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Nutrient requirement tables for Nutrition EDGE manual

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Abstract

This project derived estimates of metabolisable energy (ME) and protein requirements, and the relationship between intake and digestibility, for inclusion in a revised version of the northern beef training package, Nutrition EDGE. This was done to bring them into line with the Australian feeding standards (EDGE requirements currently derived from UK ARC standards based on *Bos taurus* data) and with associated changes to the adult equivalent (AE) calculations. The revised estimates of protein and ME requirements are higher, in most cases, then those currently used in the EDGE package. To some extent, this could be due to the Australian feeding standards tending to overestimate requirements for cattle grazing on tropical pastures but improved algorithms are not currently available. The revised tables are useful for the purpose of demonstrating to cattle producers the key principles of energy and protein requirements and how they change with the quality of the diet, the liveweight of the animal and its productivity either for growth or pregnancy/lactation. However, they are not suitable for making judgements on the adequacy of a specific paddock scenario to meet production targets, or to determine the amount of additional nutritional inputs required to meet those targets. For the latter case, nutritional advisors should consider using a tool such as ‘QuikIntake’ or the web-based spreadsheets associated with the GrazFeed site – their advantage is that they allow the user to work backwards from ‘known’ animal performance to calculate requirements without the need to predict diet quality other than a faecal NIRS assessment of digestibility. The constraints of current systems for estimating energy and intake requirements should be understood to avoid frustration and naïve application. For example, when the ME requirements (from either system) are translated into dry matter intake requirements, some of the required intakes are beyond what the animal would be expected to achieve even though the production rates may be achievable. Care and intuition are therefore required in their use and interpretation.

Executive Summary

The Nutrition EDGE training workshop provides northern beef producers with improved understanding of the nutritional management of cattle, based on the latest research data. This training package was being updated and revised, and this identified a specific need to update its tabulated requirements for metabolisable energy (ME) and protein, and the graphical relationship between intake and digestibility. The current requirements are derived for the UK ARC system which is based on data for *Bos taurus* cattle, and it was deemed more appropriate to derive the tabulated requirements from the Australian feeding standards. This enabled the breeds and pastures of northern Australia to be accommodated in a systematic fashion while using the algorithms considered to be those most appropriate for Australian conditions.

This project derived the revised estimates of ME and protein requirements, and reviewed the relationship between intake and digestibility, for inclusion in the revised version of Nutrition EDGE. In doing this, a number of issues and challenges were identified which has implications for the use of these tables beyond their primary role, which is to aid demonstration of the key principles of energy and protein requirements and how they change with the quality of the diet, the liveweight of the animal and its productivity either for growth or pregnancy/lactation.

The revised estimates of energy and ME requirements are higher, in most cases, than those currently used in the EDGE package. To some extent, this could be due to the Australian feeding standards tending to overestimate requirements for cattle grazing on tropical pastures but improved algorithms are not currently available.

The revised tables are not suitable for making judgements on the adequacy of a specific paddock scenario to meet production targets, or to determine the amount of additional nutritional inputs required to meet those targets. For the latter case, nutritional advisors should consider using a tool such as ‘QuikIntake’ or the web-based spreadsheets associated with the GrazFeed site – their advantage is that they allow the user to work backwards from ‘known’ animal performance to calculate requirements without the need to predict diet quality other than a faecal NIRS assessment of digestibility. The constraints of current systems for estimating energy and dry matter intake requirements should be understood to avoid frustration and naïve application. For example, when the ME requirements (from either system) are translated into dry matter intake requirements, some of the required intakes are beyond what the animal would be expected to achieve even though the production rates may be achievable. Care and expertise are therefore required in their use and interpretation.

Several approaches to deriving the relationship between intake and digestibility were explored. As expected, there was a general relationship between intake and digestibility but there was no universal, biologically-sound relationship between DMD and intake that applies across all animal types, pasture types and general grazing situations. A set of prediction curves derived from a published relationship between liveweight, liveweight gain and intake were recommended as the best option for replacing the existing EDGE manual relationships (the derivation of which is uncertain), based on (i) their simplicity of application, (ii) their more gradual increase in intake relative to digestibility, delivering lower values at high digestibility which are more consistent with expectations from tropical pastures, and (iii) their parallel alignment with the observed validation relationship.

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1 Background

The northern EDGE workshops are being updated to reflect latest R&D findings and to improve consistency and inter-connectedness. The current Nutrition EDGE manual includes nutrient requirement tables extracted from the ARC (1980) publication. These requirements for energy and protein are empirically-based and derived from experiments using predominantly *Bos taurus* cattle given temperate diets in pens. The committee reviewing the Nutrition EDGE package decided it was time to update the tables and base them on the Australian feeding standards (NRDR 2007), bringing them into line with the recent changes to the adult equivalent (AE) calculations (McLean and Blakeley 2014) which are now also based on the Australian feeding standards, i.e., the NRDR (2007) equations.

The current Nutrition EDGE manual also includes figures showing estimated dry matter (DM) intakes of steers of different liveweights and mature lactating cows, against pasture (diet) DM digestibilities (DMDs) ranging from 50 to 80%. These figures were considered to lack precision especially at the low end of the DMD range, and the origin of the original graphs is unknown. A method of generating alternative intake/DMD prediction curves for steers was required which had more acceptable levels of precision.

This project conducted the analyses required for these new estimates, and this report presents the new estimates and discusses their integration into the Nutrition EDGE manual.

2 Projective objectives

1. Revise the current tables for beef cattle in the Nutrition EDGE manual outlining the metabolisable energy (ME) and crude protein (CP) requirements of grazing cattle, using the Australian feeding standards (Nutrient Requirements of Domesticated Ruminants; NRDR 2007) to estimate requirements.

2. Review and revise the relationships between diet digestibility and the intake of tropical grass forages (non-legume) by steers (*B. indicus* crossbred) of varying liveweights and by mature lactating *B. indicus* cows at various times after calving, as are currently included in the Nutrition EDGE manual.

3. Provide a brief report on the implications of the changes to the requirements tables. The current requirements are to be plotted against revised requirements for cattle, both confined and grazing (walking 7 km/d). This would highlight the scope of the changes and the implications for their use in the EDGE workshops and by extension staff in general.

3 Methodology

The revised tables have been formulated using the 'QuikIntake' spreadsheet calculator (QI; S.R. McLennan and D.P. Poppi, unpublished) which encapsulates the equations from the Australian feeding standards (NRDR 2007). The QI spreadsheet is continuously updated in line with revisions to the equations in the feeding standards and its companion software, 'GrazFeed', as are outlined in an on-line technical paper (Freer *et al*. 2012; latest version). Other software scrutinised in the current exercise were the web-based Excel programs which accompany NRDR and GrazFeed, viz., 'CattleExplorer', 'ME_required' and 'CP_required', to ensure the latest equations were in use in QI.

3.1 Animal classes considered

Two 'types' of steer have been included in the revised tables.

1. *B. taurus* steer. The animal used was a Shorthorn steer with a Standard Reference Weight (SRW) of 600 kg, as defined in NRDR (2007; page 39).

2. *B. indicus* crossbred steer. In this case the animal was a crossbred steer of 75% *B. indicus* content and with a SRW of 660 kg.

By definition, these SRWs can vary according to the environment in which the animals are grown, in keeping with changes in their mature size in different growing environments, but for the current exercise the SRWs 'suggested' in NRDR (2007) were used. They are also consistent with those used in the adult equivalents (AE) calculator (McLean and Blakeley 2014) and probably do represent the relative differences in mature size between the two cattle types. Nevertheless, in some environments the SRW should be changed to better reflect the grazing environment, but the tabular format of the current exercise cannot easily accommodate multiple SRWs.

One of the factors affecting the ME requirements of cattle in the Australian feeding systems, and in particular their maintenance ME requirements, is their age. Thus it was necessary to allocate an age for each LW category for the steers. For consistency, the same LW/age relationship was used for steers of both genotypes, this being 4, 8, 20, 30, 38 and 44 months of age at LW 100, 200, 300, 400, 500 and 600 kg, respectively. It should be noted though that the effect of age is relatively minor so using the same age/LW relationships for both genotypes, despite their different SRWs, had minimal effect.

In relation to the breeding animals, only one breed was used in the revised table – the (75%) *B. indicus* crossbred animal. The current EDGE tables do not indicate the breed of cattle to which they refer but, being based on the UK system, it was likely to be *B. taurus* in origin. In addition, these tables do not indicate the age of the animals, the quality of the diet, i.e., the M/D or 'q' value (ME/GE, as used in ARC 1980) or the level of activity. The following is a description of the animals used to populate the table referring to reproductive cattle.

1. Pregnant heifers, last third of pregnancy: *B. indicus* crossbred (75% *indicus*) heifer, 550 kg SRW, 2.5 years old, day 200 of gestation, expected calf birth weight (BW) of 35 kg, heifer walking 7 km/d with a diet of M/D = 8.0 MJ/kg DM (about 56.5% DMD).

2. Dry pregnant mature cow: *B. indicus* crossbred (75% *indicus*) cow, 550 kg SRW, 6 years old, day 200 of gestation, expected calf BW of 35 kg, cow walking 7 km/d with a diet of M/D = 8.0 MJ/kg DM.

3. Lactating first-lactation cows, with calf 4 months old: *B. indicus* crossbred (75% *indicus*) cow, 550 kg SRW, 3 years old, day 90 of lactation, growing at 0.1 kg/d, cow producing 5 kg/d of milk and walking 7 km/d, calf BW 35 kg and growing at 0.8 kg/d and with current

LW 130 kg, calf receiving 35% of ME from pasture, walking 4 km/d with a diet of M/D = 8.0 MJ/kg DM.

4. Lactating mature cows, with calf 4 months old: as for '3' above except the cow age was 6 years and it was producing 8 kg/d of milk.

5. Bulls: *B. indicus* crossbred (75% *indicus*) bulls, 770 kg SRW, with ages of 2.5, 3.5, 4.5 and 4.5 years for LWs 500, 600, 750 and 800 kg, respectively, walking 7 km/d and consuming a diet of 8 MJ/kg DM.

3.2 Determination of ME requirements

As mentioned above, the ME requirements were determined according to the equations in the NRDR (2007) feeding standards, using the spreadsheet calculator 'QuikIntake'. A detailed description of this process is given later. The main inputs included the energy density of the diet (M/D), which varied from 5 to 13 MJ/kg DM, the sex and breed of the animal (which determined its SRW), its age and LW and the specified level of production, i.e., LWG (kg/d) for steers or days of pregnancy/lactation for cows. The M/D was calculated from DMD using the equations provided in NRDR (2007) and both M/D and DMD have been included in the tables for reference.

In the case of the steers, requirements were determined for the two genotypes of animals either confined (no walking) or walking 7 km/d on level ground. The latter was consistent with the activity assumed in the AE calculator (McLean and Blakeley 2014). As indicated above, the requirements of the heifers, cows and bulls were based solely on the animals walking 7 km/d.

3.3 Determination of protein requirements

The equations from NRDR (2007) required to calculate protein requirements of cattle have been included in the latest version of QI. Only a brief description of the inputs are included here and the reader is referred to the feeding standards (NRDR 2007) and to the spreadsheets 'CattleExplorer' and 'CP_required' for further detail on the equations used. For non-pregnant and non-lactating cattle, the CP requirements were determined as the sum of the endogenous urinary and endogenous faecal CP, the dermal CP loss and the protein in gain. The endogenous urinary protein (EUP) is a function of the animal's LW although the lower excretion rates of *B. indicus* breeds relative to their British and European counterparts were accounted for by applying a multiplier of 0.8. The dermal loss is also a function of LW. The endogenous faecal protein (EFP) output is a function of total DM intake, so an estimate of intake was required. In the current exercise DM intake was determined by dividing the total ME required for a given level of production, as estimated by QI (see above), by the M/D of the diet. Thus there is a strong link between the ME and CP requirements of the animal. The protein in gain was determined according to the functions in the feeding standards which include the LWG of the animal, its stage of maturity (LW relative to SRW), and the level of feeding (multiples of maintenance requirements), all of which denote the amount of protein deposited in the total gain of the animal.

Having summed all of these elements as the total CP requirements, this total was then converted into the equivalent in the form of digestible protein leaving the stomach (DPLS) which is equal to the total CP required divided by 0.7, to account for the 70% efficiency of use of the DPLS for various outcomes, i.e., for EUP, EFP, dermal loss and protein in gain. Having determined total requirements these were then divided into the separate requirements for RDP and UDP. The RDP required for microbial crude protein (MCP) production is a function of ME intake (= MEI * 8.25; i.e., 8.25 g MCP/MJ of ME, or *ca*. 130 g MCP/kg digestible organic matter; DOM), but only about 60% of this MCP is available in the intestines as digestible protein for absorption. Thus the needs for RDP are determined first and this is subtracted from the total DPLS with the remainder being the UDP requirements (with an efficiency of use of 0.7 also applied). In the tables the requirements for RDP are shown first, then the UDP need. If only one figure is shown this indicates that all the animal's needs can be met with just RDP, as often occurs with older growing cattle. Younger cattle often have a need for UDP as well as RDP for growth. **It is important to understand that in some situations, especially with mature animals, all of the protein requirements could be met by RDP but in some instances a UDP requirement is also indicated. This often occurs because RDP use is limited by the availability of fermentable energy (DOM)**, at least at the low efficiency of 130 g MCP/kg DOM, so the shortfall is made up with UDP. A higher efficiency of utilisation of RDP would reduce the need for UDP. Under grazing conditions the actual efficiency is unknown so the value of 130 g/kg DOM is an approximation only. With respect to female cattle, in addition to the protein requirements for maternal growth there is also a requirement for conceptus growth in pregnant animals and for milk produced by lactating animals.

The reader is referred to NRDR (2007) and Freer *et al*. (2012) for a more detailed description of these equations and calculations.

3.3.1 General considerations regarding estimated ME and protein requirements

The tables produced outline the ME and protein requirements of cattle of different LWs, or stages of pregnancy/lactation, to achieve a specified level of production, e.g., LWG. However, **it should be stressed that specifying a need for energy or protein does not mean that the animal will be able to consume that amount of nutrients**, **or that the desired level of production will be achieved**, as the physical constraint on voluntary intake will at some point limit the animal's ability to consume those nutrients. This threshold on voluntary intake declines with declining quality of the diet. Thus a steer consuming a low quality diet (say 7 MJ/kg DM) will not be able to consume sufficient DM to reach the ME target required for a LWG of, say, 1.0 kg/d; in fact it may not be able to eat sufficient DM to even maintain LW. **This caveat needs to be placed on the tables.** Where an unrealistically high intake would be required to allow a certain LWG, the cells of the table have been left empty but in other cases where requirements have been included, judgement is still needed by the user as to whether the required intake or performance is achievable.

The DM intake (kg/d) required for a specified production level can be calculated by dividing the total ME required (MJ/d) by the energy density of the diet (M/D; MJ/kg DM), and this can be converted to an intake expressed on a LW basis (%W/d) by further dividing by the LW of the animal and multiplying by 100 to express it as a percentage.

The calculated DM intakes by steers required to achieve the ME requirements for a certain level of production have been included in the Excel spreadsheet, for reference. The shaded areas indicate a subjective assessment of intakes which would probably be unattainable given the LW of the steer, the M/D of the diet and the level of production targeted. These could be used to revise which cells are included in the various ME and CP requirement tables.

3.4 Estimation of intake from the digestibility of the diet

In order to revise these prediction curves some assumptions need to be made as there are more variables than just DMD that affect intake under practical feeding situations. For instance, it is inconceivable that the animals will not be increasing their productivity as DMD increases but the curves are supposed to reflect only the effect of DMD on intake. A description of the assumptions made for the steers are included below.

Only revision to Figure 29 (steers) of the EDGE manual has been attempted. There is insufficient information on the inputs and assumptions used in generating the manual's Figure 30 (lactating cows) to attempt any revision (see later). Changes in DMD are likely to be associated with changes in not only intake but also in cow liveweight gain (LWG) and milk production which in turn will affect intake over and above any effects of DMD alone. As the assumptions used in the current figure for cows are unknown they cannot be reproduced using the methods described below.

It is important to stress that there is no way of categorically determining whether any new curves are better than the existing ones without a detailed study set up to 'measure' voluntary intake of cattle grazing pastures of varying quality (including tropical species), a pursuit which has proved extremely difficult in the past.

The methods used to generate new prediction curves for steers included:

(i) The equations from the Australian feeding standards (NRDR 2007; hereafter NRDR), which have been included in the software package 'GrazFeed', as described in Chapter 6 ('Prediction of Feed Intake') of that publication.

(ii) The 'QuikIntake' (QI) spreadsheet calculator, based on a confined animal (zero grazing/walking).

(iii) The QI spreadsheet calculator, based on an animal walking 7 km/d on level ground.

(iv) The Minson and McDonald (1987; hereafter M&M) prediction equation.

A brief description of each of these is included together with their basic assumptions.

3.4.1 Setting the boundaries and general assumptions

Where it was relevant the animal involved was assumed to be a *B. indicus* crossbred (75% *indicus*) steer with a SRW (see definition below) of 660 kg. This is consistent with the value used in the adult equivalents (AE) calculator (McLean and Blakeley 2014). The effect of varying the SRW was investigated.

The current Nutrition EDGE figure includes predictions based on diets of DMD ranging from 40 to 80% but DMDs at the upper extremity of the range are not going to be reached on tropical pastures. In this exercise, intakes were initially predicted between 50 and 70% DMD, the 'usual' range for cattle grazing tropical pastures in northern Australia. In the final analysis the range was extended to 40-70% DMD.

3.4.2 Australian feeding standards / GrazFeed

This method of predicting intake has been described in Chapter 6 of NRDR and is that used in the GrazFeed software version of these feeding standards. The method is based on an estimate, firstly, of the 'Potential Intake' of feed by the animal which is defined as the amount of feed eaten when feed supply is abundant and the animal selects a diet with a DMD of at least 80%, or an M/D of at least 11 MJ/kg DM. The main factors defining potential intake are the body size of the animal and its physiological state. However, potential intake may be reduced by disease and thermal stress. The next step in intake prediction is to derive an estimate of 'Relative Ingestibility' of the diet, which represents the proportion of the potential intake that the animal can be expected to consume under existing conditions. Relative ingestibility is thus a function of the extent to which the chemical composition of the selected diet restricts its intake (e.g., its DMD), as well the sward structure and pasture availability which limits the animal's ability to harvest herbage in the time available. Relative ingestibility is thus expressed as a fraction (0-1). For the current exercise it is assumed that herbage availability is not limiting and that the animals are disease-free and grazing in a thermo-neutral environment.

The predicted intake is calculated as the product of the potential intake (kg DM/d) and the relative ingestibility (fractional).

Calculation of potential intake

As mentioned above potential intake refers to the upper limit of the voluntary intake of the animal and is a function of the animal's body size and physiological state. Current weight of the animal though is not a good predictor of body size as it is confounded by stage of development and body condition. Thus animals at the same body weight could differ in age, frame size and body condition by virtue of the different growth paths to that point and would be expected to have different potential intakes. An example would be a tall, lean, older steer vs. a young, shorter, fat steer of the same body weight. Thus the calculation of potential intake is to some extent based on the 'normal weight' of the animal. The normal weight refers to the animal's position on an allometric growth curve, such as that described by Brody (1945). Another key factor in determining potential intake is the SRW of the animal which is defined by the weight of a mature animal (completed skeletal growth) when its condition score is in the middle of the range. Possible SRWs are provided in a table in the feeding standards (NRDR) but it is stressed by the editors that these are not constants and that the SRW can vary with the environment in which the animal grows, as this will affect the final mature size of the animal. This is a difficult concept for many to grasp. A change in the SRW can have a considerable effect on the calculated potential intake and thus on the eventual predicted forage intake.

Calculation of relative ingestibility

The calculation of relative ingestibility is based on the recognised general linear relationship between apparent digestibility and voluntary intake of the diet. However, it is also acknowledged from the literature that such relationships vary with the forage involved, with different slopes of the regression line reported for different plants and even different species of the same genus. It has also been well demonstrated that the intake/DMD relationship is quite different for tropical (C4) and temperate (C3) forages, whereby at same DMD, intake is much higher for cattle consuming tropical compared with temperate pastures. However, the upper limit of digestibility usually encountered is also lower for the tropical species (around 70% maximum). These differences have been accommodated in GrazFeed by including separate but parallel linear relationships (same slope, different intercept) between DMD and relative ingestibility for the tropical and temperate pastures. A further relationship is provided for legume species and provision is made to include the proportion of legume in mixed pastures where the major species is C3 or C4. In summary, if pasture is non-limiting in supply and the animal's ability to harvest it is not compromised, the major factor affecting relative ingestibility is the DMD of the diet. The relative ingestibility is expressed as a fraction (0-1) and multiplied by the potential intake to arrive at a predicted intake of pasture. In the current simulation it is assumed that the legume content in the pastures is zero.

3.4.3 'QuikIntake'

The QI spreadsheet calculator (S.R. McLennan and D.P. Poppi, unpublished) includes the equations from the Australian feeding standards (NRDR) and predicts intake, firstly of metabolisable energy (ME) and thence of DM, by back-calculation from observed animal performance. This is the reverse of the 'normal' usage of the feeding standards where known or predicted nutrient intake is used to predict animal performance. The main variables incorporated in the QI spreadsheet are a description of the selected diet in the form of a DMD value, a description of the animal in terms of the breed, sex, LW and age and an observed or 'expected' (historical) LW change. The breed and sex of the animal provide the basis for defining the SRW (see earlier) for the particular animal although this should include some local knowledge about the likely mature weight of similar animals in the present environment. For breeding cattle there is also provision for a description of the stage of pregnancy or lactation. The quality of the diet is defined by its DMD, as determined for instance using faecal near infra-red spectroscopy (F.NIRS), and this is converted by simple equation to an ME content (M/D; MJ/kg DM). The total ME requirements are determined, using the various equations of the feeding standards, for the maintenance of the animal, for its activity levels (grazing and walking on ground of a stated elevation) and for its production over and above maintenance, i.e., for the observed LWG, pregnancy and lactation. The DM intake is then determined by dividing this total ME intake by the energy density of the diet (M/D) to express intake as kg/d DM or as a proportion of LW (%W/d).

The contribution of the described animal in terms of adult equivalents (AEs) is also calculated as multiples of either 450 kg LW or of ME intake (MEI) of 72.6 MJ/d, the latter representing a *B. indicus* crossbred steer at maintenance consuming a diet of 7.75 MJ/kg DM (ca. 55% DMD) and walking 7 km/d on level ground (see McLean and Blakeley 2014).

The current exercise is based on predicting *ad libitum* intake of cattle with DMD of the diet varying between 50 and 70%. However, QI also requires an estimate of the LWG of the animals (and pregnancy and lactation status for females). For this exercise the LWG is assumed to increase with DMD in the same manner as suggested by Minson and McDonald (1987), i.e., the assumed LWGs for diet DMD of 50, 55, 60, 65 and 70% were 0, 0.25, 0.50, 0.75 and 1.00 kg/d, respectively. The age of the animal is also an unknown so the assumed ages for steers of LW 200, 300, 400, 500 and 600 kg were 8, 20, 30, 38 and 44 months, respectively. Age does not have a major effect on the intake predictions.

The simulations were carried out for steers in confinement (zero activity) and for steers walking 7 km/d, as was used in the AE calculator.

3.4.4 Minson and McDonald (1987) (M&M)

The method set out in M&M was essentially centred on first estimating the quality of the forage selected by grazing cattle based on their LW and LWG, and then using this forage quality estimate in conjunction with the ARC (1980) energy requirement tables to determine the amount of forage of this quality that would need to be consumed by cattle (growing cattle only) of a certain LW to achieve a particular LWG.

This method assumed that forage was non-limiting in availability, and it also used the simplified assumption that growth rate of the cattle was linearly related to the DMD of the pasture eaten, where 50% DMD corresponded to zero growth rate and 70% DMD coincided with a growth rate of 1.0 kg/d. Using these assumptions and back-calculations from the ARC tables the authors derived a multiple regression equation to estimate intake from LW and LWG. The intake predictions were then presented in tabular format with LW varying between 100 and 600 kg and LWGs varying from minus 0.5 to +1.0 kg/d. As the ARC energy requirement tables are based on animals in confinement, with a small allowance for activity (4.3 kJ/kg LW/d; i.e., 1.72 MJ/d for a 400 kg steer), the predictions from the M&M equations will also relate primarily to confined animals. It should also be noted that the ARC tables used in deriving the equation referred to steers of breeds of medium mature size and heifers of breeds of large mature size, thereby probably aligning well with the *B. indicus*-derived breeds but not with the larger European breeds.

3.4.5 General comments

A caveat needs to be placed on all of the results of these predictions of intake. For any combination of diet DMD (or M/D) and animal LW it is possible to estimate *ad libitum* intake by the animals. However, this does not mean that the predicted intake is attainable. There is a limit to the intake of DM that an animal can achieve which, for forage diets, is largely constrained by physical factors related to the retention time of digesta in the gastrointestinal tract of the animal. Intake predictions over and above this upper threshold are non-sensible. Some of the intakes presented in the attached figures will exceed this threshold and the figures should be considered with caution. However, as there are no clear-cut rules on this aspect a degree of subjectivity is required in assessing the results of these various simulations.

4 Results

4.1 ME requirements of steers predicted by ARC (as per the Nutrition EDGE tables)

The ME requirements currently presented in the Nutrition EDGE manual are from ARC (1980) and are based on steers of breeds of medium size, confined in pens but with a small allowance for activity (4.3 kJ/kg W.d; i.e., 1.72 MJ/d for a 400 kg steer). ME requirements in the EDGE manual are given for various combinations of LW, LWG and dietary M/D with some cells in the table left empty where the growth rate was considered to be unachievable at the given diet quality.

Table 1 shows the ARC-derived ME requirements (from the current manual) converted to DM intakes by dividing the ME intake value by the M/D of the diet and then expressing this as a percentage of LW. This was done to illustrate the magnitude of the DM intakes required to achieve stated ME intakes. Some of the DM intakes in Table 1 seem unrealistically high. Thus, within Table 1, an arbitrary assessment has been made of the achievable DM intakes (non-shaded cells) by steers for the particular LW and diet quality, at least for tropical forage diets.

Table 1. Intakes of DM (%W/d) required by steers of varying liveweight (LW) to achieve the necessary intakes of metabolisable energy (ME) tabulated in the existing Nutrition EDGE table[1]

ME of diet	LW	LW gain (kg/d)						
(MJ/kg DM)	(kg)	0	0.25	0.50	0.75	1.00	1.25	1.50
	100	3.8	5.0	7.0	—	—	—	—
5	200	3.1	3.8	5.3	—	—	—	—
(39.0% DMD)	300	2.7	3.5	4.6	—	—	—	—
	400	2.4	3.2	4.2	—	—	—	—
	500	2.3	2.9	4.3	—	—	—	—
	600	2.1	2.7	3.6	—	—	—	—
	100	2.6	3.3	4.4	6.1	—	—	—
7	200	2.1	2.6	3.4	4.4	—	—	—
(50.6% DMD)	300	1.8	2.3	2.9	3.8	—	—	—
	400	1.6	2.1	2.6	3.4	—	—	—
	500	1.5	1.9	2.4	3.2	—	—	—
	600	1.5	1.8	2.3	3.0	—	—	—
	100	1.9	2.4	3.0	3.9	5.2	—	—
9	200	1.5	1.9	2.3	2.9	3.7	—	—
62.3% DMD	300	1.3	1.6	2.0	2.5	3.1	—	—
	400	1.2	1.5	1.8	2.3	2.9	—	—
	500	1.1	1.4	1.7	2.1	2.6	—	—
	600	1.1	1.3	1.6	2.0	2.5	—	—
	100	1.5	1.8	2.3	2.8	3.5	4.5	6.0

ME of diet	LW	LW gain (kg/d)						
(MJ/kg DM)	(kg)	0	0.25	0.50	0.75	1.00	1.25	1.50
11	200	1.2	1.4	1.7	2.1	2.5	3.2	4.0
73.9% DMD	300	1.0	1.2	1.5	1.8	2.2	2.7	3.4
	400	1.0	1.1	1.4	1.7	2.0	2.5	3.1
	500	0.9	1.1	1.3	1.5	1.9	2.3	2.8
	600	0.8	1.0	1.2	1.4	1.7	2.1	2.7
	100	1.2	1.5	1.8	2.2	2.5	3.2	3.9
13	200	1.0	1.2	1.3	1.6	1.9	2.3	2.8
85.5% DMD	300	0.8	1.0	1.2	1.4	1.7	2.0	2.4
	400	0.8	0.9	1.1	1.3	1.5	1.8	2.1
	500	0.7	0.8	1.0	1.2	1.4	1.7	2.0
	600	0.7	0.8	0.9	1.1	1.3	1.6	1.9

[1] Intake was calculated as the ME requirements (MJ/d) divided by the energy density of the diet (M/D; MJ/kg DM). Shaded cells indicate (on subjective assessment) intakes which are probably unachievable for the specified steer liveweight and diet quality

For instance, it is well known that intakes (expressed on a LW basis) will increase as the quality of the diet increases but, for a given quality of diet, will generally decrease with increasing LW of the animal. From our own experience with steers in pens, light steers (ca. 200 kg) will eat about 1.6-2.0%W/d of a 50% DMD (6.9 MJ/kg DM) tropical grass hay whilst older steers (ca. 450 kg) will only eat about 1.3-1.6%W/d of the same hay. Most steers will only maintain weight at best on hay of this quality. The maximum intake by steers of a tropical forage will thus increase with the quality (M/D) of the diet but the absolute upper threshold is probably in the order of 2.5%W/d (maybe slightly higher for the young, very light steers) for a fresh, green, leafy new-season pasture (say, 65% DMD or 9.5 MJ/kg DM). The arbitrary assessment carried out in Table 1 takes into account both the LW of the steer and quality of the diet in determining the likely intake threshold for that situation, i.e., if the intake is likely to be achieved. A considerable proportion of the intakes shown in Table 1 is above these perceived thresholds (shaded cells) and their inclusion is therefore questioned.

Thus even the current Nutrition EDGE tables, based on ARC (1980), include ME requirement values well outside what are achievable and the table should be adjusted accordingly. For instance, steers given a diet of M/D = 5.0 MJ/kg DM (computes to 39.0% DMD) will not even come close to maintaining LW on this diet, so this section of the table should be deleted. The alternative would be to increase the range of growth rates to include LW loss. Diets of M/D=13 MJ/kg DM (about 85% DMD) will only relate to feedlot diets if at all and could also be omitted. The upper limit for energy density in the diet for tropical forages should be around 10 MJ/kg DM, and possibly at about 11 MJ/kg DM for temperate forages, so a reasonable range of diet quality would be from 7 to 11 MJ/kg DM if the current LWG range is retained.

4.2 ME requirements of steers predicted by QuikIntake

The ME requirements estimated using QI are tabulated in Appendix 1. Separate tables are given for *B. taurus* (i.e., Shorthorn) and *B. indicus* crossbred (75% *indicus*) steers, each with either nil activity (confined) or walking 7 km/d (as per the AE calculator). These requirements have been compared to those from ARC (1980) as currently included in the Nutrition EDGE manual, in the two figures shown below.

The caveat should be clearly placed on these tables that they define the requirements of animals to reach a certain target, not whether that target is attainable. Inability of the animal to consume sufficient DM places an upper threshold on the ME (or protein) intake.

Fig. 1 shows the ME requirements for steers of LW either (A) 200 or (B) 400 kg, for a range of growth rates (0-1.25 kg/d) when the diet quality was constant at 9 MJ/kg DM (ca. 62.2% DMD). The ME requirements estimated using QI are compared with those currently used in Nutrition EDGE (ARC values). In addition, the predicted intakes of ME from Minson and McDonald (1987) are plotted for comparison.

Several conclusions can be drawn from the data sets plotted in Fig. 1:

(i) Using the calculations of QI, *B. taurus* steers have a higher ME requirement to achieve a given LWG compared with their *B. indicus* crossbred counterparts. The difference between genotypes increases in absolute terms as LW of the steers increases (from *ca*. 4 MJ/d difference for 200 kg steers to 16 MJ/d for 600 kg steers, averaged over all diet qualities and growth rates), but the percentage difference was relatively constant across LWs with *B. taurus* steers having 20% greater ME requirement, on average across diet quality, for the same gain as *B. indicus* crossbred steers (data not shown in Fig. 1).

(ii) The ARC-predicted ME requirements are fairly similar to those predicted using QI for *B. indicus* steers (nil activity) over most of the LWG range, the biggest discrepancy occurring at the higher growth rates. The ARC-predicted ME requirements appear to rise at an increasing rate with growth rate of the steers whereas the QI trend for the same LWG range appears relatively linear (Fig. 1). One can only surmise that the ARC trends are in line with increasing energy requirements for fat deposition at higher growth rates. These patterns of difference between systems (ARC vs NRDR) were consistent for steers of LW 200, 400 and 600 (not shown) kg.

(iii) The inclusion of an ME allowance for walking increased the ME requirements by about 12 MJ/d, or 18%, on average across LWs, LWGs and diet qualities. The effect tended to be relatively constant in absolute terms (MJ/d) across growth rates (see Fig. 1) but, on a percentage basis, increased with the LW of the steers (*ca*. 10% at 200 kg to 23% at 600 kg).

(iv) The most concerning feature of Fig. 1 was that the predicted ME requirements for even modest growth rates of steers on this quality of diet (9 MJ/kg DM) required DM intakes beyond the apparent scope of the steers to achieve. This was the case with the EDGE (ARC) as well as the QI systems. In these figures the relationship between ME intake and DM intakes (from 1 to 3%W/d) are shown as horizontal dashed lines. Thus, according to QI calculations, 200 kg steers consuming a diet of 9 MJ/kg DM (62.2% DMD) would require the very high intakes of ME of 49 and 59 MJ/d, equivalent to 2.7 and 3.3%W/d of DM, for (confined) *B. indicus* crossbred and *B. taurus* steers, respectively, to achieve a growth rate of 0.75 kg/d, which should be easily achievable on this quality diet. The corresponding DM intakes for steers of the two genotypes walking 7 km/d are 3.1 and 3.7%W/d, respectively. The predicted intake of ME according to the M&M multiple regression equation (based on the ARC tables) are shown as crosses in Fig. 1 and indicate considerably lower ME and DM intakes (e.g., 2.5%W/d for 0.75 kg/d gain) compared to both the ARC and the QI predictions, at the higher growth rates.

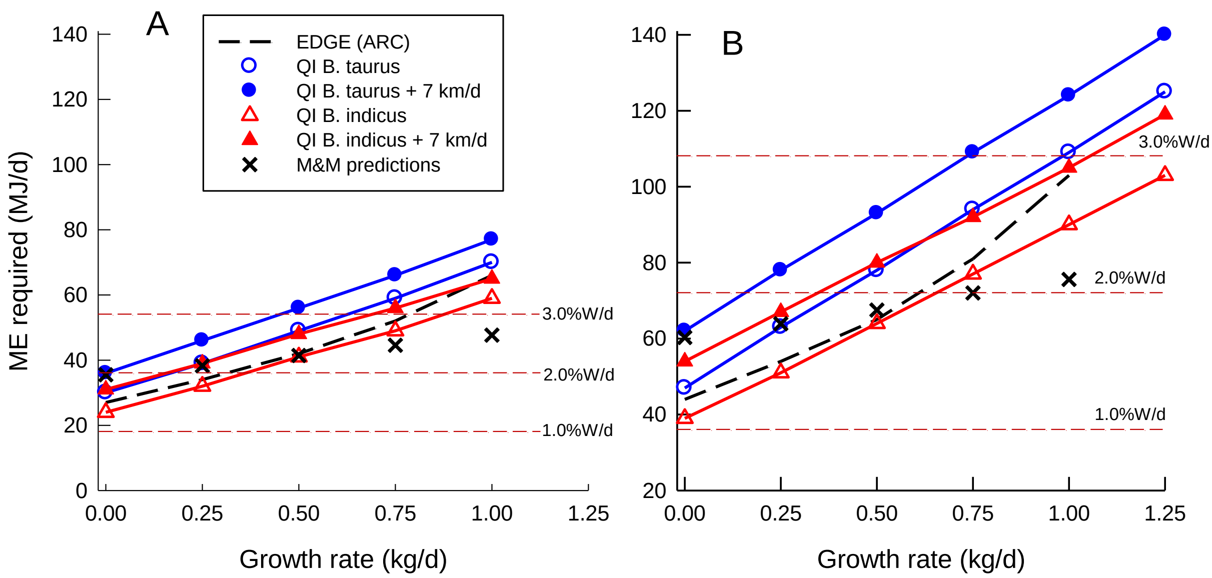

Fig. 1. The metabolisable energy (ME) requirements of *Bos taurus* and *B. indicus* crossbred steers of initial liveweight (A) 200 kg or (B) 400 kg, either in confinement (no activity; open symbols) or walking 7 km/d (filled symbols) and receiving a diet of energy density (M/D) 9 MJ/kg DM, to achieve various growth rates, as determined by the ARC (1980) and presented in the Nutrition EDGE manual (EDGE (ARC); dashed line), by the QuikIntake (QI) spreadsheet calculator using the Australian feeding standard equations (NRDR 2007; solid lines), and by the Minson and McDonald (1987) multiple regression equation (M&M predictions; crosses). Breed type is not specified in the EDGE (ARC) and M&M predictions and probably relates to *B. taurus* cattle. The horizontal dashed lines in each figure show the ME requirements corresponding to DM intakes of 1, 2 or 3%W/d.

It appears that changing from the ARC to the Australian feeding standards (QI) will lead to increases in the estimated requirements of steers for ME, at least for *B. taurus* steers, and that some of the calculated ME requirements correspond with DM intakes beyond the limits of the animals to achieve with the quality of the diet, although experience tells us that the growth rates would be achievable. The situation is exacerbated by the addition of a walking activity which naturally increases ME requirements. In the example shown in Fig. 1, steers consuming a diet of 9 MJ/kg DM (ca. 62% DMD) should be able to grow at 1 kg/d while consuming less than 3%W/d of DM but this is not what is indicated. The closest agreement between the EDGE and QI requirements were for *B. indicus* steers confined to nil activity; the main deviation between these models was at the high growth rate of 1 kg/d. This is surprising in that although the ARC tables relate to steers with minimal activity, they are known to be derived mainly from trials using *B. taurus* cattle.

4.3 Protein requirements of steers predicted by QuikIntake

The RDP and UDP requirements estimated using QI are tabulated in Appendix 2 for *B. taurus* and *B. indicus* crossbred steers, each with either nil activity (confined) or walking 7 km/d. These requirements have been compared to those from ARC (1980) as detailed in the Nutrition EDGE manual in Fig. 2 below.

Notes relating to Fig. 2.

(i) The protein requirement trends in Fig. 2 tend to closely mirror those of ME requirements shown in Fig. 1. This is understandable since, as previously stated, the endogenous faecal protein (EFP) component is a function of DM intake and thus also of ME intake. Furthermore, the equations used in calculating the protein content of gain are similar to those calculating the energy content of gain. Thus, as a large proportion of the total protein requirements is associated with the EFP and protein in gain, the CP and ME requirements will tend to increase in parallel as growth rate of the steers increases.

(ii) There is close agreement between the protein requirements determined using the ARC (based presumably on *B. taurus* cattle) and those of QI for *B. indicus* crossbred steers with nil activity, but those determined by QI for *B. taurus* steers are considerably higher (Fig. 2).

(iii) Adding an activity cost for walking (7 km/d) increased the RDP requirement of 400 kg steers by, on average over all diet qualities (7-13 MJ/kg DM), 113 g/d or 17% for *B. taurus* and by 139 g/d or 29% for *B. indicus* crossbred steers, respectively.

(iv) The QI tables of protein requirements suggest a higher need for UDP than the corresponding ARC (EDGE) tables. In the latter only lightweight steers of 100-200 kg had any requirement for UDP; the main part of protein requirements came from RDP. By contrast, the QI calculations suggest that UDP is also required by heavier steers at times, especially for higher growth rates. This is probably related to the fact that, in the current exercise, the total protein requirements were divided into needs for RDP and UDP by first estimating RDP requirements on the basis of what is required for MCP production relative to the fermentable energy available, i.e., 130 g RDP/kg DOM (with allowances for utilisation efficiency), and then allocating the remainder to UDP. This efficiency of MCP production is at the lower end of the feeding standards recommendations (130-170 g MCP/kg DOM) and so may underestimate RDP, and consequently overestimate UDP, requirements. Having said this, the efficiencies of use of RDP on tropical pastures in practice can often be as low as 60 g MCP/kg DOM, so the requirements for UDP may be even higher than indicated in the tables on these pasture types when low in quality. The tables only provide an indication and using 130 g RDP/kg DOM is a good starting point for tropical forages.

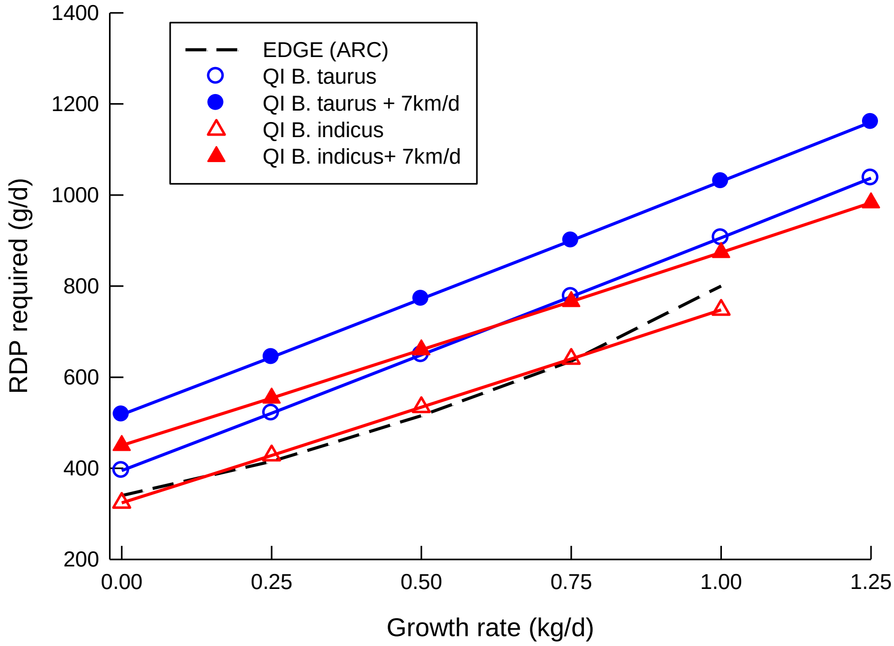

Fig. 2. The rumen degradable protein (RDP) requirements of 400 kg *Bos taurus* and *B. indicus* crossbred steers either in confinement (no activity; open symbols) or walking 7 km/d (filled symbols) and receiving a diet of energy density (M/D) 9 MJ/kg DM, to achieve various growth rates, as determined by the ARC (1980) and presented in the Nutrition EDGE manual (EDGE (ARC); dashed line) or by the QuikIntake (QI) spreadsheet calculator using the Australian feeding standard equations (NRDR 2007; solid lines). Breed type is not specified in the EDGE (ARC) table but probably relates to *B. taurus* cattle.

Fig. 3 shows the RDP and UDP requirements of 200 kg steer of the different genotypes, with and without activity.

Notes relating to Fig. 3

(i) As discussed above the requirements for RDP, and for protein in total, are greater for *B. taurus* steers than for their *B. indicus* counterparts. The additional protein requirements for walking activity are also shown in this figure.

(ii) At maintenance the steers could meet all of their protein requirements from RDP alone.

(iii) As growth rates increased there was an increasing need for UDP as well as RDP to meet requirements.

(iv) The requirements for UDP tended to be lower for the steers walking 7 km/d relative to their ‘inactive’ counterparts. This was probably related to the predicted higher ME intake by the walking steers and thus the higher RDP requirements and by corollary, lower UDP requirements.

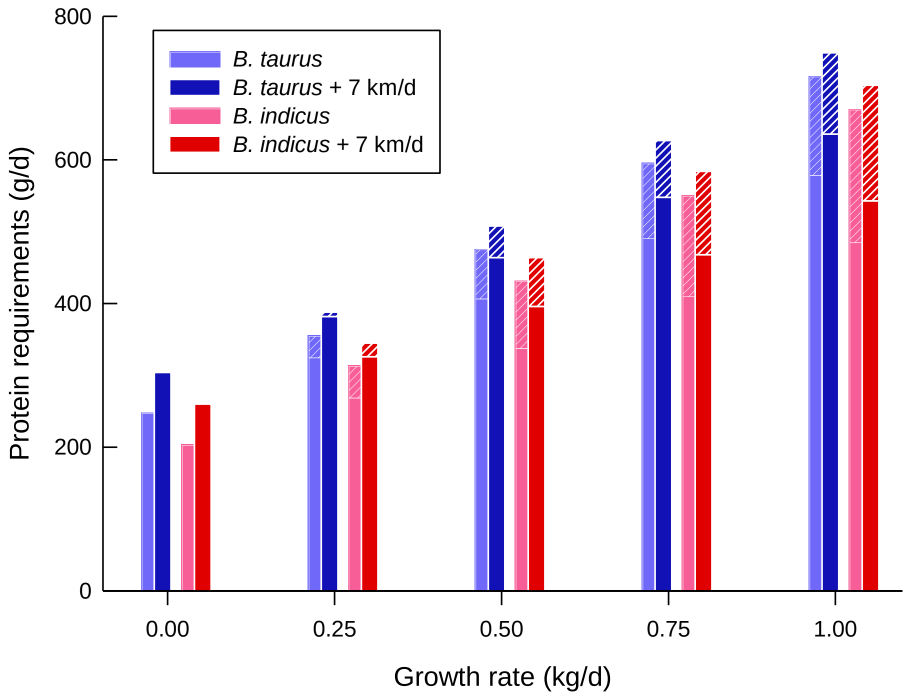

Fig. 3. The rumen degradable protein (RDP; solid bars) and undegraded dietary protein (UDP; hatched bars) requirements of 200 kg *Bos taurus* and *B. indicus* crossbred steers either in confinement (no activity) or walking 7 km/d and receiving a diet of energy density (M/D) 9 MJ/kg DM, to achieve various growth rates, as determined by the QuikIntake (QI) spreadsheet calculator using the Australian feeding standard equations (NRDR 2007).

4.4 ME and protein requirements of heifers, cows and bulls predicted by QuikIntake

The revised ME requirements of heifers and cows predicted by QI are tabulated in Appendix 3. These estimates for ME requirements of dry cows are reasonably similar to those from the current Nutrition EDGE manual but the protein requirements for these animals tend to be somewhat lower. The general similarity between current and revised ME requirements is surprising in that the EDGE tables probably relate to *B. taurus* cattle with minimal activity whilst those predicted using QI are for *B. indicus* crossbred cattle walking 7 km/d. Perhaps the lower requirements of *B. indicus* cattle are compensated for by their activity allowance. However, with the lactating cows the ME and protein requirements estimated using the Australian feeding standards (QI) tend to be considerably higher than those currently presented in EDGE. This probably reflects the different assumptions made with the two systems as well as the fact that two different systems have been used to arrive at the values (ARC and NRDR). The assumptions about the animals and their production have not been detailed for the current Nutrition EDGE table so differences might be a result of higher milk production estimates or higher growth rates assumed for 4 month old calves. With the lactating cattle, QI predicts a need for both RDP and UDP whereas there is no distinction given in the current EDGE table. As alluded to earlier this is probably related to the fact that, using the NRDR (2007) system, there is insufficient energy intake to utilise the RDP and the shortfall needs to be made up with UDP. Regardless, the revised table illustrate the much higher requirements for energy and protein of lactating compared with dry cows. The revised ME requirements for bulls are about 10-20% higher than for the current EDGE table but the latter give no indication of the quality of the diet, so an informed comparison is difficult. The revised protein requirements are also slightly higher.

4.5 Estimation of intake from the digestibility of the diet

For all predictions using all methods, intake (as %W/d) decreased progressively with increasing LW at any diet DMD value. This is consistent with observations that under practical feeding conditions older, heavier cattle eat less, on a LW basis, than their younger, lighter counterparts.

4.5.1 Predictions from the feeding standards (NRDR 2007) – using the potential intake and relative ingestibility of the diet

The results of the simulations based on the feeding standards are presented in Fig. 4. There is close agreement between the current EDGE intake predictions and those based on the NRDR (2007) where the steers are assumed to have a SRW of 660 kg and the forage base is a C3 (temperate) species (Fig. 4A). However, changing the forage type from a C3 to a C4 (tropical) resulted in marked increases in the prediction of voluntary intake at any DMD to the extent that a 200 kg steer is predicted to consume nearly 3%W/d of a 50% DMD diet. This arises due to assumption in the NRDR calculations that intake is higher for C4 compared to C3 plants at any DMD, leading to corresponding higher values for relative ingestibility for C4 plants. As the potential intake does not differ for the two forage types, this being largely related to the LW of the animal and its SRW, the intake predictions (product of potential intake and relative ingestibility, or DMD) are also higher for C4 compared with C3 forage types.

Reducing the SRW of the steers from 660 to 550 kg, where a common forage type (C3) is consumed, results in considerable reductions in the predicted intake at any DMD value (Fig. 4B). The effect apparently increases with increasing LW of the steers. In this case the potential intake is reduced as SRW declines but there is no change in the relative ingestibility at any given value for DMD. This figure shows the importance of correctly defining the SRW of the cattle involved. It also shows that when using this approach for intake prediction there is no single relationship between DMD and intake that applies across cattle types and environments.

As discussed earlier, predicted intake (as a proportion of LW) declined in each case with increasing LW of the steers.

4.5.2 Predictions using QuikIntake – back-calculation from LW change

The results of the simulations based on the QI calculator are presented in Fig. 5. QuikIntake uses the equations from the NRDR (2007) updated according to the most recent version of the web-based GrazFeed technical manual (current version: Freer *et al*. 2012). These predictions are based on back-calculation from LWG using the diet DMD to define the energy content of the diet. They do not use a potential and relative intake approach described above (see Fig. 4). Assumed values for LWG of the steers are aligned with the DMD of the diet, as described earlier.

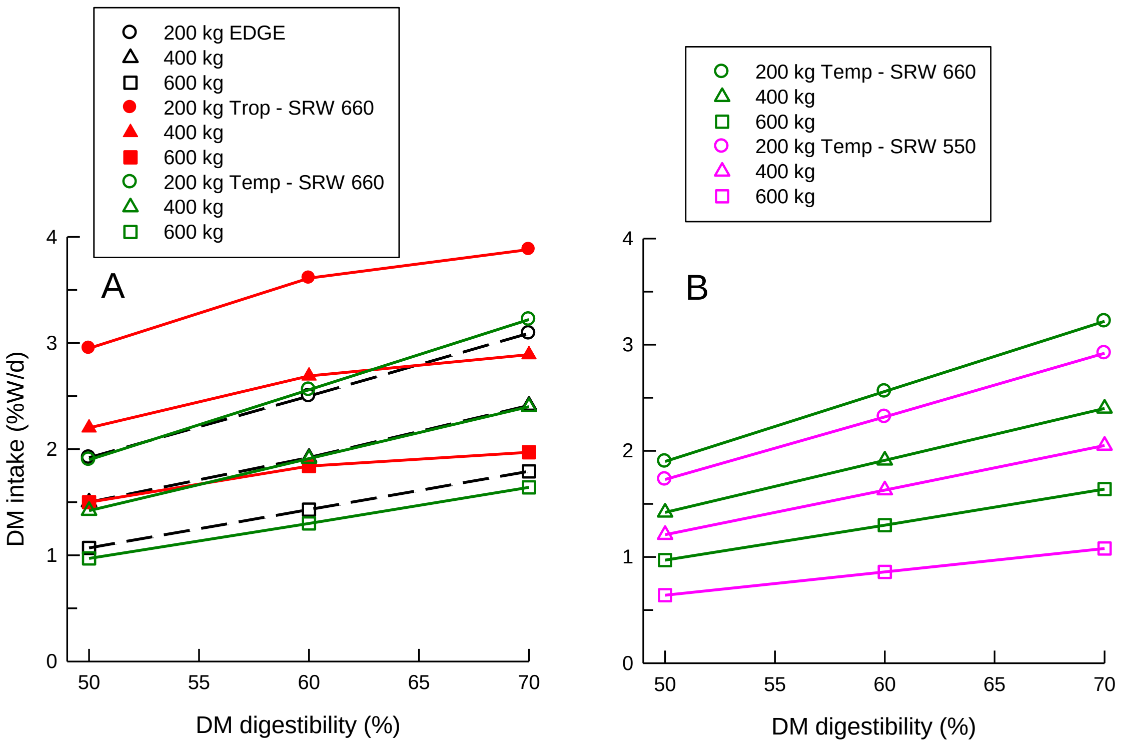

Fig. 4. Relationship between DM digestibility and DM intake for steers of various liveweights (200–600 kg) according to the predictions of the Australian feeding standards (NRDR 2007), compared with those included in the Nutrition EDGE manual (dashed lines in graph A). (Fig. 4A: intake predictions for steers with a standard reference weight (SRW) of 660 kg and where the forage (nil legume) is either a C4 (Trop; red lines) or C3 (Temp; dark green lines) type; and Fig. 4B: intake predictions for steers on a C3 forage and having a SRW of either 660 (dark green lines) or 550 kg (pink lines)).

Assuming a SRW of 660 kg (consistent with that used for this breed of steer in the AE calculator) and that the steers are confined (no grazing), the predicted intakes using QI are similar to those currently in the EDGE manual at low DMD values, especially for steers between 200 and 400 kg, but deviate at the higher DMD of 70% (Fig. 5A). Unlike the current EDGE values, where there is a near-linear relationship between intake and DMD across the full range of DMD, the intake response predicted by QI tends to level out as DMD increases in response to the higher M/D of the diet and thus lower intake required to provide the necessary ME for growth. For example, with the 400 kg steer, at 50% DMD the predicted total MEI is 41.9 MJ/d on a diet of M/D 6.9 MJ/kg DM; at 70% DMD, MEI is 82.6 MJ/d on a diet of M/D 10.3 MJ/kg DM. Thus the predicted DM intakes (MEI divided by M/D) are 6.1 kg/d and 8.0 kg/d, respectively, not as large as difference in MEI alone might suggest.

Adding an activity component in the form of walking 7 km/d markedly increases the energy requirements of the animal and thus the predicted DM intakes. The effect is greatest at low DMD (and thus low LWG) as the energy cost of walking is (approximately) a constant in absolute terms (MJ/d) but represents a bigger proportion of total ME requirements at low compared with high LWG (and thus also DMD). The walking component is consistent here with that used in the new calculation of adult equivalents (McLean and Blakeley 2014).

There is very little effect of reducing the SRW of confined steers from 660 to 550 kg when QI is used to estimate ME requirements and intake (Fig. 5B), in contrast with the NRDR method used above (see Fig. 4 for comparison).

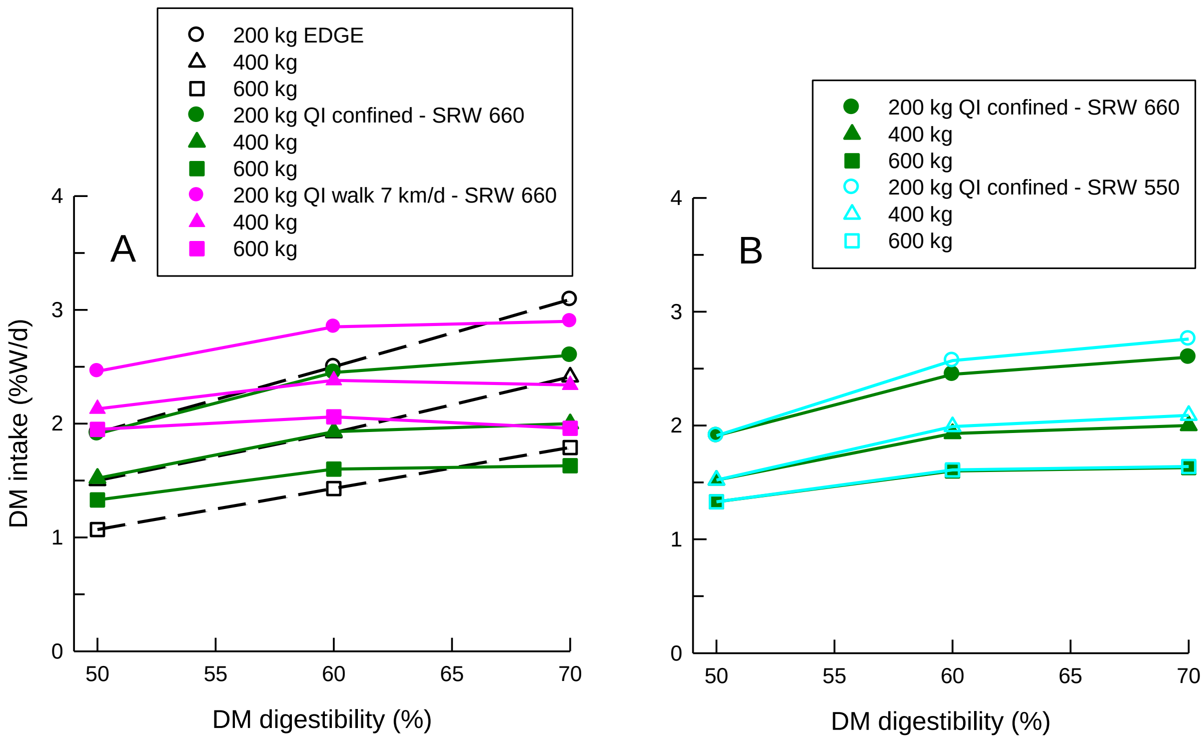

Fig. 5. Relationship between DM digestibility and DM intake for steers of various liveweights (200–600 kg) according to the predictions of the QuikIntake spreadsheet calculator (QI), compared with those included in the Nutrition EDGE manual (dashed lines in graph A). (Fig. 5A: intake predictions for steers with a standard reference weight (SRW) of 660 kg and where the steer is either confined (dark green lines) or is walking 7 km/d (pink lines); and (Fig. 5B: intake predictions for steers confined and having a SRW of either 660 (dark green lines) or 550 kg (light blue lines)).

4.5.3 Predictions using Minson & McDonald (1987) equation (M&M)

The results of the simulations based on the M&M equation are presented in Fig. 6. The multiple regression equation of M&M delivered near-linear prediction responses for intake (the slope increased slightly with increasing DMD) which indicated overall a more gradual increase in intake as DMD increased than shown by the current EDGE figures (Fig. 6A). For instance, when the DMD was 70% the EDGE curve indicated an intake of 3.1%W/d compared to about 2.7%W/d for the M&M predictions.

Fig. 6B shows a comparison between the M&M predictions of intake and those from the QI analysis for steers with nil activity allowance. There is relatively close agreement across LWs for the intake predictions of M&M and those of QI for confined steers, the main difference being that the latter are more curved than the former. It should be remembered that the M&M equation was derived from the ARC tables which made only a small allowance for activity and certainly not the equivalent of an animal walking 7 km/d. As shown in Fig. 5B, adding a walking component to the QI predictions considerably increases the intake predictions. For instance, for a 200 kg steer the addition of walking activity increases the maintenance energy requirements by 29-24% and the total ME requirements by 29-12% for diets progressively increasing in DMD from 50 to 70%, respectively (data not shown in figures). This considerably increases the intake predictions; for example, the QI-predicted intakes for a 200 kg steer walking 7 km/d were 2.45%W/d at 50% DMD and 2.9%W/d at

70% DMD, whereas the comparable predicted intakes for confined steers were 1.91 and 2.60%W/d, respectively.

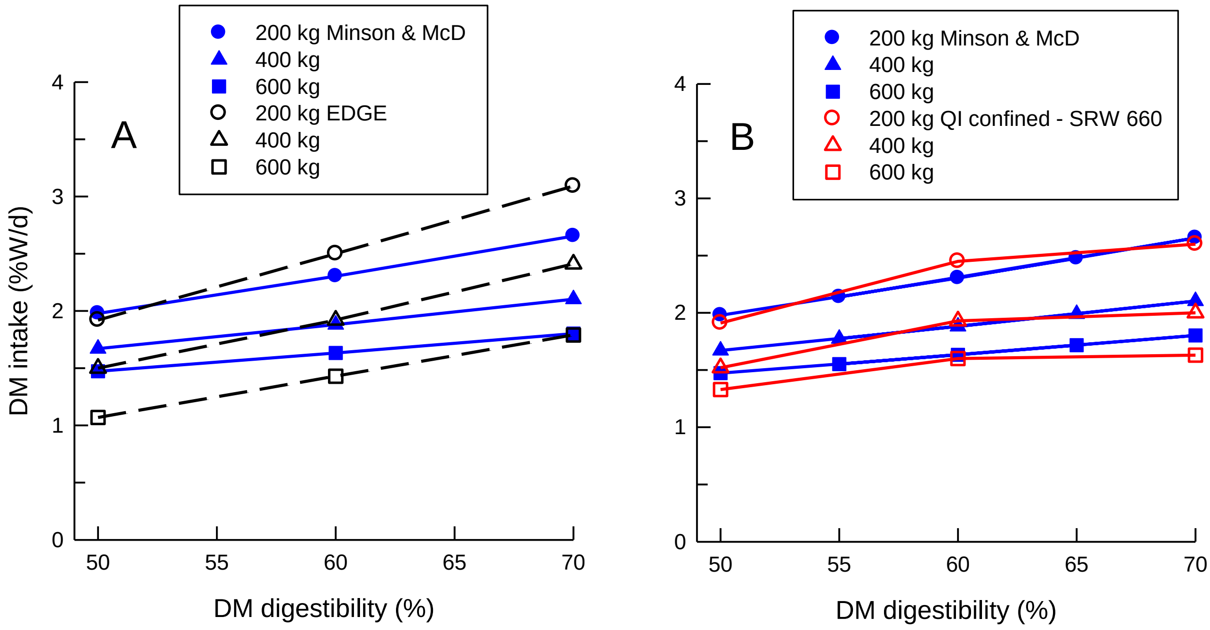

Fig. 6. Relationship between DM digestibility and DM intake for steers of various liveweights (200–600 kg) according to the predictions of the Minson and McDonald (Minson & McD; 1987) equation and of the QuikIntake spreadsheet calculator (QI), compared with those included in the Nutrition EDGE manual (dashed lines; graph A). (Fig. 6A: intake predictions for steers according to the Minson and McDonald equation (blue lines); and Fig. 6B: intake predictions using QuikIntake for steers (SRW 660 kg) confined (no walking; red lines) compared with the predictions of Minson and McDonald (blue lines)).

5 Discussion

5.1 Revised estimates of energy and protein requirements

As alluded to earlier, the first question that needs to be answered is: **who will be the end-user** of these newly-derived tables and **for what will they be used**? If the answer is that they will be used mainly to demonstrate to cattle producers the key principles of energy and protein requirements and how they change with the quality of the diet (M/D), the LW of the animal and its productivity either for growth or pregnancy/lactation, then providing tables based on the Australian feeding standards instead of the UK system (ARC 1980) will not provide any real advancement. The key principles are the same for both systems; they only differ quantitatively and the existing tables would suffice. If this is the main purpose of providing these requirement tables then the recommendation is to include only one set of the newly-derived tables - those relating to *B. indicus* crossbreds walking 7 km/d. They encompass the key principles relating to energy and protein use and requirements.

If, on the other hand and as seems the case to some extent, the tables are also being used by beef extension (Future Beef) personnel to make judgements on the adequacy of an existing production scenario to meet particular production targets, or to determine the amount of additional nutritional inputs required to meet those targets, then the goal should be to provide the most accurate information available. **It makes sense that the**

information provided in the current Nutrition EDGE tables, which are derived from the UK ARC (1980) system developed empirically using data from experiments based on mainly *B. taurus* cattle and temperate diets fed in pens, should be replaced by that based on the Australian feeding standards (NRDR 2007) which can accommodate the types of animals and forages commonly encountered in northern Australia. This would also be consistent with current changes to the estimation of AEs which also uses the NRDR (2007) system. Such a change though clearly raises two issues.

Firstly, the *revised tables based on QI calculations, and thus on the local feeding standards, have higher predictions of requirements in most cases for both ME and protein than those currently reported in the ARC-derived tables in Nutrition EDGE*. When the ME requirements are translated into DM intake requirements, some of the required intakes are well beyond what the animal would be expected to attain for a diet of that quality yet the growth rate is known to be achievable under the same conditions. This suggests that the Australian feeding standards are tending to regularly over-predict both ME and DM intake requirements. Some support for this contention has been provided in previous research (McLennan 2005 (Project NBP.331 Final Report); McLennan 2013 (Project B.NBP.0391 Final Report)). The answers to this dilemma are currently not available. It should be noted that even the ARC tables are at times associated with ME requirements which require DM intakes outside the capacity of grazing cattle. It is somewhat ironic that in the current exercise the best agreement between the ARC requirements and those of the NRDR system were when the latter used *B. indicus* crossbred steers with no activity allowance yet the ARC tables would undoubtedly be derived from experiments using temperate breeds of cattle (with minimal activity allowance) and temperate diets. Nevertheless, changing the tables to those predicted using NRDR (2007) will lead to some frustration by users when the required DM intakes are calculated and seen to be excessive even though the production rates are achievable. Adding an activity allowance for 7 km/d walking will exacerbate this situation by further increasing DM intake requirements. The user needs to apply some judgement on whether an intake or production target is attainable when using these tables.

It is understood here that if the ME requirements are slightly exaggerated by NRDR (2007) so too will be the protein requirements as these are closely aligned.

If the tabular format for representing requirements is to be used, then a decision is required on whether to include the walking activity allowance or not. As indicated above, including it increases ME and protein requirements and the DM intake required to achieve those requirements. The current calculations indicated that the activity cost was, on average, about an 18% increase in ME requirement but this increased with LW of the steers (10-23% for 200-600 kg steers). If activity is not included in the tables allowance could be made to increase ME requirements by suggesting the user add an increment of between 10 and 20% over the range of 200 to 600 kg LW, on a sliding scale. The effects on RDP and UDP are less predictable though and it would be more problematical to add a proportional activity allowance.

The second main issue, and one that has been touched on above, is that to cover all combinations of breed, sex, variable SRW, pregnancy and lactation status, activity levels, etc., would require a multitude of tables far beyond the scope of the Nutrition EDGE manual. This is the reason the NRDR (2007) booklet does not include tables; instead the equations are encapsulated in the software package ‘GrazFeed’. This allows the user to input the key information on an animal and production situation for a specific answer. It has been found though that there are problems with using GrazFeed with tropical cattle and tropical grazing systems, and some of these relate to the method of estimating diet quality and the reliance on a relationship between intake and DMD.

The alternative is to use a spreadsheet approach such as QI or the web-based spreadsheets associated with the GrazFeed site, viz. 'ME_required' and 'CP_required'. Their advantage is that they allow the user to work backwards from 'known' animal performance to calculate requirements without the need to predict diet quality other than a faecal NIRS assessment of DMD. **Extension personnel would be much better served by using this approach than relying on tables covering a small number of situations. This is a recommendation from the current study**. The caveat is that QI is a servant of the NRDR (2007) system and will provide some variable over-estimate of requirements. This can only be remedied with an overhaul of the current feeding standards, at least for tropical feeding systems.

It is also recommended that some sections of the tables are deleted, viz. those that involve unattainable growth rates or intakes for the quality of the diet (M/D) and/or the production level for the LW of the animal. Inclusion of these sections provides a false expectation that the intakes can be attained. The sections for diet M/D of 5-6 MJ/kg DM, where even LW maintenance is not feasible, and for M/D>12 MJ/kg DM, which is unlikely to be attained even in feedlots, should be omitted.

The current Nutrition EDGE table showing ME and protein requirements of heifers, cows and bulls seems rather *ad hoc*, relating to seemingly random, limited groups of cattle in various stages of pregnancy and lactation and with varying growth rates. The derivation of these tables is unknown but appear to be provided to show generally the effects of different physiological states on ME and protein requirements. **Replacement of the current table with that revised using the NRDR (2007) system is recommended. For cattle advisors, the use of a more embracing spreadsheet application is again recommended**.

No changes have been made to the calcium and phosphorus requirements previously set out in Nutrition EDGE as their review was not within the scope of the project.

5.2 Relationship between intake and digestibility

Researchers have for many decades investigated the possibility of a relationship between intake and a single descriptor of feed quality, such as DMD, without success. The general consensus is that intake is a function of multiple factors defining feed quality. Thus there is, unfortunately, no universal, biologically-sound relationship between DMD and intake that applies across all animal types, pasture types and general grazing situations. There is a general relationship between intake and DMD consistent with the principle that a key determinant of voluntary intake is the rate of passage of feed matter through the alimentary tract, and digestibility of plant material especially in the rumen is a key determinant of passage rate. Thus there will be a general relationship between intake and DMD. Previous research has shown that the relationship varies quite markedly with the plant type, for instance the genus or even species of plants of the same genus. In particular the relationship appears to differ considerably between C3 and C4 plant types such that, at the same DMD, the intake is usually considerably greater with C4 compared with C3 plants. This fact is acknowledged in the use of separate linear relationships for C3 and C4 plants in GrazFeed predictions. However, at my most recent meeting with Dr Mike Freer, a key contributor and editor of the Australian NRDR (1987) feeding standards and its software companion, GrazFeed, he suggested that perhaps a single relationship could be used for both plant types.

All methods of prediction of intake show a progressive decline in intake prediction (%W/d) with the LW of the animal, for any given DMD value. This is consistent with observations in practice.

The various methods of prediction of intake explored here have delivered intake/DMD relationships of different shapes. None are linear although the existing EDGE manual curve and the M&M curve approach linearity. In the latter case this is partly predicated by their assumption that LWG is linearly related to DMD, and in their equation LWG is one variable determining intake for animals of any given LW. By contrast, the relationships derived using QI show a definite trend for intake to plateau or even decline as DMD increases. Several factors contribute to this finding. The first is that in order to use QI for these simulations it was necessary to assume a LWG and in this case the linear relationship between DMD and LWG proposed by M&M was used, whereby 50% DMD = 0.0, 60% = 0.5 and 70% DMD = 1.0 kg/d LWG. The veracity of this relationship can be challenged but the general concept is sound. Thus as DMD increases so too does LWG and as a result the total MEI predicted by QI will also increase. This total MEI is the sum of the ME required for maintenance, which is relatively constant for confined animals of a set LW across a range of DMDs and growth rates (note that LWG is increased proportionately with DMD), and that required for gain which is the main variable. Furthermore, as DMD increases so too does M/D of the diet. As LWG increases the energy for growth increases in rough proportion but as MEm is relatively constant at any LW, the total MEI does not increase in direct proportion to LWG. Thus increases in intake are the consequence of this variable MEI divided by the increasing M/D of the diet, so that intake also does not increase in direct proportion with LWG and DMD.

Adding an energy cost for activity, in this case walking 7 km/d on level ground (in keeping with the AE calculator), markedly increases the maintenance requirements of the animal (walking and grazing activity is added to the maintenance component) and thus the predicted intake at any DMD value. The walking component (7 km/d) added, on average across DMDs, 26, 37 and 43% to the ME for maintenance or 19, 27 and 32% to the ME required overall (maintenance plus ME for growth) for 200, 400 and 600 kg steers, respectively. In the 'ME_required' spreadsheet produced in association with the GrazFeed model, Freer suggests adding about 15% to the maintenance requirements for walking activity of a grazing animal, although this can be changed in the spreadsheet. Using the 7 km/d standard in the present exercise, and the equations from the feeding standards to calculate the ME required for this activity, the predicted DM intake is increased by 19, 27 and 32% for 200, 400 and 600 kg steers across DMD values, respectively, or an average of 0.45%W/d across LWs and DMDs. The effect is greatest at low DMD. These intake increases seem too high relative to practical experience and a lower increase could be used but this would not be consistent with the 7 km/d cost included in the AE calculator (McLean and Blakeley 2014).

With the NRDR predictions, the relationship between DMD and intake approaches linearity for a C3 plant type but with C4 plants there is a definite levelling out of intake as DMD increases beyond 60%. This seems related to the fact that relative ingestibility increases proportionately with DMD for C3 plants but reaches plateau (relative ingestibility = 1.0) when the DMD is about 64% for C4 plants; potential intake is constant when LW is fixed.

The intake predictions based on the C4 relationship between DMD and relative ingestibility are extremely high, with intakes of nearly 3%W/d for a 200 kg steer consuming a diet of 50% DMD (and presumably just maintaining LW). At the other extreme the predicted intake for this steer when the DMD is 70% is 3.9%W/d. The corresponding intakes for a C3 pasture are 1.9 and 3.2%W/d, respectively, which seem much more reasonable although still higher than expected. This finding would explain the gross over-prediction of intake, or under-prediction of LWG from known intake, when the GrazFeed model is applied to tropical grazing situations. If this method is to be used to predict intakes from DMD it seems necessary to use the C3 relationships even for C4 pastures.

Intake prediction using this method is very sensitive to the SRW of the animals, which impacts on potential intake, so it is important that careful consideration is given to this factor. This also shows that using a single response curve for DMD/intake across breeds and environments is an oversimplification if this method is to be applied.

The predictions of intake using the M&M method employ a relatively simplistic approach, as has been described above, and relies on energy requirements tabulated in the ARC (1980) feeding standards from the UK. In practice the M&M method has been found to give meaningful estimates of intake despite the fact that, being linked to the UK system, they are based empirically on (i) mainly *B. taurus* cattle given temperate diets; (ii) confined animals with a small energy allowance for activity (4.3 kJ/kg W.d; or 0.86, 1.72 and 2.58 MJ/d for 200, 400 and 600 kg steers, respectively); and (iii) one type of animal, i.e., bullocks of breeds of medium mature size and heifers of breeds of large mature size. The generated curves have more gradual slope than the existing EDGE curves and thus seem more consistent with practical findings.

Considering Figure 30 in the current Nutrition EDGE manual, if the above methods were used to reproduce this figure using changes in DMD only, i.e., keeping cow LWG and milk production constant, then intake would decrease with increasing DMD as less pasture would be required at higher DMD to meet the energy demands for a specified level of production. In real life increases in DMD would be accompanied by increases in LW and milk production and accordingly, intake would increase to meet these higher demands for ME as DMD increased.

Data from the Growth Path Optimisation project (B.NBP.0391; McLennan 2013) pen feeding studies have been included in Fig. 7 for comparison with the prediction curves derived using the NRDR, QI (confined animals) and the M&M equation, as well as the existing Nutrition EDGE curves, for 200 kg *B. indicus* crossbred steers with a SRW of 660 kg (see simulations above). In the case of QI and M&M, it was assumed that the steers lost 0.75 kg/d when the DMD was 40%. This observed data is for *B. indicus* crossbred steers, 8-12 months of age and of average LW 228 kg, fed a range of forage types (C3 and C4) *ad libitum* in pens (confined – no walking). The DMD ranged from 40.0-65.1% (average 54.1%) and intakes ranged from 0.95-2.44%W/d (average 1.59%W/d). Fig. 7 shows that the observed intakes were generally lower than the various predictions, i.e., most methods of prediction tended to over-estimate intake. The M&M predictions were parallel to the observed but displaced by about 0.45%W/d, the same amount allocated to walking 7 km/d (see above).

In summary, some of the prediction methods indicate an almost linear relationship between intake and DMD but there is logic in a bent-stick relationship whereby intake flattens out as DMD increases. This is due to the fact that the other variable changing with increasing DMD (and thus M/D) is LWG which is a function of the amount of energy consumed over and above that required for maintenance of the animal (almost constant for a set LW). QI predicts such a broken-stick model. None of the prediction methods closely agreed with the intakes observed for steers in pens; all over-estimated intake over the main part of the range. Thus it could be argued that no method appears a major improvement on the prediction curves already reported in the Nutrition EDGE manual. The predictions of M&M appeared to provide a more gradual slope than the existing EDGE relationship, with lower intakes at the upper end of the range, and one that was approximately parallel (similar slope) to that of the 'observed' relationship but displaced (over-estimated) by about 0.45%W/d.

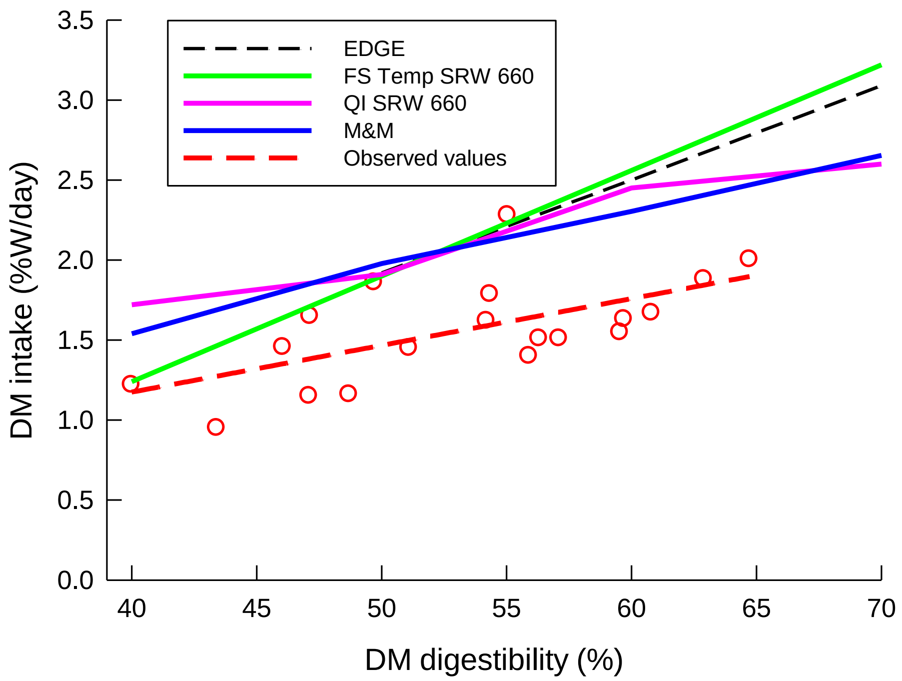

Fig. 7. Relationship between DM digestibility and DM intake for steers of ~200 kg according to the predictions of (i) the Australian feeding standards (NRDR 2007) where the standard reference weight (SRW) is 660 kg and the diet is a C3 forage, (ii) the QuikIntake (QI) spreadsheet calculator using a SRW of 660 kg for confined animals, and (iii) the Minson and McDonald (1987; M&M) equation, compared with that included in the Nutrition EDGE manual and that based on observed data from pen feeding studies using steers confined in pens (details in the text). Data points indicate group averages for steers on a range of C3 and C4 forage diets.

Recommendation for presentation of intake-digestibility relationship

The M&M curves are suggested as the best compromise for replacing the existing EDGE relationship for steers (Figure 29 in current manual) (see Fig. 8), based on (i) their simplicity of application, (ii) their more gradual increase in intake relative to DMD, delivering lower values at high DMD which are more consistent with expectations from tropical pastures, and (iii) their parallel alignment with the observed validation relationship. As the M&M line is displaced from the validation line by approximately the same intake value (0.45 %W/d) as was determined above to be the energy cost of walking 7 km/d, no further adjustment is suggested. Thus the M&M relationships are presented for steers of different LWs with moderate grazing activity. These relationships between DMD and intake demonstrate the key principles of (i) intake increasing with DMD, and (ii) intake decreasing with LW at any given DMD value, and are thus suitable for use in the EDGE manual for 'educating' producers. They will fall short of being an accurate predictive tool for field workers but it is naïve to envisage a single relationship to encapsulate all of the permutations of breed, SRW, forage type etc., as discussed previously. Furthermore, some assumptions have had to be made on the effects of DMD on animal production, i.e., LWG, which is not a constant across the range of DMDs. As also cautioned, care should be taken in using the relationships where intakes fall beyond expected limits.

Figure 30 in the Nutrition EDGE manual shows the corresponding relationships between intake and DMD for cows at different stages after calving. This figure is impossible to reproduce without information about the cows including their breed, age, LW, LW change, level of milk production, etc. If LW of the cow and milk production was kept constant (LW maintenance) intake would decline with increasing DMD as less pasture would be required at higher DMD (higher M/D) to meet the ME demands for this level of production. However, under practical feeding situations the production of the cow would increase with increasing DMD and thus intake would also be expected to increase, as the current figure indicates. Because the parameters of production have not been provided it is recommended that there are **no changes to Figure 30 in the current manual as it currently demonstrates the key principles of higher energy demands for higher production.**

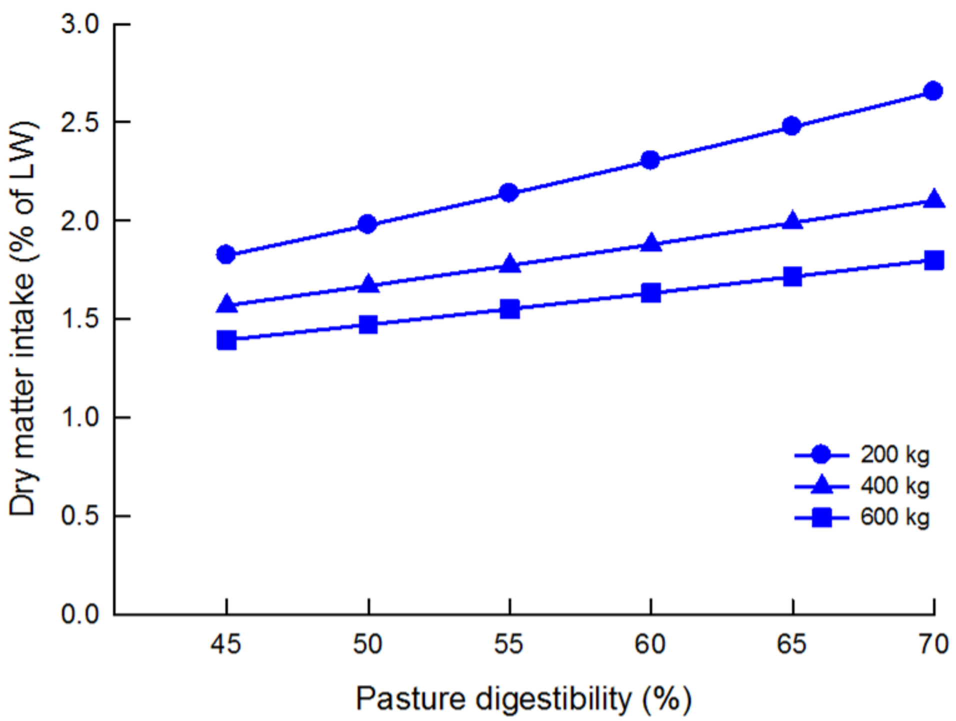

Fig. 8. Predicted dry matter intakes of forage by 200, 400 and 600 kg steers across a range of pasture digestibilities (theoretical relationships, adapted from Minson and McDonald 1987).

6 Success in achieving objectives

Objective 1: Revise the current tables for beef cattle in the Nutrition EDGE manual outlining the metabolisable energy (ME) and crude protein (CP) requirements of grazing cattle, using the Australian feeding standards (Nutrient requirements of Domesticated Ruminants; NRDR 2007) to estimate requirements.

- The tables have been fully revised based on the Australian feeding standards and utilising the ‘QuikIntake’ spreadsheet calculator.
- For demonstrating to cattle producers the key principles of energy and protein requirements and how they change with the quality of the diet (M/D), the LW of the animal and its productivity either for growth or pregnancy/lactation, then the EDGE manual should incorporate those revised tables relating to *B. indicus* crossbreds walking 7 km/d. These encompass the key principles relating to energy and protein use and requirements.

Objective 2: Review and revise the relationships between diet digestibility and the intake of tropical grass forages (non-legume) by steers (*B. indicus* crossbred) of varying liveweights and by mature lactating *B. indicus* cows at various times after calving, as are currently included in the Nutrition EDGE manual.

- Several approaches to deriving the relationship between intake and digestibility were explored (including the Australian feeding standards as incorporated into ‘GrazFeed’, the ‘QuikIntake’ spreadsheet calculator, and the Minson and McDonald (1987) prediction equation.
- As expected, there was a general relationship between intake and digestibility but there is no universal, biologically-sound relationship between DMD and intake that applies across all animal types, pasture types and general grazing situations.
- The Minson and McDonald prediction curves were recommended as the best option for replacing the existing EDGE manual relationships (the derivation of which is uncertain), based on (i) their simplicity of application, (ii) their more gradual increase in intake relative to DMD, delivering lower values at high DMD which are more consistent with expectations from tropical pastures, and (iii) their parallel alignment with the observed validation relationship.
- As the key parameters relating to the description and levels of production of the *B. indicus* cow are not provided it was not possible to revise the current relationships shown in the Nutrition EDGE manual, so the current figure should be retained as it demonstrates the key principles of increasing intake with increasing DMD and the increasing nutrient requirements with increasing time after calving.

Objective 3: Provide a brief report on the implications of the changes to the requirements tables. The current requirements are to be plotted against revised requirements for cattle, both confined and grazing (walking 7 km/d). This would highlight the scope of the changes and the implications for their use in the EDGE workshops and by extension staff in general.

- The scope of the recommended changes to the Nutrition EDGE manual, the implications of such, and the limitations of all systems for estimating requirements and intake were discussed. In addition, the report discussed the appropriateness of various estimates and tools for demonstrating principles versus diagnosing and formulating responses to nutritional issues in the field.

7 Bibliography

ARC (1980) 'The nutrient requirements of ruminant livestock'. Technical review by the Agricultural Research Council working party. (Commonwealth Agricultural Bureaux: Farnham)

Brody S (1945) 'Bioenergetics and growth'. (Reinhold Publishing Corporation: New York)

Freer M, Moore AD, Donnelly JR (2012) The GRAZPLAN animal biology model for sheep and cattle and the GrazFeed decision support tool. CSIRO Plant Industry Technical Paper (revised December 2012). At: www.csiro.au/en/Organisation-Structure/Divisions/Plant-Industry/GRAZPLAN-supporting-documents-and-programs.

Minson DJ, McDonald CK (1987) Estimating forage intake from the growth of beef cattle. *Tropical Grasslands* **21**, 116-122.

McLean S, Blakeley S (2014) Adult equivalent methodology – A method to accurately and consistently calculate cattle grazing loads in northern Australia. Final Report to Meat and Livestock Australia Ltd - Project B. NBP.0779.

McLennan SR (2005) Improved prediction of the performance of cattle in the tropics. Final Report to Meat and Livestock Australia Ltd - Project NBP.331.

McLennan SR (2013) Optimising growth paths of beef cattle in northern Australia for increased profitability. Final Report to Meat and Livestock Australia Ltd - Project B. NBP.0391.

NRDR (2007) 'Nutrient requirements of domesticated ruminants.' (CSIRO Publishing: Melbourne, Australia)

8 Appendices

8.1 Appendix 1 - Tables of ME requirements for steers

These estimates of ME requirements are for selected breed/activity combinations based on NRDR (2007) feeding standards, using the spreadsheet calculator 'QuikIntake'.

Table I. Metabolisable energy (ME) requirements (MJ/d) of steer for maintenance and growth: (i) *Bos taurus* steers, nil activity allowance

M/D of diet (MJ/kg DM)	Liveweight (kg)	Liveweight gain (kg/d)						
		0	**0.25**	**0.50**	**0.75**	**1.00**	**1.25**	**1.50**
5 (39.0% DMD)	100							
	200							
	300	45	68	91				
	400	54	82	109				
	500	62	93	123				
	600	71	102	133				
6 (44.8% DMD)	100							
	200							
	300	43	62	82				
	400	52	75	98				
	500	60	86	111				
	600	68	94	120				
7 (50.6% DMD)	100	19	28	37				
	200	32	44	57				
	300	42	58	75				
	400	50	70	90				
	500	59	80	102				
	600	66	88	111				
8 (56.5% DMD)	100	18	26	34	43			
	200	31	41	52	64			
	300	40	55	69	84			
	400	49	66	83	101			
	500	57	75	94	113			
	600	64	83	103	122			
9 (62.3%	100	18	24	32	39	47		
	200	30	39	49	59	70		
	300	39	52	65	78	92	105	

M/D of diet (MJ/kg DM)	Liveweight (kg)	Liveweight gain (kg/d)						
		0	0.25	0.50	0.75	1.00	1.25	1.50
DMD)								
	400	47	63	78	94	109	125	
	500	55	72	88	105	122	139	
	600	62	79	97	114	131	149	
10 (68.0% DMD)	100	17	23	30	37	44	52	60
	200	29	37	46	55	65	75	85
	300	38	50	61	73	85	98	110
	400	46	60	74	88	102	116	131
	500	53	68	84	99	114	129	144
	600	60	76	92	107	123	138	154
11 (73.9% DMD)	100	17	22	28	34	41	48	56
	200	28	36	44	52	61	70	79
	300	37	47	58	69	80	91	103
	400	45	57	70	83	96	108	121
	500	52	66	79	93	107	121	134
	600	59	73	87	101	115	130	144
12 (79.7% DMD)	100	16	21	27	32	39	45	52
	200	27	34	42	49	57	66	74
	300	36	45	55	65	75	86	96
	400	44	55	67	78	90	102	114
	500	50	63	76	88	101	113	126
	600	57	70	83	96	109	122	135
13 (85.5% DMD)	100	16	20	25	31	36	42	49
	200	26	33	40	47	54	62	70
	300	35	44	53	62	71	81	90
	400	42	53	64	74	85	96	107
	500	49	61	72	84	96	107	119
	600	56	68	80	92	104	116	128

Note: shaded cells indicate intakes possibly unattainable due to the quality of the diet and LW of steer

Table II. Metabolisable energy (ME) requirements (MJ/d) of steer for maintenance and growth: (ii) *Bos taurus* steers walking 7 km/d

M/D of diet (MJ/kg DM)	Liveweight (kg)	Liveweight gain (kg/d)						
		0	0.25	0.50	0.75	1.00	1.25	1.50
5	100							
	200							
	300	57	80	104				
	400	71	99	127				
	500	84	114	144				
	600	96	128	159				
6	100							
	200							
	300	55	75	94				
	400	69	92	115				
	500	82	107	132				
	600	94	120	146				
7	100	22	31	40				
	200	39	51	64				
	300	54	70	87				
	400	67	87	107				
	500	79	101	122				
	600	91	113	135				
8	100	22	29	37	46			
	200	38	48	60	71			
	300	52	66	81	96			
	400	65	82	99	117			
	500	76	95	114	133			
	600	88	107	126	146			
9	100	21	27	35	42	51		
	200	36	46	56	66	77		
	300	50	63	76	89	103	116	
	400	62	78	93	109	124	140	
	500	74	90	107	124	141	158	
	600	84	102	119	136	154	171	
10	100	20	26	33	40	47	55	63
	200	35	44	53	62	71	81	92
	300	48	60	72	84	96	108	121
	400	60	74	88	102	116	130	145

M/D of diet (MJ/kg DM)	Liveweight (kg)	Liveweight gain (kg/d)						
		0	**0.25**	**0.50**	**0.75**	**1.00**	**1.25**	**1.50**
	500	71	86	101	116	131	147	162
	600	81	97	113	128	144	159	175
11	100	20	25	31	37	44	51	59
	200	34	42	50	58	67	76	85
	300	46	57	68	78	89	101	112
	400	58	70	83	96	108	121	134
	500	68	82	95	109	123	137	151
	600	78	92	106	120	135	149	163
12	100	19	24	29	35	41	48	55
	200	33	40	47	55	63	71	80
	300	45	54	64	74	84	94	105
	400	55	67	78	90	102	114	126
	500	65	78	90	103	115	128	141
	600	75	88	101	114	127	140	153
13	100	18	23	28	33	39	45	51
	200	32	38	45	52	59	67	75
	300	43	52	61	70	79	89	98
	400	53	63	74	85	96	107	118
	500	62	74	85	97	109	120	132
	600	71	83	95	107	119	131	143

Note: shaded cells indicate intakes possibly unattainable due to the quality of the diet and LW of steer

Table III. Metabolisable energy (ME) requirements (MJ/d) of steer for maintenance and growth: (iii) *Bos indicus* crossbred (75% *indicus)* steers, nil activity allowance

M/D of diet (MJ/kg DM)	Liveweight (kg)	Liveweight gain (kg/d) 0	0.25	0.50	0.75	1.00	1.25	1.50
5	100							
	200							
	300	36	55	75				
	400	44	67	90				
	500	51	76	102				
	600	58	84	111				
6	100							
	200							
	300	35	51	67				
	400	43	62	81				
	500	50	71	92				
	600	56	78	100				
7	100	16	23	32				
	200	26	36	47				
	300	34	48	61				
	400	41	58	74				
	500	48	66	84				
	600	54	73	92				
8	100	15	22	29	37			
	200	25	34	44	53			
	300	33	45	57	69			
	400	40	54	69	83			
	500	46	62	78	94			
	600	53	69	86	102			
9	100	15	20	27	34	41		
	200	24	32	41	49	59		
	300	32	42	53	64	75	87	
	400	39	51	64	77	90	103	
	500	45	59	73	87	101	116	
	600	51	66	80	95	110	125	
10	100	14	19	25	32	38	46	53
	200	24	31	38	46	54	63	72
	300	31	41	50	60	70	81	91
	400	38	49	61	72	84	96	108
	500	44	56	69	82	95	107	120

M/D of diet (MJ/kg DM)	**Liveweight (kg)**	**Liveweight gain (kg/d)**						
		0	**0.25**	**0.50**	**0.75**	**1.00**	**1.25**	**1.50**
	600	50	63	76	89	103	116	129
11	100	14	19	24	30	36	42	49
	200	23	29	36	43	51	59	67
	300	30	39	48	57	66	75	85
	400	37	49	59	70	80	91	102
	500	43	54	66	77	89	100	112
	600	48	60	72	84	96	108	120
12	100	13	18	23	28	33	39	46
	200	22	29	36	42	49	56	63
	300	29	37	45	54	62	71	79
	400	36	45	55	64	74	84	94
	500	41	52	62	73	84	94	105
	600	47	58	69	80	91	102	113
13	100	13	17	22	26	32	37	43
	200	22	27	33	39	45	52	59
	300	29	36	43	51	59	67	75
	400	35	43	52	61	70	79	89
	500	40	50	60	69	79	89	99
	600	46	56	66	76	86	97	107

Note: shaded cells indicate intakes possibly unattainable due to the quality of the diet and LW of steer

Table IV. Metabolisable energy (ME) requirements (MJ/d) of steers for maintenance and growth. (iv) *Bos indicus* crossbred (75% *indicus)* steers walking 7 km/d

M/D of diet (MJ/kg DM)	Liveweight (kg)	Liveweight gain (kg/d) 0	0.25	0.50	0.75	1.00	1.25	1.50
5	100							
	200							
	300	49	68	88				
	400	62	85	108				
	500	74	99	124				
	600	85	111	138				
6	100							
	200							
	300	48	64	80				
	400	60	79	98				
	500	72	92	114				
	600	82	104	126				
7	100	19	27	35				
	200	34	44	55				
	300	46	60	74				
	400	58	75	91				
	500	69	87	105				
	600	80	99	117				
8	100	18	25	32	40			
	200	32	41	51	60			
	300	45	57	69	81			
	400	56	70	85	99			
	500	67	83	98	114			
	600	77	93	110	126			
9	100	18	24	30	37	45		
	200	31	39	48	56	65		
	300	43	54	64	75	87	98	
	400	54	67	80	92	105	119	
	500	64	78	92	106	121	135	
	600	74	89	103	118	133	148	
10	100	17	23	28	35	41	49	56
	200	30	37	45	53	61	69	78
	300	42	51	61	71	81	91	102
	400	52	63	75	87	98	110	122
	500	62	74	87	100	113	125	138

M/D of diet (MJ/kg DM)	**Liveweight (kg)**	**Liveweight gain (kg/d)**						
		0	**0.25**	**0.50**	**0.75**	**1.00**	**1.25**	**1.50**
	600	71	84	98	111	124	137	151
11	100	17	22	27	32	39	45	52
	200	29	35	42	50	57	65	73
	300	40	48	57	66	75	85	94
	400	51	62	72	83	93	104	115
	500	59	71	82	94	105	117	129
	600	68	80	92	104	116	128	140
12	100	16	20	25	31	36	42	48
	200	29	35	41	48	55	62	69
	300	38	46	54	62	71	79	88
	400	48	57	67	76	86	96	106
	500	56	67	77	88	99	109	120
	600	65	76	87	98	109	120	131
13	100	15	20	24	29	34	40	45
	200	27	32	38	44	50	57	64
	300	36	44	51	59	67	74	83
	400	45	54	63	72	81	90	99
	500	53	63	73	83	92	102	112
	600	61	72	82	92	102	112	123

Note: shaded cells indicate intakes possibly unattainable due to the quality of the diet and LW of steer

8.2 Appendix 2 -Tables of CP requirements for steers.

These estimates of ME requirements are for selected breed/activity combinations based on NRDR (2007) feeding standards, using the spreadsheet calculator ‘QuikIntake’.

Table I. Rumen degradable (RDP) and undegraded (UDP) protein requirements (g/d) of steer for maintenance and growth: (i) *Bos taurus* steers, nil activity allowance

M/D of diet (MJ/kg DM)	LW (kg)	Protein form (RDP/ UDP) [A]	Liveweight gain (kg/d) 0	0.25	0.50	0.75	1.00	1.25	1.50
5	100								
	200								
	300	RDP/UDP	370/79	560/116	754/153				
	400	RDP/UDP	447/84	676/105	905/126				
	500	RDP/UDP	518/87	766/100	1015/112				
	600	RDP/UDP	585/90	842/97	1099/104				
6	100								
	200								
	300	RDP/UDP	358/35	517/56	678/76				
	400	RDP/UDP	433/31	623/33	815/33				
	500	RDP/UDP	502/26	709/17	916/8				
	600	RDP/UDP	567/21	781/6	995				
7	100	RDP/UDP	158/22	230/86	306/148				
	200	RDP/UDP	263/16	364/57	469/97				
	300	RDP/UDP	347/7	483/21	621/34				
	400	RDP	419	583	747				
	500	RDP	486	663	841				
	600	RDP	549	732	916				
8	100	RDP/UDP	153/13	216/76	283/137	354/194			
	200	RDP/UDP	255	343/41	435/78	530/114			
	300	RDP/UDP	336	455	576/9	699/18			
	400	RDP	407	549	692	837			
	500	RDP	471	626	781	937			
	600	RDP	532	692	853	1013			
9	100	RDP/UDP	149/7	204/70	264/130	328/188	395/243		
	200	RDP/UDP	248	326/30	408/68	492/104	580/137		
	300	RDP/UDP	326	432	539	649/4	760/12	873/18	
	400	RDP	395	521	649	777	906	1037	
	500	RDP	457	595	733	872	1010	1150	
	600	RDP	516	659	802	944	1087	1230	
	100	RDP/UDP	145/3	195/66	248/127	306/185	367/241	432/293	500/343
	200	RDP/UDP	241	312/24	385/62	461/98	540/133	622/165	706/196

M/D of diet (MJ/kg DM)	**LW (kg)**	**Protein form (RDP/ UDP)** [A]	**Liveweight gain (kg/d)**						
			0	**0.25**	**0.50**	**0.75**	**1.00**	**1.25**	**1.50**
10	300	RDP/UDP	317	412	509	608	708/5	810/13	914/19
	400	RDP	384	498	613	729	845	962	1081
	500	RDP	444	569	693	818	943	1069	1195
	600	RDP	502	630	759	888	1017	1146	1275
11	100	RDP/UDP	141	186/64	235/126	287/185	342/241	401/295	464/346
	200	RDP/UDP	234	298/20	365/59	434/97	506/132	580/166	656/198
	300	RDP/UDP	308	395	483	572	663	756/13	850/21
	400	RDP	373	476	581	686	792	898	1005
	500	RDP	432	545	658	771	885	999	1113
	600	RDP	488	604	721	838	955	1072	1190
12	100	RDP/UDP	137	178/63	223/125	271/185	322/243	376/298	433/350
	200	RDP/UDP	228/0	287/18	348/58	411/97	477/134	545/169	615/202
	300	RDP/UDP	300	379	460	542	625	710/16	796/26
	400	RDP	363	458	553	650	747	844	943
	500	RDP	420	524	627	731	835	940	1045
	600	RDP	475	582	689	796	903	1011	1118
13	100	RDP/UDP	133	172/62	213/126	257/187	304/245	354/302	407/355
	200	RDP/UDP	222	276/17	333/59	391/98	452/137	514/173	579/208
	300	RDP/UDP	292	365	440	515	592/10	671/22	750/33
	400	RDP	353	441	529	618	708	798	889
	500	RDP	409	505	600	696	793	889	986
	600	RDP	462	561	660	759	858	957	1056

[A] Where no value is given for UDP this indicates all requirements can be met with RDP only.

Table II. Rumen degradable (RDP) and undegraded (UDP) protein requirements (g/d) of steer for maintenance and growth: (ii) *Bos taurus* steers walking 7 km/d

M/D of diet (MJ/kg DM)	LW (kg)	Protein form (RDP/ UDP) [A]	Liveweight gain (kg/d)						
			0	0.25	0.50	0.75	1.00	1.25	1.50
5	100								
	200								
	300	RDP/UDP	474/68	665/105	859/142				
	400	RDP/UDP	590/69	819/90	1048/111				
	500	RDP/UDP	698/69	946/81	1195/93				
	600	RDP/UDP	800/67	1056/74	1314/81				
6	100								
	200								
	300	RDP/UDP	460/12	619/33	781/53				
	400	RDP	573	763	955				
	500	RDP	678	884	1092				
	600	RDP	776	990	1205				
7	100	RDP/UDP	186/13	258/77	334/139				
	200	RDP/UDP	325	426/38	531/78				
	300	RDP	446	582	721				
	400	RDP	555	718	882				
	500	RDP	656	834	1012				
	600	RDP	752	936	1119				
8	100	RDP/UDP	180/2	243/66	310/126	381/184			
	200	RDP/UDP	314	402/18	494/56	589/92			
	300	RDP	431	550	671	794			
	400	RDP	536	679	822	967			
	500	RDP	634	789	944	1100			
	600	RDP	727	887	1047	1208			
9	100	RDP/UDP	175	230/59	290/119	353/177	421/232		
	200	RDP/UDP	304	382/6	464/44	548/79	636/113		
	300	RDP	416	522	630	739	850	963	
	400	RDP	518	644	772	900	1030	1160	
	500	RDP	612	750	888	1026	1165	1304	
	600	RDP	701	843	986	1129	1272	1415	
10	100	RDP/UDP	169	219/54	273/115	331/174	392/230	457/283	525/334
	200	RDP/UDP	294	365	438/37	514/73	593/108	675/141	759/172
	300	RDP	402	497	594	693	793	895	998
	400	RDP	499	613	728	844	960	1078	1196
	500	RDP	589	713	838	963	1088	1214	1339
	600	RDP	675	803	932	1061	1190	1319	1448

M/D of diet (MJ/kg DM)	LW (kg)	Protein form (RDP/ UDP) [A]	Liveweight gain (kg/d)						
			0	**0.25**	**0.50**	**0.75**	**1.00**	**1.25**	**1.50**
11	100	RDP/UDP	164	209/52	258/114	310/173	366/230	425/284	487/336
	200	RDP/UDP	284	348	415/34	484/71	555/107	629/141	706/174
	300	RDP	386	473	561	651	742	834	928
	400	RDP	479	583	687	792	898	1005	1112
	500	RDP	565	678	791	905	1018	1132	1246
	600	RDP	647	764	881	998	1115	1232	1349
12	100	RDP/UDP	159	200/51	245/114	293/174	344/232	398/287	455/340
	200	RDP/UDP	274	333	394/34	457/72	523/109	591/145	661/178
	300	RDP	371	451	531	613	697	782	868
	400	RDP	459	554	650	747	844	941	1039
	500	RDP	541	645	748	852	957	1061	1166
	600	RDP	619	726	834	941	1048	1155	1263
13	100	RDP/UDP	154	192/51	234/114	278/176	325/235	374/291	427/345
	200	RDP/UDP	264	318	374/35	433/75	494/113	556/150	621/185
	300	RDP	356	429	504	580	657	735	815
	400	RDP	439	527	615	704	794	884	975
	500	RDP	517	612	708	804	900	997	1093
	600	RDP	591	690	789	888	987	1086	1185

[A] Where no value is given for UDP this indicates all requirements can be met with RDP only.

Table III. Rumen degradable (RDP) and undegraded (UDP) protein requirements (g/d) of steer for maintenance and growth: (iii) *Bos indicus* crossbred steers (75% indicus), nil activity allowance

M/D of diet (MJ/kg DM)	LW (kg)	Protein form (RDP/ UDP) [A]	Liveweight gain (kg/d)						
			0	0.25	0.50	0.75	1.00	1.25	1.50
5	100								
	200								
	300	RDP/UDP	304/65	459/116	619/166				
	400	RDP/UDP	367/70	555/107	745/142				
	500	RDP/UDP	426/74	634/101	843/128				
	600	RDP/UDP	481/76	699/101	917/127				
6	100								
	200								
	300	RDP/UDP	294/30	424/67	557/103				
	400	RDP	356/27	512/47	671/66				
	500	RDP	412/23	585/33	759/42				
	600	RDP	465/19	647/26	829/32				
7	100	RDP/UDP	130/18	194/87	164/154				
	200	RDP/UDP	216/13	301/66	390/117				
	300	RDP/UDP	285/6	396/38	510/68				
	400	RDP/UDP	345	479/12	615/24				
	500	RDP	399	548	697				
	600	RDP	451	607	763				
8	100	RDP/UDP	126/10	182/79	243/144	308/207			
	200	RDP/UDP	210	284/52	362/102	443/149			
	300	RDP/UDP	276	373/20	473/48	575/75			
	400	RDP	334	451	570	690			
	500	RDP	387	517	647	778			
	600	RDP	437	573	709	846			
9	100	RDP/UDP	122/5	172/74	226/139	284/202	346/261		
	200	RDP/UDP	204	270/44	339/93	411/140	486/185		
	300	RDP/UDP	268	354/9	443/37	533/63	626/89	720/113	
	400	RDP/UDP	324	428	534	640	748	857/11	
	500	RDP	376	491	607	723	840	958	
	600	RDP	424	545	666	788	909	1031	
10	100	RDP/UDP	119/2	164/71	213/136	265/200	320/260	379/318	442/373
	200	RDP/UDP	198	257/39	320/88	385/136	453/182	523/226	597/267
	300	RDP/UDP	260	338	418/31	500/58	583/84	668/109	755/133
	400	RDP/UDP	315	409	504	600	697	795	894/13
	500	RDP	365	469	574	679	784	890	996

M/D of diet (MJ/kg DM)	**LW (kg)**	**Protein form (RDP/ UDP)** [A]	**Liveweight gain (kg/d)**						
			0	**0.25**	**0.50**	**0.75**	**1.00**	**1.25**	**1.50**
	600	RDP	412	521	631	740	850	959	1069
11	100	RDP/UDP	116	156/69	201/135	248/199	298/261	352/319	409/375
	200	RDP/UDP	192	246/36	303/86	362/135	424/181	488/226	554/269
	300	RDP/UDP	253	324	396/27	470/56	546/83	623/109	702/134
	400	RDP	306	405	491	578	666	755	845
	500	RDP	355	449	544	639	735	831	928
	600	RDP	401	500	599	698	798	897	997
12	100	RDP/UDP	112	150/68	190/135	234/200	280/262	329/322	381/380
	200	RDP/UDP	187	245/29	297/81	351/131	407/179	466/225	527/269
	300	RDP/UDP	246	311	378/26	445/56	515/85	586/112	658/138
	400	RDP/UDP	298	376	455	535	616	698	780/19
	500	RDP	345	432	519	606	694	782	871
	600	RDP	390	481	572	663	754	845	937
13	100	RDP/UDP	109	144/68	181/136	221/202	264/265	310/326	358/385
	200	RDP/UDP	182	228/33	276/86	326/136	378/185	432/233	489/278
	300	RDP/UDP	240	300	361/27	424/58	488/88	553/117	620/145
	400	RDP/UDP	290	362	435	509	584	659/14	735/26
	500	RDP	336	416	496	577	658	739	821
	600	RDP	380	463	547	631	716	800	885

[A] Where no value is given for UDP this indicates all requirements can be met with RDP only.

Table IV. Rumen degradable (RDP) and undegraded (UDP) protein requirements (g/d) of steer for maintenance and growth: (iv) *Bos indicus* crossbred steers (75% indicus) walking 7 km/d

M/D of diet (MJ/kg DM)	LW (kg)	Protein form (RDP/ UDP) [A]	Liveweight gain (kg/d)						
			0	0.25	0.50	0.75	1.00	1.25	1.50
5	100								
	200								
	300	RDP/UDP	410/54	566/105	726/155				
	400	RDP/UDP	514/55	702/91	892/127				
	500	RDP/UDP	611/54	819/82	1028/109				
	600	RDP/UDP	703/53	920/78	1139/103				
6	100								
	200								
	300	RDP/UDP	398/6	528/43	661/79				
	400	RDP/UDP	499	656/14	814/33				
	500	RDP	593	767	941				
	600	RDP	683	864	1046				
7	100	RDP/UDP	158/9	223/78	292/145				
	200	RDP/UDP	279	364/46	453/97				
	300	RDP/UDP	386	497/6	611/36				
	400	RDP	484	618	754				
	500	RDP	575	723	873				
	600	RDP	661	817	973				
8	100	RDP/UDP	153	209/68	270/134	335/197			
	200	RDP/UDP	269	344/29	421/79	503/126			
	300	RDP/UDP	373	470	570/11	672/38			
	400	RDP	467	584	703	823			
	500	RDP	555	685	815	946			
	600	RDP	638	774	911	1047			
9	100	RDP/UDP	148	198/62	252/128	310/191	372/251		
	200	RDP/UDP	260	326/19	396/68	468/116	543/161		
	300	RDP/UDP	360	446	535	625/23	718/49	812/74	
	400	RDP	450	554	660	766	874	983	
	500	RDP	534	650	766	882	999	1117	
	600	RDP	615	735	857	978	1100	1221	
10	100	RDP/UDP	144	189/59	237/125	289/188	345/249	404/308	467/363
	200	RDP/UDP	252	311/13	373/63	439/111	506/157	577/201	650/244
	300	RDP/UDP	347	425	504	586/17	669/43	755/69	842/93
	400	RDP	433	527	622	718	815	913	1012
	500	RDP	514	618	722	827	933	1038	1145

M/D of diet (MJ/kg DM)	LW (kg)	Protein form (RDP/ UDP) [A]	Liveweight gain (kg/d) 0	0.25	0.50	0.75	1.00	1.25	1.50
	600	RDP	590	699	809	918	1028	1137	1247
11	100	RDP/UDP	139	180/57	224/124	271/188	322/250	375/309	432/366
	200	RDP/UDP	242	296/10	353/60	412/109	474/156	538/202	604/245
	300	RDP/UDP	333	403	476	550/15	626/43	703/69	782/94
	400	RDP	428	513	600	687	775	864	954
	500	RDP	491	586	680	776	871	968	1064
	600	RDP	564	663	762	862	961	1061	1161
12	100	RDP/UDP	134	172/56	212/124	256/189	302/252	351/312	403/370
	200	RDP/UDP	241	291	343/56	397/106	454/154	512/201	573/246
	300	RDP/UDP	319	383	450	518/17	587/46	658/74	731/100
	400	RDP	396	474	553	633	714	796	878
	500	RDP	468	555	642	729	817	905	994
	600	RDP	537	628	719	810	901	993	1084
13	100	RDP/UDP	130	165/56	202/124	242/191	285/254	330/316	378/375
	200	RDP/UDP	224	270	318/62	368/113	420/162	474/210	531/256
	300	RDP/UDP	304	364	426	488/21	552/52	618/81	685/109
	400	RDP	377	449	522	596	671	746	822
	500	RDP	445	525	605	686	767	848	930
	600	RDP	510	594	678	762	846	930	1015

[A] Where no value is given for UDP this indicates all requirements can be met with RDP only.

8.3 Appendix 3 - ME and protein requirements of heifers, cows and bulls

Table I. Daily requirements of *Bos indicus* crossbred heifers, cows and bulls, walking 7 km/d, for metabolisable energy (ME), rumen degradable protein (RDP), undegraded dietary protein (UDP), calcium and phosphorus for maintenance and production

Liveweight (kg)	Daily gain (kg)	Daily requirements ME (MJ)	RDP/UDP [A] (g)	Calcium (g)	Phosphorus (g)
Pregnant heifers – last third of pregnancy					
350	0.4	62	512	20	15
400	0.4	68	564	22	16
450	0.4	74	614	23	18
Dry pregnant mature cows – last third of pregnancy					
350	0	45	373	12	12
350	0.4	58	496	20	15
400	0	50	412	13	13
400	0.4	64	532	22	16
450	0	55	452	15	15
450	0.4	70	579	23	18
500	0	59	492	17	17
500	0.4	75	623	25	20
550	0	64	532	18	18
550	0.4	80	665	26	21
Lactating first-lactation cows – with calf four months old					
350	0.1	96	798/145	27	19
400	0.1	103	849/128	28	20
450	0.1	108	898/112	29	22
Lactating mature cows – with calf four months old					
350	0.1	93	772/351	23	18
400	0.1	99	821/336	25	19
450	0.1	105	867/321	26	21
500	0.1	110	911/307	28	22
550	0.1	115	953/293	29	24
Bulls					
500	0.4	100	825	23	19
600	0.4	112	927	25	22
750	0.4	128	1063	26	25
800	0.4	134	1110	27	27

[A] Where only one value is given this is RDP and there is no UDP requirement.

These estimates of ME and protein requirements for heifers, cows and bulls are based on NRDR (2007) feeding standards, using the spreadsheet calculator 'QuikIntake'.