The use of faecal NIRS to improve nutritional management of cattle in northern Australia

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Summary

NIRS analysis of faeces (F.NIRS) of cattle fed tropical forage diets can measure the crude protein (CP) concentration, dry matter digestibility (DMD) and the proportion of grass to non–grass in the diet. With forage diets containing urea, loose mineral mixes or small amounts (≤2.3 g DM/kg liveweight.day) of molasses, F.NIRS calibrations derived from forage–alone diets satisfactorily predict the forage ingested. Greater amounts of molasses, protein meal or cereal grain supplement sometimes cause unacceptable errors. When large amounts of supplement are fed intermittently, F.NIRS predictions of the forage component of the diet can be obtained from faeces sampled 48–72 h after ingestion of the supplement. The standard errors of cross validation (SECVs) for prediction of dietary CP and DMD are 0.9 and 3.0 percentage units, respectively. Liveweight change of animals can be predicted but the SECV is high (133–217 g/day). The ratio, DMD/CP, provides a measure of the availability of metabolizable energy to rumen degradable nitrogen (RDN) in the diet. A liveweight response to supplementary RDN can be expected in cattle grazing tropical pastures when the DMD/CP ratio exceeds 8–10. F.NIRS is valuable to understand the nutrition of grazing cattle and thus improve productivity and rangeland sustainability.

Keywords: cattle, NIRS, faeces, nutrition, supplementation, rumen degradable nitrogen

Introduction

The difficulties of estimating the diet ingested by grazing ruminants, particularly when selection of pasture is intense such as in extensive rangelands and in the tropics, are well known. Each of the established technologies (e.g., oesophageal fistulated animals, faecal markers, histological analysis of faeces) involves serious disadvantages. NIRS (near infrared reflectance spectroscopy) is widely used for analysis of the nutritive value of feedstuffs. NIRS for analysis of faeces (F.NIRS) to predict dietary characteristics of grazing herbivores was first reported by Brooks *et al.* (1984), and has since been developed by teams led by Jerry Stuth in Texas and by David Coates in northern Australia. These groups have shown that F.NIRS can be used reliably to measure many attributes of the diet of grazing ruminants. Advantages are associated with the measurement being based on faeces, which should reflect the diet selected by the grazing animal, and the simplicity, speed and cost of NIRS analysis once calibration equations are established. The potential role of F.NIRS in the cattle industry of northern Australian has been discussed by Coates (2000, 2001, 2002). This paper provides an overview of the utility of F.NIRS to measure the diet selected by grazing cattle and to improve nutritional management in the rangelands of northern Australia.

Some principles of NIRS

The physical and chemical basis of NIRS and the mathematical treatment of spectra to measure the constituents of feedstuffs have been described (Norris *et al*. 1976; Murray 1993; Givens and Deaville 1999; Deaville and Flinn 2000). Spectra are related to the concentration of feed constituent using samples of known composition to generate calibration equations; these are used to predict the composition of unknown samples. In F.NIRS, the spectra are usually related directly to characteristics of the diet (e.g., CP concentration) or the animal (e.g., intake, growth). The former is usually accomplished using pen–fed or oesophageal fistulated animals to obtain representative samples of the diet and faeces and to measure voluntary intake.

Development of calibration equations usually depends on mathematical pre–treatment of the spectral data followed by statistical modelling involving principal component or partial least squares analysis to relate an independent variable (constituent concentration) to absorbance at various wavelengths. These are empirical relationships and it is usually not possible to relate the spectral data to specific chemical compounds. Large data sets that encompass the full range of sample types of interest are required to generate robust calibration equations. The Mahalanobis distance method is usually used to confirm the spectral similarity of samples. The goodness of fit of a calibration equation, or of prediction for an unknown sample, is described in terms of the standard error of calibration (SEC), the standard error of cross–validation (SECV), the standard error of prediction (SEP) and the coefficient of determination (R^2).

Dietary and animal characteristics predicted by F.NIRS in cattle consuming forage

F.NIRS calibration equations have been developed to predict the crude protein (CP) concentration, digestibility of DM (DMD), the proportion of non–grass and the voluntary intake of DM and digestible DM of diets selected by cattle grazing northern Australian pastures (Coates 2004). The reliability of F.NIRS prediction is usually comparable with that for direct NIRS analysis of forage. Although there are sound reasons to develop separate calibrations for various classes of samples, the limited size of most of the data sets available has led to the use of a single general calibration equation for most characteristics.

The F.NIRS calibration equations of Coates (2004) and Lyons and Stuth (1992) for dietary CP concentration had SECVs of about 0.9 percentage units, indicating that most estimates are within 0.9 percentage units of the true value. A lower SECV (0.5 percentage units) was reported by Boval *et al.* (2004), but was derived from only two tropical grass species at one site. Separate calibration equations were developed by Coates (2004) to predict the CP concentrations of low, medium and high protein forage diets; although the separate equations had similar SECVs and R^2, the error in the prediction of very low and very high CP diets was reduced. F.NIRS calibrations tend to underestimate the CP concentration of diets consisting of a mixture of low– and high CP content forages such as occurs with supplementation of low quality hay with legume hay, or when new growth is present within senesced pasture. This error may be caused by the disproportionately high contribution of less digestible components to faecal DM, but also because the N in higher quality forage is likely to be more soluble with proportionally less undigested protein being present in faeces. Moreover, CP content of grasses grown with high–rate N fertilization tends to be underestimated, possibly because much of the forage N is present in non–protein forms.

Prediction of DM digestibility of tropical forages is complicated by choice of the laboratory procedure used to determine *in vitro* digestibility, differences between *in vitro* digestibility of forages and the equivalent oesophageal extrusa, and the often–poor relationships between *in vitro* and *in vivo* digestibility. As voluntary digestible DM intake of tropical forages is often more closely related to *in vitro* digestibility than to *in vivo* digestibility (Minson 1990; Coates 2004), the former may be a better measure of the metabolizable energy intake of grazing animals. The SECVs for F.NIRS calibration equations for DM digestibility have usually been 2–3 percentage units (Lyons and Stuth 1992; de la Roza *et al*. 2002; Boval *et al*. 2004; Coates 2004). Comparisons between reports of the SECVs for voluntary DM and digestible DM intake are complicated by the variety of units used; Coates (2004) reported SECVs of 2.4 and 1.4 g/kg liveweight.day, respectively. This error for prediction of voluntary DM intake is comparable with the errors associated with the use of the faecal markers to measure voluntary intake (Flinn *et al*. 1992).

Differences in the ratio of ^{12}C / ^{13}C between tropical grasses, which have the C4 photosynthetic pathway, and of most other plants, which have the C3 photosynthetic pathway, were used by Coates (2004) to calculate the proportions of these plant types in faeces, and therefore in the diet, and to develop F.NIRS calibrations for these proportions. However, when this calibration is applied to faeces from animals ingesting C3 temperate grasses such as ryegrass or oats, the diet is predicted to be about 80% grass rather than zero grass as would be expected. Thus, even though the $^{12}C/^{13}C$ ratio provided the reference values, the F.NIRS calibration equation appears to be actually detecting some other characteristics such as the structure of digested plant material. F.NIRS calibration equations have also been developed to predict the proportion of a specific species (e.g., browse or a *Trifolium* species) in temperate grass diets (Walker *et al*. 2002; Decruyenaere *et al*. 2004), demonstrating that calibrations can be developed to measure the proportions of species when all the plants consumed are C3. Despite the limitations in use of the $^{12}C/^{13}C$ ratio to develop the calibration, the Coates (2004) equation is a valuable indicator of the proportion of grass in the diet, while the species of plants likely contributing to the non–grass component of the diet can often be assessed from the season of the year and field observations.

F.NIRS calibrations to predict the liveweight change of cattle clearly must accommodate the difficulty that many factors potentially influence liveweight change. Coates (2004) reduced the effect of variables other than metabolizable energy intake by restricting the data set to young *Bos indicus* cross cattle grazing with adequate pasture on offer and without any identified diseases or mineral deficiencies. Calibration equations for liveweight change are consistent with those for prediction of digestible DM intake of penned animals (Coleman *et al*. 1989; Boval *et al*. 2004; Coates 2004). The Coates (2004) calibration equations for liveweight change were improved by using separate equations for specific pasture systems, but the errors were still appreciable (SECV: 133–217 g/day). The most reliable equation was associated with the northern speargrass and *Aristida/Bothriochloa* pasture regions, perhaps because the majority of reference measurements originated from these regions. Large error has sometimes occurred with prediction of liveweight change of cattle grazing buffel or Mitchell grass pastures, or where a substantial part of the diet consisted of browse species such as mulga *(Acacia aneura).*

Calibration equations have also been developed by Coates (2004) to estimate the concentrations of N and ash in faeces. These measurements can provide useful ancillary information to assist interpretation of F.NIRS predictions of diet quality. A high concentration of N in faeces relative to the predicted dietary CP content indicates that the diet may contain a high proportion of indigestible N such as condensed tannin–protein complexes. A high concentration of faecal ash (>30%) leads to errors in the predictions of dietary constituents and is most often due to soil contamination of the sample. NIRS is generally less suitable for measurement of mineral content.

Effects of physiological state of the animal on F.NIRS predictions

F.NIRS predictions of diet quality appear not to be affected by the age or the lactational status of animals. For example, F.NIRS predictions of dietary CP and DMD did not differ between weaner and yearling steers fed hays ranging in quality (Table 1). Similarly, in herds consisting of yearling steers and three– or four–year old cows that grazed together, the differences between age groups in the predicted dietary CP or DMD were only up to one–third of the respective SECV (R.M. Dixon, unpublished). Where lactating and non–lactating cows grazed together on either wet or dry season pastures, predictions of dietary CP and DMD usually differed by less than half of the respective SECV (R.M. Dixon, unpublished). Lyons and Stuth (1992) reported that calibration equations for dietary CP and DMD developed using oesophageal fistulated cows were not affected by lactational status.

As Coate's (2004) F.NIRS calibration equations for liveweight change were based on young cattle, not unexpectedly, the actual liveweight change of mature animals is often lower than the F.NIRS prediction. For example, in a herd of steers ranging from one– to three years of age and grazing native pasture near Gayndah in the southern speargrass pasture region, F.NIRS predictions were similar for all age groups even though the measured annual liveweight gain of the three–year–old steers was only about half that of the yearling steers. The current F.NIRS calibration equations can satisfactorily predict the liveweight change of the non–pregnant, non–lactating breeder. In an experiment at Swans Lagoon near Townsville, the cumulative liveweight change from January to July predicted from F.NIRS differed, on average over three years, from the measured liveweight change by only 8 kg in young breeders (R. M. Dixon, unpublished). However, much of the data used to construct the liveweight–change F.NIRS calibration equations were obtained from herds in similar pasture systems; predictions of liveweight change of non–lactating breeders in other pasture systems may involve greater error. Due to their higher nutritional requirements, lactating breeders will gain less liveweight, or lose more liveweight, than non–lactating breeders grazing under the same conditions. However, with knowledge of the magnitude of the liveweight difference between lactating and non–lactating breeders for a specific genotype and environment, the F.NIRS predictions of liveweight change can be adjusted to provide a measure of the rate of liveweight change of lactating breeders.

Effects of supplementation on F.NIRS predictions

Urea supplements have no discernable effect on predictions using F.NIRS calibration equations derived from forage–only diets. In nine pen experiments (D.B. Coates and R.M. Dixon, unpublished), cattle were fed various low–quality tropical grass hays alone or supplemented with sufficient urea to increase the CP content of the total diet by 1.8–5.0%. The urea supplement was either mixed with a small amount of molasses (<0.5 g molasses DM/kg liveweight, equivalent to 200 g as–fed molasses for a 300 kg animal) or was part of a loose mineral mix. The urea supplements increased the F.NIRS prediction of the CP content of the diet by, on average, only 0.1% and that of DMD by 0.3%. In addition, in four experiments (R.M. Dixon, unpublished) where grazing cattle were either not

Table 1 Effects of age of the animal on F.NIRS predictions of the crude protein (CP) content and *in vitro* DM digestibility of the diet of cattle fed in pens on three tropical forage hays (n = 3) (D.B. Coates, unpublished).

Type of hay	Age of animal	F.NIRS prediction	
		CP (%)	DMD (%)
Native pasture[a]	Weaner	2.5	31
	Yearling	2.8	32
Chloris gayana	Weaner	8.8	51
	Yearling	8.5	50
Glycine wightii	Weaner	11.0	50
	Yearling	10.8	50

[a]Cut from nominally northern speargrass pasture and composed of *Heteropogon contortus, Chrysopogan fallax, Themeda triandra* and other *species*

supplemented or supplemented with sufficient urea to increase CP content of the total diet by 1–2%, there was no discernable effect of the supplement on the F.NIRS predictions of dietary CP and DMD. Thus, when F.NIRS calibration equations derived from forage–only diets are used to predict the quality of forage diets supplemented with urea, the F.NIRS predictions of diet quality are a measure the quality of the forage component of the diet.

Molasses–urea supplements may affect the F.NIRS predictions of dietary CP and DMD in some circumstances. In a series of experiments (Table 2), when the amount of molasses–urea supplement consumed was ≤2.3 g DM/kg liveweight.day and ≤11% of the diet (equivalent to less than about 900 g as–fed molasses for a 300 kg animal), diet CP and DMD predicted by F.NIRS using forage–only calibration equations were always similar to those for the forage fed without supplement. However, when 3.2–4.5 g molasses–urea supplement DM/kg liveweight.day was fed, the results differed between experiments. F.NIRS predicted diet CP was increased by 0.6 percentage units in two experiments, and predicted DMD was increased by ≥ 3 percentage units in four of the five experiments. Differences between experiments may have been associated with variation in the type of molasses. It is also possible that the supplement influenced diet selection in the grazing experiments but not in the pen experiments. When 5.9 g supplementary molasses–urea DM/kg liveweight.day were ingested, the F.NIRS predicted CP content of the diet was increased by 1.5 percentage units although the actual increase was 3.4 percentage units. Conversely, the 5.3 percentage unit increase in the F.NIRS predicted DMD was much greater than the actual increase of 2.1 percentage units measured in the experiment. Thus F.NIRS calibrations derived from forage–only diets can be only be used for prediction of the quality of the forage ingested when the molasses–urea supplement comprises less than about 2.3 g DM/kg liveweight.day and is less than about 10% of the total diet, and not when there are larger amounts of molasses in the diet.

Supplements of cereal grain or protein meals for forage diets can have large effects on F.NIRS predictions from calibration equations derived from forage–only diets. As little as 1.5 g DM/kg liveweight.day of a supplement based on cottonseed meal and sorghum grain led to unacceptable error (Lyons *et al.* 1993). It is possible to develop acceptable F.NIRS calibrations to predict both the total and forage components of mixed forage–concentrate diets if measurements are made with such diets (Gibbs *et al.* 2002). Mburuja (1995) reported poor fits of calibration equations to mixed forage–concentrate diets, but in this experimentation only a

Table 2 Effects of molasses–urea supplementation of tropical grass hays or of grazed tropical pastures on the actual and F.NIRS predicted crude protein content and DM digestibility of the diets of cattle. The predictions were made using F.NIRS calibration equations based on forage–only diets.

	Intake (g DM/kg LW.day)		Crude protein (%)			DM digestibility (%)	
Experiment and forage	Forage	Suppl't	Forage alone	Change in F.NIRS prediction	Expected change	Forage alone	Change in F.NIRS prediction
1. Blue couch	17.5	2.3	6.8	–0.1	+1.2	56	–2
(Digitaria didactyla) hay	22.3	4.5	6.8	+0.2	+1.6	56	0
2. Indian couch	20.7	2.3	7.1	–0.2	+1.0	53	0
(Bothriochloa pertusa) hay	20.9	4.5	7.1	+0.1	+1.9	53	+3
3. *Urochloa mosambicensis* hay	18.4	4.4	6.8	+0.3	+1.4	53	+4
4. Forage sorghum hay	15.0	4.5	5.9	+0.6	+1.7	54	+3
5. Grazed speargrass	20[a]	1.2	5.7	–0.7	+5.2	51	0
(Heteropogon contortus) pasture	20[a]	1.2	3.9	–0.3	+5.1	46	+1
6. Grazed speargrass–	20[a]	1.8	6.8	–0.3	+4.1	52	0
Stylosanthes spp. pasture	20[a]	1.7	4.6	–0.3	+4.1	48	–1
	20[a]	2.0	4.6	0	+4.4	47	0
7. Pangola *(Digitaria*	22.5	3.2	5.7	+0.6	+2.1	47	+3
decumbens) hay	21.5	5.9	5.7	+1.5	+3.4	47	+5

[a]Pasture intake assumed to be 20 g DM/kg liveweight.day.
Experiments 1–4, D.B. Coates, unpublished; experiments 5 and 6, grazing experiments at Swans Lagoon with three and five paddock replicates per diet respectively, R.M. Dixon, unpublished; experiment 7, R.M. Dixon and S.R. McLennan, unpublished

small sample set was used. An alternative approach, which can be adopted when cattle are fed concentrate supplements intermittently, is to sample faeces several days after ingestion of supplement in the expectation that the composition of faeces after this interval will reflect the forage component of the diet (Lyons *et al.* 1993). In steers fed a low quality hay daily and supplements in two meals per week, F.NIRS provided correct predictions of the CP content and DMD of the forage from faeces sampled 48–72 h after meals of up to 18 g cottonseed meal DM/kg liveweight, or 36 g cottonseed meal–sorghum grain DM/kg liveweight were ingested (Table 3). With assumptions about the voluntary intake of forage and intake of the supplement, estimates of the CP and DMD of the total diet can be calculated. In the same experiment (Table 3), F.NIRS predictions from faeces sampled 0–24 h after supplements were ingested were sometimes erroneous, regardless of whether the steers ingested supplements daily or intermittently, although the faecal NIRS predictions were more representative of the basal forage diet than of the total diet.

Use of F.NIRS to predict animal responses to supplementary rumen degradable nitrogen

In many areas of northern Australia cattle productivity is constrained by the low nutritive value of senesced pastures. Typically cattle only maintain, or lose, liveweight during the mid– to late dry season. Rumen degradable nitrogen (RDN) is usually the first–limiting nutrient for cattle grazing dry season pastures. Supplementation with urea during the dry season may improve liveweight by up to 35 kg, and in breeder–herds with low calving rates (e.g., 55–65%) can improve this rate by up to 15 percentage units (Winks 1984; Dixon and Doyle 1996; Dixon 1998). It is widely practiced in the northern industry. Although supplements that provide substantial amounts of metabolizable energy and undegraded dietary protein (e.g., molasses–urea, protein meal or cereal grains) are occasionally needed for young weaners and cows lactating during the dry season, the present discussion is limited to the use of F.NIRS with RDN supplementation. Key considerations for efficient management of RDN supplementation include when to commence supplementation as pasture quality declines and how much to provide. Most producers rely on subjective assessment of the pasture and of the cattle. Experiments have shown that a response to RDN supplementation can be expected when ingested forage contains less than 1% N (Minson 1990; Hogan 1996) or, at least for speargrass pastures, when faecal N concentration decreases to less than 1.3% (Winks *et al*. 1979). F.NIRS measures both these criteria, but also measures DMD to provide an estimate of metabolizable energy concentration of the diet.

The ratio, DMD/CP, represents a simple criterion to indicate whether the rumen fermentation and pasture intake are likely to be limited by effective rumen degradable protein (ERDP) supply. This approach was developed by Hogan (1982) except that calculations were based on digestible organic matter in the DM (DOMD), rather than digestible DM in the DM (DMD). DOMD is about 0.93 of DMD for forages of 40–55% digestibility (SCA 1990). Experiments with a wide range of temperate forages fed to sheep showed a curvilinear relationship

Table 3 F.NIRS predictions made with forage–only calibration equations of the crude protein (CP) concentration and the DM digestibility of the diet of cattle in pens (n = 3 per diet) fed Pangola *(Digitaria decumbens)* grass hay alone or with supplements of cottonseed meal (CSM) or a mixture of cottonseed meal and sorghum grain (CSM–sorghum). The supplements were fed either daily or in two meals each week.

Type of supplement	**Nil**	**CSM**		**CSM–sorghum**	
Amount of supplement	**0**	**L1**	**L2**	**L2**	**L3**
Prediction of diet CP (%)					
Unsupplemented	6.0	–	–	–	–
Supplemented daily	–	5.8	6.3	6.2	7.2
Supplemented intermittently, 0–24 h samples	–	5.9	6.4	6.1	7.0
Supplemented intermittently, 48–72 h samples	–	5.7	5.9	6.3	5.1
Prediction of diet DM digestibility (%)					
Unsupplemented	49	–	–	–	–
Supplemented daily	–	49	49	51	52
Supplemented intermittently, 0–24 h samples	–	50	48	51	52
Supplemented intermittently, 48–72 h samples	–	50	48	49	49

The amounts of CSM were 2.3 (L1) and 4.5 (L2) g/kg liveweight daily, or three–times and four–times this amount in steers fed two meals of supplement each week. Twice these amounts of CSM–sorghum supplement (L2 and L3) were fed. In steers supplemented daily, faecal samples were collected daily (n = 7). In steers supplemented intermittently, faecal samples were collected 0–24 h and 48–72 h after the supplements were provided (n = 2) and were bulked for analysis. (R.M. Dixon and S.R. McLennan, unpublished).

between DOMD/CP and rumen ammonia concentration. A rumen ammonia concentration of 20 mg/L, which is likely to be insufficient for maximum microbial fermentation and growth, corresponded to a DOMD/CP of 10 (equivalent to a DMD/CP of 10.8). Hogan *et al*. (1989) subsequently showed that in sheep fed tropical grasses rumen ammonia was likely to be deficient for rumen fermentation when the DOMD/CP was 5.5 (equivalent to a DMD/CP of 6). Little corresponding information is available for *Bos indicus* cattle fed tropical forages. However, Hogan (1996) suggested that deficiencies of ERDP occur in cattle ingesting temperate and tropical grasses at a DOMD/CP greater than 7 (DMD/CP of 7.6) and 5 (DMD/CP of 5.4), respectively. Stuth *et al*. (1999) suggested that ERDP is likely to be deficient when DOMD/CP measured by F.NIRS is greater than 7 (DMD/CP = 7.6), but the origin of these values was not clear.

Urea supplementation experiments with cattle in pens fed forage could be expected to provide evidence for a critical DMD/CP ratio above which cattle will respond to supplementary urea. In the majority of published experiments with *Bos indicus* cattle fed tropical forages, the DMD/CP ratio has been greater than 10 and the increase in voluntary forage intake due to urea has usually been in the range 10–40% (Ernst *et al*. 1975; Hunter and Siebert 1980, 1985b, 1987; Hennessy *et al*. 2000). Even greater increases in intake (40–100%) have been reported in some experiments (Lindsay *et al*. 1982; Mullins *et al*. 1984). Few experiments have reported the effects of urea supplementation on voluntary intake when the DMD/CP ratio was less than 10. In some such experiments (Hunter and Siebert 1985b, 1987; Bakrie *et al*. 1988) there was only a small increase (–11% to +6%) in voluntary forage intake, but a 28% increase reported by Hunter and Siebert (1980) was similar to the increase in intake when the DMD/CP values were greater than 10. Much of the variability may be ascribed to differences in experimental procedures, forage protein degradability and the leaf content and digestibility of the forage (Minson 1990; Rafiq *et al*. 2002).

An alternative approach is to use F.NIRS predictions of diet quality as inputs into a rumen model to calculate the supply of ERDP with low protein forages, but there are many uncertainties in the calculations. SCA (1990) and AFRC (1993) feeding standards assume that the transfer of endogenous RDN into the rumen is equal to the loss of ammonia N by absorption through the rumen wall. However, with low protein forage diets, the net transfer of endogenous N into the forestomachs has been shown in sheep to be equivalent to 20–100% of dietary N intake (Hogan and Weston 1970), and in cattle fed speargrass hay to be 120% of dietary N intake (Hunter and Siebert 1980). Thus, recycling of endogenous N to the rumen may make an important contribution to ERDP with such diets. A rumen model to calculate ERDP availability will need estimates of a number of parameters of flow of N, for which limited experimental data is available for cattle, or even for sheep, fed low quality forage diets. Firstly, information on the degradability of forage protein is required. Secondly, estimates of the transfer of endogenous urea and non–urea N to the rumen and of the degradability of the latter are required. Measurements of daily endogenous urea N transfer to the rumen of cattle fed forage diets containing less than 6% CP range from 10–50 mg/kg liveweight (Norton *et al*. 1979; Hennessy and Nolan 1988; Kennedy *et al*. 1992). Thirdly, the amount of rumen ammonia absorbed through the rumen wall and thus not available for rumen microbial synthesis needs to be estimated. In sheep fed low protein forage, this may be up to 24% of rumen ammonia (Nolan and Stachiw 1979; Hettiararchchi *et al*. 1999). Since ammonia absorption is highly dependent on rumen pH, estimation of this rate will require accurate prediction of rumen pH. Fourthly, an estimate is needed of the amount of ERDP required for microbial synthesis. The efficiency of microbial protein synthesis (MCP) in cattle fed tropical forages is usually 50–100 g/kg digestible organic matter (Hart and Leibholz 1983; Dixon *et al.* 1998; Bowen 2003). This is lower than that usually observed for temperate forage diets (80–230 g/kg digestible organic matter; SCA 1990). A low efficiency of MCP synthesis will reduce the amount of ERDP required. Thus, in cattle fed low quality forages the prediction from dietary constituents of the amount of ERDP required is likely to be subject to large error.

Despite these uncertainties, we calculated the availability of ERDP/kg digestible organic matter for various values of DMD and CP using the following assumptions: rumen degradability of forage protein = 70%; daily transfer of endogenous urea N to the rumen = 20 mg/kg liveweight; daily transfer of non–urea endogenous N to the rumen = 0.5 g salivary protein N plus 1.5 g epithelial N per kg DM (Norton 1984); degradability = 50% and 10% respectively; rumen ammonia absorbed through the rumen wall = 20%. These calculations suggest that availabilities of 90 and 120 g ERDP/kg digestible organic matter are equivalent to DMD/CP ratios of 8 and 5.7 respectively. This is consistent with the proposals of Hogan (1996) and Stuth *et al*. (1999) that ERDP will be deficient when DMD/CP is greater than 6–8. The DMD/CP ratio appears to be the most useful of F.NIRS indices for predicting RDN supplementation responses in the field and has the advantage of simplicity.

Evidence from field trials for the DMD/CP ratio at which responses to RDN supplementation can be expected

Field trials, where grazing cattle have been not supplemented or provided with RDN supplements and animal liveweight and F.NIRS measurements also made regularly provide direct evidence of the DMD/CP ratio above which animal liveweight responses can be expected. DMD/CP ratios and liveweight change for cattle grazing a *Bothriochloa pertusa* pasture on a low fertility soil near Charters Towers during two low rainfall years are shown in Figure 1. Urea supplement unequivocally improved liveweight when the DMD/CP ratio was greater than 10. Results for a second site on Mitchell Grass Downs near Julia Creek indicated that an animal response to urea supplementation occurred when the DMD/CP was greater than 10 (Figure 2). During two subsequent dry seasons at the same site, the DMD/CP ratio was consistently less than 10 and a liveweight response to urea supplement did not occur until late in the dry season; dietary CP was apparently maintained by the availability of forbs which would be of higher CP content, and possibly higher in N degradability, than the senesced Mitchell and Flinders grasses.

Trial results from northern speargrass pastures at Swans Lagoon near Townsville support the hypothesis that responses to urea supplementation can be expected when DMD/CP is greater than 8. In this environment, a urea supplementation response can be expected when faecal N concentrations decrease to less than 1.3% N (Winks *et al*. 1979). Recent trials have shown that this coincides with a DMD/CP ratio measured by F.NIRS of 8–9.

More information is needed for a range of pasture systems on the DMD/CP ratio at which an animal response occurs to RDN supplementation. The critical DMD/CP value can be expected to vary with the degradability of forage protein, species, maturity and phenotype of forage, and with animal genotype and physiological state. When fed low protein forages, *Bos indicus* cattle are less susceptible to RDN deficiency than *Bos taurus* cattle, with lower N excretion and a greater ability to maintain rumen ammonia concentrations (Winks *et al*. 1972; Hunter and Siebert 1985a; Hennessy *et al*. 1995, 2000). Nevertheless, in general, a response to RDN supplements appears very likely when the DMD/CP ratio is greater than 10 and, at least for speargrass pastures, is likely when the DMD/CP is greater than 8. An animal response obviously also depends on factors other than sufficiency of ERDP, most importantly the availability of enough pasture with sufficient leaf to sustain an increase in voluntary forage intake (Rafiq *et al*. 2002).

Using F.NIRS to predict the amount of supplementary RDN required by grazing cattle

F.NIRS estimates of the metabolizable energy and CP contents of the diet should allow estimation of the amounts of RDN required and the magnitude of the animal response. Recommendations on the amount of supplementary urea needed by cattle for dry season conditions in northern Australian are usually based on the dose–response field experiments in the northern speargrass pasture system of Winks *et al.* (1972, 1979). These experiments indicated that in young *Bos indicus* cross cattle of 250–340 kg liveweight, in most years about 30 g supplementary urea per day was sufficient to achieve most of the possible liveweight response. This led to general recommendations of 30 g urea per day for weaner and yearling cattle, and by scaling for liveweight, 50–60 g supplementary urea for a breeder cow. However, it is clear from the original experimental results (Figure 3) that the amount of supplementary urea required for the maximum animal response varied widely between years, from about 15–90 g. Subsequent pen experiments examining dose–responses of urea supplement for low quality forages support the hypothesis that up to 90 g urea per day may be needed to achieve the maximum animal response (Kennedy *et al.* 1992; Hennessy *et al.* 2000).

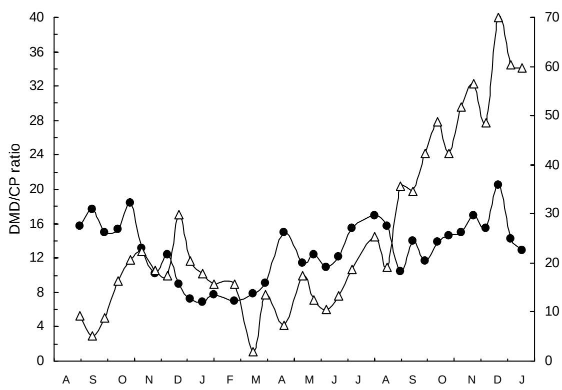

Figure 1 Effect of urea–S supplied in the drinking water of steers (initial liveweight 275 kg) at Forest Home, Charters Towers, during the 2001 and 2002 dry seasons. The ratio DMD/CP (•) was measured by F.NIRS. The cumulative liveweight benefit (kg) of feeding the supplement, relative to unsupplemented steers, is shown (Δ).

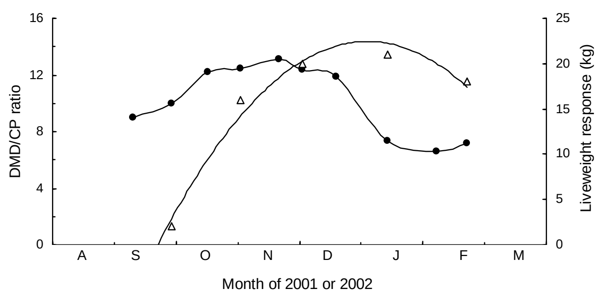

Figure 2 Effect of urea–based loose mineral mix supplement for steers (initial liveweight 230 kg) at Toorak, Julia Creek, during the 2001 dry season. The ratio DMD/CP (•) was measured by F.NIRS. The cumulative liveweight benefit (kg) of feeding the supplement, relative to unsupplemented steers, is shown (Δ).

The DMD/CP ratio should provide a measure of the deficiency of ERDP. The maximum DMD/CP ratio of the diet selected by cattle grazing tropical grass pastures is likely to be about 16. We speculate that if 90 g supplementary urea were required when the DMD/CP = 16, and if no supplementary urea were required when the DMD/CP = 7, then the amounts of supplementary urea shown in Table 4 for various DMD/CP ratios are likely to be appropriate. Although these amounts are speculative, they are likely to be more appropriate than providing a fixed amount of supplementary urea when, from nutritional principles, the amount required will vary.

The amounts of supplementary urea proposed in Table 4 may differ from the amounts calculated using the F.NIRS estimates of diet metabolizable energy and CP and the SCA (1990) or AFRC (1993) feeding standards. These feeding standards are likely to overestimate the actual requirements of *Bos indicus* cattle grazing tropical dry season pastures for RDN. Firstly, as discussed above, no allowance is made in these feeding standards for the contribution of endogenous N to ERDP even though it is clearly important with low protein forage diets. Secondly, the SCA (1990) and AFRC (1993) calculations are derived principally from measurements on *Bos taurus* cattle fed temperate forages of at least moderate CP content. However, when consuming low quality tropical forage diets, *Bos indicus* cattle appear to have lower requirements for supplementary RDN than *Bos taurus* cattle. In contrast to the influence of these factors, when supplementary urea is provided as loose mineral mixes, blocks or molasses–urea to cattle grazing in extensive rangelands, the supplement is usually ingested over a short interval; this is likely to lead to inefficient contribution of the urea to ERDP (Romero *et al.* 1976).

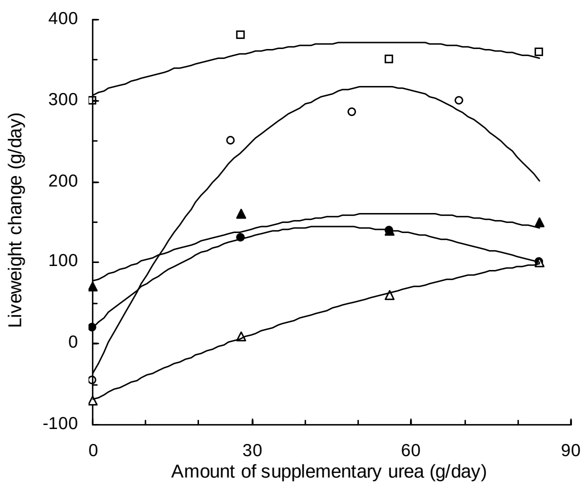

Figure 3 Liveweight responses of young *Bos indicus* cross cattle grazing northern speargrass pastures to various levels of urea mixed with 230–250 g molasses and fed using roller drums during each of five dry seasons (Winks *et al.* 1972, 1979). About 6–8 g urea per day would have been required to ferment the molasses component of the supplement.

The recommendations based on the field experimentation at Swans Lagoon are likely to be more appropriate than the feeding standards since the measurements were derived directly from *Bos indicus* cross cattle grazing tropical dry season pastures. An important further consideration is that each of the supplement delivery systems used in the extensive rangelands usually involves some risk of urea toxicity due to excessive intake of supplement by some animals. Management procedures have evolved, mainly from observation and experience, to provide amounts of supplementary urea such as 30 g for young animals, but care would be needed to avoid an increased risk of urea toxicity if much larger amounts of supplementary urea are provided. Many managers may decide that the risk of urea toxicity is more important than an increase in animal productivity possible under some circumstances due to providing large (e.g., greater than 60 g urea/head.day), rather than moderate, amounts of supplementary urea.

Conclusions

F.NIRS is still an emerging technology and application that is more widespread is constrained by a number of factors. There are difficulties with the application of F.NIRS to regions and pasture systems that are not represented adequately in existing calibration data sets, e.g., where cattle ingest appreciable amounts of browse, graze temperate pastures and for herbivores other than cattle. Secondly, the error associated with the prediction of attributes may be substantial. Thirdly, there is an ongoing need, as with all NIRS measurement, for validation and expansion of calibration equations. Nevertheless, F.NIRS is a major advance to improve understanding of the nutrition of grazing cattle, particularly in extensive rangelands. F.NIRS can provide estimates of diet quality, which are sufficiently reliable for many purposes, which cannot be obtained by any other technology, and which allow application of nutritional science to grazing cattle in a manner, which has never previously been possible.

DMD/CP ratio	Amount of supplementary urea per head per day
8–9	20
9–10	30
10–12	50
12–14	70
Greater than 14	90

Table 4 Recommended amounts of supplementary urea for cattle of 250–350 kg liveweight when the DMD/CP ratio is measured with faecal NIRS. Care would be needed to avoid urea toxicity when the larger amounts of urea indicated below are fed, particularly to animals of low liveweight.

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