, of which estimates can be made by observation of distance from water during grazing by rangeland cattle.

5.2.2 CNCPS

The CNCPS provides an estimate of DM intake based on the SBW of the animal and the NE value of the diet for maintenance with adjustments for breed, body fat, temperature, mud and feed additives. However, the model requires an actual DM intake to operate and uses its predicted value more as a benchmark for diagnostic purposes (see CNCPS v. 5.0, model biology overview). In our study predicted DM intakes were markedly different from measured intakes (see Figure 10). Therefore, to predict intake, the model can be iterated manually until the lowest of ME- or MP-allowable gains equal the actual gain.

The main challenge with the use of the CNCPS for grazing cattle lies in providing an adequate description of the diet. However, with the emergence of faecal NIRS screening of grazing cattle (Stuth *et al.* 1999; Coates 1999), basic estimates of the DMD and the CP, ADF and NDF content of the diet selected by cattle can be obtained. To use this information alone with the CNCPS would demand a level 1 solution unless surrogate values for carbohydrate and protein pool sizes and degradation rates were obtained from analysis of similar forages to allow level 2 resolution. This is a realistic possibility providing some tropical forages of the types likely to be encountered are appropriately analysed or are already present in the feed library. There exists already a considerable tropical feed library (Tedeschi *et al.* 2002b).

Given the dearth of information on diet composition available under extensive grazing conditions it would initially seem more appropriate to use a level 1 than a level 2 solution. With the diets evaluated in the above simulations, there was little difference between results for the two solutions. Lanna *et al.* (1996), by contrast, reported greater accuracy in prediction of performance of *B. indicus* cattle under tropical conditions using the CNCPS compared with the NRC, when the average growth rate of male cattle was 0.92 kg/d. The only faecal NIRS output for energy content is DMD and at present there is no equivalent feed input option in the CNCPS. A possible solution to this disparity between known diet composition and that required to use the CNCPS is to import a forage of similar description and composition from the feed library, change those attributes such as CP and NDF content for which data is available from faecal NIRS analysis, and then adjust the carbohydrate-B2 (CHO-B2; available fibre) degradation rate within the level 2 framework until predicted M/D is the same as that calculated from DMD. The protein-B3 degradation rate should be adjusted in parallel to equal that of CHO-B2 (Fox *et al.* 2003). If the CNCPS is to be targeted towards the type of conditions regularly encountered in the tropics of northern Australia, our recommendation is that provision is made within the model to enter DMD directly and for TDN to be calculated from it.

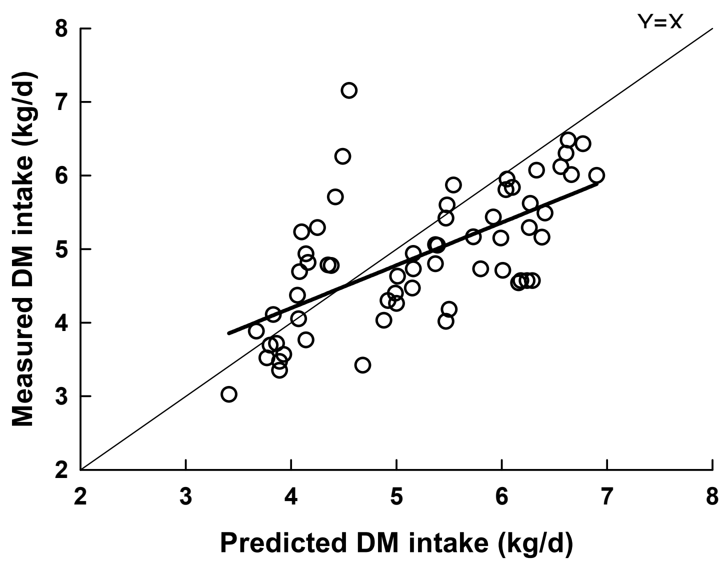

Figure 10. Relationship between the measured dry matter (DM) intake and that predicted using the CNCPS. The regression equation is as follows:
Y = 1.874 + 0.581 X, (R^2 = 0.98; rsd = 0.710; bias = -5.8%).

Pasture intake can similarly be predicted when supplements are fed to cattle in known amounts. For instance, with the SCA system, the MEI from the supplement can be subtracted from the predicted total MEI, and the remainder apportioned to the forage. Recently established faecal NIRS equations allow determination of the composition of the pasture component alone even when supplements are fed, so that the M/D of the pasture can be derived (S.J. Gibbs, pers. comm.). With the CNCPS, supplement intake can be entered and hay intake iterated until predicted and actual LWC match, in the manner previous described.

A key prerequisite for the use of either system is accurate characterisation of the animal in terms of its SRW and final body composition. As discussed above, these factors impinge on the computation of the energy value of gain and thus influence the relationship between LWC and DMI. The user must therefore clearly define the target animal before considering the use of these models. Based on our findings, we recommend that for *B. indicus* cattle in northern Australia, a SRW of 660 kg be used for steers (550 kg for females) in SCA and GrazFeed simulations and that for the CNCPS, a SRW of 400 kg at 22% fat and an MSBW of 480 kg seems appropriate.

5.3 Prediction of liveweight gain from diet composition and pasture description

Liveweight gain is a function of intake and diet composition and the latter can be estimated from faecal NIRS screening, as described earlier. Voluntary intake is similarly a function of diet quality but overriding any such relationship under practical grazing conditions is pasture availability. Thus some description of the herbage mass on offer, and the extent of defoliation, is required. When herbage mass (or leaf mass) per unit area falls below a certain threshold, the animal's intake will be limited by its ability to satisfy its appetite in the time available. The extent of defoliation of this herbage mass also affects intake by the effect on bite size (Stobbs 1973, 1975). Grazing animals select mostly leaf which contrasts with hand-fed animals which receive variable proportions of leaf and stem. Poppi *et al.* (1981) showed that intake of leaf was markedly higher than for stem of the same DMD. At present neither the limits of defoliation or the critical herbage mass have been defined for extensive native pastures.

In the context of this section, estimation of intake from diet composition is considered as a vital first step in the prediction of LWC but accurate determination of intake in this manner would be a significant achievement in itself, and obviate the need for back-calculation from LWC where information on this is limiting. The CNCPS includes a predictive equation for intake, as discussed above, and GrazFeed and SCA share an approach based on determining the potential and the relative intake of the animals. In the foregoing discussion the inaccuracies of both models in predicting intake of our diets have been detailed. This is discussed further below.

CNCPS. For LWC predictions, the CNCPS requires a description of the diet composition and of the animal, as previously discussed. If a provisional intake is first entered, the model will predict an intake based on animal and diet characteristics. This predicted intake can then be entered and the growth rate predicted, being the lowest of ME- or MP-allowable gain. When supplement is included in the diet in known amounts, the known supplement intake can be inserted and hay intake entered equivalent to the model-predicted DMI minus supplement intake. To provide for situations where pasture availability is likely to be limiting, the CNCPS includes a table by which to proportionally scale down intake and then use this revised intake in the model. The applicability of this correction to extensive grazing conditions has not been evaluated, but the concept is worthy of further investigation.

GrazFeed. GrazFeed has been designed for use with grazing ruminants. As detailed earlier, it computes the quality of the diet selected on the basis of user inputs on the total herbage mass and pasture height and the proportions and CP content and DMD of the green and dead components of the pasture. Predicted intake is then calculated as the product of potential and relative intake, with adjustments for protein availability, and the predicted intake is used to estimate LWC (see earlier). Thus GrazFeed can be used directly for LWC predictions provided the necessary information on the pasture is available. Unfortunately, that information is not easily obtained under extensive grazing conditions. Furthermore, the applicability of this method of characterising the diet selected by ruminants grazing tropical (C4) grasses, with different scope for selective grazing, different sward structure and wider differences between leaf and stem DMD than temperate pastures, has been questioned (Freer 2002). Where tropical pastures are involved, our recommendation is that the actual values for CP content and DMD of the diet, as derived from faecal NIRS analysis, be used instead of those simulated as above. Modifications to the input components of GrazFeed would be needed to accommodate this change. There would still need to be an estimate of herbage mass on offer and some determinant of the limit of defoliation to establish thresholds below which intake is restricted.

GrazFeed also readily accommodates the inclusion of supplements. In this model the supplement is inserted as an additional pool, similar to the various digestibility pools, and a substitution rate is computed so that pasture intake can be predicted (see Freer 2002). Given the above detailed inadequacies in the diet selection procedures in the model for tropical diets, and our suggested changes to direct user input of diet CP content and DMD, another approach will be required to establish the effect of supplement on pasture intake. This would need to be in the form of a substitution equation which predicts pasture intake when supplement intake and dietary pasture (from NIRS) and supplement composition is known. The same equation could be used to derive pasture intakes for inclusion in the CNCPS. The complexity of the interaction between supplement and pasture intake, including aspects of supplement composition, pasture quality and availability, physiological state of the animal, and frequency of feeding (Dove 2002) make this a difficult assignment. Nevertheless, attempts have been made to account for some of these factors, as exampled by the multi-factor equation derived by Moore *et al.* (1999). The applicability of such relationships needs to be evaluated.

With both existing models, intake is effectively related to some attribute of energy content of the diet, i.e., the dietary content of net energy for maintenance with the CNCPS and the DMD in GrazFeed. In the latter a linear relationship between relative ingestibility and DMD is assumed albeit that this function differs according to pasture type. Tropical grasses are associated with higher intakes at the same DMD as temperate grasses, so separate regressions with similar slope but different intercepts are used. However, various workers have shown that intake cannot be predicted accurately with a simple single-factor variable such as DMD (Mertens 1973; Moore and Kunkle 1999; Coleman *et al.* 2004), and Minson (1982) showed that whilst there was a linear relationship between intake and digestibility with tropical grasses, this varied with the species of grass. Moore and Kunkle (1999) proposed a multi-factorial relationship between voluntary intake and CP, TDN (based on DMD) and ADF which accounted for more variability than any single variable alone, albeit there was still considerable variability associated with this relationship. Nevertheless, relationships such as this could be used manually to provide an estimate of intake to use in the models for growth rate prediction, e.g., in the CNCPS.

We have not tried here to assess the ability of the models to predict growth rate using our data set and diet composition alone, i.e., without intake. Whilst it is legitimate to use known intake and diet composition to predict growth rate and thereby evaluate the energy use relationships built into the models, as we have done above, the deficiencies in the intake / diet composition relationships discussed earlier are compounded by the fact that our data is based on mixed diets with chaffed hay as the basal component. Their application to grazing situations with predominantly forage diets is tenuous. Pen feeding experiments provide a mixed leaf/stem diet considerably different from that expected under most grazing situations where animals tend to select for leaf wherever possible. Poppi *et al.* (1981) highlighted the much greater intake by cattle of leaf than stem of tropical plants at the same DMD. Differences in leaf/stem ratio in hay could also explain some of the variability between experiments in responses to added nutrients (Minson 1982). This problem of application is likely inherent in the existing models where diet composition / intake relationships are also primarily derived from hand-fed animals. Thus the relationship of intake with some aspect of diet composition is likely to be different for grazing compared with hand-fed animals. The latter will have a relationship based on mixtures of leaf and stem whilst the grazing animal requires a relationship based on leaf alone.

Lack of precision in the prediction of voluntary intake of grazing animals continues to be a major source of error contributing to poor prediction of growth rate. On the basis of the simulations carried out, the prediction of intake presents a greater source of error than determination of energy utilisation for growth in GrazFeed when applied to tropical diets, and the same probably applies generally. There may be less or similar variation around an intake / faecal NIRS relationship, or even a LWC / faecal NIRS relationship, and if so these may prove a more expedient approach to prediction of intake or grazing animal performance. Whilst such relationships exist, they are still in the developmental stages (D.B. Coates, pers. comm.).

6 Success in achieving objectives

Objective 1: Achieved.

Initial simulations carried out indicated that the equations describing the utilisation of energy for growth by cattle, as incorporated in the feeding standards and DSMs, were sound and were appropriate for the tropical cattle and diets being tested. This finding underpinned the subsequent investigations of model efficacy. The prediction of growth of animals based on a description of diet and animal characteristics was carried out using GrazFeed, the CNCPS and the equations from the SCA (1990) feeding standards for ruminants. The CNCPS and SCA provided good predictions of liveweight gain (LWG) when a known intake was used in conjunction with a reasonably detailed description of the diet and the experimental animal. Predictions with GrazFeed were, by comparison, poor. However, the models did not predict intake well based on diet and animal descriptors alone and therefore could not be expected to predict intake well either. The poor predictions of intake resulted from inherent variability in the intake / diet characteristics (e.g., dry matter digestibility; DMD) relationship and this error appeared larger than that of predicting LWG from known intake. GrazFeed and CNCPS also include a feature whereby intake, and thus LWG, is determined on the basis of either MP or ME supply. Under-prediction of microbial crude protein (MCP) production, a major contributor to MP, in GrazFeed appeared to further limit intake and thus lead to under-prediction of LWG. Improvements in prediction of animal growth are reliant on better predictions of intake from diet quality attributes.

Objective 2: Achieved.

At present, the DSMs require quite detailed description of the pasture and the diet in order to predict LWG when intake is not known. GrazFeed uses a relatively complex sub-model to predict diet selection based on the herbage mass and height, the proportion of green and dead pasture and the CP content and DMD of the green and dead components. This process does not work with tropical pastures and at present no alternative is available. We believe that direct input of the CP content and DMD of the diet, as determined with faecal NIRS, should sufficiently describe the diet for predictions of LWG to be made. The problem remains one of the model first accurately predicting intake, as detailed above. If further diet descriptors are required, these would need to be provided but at present the main contenders are elements of fibre content, e.g., NDF and ADF, which will be provided by faecal NIRS. The alternative is to use faecal NIRS to predict intake directly and use this intake in GrazFeed with diet descriptors to predict LWG.

The CNCPS, depending on which level solution is used, has varying demands for pasture descriptors. In its simplest form (level 1), only those elements required to calculate total digestible nutrient (TDN) content are needed but even these may be beyond what can be provided by faecal NIRS. By contrast, the level 2 solution requires complex description of the diet components in terms of the various carbohydrate and protein fractions and their degradation and passage rates. These will not be available for grazing animals. However, surrogate values for these attributes can be obtained from the feed libraries associated with the model and entered in conjunction with those dietary characteristics that are available, e.g., CP and NDF content, and DMD. There is no option in the CNCPS to enter DMD directly but a direct calculation of TDN content from DMD is desirable under our grazing circumstances.

We are confident that faecal NIRS can provide all of the necessary diet quality descriptors (e.g., DMD and CP and perhaps NDF content) to predict LWG from known intake, but the poor prediction of intake with any diet descriptors remains a problem.

The other major need is a description of the herbage mass and the level of defoliation, as this can place a further constraint on intake. At the very least these parameters are required but the thresholds for each are not yet known or understood.

Objective 3: Achieved.

Recommendations on the appropriate equations to determine the various elements of energy use, e.g., the maintenance requirements for ME (ME_m) and efficiency of use of energy above maintenance (k_g) have been made in the review paper and have been reported to the model designers. The other modifications needed to the DSMs have been discussed above. They relate to the disabling of the diet selection sub-model in GrazFeed and the direct input of diet characteristics from faecal NIRS in both GrazFeed and the CNCPS. The GrazFeed designers have committed to make the changes which will generate a tropical version of the model.

7 Impact on meat and livestock industry – now & in five years time

- The equations used to calculate energy utilisation by cattle for growth, as derived from the feeding standards and incorporated in various decision support models, have been evaluated. In general, the equations have been found to be robust, and we have concluded that these equations apply equally well to cattle fed tropical diets as they do for those on temperate diets. This finding provides confidence that the pursuit of a reliable decision support system for northern Australian grazing systems in the future is underpinned by sound nutritional principles.
- The results of our study provide a link between the outputs of faecal NIRS analysis (e.g., MLA Project NAP3.121), describing the diet quality of grazing animals, and the prediction of animal performance and development of feeding strategies for various production goals of northern cattlemen. The extent to which this pursuit has been achieved is discussed below.
- The various models evaluated can be used now to predict intake of grazing cattle from measured liveweight gain (LWG) or from historical records of LWG. At present the CNCPS and the SCA equations provide the most accurate predictions of intake by this method, but the eventual choice is a personal one. Some consistency between agencies seems appropriate though.
- Based on the methods described above and using SCA equations, an intake calculator, “QuikIntake”, has been developed as a simple predictive tool for use by researchers, producers and advisors. This calculator can be used to set appropriate stocking rates for efficient but ecologically sensitive use of pastures. It will represent a useful management tool now and in the future. Our studies have raised the question of whether it is still appropriate to persist with defining adult equivalents (AE) for stocking rate determinations, or simpler to proceed with an intake (from LWG) and pasture utilisation rule, with liveweight included as an intake parameter, to decide on stocking rate.
- The models tested do not predict with any accuracy the intake by grazing animals from a description of diet quality and animal characteristics and thus could similarly not be expected to predict LWG with any accuracy. Further developments in this area will require more robust relationships between intake and dietary characteristics. At present these do not exist but the emerging intake / faecal NIRS relationships provide some prospects worthy of investigation. If intake can be determined in this way, the existing models, with some modification, could be used directly for predicting grazing animal performance.
- The study has provided feedback to the various modellers associated with GrazFeed and the CNCPS on the soundness of their models for use under tropical rangeland conditions, and also provided direction on the way in which the models could be modified to accommodate the limited information on the diet of grazing animals which will remain a constraint in northern Australia.
- The results of this study, including the intake calculator, can be immediately used by field workers and also incorporated into existing training courses for cattle producers, including the Northern Nutrition, Grazing Land Management and Reproduction courses sponsored by MLA / EDGE network.

8 Conclusions and recommendations

8.1 Conclusions

For the purpose of this section, the SCA, GrazFeed and the CNCPS are referred to as models.

- The accepted principles of energy utilisation apply to cattle consuming tropical diets.
    - For the tropical breed of cattle used in our experiments receiving tropical hays with and without supplements, the accepted principles of energy utilisation, as espoused in the various feeding standards, viz., a close linear relationship between metabolisable energy (ME) intake above maintenance and liveweight gain or energy retention, applied.
- There are some substantial differences between the models in (i) how they calculate the main variables of energy use for maintenance and growth of animals, (ii) the eventual values obtained for these variables, and (iii) the summative effect of these variables on liveweight gain (LWG).
    - These include, for instance, differences in (i) the maintenance requirements for ME (ME_m) and how it changes with ME intake, (ii) the efficiency of use of ME in excess of maintenance for growth (k_g,), and (iii) the energy value of gain and its relationship with the physiological stage of maturity (e.g., with standard reference weight or mature body size).
    - It was not possible to isolate any one factor in terms of its contribution to differences in LWG predictions; the effect is cumulative.

SCA:

- basic equations for energy use appear robust and provide good predictions of LWG - from known intake;
- energy use equations cannot be used for predictions of LWG when intake is not known;
    - no prediction of intake
    - no account of metabolisable protein (MP) supply;
- can be used for back-calculation of intake from known LWG or historical estimates of LWG;
- amenable to basic input data likely to be available for cattle grazing rangelands, i.e., DMD and CP content from faecal NIRS;

GrazFeed:

- has been designed for use with grazing ruminants;
- requires modification for practical use in northern Australia to allow users to bypass the diet selection sub-model, which is not appropriate for tropical rangelands and introduces intake errors. These modifications relate to direct input of diet composition and a pasture description (see Recommendations);
- uses the same equations as SCA for determining energy utilisation, with some minor modifications, and based on the experience with SCA simulations, these underlying equations are sound;
- despite the similarities with SCA, GrazFeed did not provide good predictions of LWG from known intake and this seemed related to the determination of MP adequacy in the diet.

CNCPS:

- has not been expressly designed for prediction of growth rate by grazing animals in that it requires an intake estimate, a detailed description of the diet (for level 2 solution) unlikely to be available for grazing animals, and moderate user knowledge and experience for its effective use;
- requires modification for practical use in northern Australia in relation to input of diet composition (see Recommendations);
- equations used appear robust in the predictions of energy utilisation and provided good predictions of LWG of the cattle - from known intake;
- level 2 solution requiring complex description of diet characteristics provided only marginally better prediction of LWG than the level 1 solution using simpler diet description and calculation of energy density, e.g., total digestible nutrients (TDN). Level 1 solution likely to be more relevant for rangeland situation;
- provided poor predictions of intake from inputs of diet composition alone;
- based on the good predictions of LWG from known intake, should provide good predictions of intake by back-calculation and iteration from known LWG.

General:

- Both GrazFeed and the CNCPS are well supported by strong research teams.
- Despite the good predictions of LWG from known intake with SCA and the CNCPS, and less so with GrazFeed, there was considerable variability associated with the growth rate predictions for all three models, although this variability is likely to be acceptable under practical extensive grazing conditions.
    - The cause of this variability is not apparent but it is likely that the current prediction equations could be modified to improve the predictions, most likely through re-analysis of the data and development of empirical multiple regression equations incorporating various parameters of diet composition. However, the outcome is not certain.
- Neither GrazFeed nor the CNCPS predicted intake accurately from a knowledge of diet composition and animal characteristics alone, thereby demonstrating that:
    - knowledge of intake of cattle, with and without supplement, is essential for accurate prediction of LWG of grazing cattle with these models;
    - prediction of LWG from these descriptors alone (in the tropics) would also be poor; as intake prediction is a vital precursor;
    - both models suffer from an inherent variability in the current intake / diet characteristics (e.g., DMD) relationships which are furthermore based on pen feeding experiments with different diet characteristics, e.g., leaf/stem ratio, than occurs under grazing conditions, i.e., predominantly selection of leaf.
- In view of the above conclusions on the SCA simulations, the spreadsheet intake prediction tool, “QuikIntake”, developed in this project, will represent a useful and relatively accurate management tool for use by researchers, producers and advisors for predicting intake of grazing cattle from measured, historical or estimated LWG.

- Both GrazFeed and the CNCPS use the concept that MP supply might be first limiting rather than ME, which affects the prediction of LWG from diet composition but not the back-calculation of intake from known LWG.
- Microbial crude protein (MCP) production is the main source of the MP in tropical forage diets and GrazFeed and the CNCPS differ in their prediction of MCP production, with CNCPS providing a good prediction of MCP production and GrazFeed under-predicting it, based on measured values.

8.2 Recommendations

- In view of the problems associated with the current intake / diet composition relationships, two strategies should be explored:
    1. investigate and validate other such relationships perhaps involving a multi-component description of diet quality;
    2. compare the error of prediction of intake from an intake / faecal NIRS relationship with that of existing conventional relationships for intake determination.
- Existing models, if they are to be used in extensive rangeland systems, need to be modified to accept more limited but accurate input data from faecal NIRS;
    - With GrazFeed, a tropical version is required which disables the diet selection sub-model and allows direct input of diet DMD and CP content from faecal NIRS analysis together with some measure of herbage mass and the limit of defoliation;
    - With the CNCPS, allowance should be made to directly input DMD of the diet and to use this to estimate TDN, rather than the tabular (level 1) or mechanistic (level 2) approaches currently used.
- The findings of this study for growing cattle need to be extended to a similar exercise for cows, especially as it relates to intake predictions. The main issues here will be:
    - lack of a comparable data set for cows;
    - information (e.g., LWG and body condition score changes etc.) needs to be collected from current large scale grazing experiments, e.g., “Pigeon Hole” project;
    - have to assume that because the energy use equations were robust for growing cattle, the same applies with reproductive animals.
- Research is required to provide a clear definition of when herbage mass / pasture structure limits intake of cattle grazing tropical pastures, rather than pasture quality upon which intake / diet characteristic relationships are currently based (as detailed above).
- The information generated in this study, especially the intake predictions provided by the QuikIntake spreadsheet model, needs to be included in the Northern Nutrition, Grazing Land Management and Reproduction workshops.

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