Faecal near infrared spectroscopy to measure the diet selected and productivity of grazing ruminants

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Abstract. In ruminants near infrared spectroscopy of faeces (F.NIRS) can measure the concentrations of faecal constituents such as N and fibre. It can also directly estimate many diet attributes, including total N, fibre, digestibility and the major plant groups (*e.g.* monocots versus dicots, and some plant species). In some situations F.NIRS can be used to estimate voluntary intake and liveweight change, but it is difficult to encompass animal effects (*e.g.* lactation, maturity), pasture availability or mineral deficiencies. Application of F.NIRS, especially in conjunction with other measurements (*e.g.* metabolizable energy intake calculated from liveweight change, $^{13}C/^{12}C$ ratio in faeces, microbial protein synthesis and phosphorus concentrations in faeces) can provide valuable and reliable information about the nutritional status of grazing ruminants. Examples where F.NIRS has been used to measure the nutritional status of grazing cattle and sheep are described for extensive and intensive tropical production systems in northern Australia, the Caribbean, the Amazonian humid tropics, and for temperate pastures in Europe. F.NIRS can be applied to routinely and economically measure the nutrient intakes of grazing ruminants, and such information used to modify herd management.

Keywords: Grazing ruminants, nutrient intake, NIRS, ruminant production.

Introduction

Faeces contain a wide array of information about the diet and physiology of grazing herbivores (Putman 1984). Deriving information from faeces has advantages in that faeces can usually be sampled in the field, and the difficulties associated with measuring diet selection by the grazing herbivore are circumvented. Diet has often been estimated from faecal analysis through development of relationships between diet (*e.g.* digestibility, nitrogen (N), intake) and the concentrations of faecal constituents (*e.g.* N), but large error may occur because such relationships are often specific to the pasture and animal circumstances (Peripolli *et al.* 2011). In contrast, relationships between NIR spectra of faeces and diet attributes are generally less variable, and numerous studies have demonstrated that F.NIRS can also be used to estimate many diet attributes (Stuth *et al.* 2003; Decruyenaere *et al.* 2009; Dixon and Coates 2009). F.NIRS has the inherent advantage that a very wide range of chemical constituents and other attributes of the faeces contribute to the NIR spectra, and therefore have the potential to contribute to the calibration models which predict diet attributes from faeces.

The development of F.NIRS to estimate diet attributes of ruminants

NIRS analyses involve measurement of light absorption in the 700-2500 nm region which is closely related to important chemical bonds (OH, NH and CH). It is a well-established technique in agriculture, including for feedstuffs analyses. NIRS analysis of faeces to predict diet attributes has many similarities to NIRS measurement of forages. Faecal samples are usually dried and ground, and the spectroscopy involves similar instrumentation and chemometrics (mathematical manipulation of the spectral data). F.NIRS depends on the development, in representative sample sets, of empirical mathematical relationships (calibration equations) between faecal spectra and the diet attributes measured by established analytical or animal based procedures. Calibrations are then applied to the spectra of unknown samples to estimate constituents or attributes of interest (Williams and Norris 2001). Development of F.NIRS calibration equations requires matching diet-faecal pairs of samples; this generally requires animals in pens fed designated diets, or oesophageally fistulated grazing animals.

A comprehensive summary of measurement errors in published F.NIRS studies has been reported (Dixon and Coates 2009). The standard error of prediction of diet digestibility is typically 20-40 g/kg units, which is comparable with the error associated with measurement of forage digestibility using established *in vitro* techniques. Diet crude protein concentration can be predicted with a standard error of about 10 g/kg, and neutral detergent fibre with a standard error of about 10-20 g/kg. Voluntary intake has been predicted with a standard error of 2-4 g DM/kg liveweight, or 5-10 g DM/kg metabolic liveweight ($W^{0.75}$). However, there are additional considerations with F.NIRS estimation of voluntary intake or animal liveweight change, since the predictions are limited to a specified class of animal and do not allow for changes in intake due to animal factors (lactation, maturity, compensatory growth), mineral nutrient deficiencies, or if intake is constrained by availability of pasture. The major plant groups of monocots versus dicots, and in some situations specified plant species, in the diet can also be estimated with a standard error of about 50-60 g/kg (Coates and Dixon 2008). Application of F.NIRS, especially in conjunction with other measurements (*e.g.* estimation of metabolizable energy intake from live-weight change, $^{13}C/^{12}C$ ratio in faeces, microbial protein synthesis from purine derivative excretion, and evaluation of animal phosphorus status from the concentrations of phosphorus in blood and faeces) can provide comprehensive information about the nutritional status of grazing ruminants in specific situations. Furthermore F.NIRS allows rapid, low-cost and frequent estimations of the diet selected by grazing ruminants through seasons and years in the commercial farm context. This allows application of quantitative nutritional management to achieve target production outcomes with optimal inputs.

Examples of situations where F.NIRS has been used to estimate nutritional status of grazing ruminants

Example 1: Breeder cows grazing a native pasture in northern tropical Australia (Dixon et al. 2007)

F.NIRS was used to measure the diet selected by breeders during 4 annual cycles in a seasonally dry tropical environment in northern Australia (Fig. 1). Groups of heifers (most mid-pregnancy, some non-pregnant) were introduced to the experiment in the mid-dry season (August) and calved in November-December. Calves were weaned in April or August. Liveweight change of treatment groups (non-pregnant non-lactating, pregnant and lactating, post-weaning) was related to the quality of the diet estimated with F.NIRS. Diet quality varied widely between seasons and also between years. The diet was low in digestibility and was deficient in crude protein during the dry season from August until the seasonal break in November-December. The diet quality was high during the wet season (diet DM digestibility generally 550-650 g/kg), and then progressively declined into the following dry season. Thus the nutritional demands of lactation could be related to diet quality and cow liveweight change.

Example 2: Steers grazing Leucaena-grass pasture in subtropical Australia (Dixon and Coates 2008)

Three successive drafts of growing *Bos indicus x Bos taurus* steers grazed a paddock of *Leucaena*-C_4 grass pasture, and F.NIRS measurements at frequent intervals provided estimates of digestibility and crude protein,

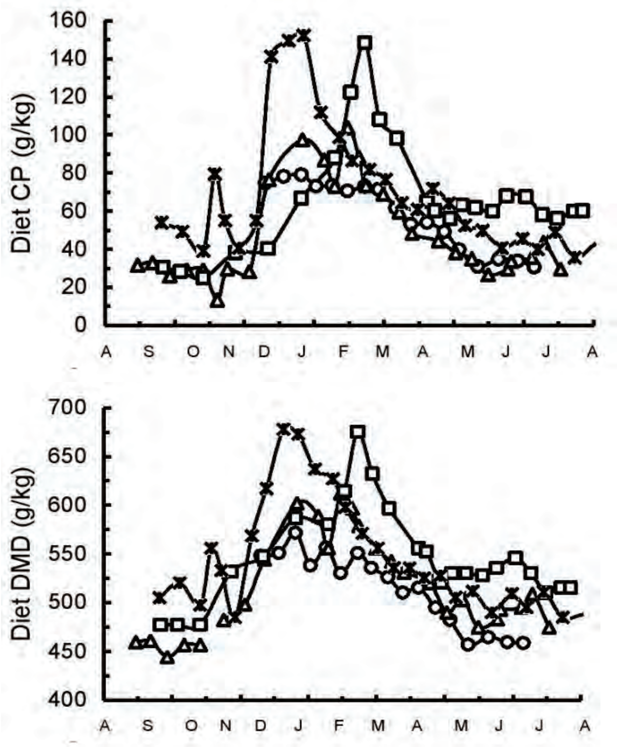

Figure 1. (top) Diet crude protein (CP, g/kg DM) and (bottom) dry matter digestibility (DMD) estimated using F.NIRS at fortnightly intervals during the annual cycle in breeder cows grazing tropical native pasture speargrass pastures during 4 consecutive years. A new group of pregnant heifers which calved in November - December replaced the previous group each year in August. Each symbol represents a draft of animals (after Dixon *et al.* 2007)

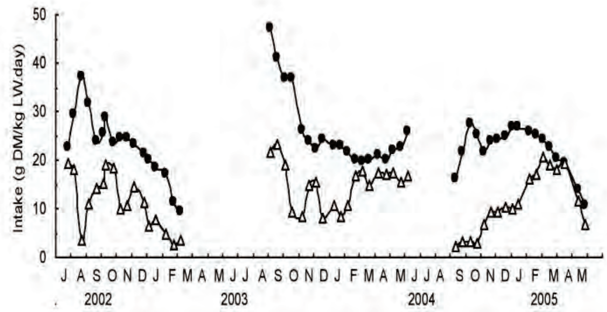

Figure 2. The estimated intakes of *Leucaena* DM (Δ) and total DM (●) (g/kg LW.day) for 3 successive drafts of steers. Total DM intake was calculated from the metabolizable energy intake estimated to be required for the measured liveweight gain and the DM digestibility of the diet. The *Leucaena* intake was calculated from the total DM intake and the proportion of *Leucaena* in the diet, while the difference between the intakes of total DM and *Leucaena* DM was grass DM intake (Dixon and Coates 2008)

and the proportion of *Leucaena*, in the diet. The intake of total pasture DM, and of grass and *Leucaena* DM, were calculated from the metabolizable energy required for the measured liveweight gain and diet digestibility (Fig. 2). The contribution of *Leucaena* to total DM intake and nutrient intake was estimated as the grazing cycle progressed through summers with variation in rainfall.

Table 1. The pasture available, leaf/stem ratio, diet digestibility of organic matter (OM), voluntary intake of digestible organic matter (DOM), and milk production, in ewes during 5 successive lactations and grazing *Digitaria decumbens* pasture in the humid tropics in the French Antilles (Boval *et al.* 2010)

Measurement	Lactation 1	Lactation 2	Lactation 3	Lactation 4	Lactation 5
Season	Dry	Dry	Intermediate	Intermediate	Wet
Herbage mass (t/ha)	2.9	3.1	3.0	2.9	3.8
Leaf/stem ratio	1.4	1.2	0.6	1.4	0.9
Diet OM digestibility (g/kg)	644	675	661	661	704
DOM intake (g/kg $LW^{0.75}$.day)	83.5	68.0	63.4	81.6	47.2
Diet crude protein (g/kg)	157	170	162	162	180
Milk output (kg/day)	1.11	1.05	1.09	1.31	0.96

F.NIRS calibration equations for liveweight change developed for cattle grazing extensive northern Australian grasslands did not satisfactorily predict liveweight of these steers grazing *Leucaena*-grass pasture. However liveweight change could be predicted with a useful accuracy if F.NIRS calibrations were modified for the specific experimental site; this indicated that satisfactory prediction of liveweight change was possible.

Example 3: The diet of lactating ewes grazing a grass pasture in the humid tropics (Boval et al. 2010)

A study measured the diet of lactating ewes rotationally grazing N fertilized grass pastures, and examined the relationships between diet quality and pasture characteristics. F.NIRS was used to measure voluntary intake, digestibility, crude protein concentration, and fibre concentration of the diet selected by the ewes (Table 1). Calibration equations previously developed by the same research group with housed sheep were used to predict the diet attributes. Digestibility and digestible organic matter intake were high for ruminants ingesting tropical pastures. Both digestible organic matter intake and milk production were negatively correlated with the organic matter digestibility, which was in contrast to expected positive correlations between diet digestibility and voluntary intake. It appeared that in these grazing ewes pasture factors such as leafiness and bulk density were more important than digestibility as constraints to metabolizable energy intake. Use of F.NIRS in the present study made possible these measurements in the grazing animal.

Example 4: Estimation of methane emission by grazing cattle in the humid, French Guyana (M. Boval and V. Blanfort, unpublished data)

Faecal samples were obtained from young *Bos indicus* cattle grazing paddocks with a variety of *Brachiaria humidicola*-based pastures. F.NIRS was used to estimate digestible organic matter intake. Methane emissions were estimated from the diet through the use of predictive models (Archimedes *et al.* 2012). Diet organic matter digestibility ranged among paddocks from 550 - 700 g/kg which was consistent with previous measurements for *Brachiaria decumbens* in comparable circumstances (Heuzé and Sauvant, 2011). Digestible organic matter intake ranged from 10-14 g/kg LW/day, and estimated methane emissions were the equivalent of 40 - 58 kg methane/year for a 400 kg animal. This range in methane emission may have been at least partly due to a range in legume content of pasture among the paddocks. Even though the estimates varied among the prediction models examined, the estimated methane emissions were still lower than the emission set by the GIEC (53-63 kg methane/cow). F.NIRS provided an easy and convenient approach to estimate the diet ingested and methane emissions in grazing cattle in a farm context. Further evaluations are ongoing; however F.NIRS may contribute to the establishment of greenhouse gas balance at farm scale certification tools necessary for payment mechanisms for environmental services.

Example 5. Digestibility and intake of lactating cows grazing temperate pasture (Decruyenaere et al. 2012)

Grass *in vivo* organic matter digestibility (G-OMD) and grass dry matter intake (G-DMI) were measured in grazing lactating dairy cows also fed concentrate supplements; the latter comprised a fixed amount of sugar beet pulp plus additional commercial supplement in proportion to milk production. Pasture comprised about 70% temperate grass species, 20% clover, and 10% miscellaneous species. During the measurement period cows (n=13) rotationally grazed 2 paddocks and the amount of supplement was allocated at the herd level. F.NIRS predictions of G-OMD and G-DMI were compared with others methods (faecal N concentration, a faecal output marker, and calculation from the nutrient requirements for the measured level of production) to estimate these parameters. For both G-OMD and G-DMI, the F.NIRS estimates were correlated ($P<0.05$) with the other predictive methods ($r = 0.61$ for G-OMD and $r = 0.63-0.88$ for G-DMI). G-OMD ranged from 689-773 g/kg, and G-DMI from 11.9-16.4 kg/cow.day. For both G-OMD and G-DMI and for all the estimation methods, the inter-cow and intra-paddock variations (expressed as the coefficient of variation (SD/mean)) ranged from 0.05 to 0.40. Since the accuracy of the predictions from the F.NIRS models, expressed as the standard error of cross-validation, was lower than these inter-animal and intra-paddock variations, it was concluded that F.NIRS could be used to quickly and easily record the progressive changes in the grass digestibility and the intake of pasture by grazing dairy cows. Thus the present study suggested that F.NIRS can predict diet characteristics of supplemented grazing dairy cows, and that this technology can be used through decision-support systems for improving the management of grazing dairy herds.

Conclusion

F.NIRS can provide rapid low-cost estimations of many diet attributes of grazing ruminants from samples of faeces which can be collected in the field. It provides a valuable research tool to measure nutrient intake of production animals, especially if it is complemented by other established measurement techniques for grazing animals. In addition, it provides a practical tool for quantitative management of the nutrition of grazing livestock in commercial situations. The greatest limitations are that research for the development and ongoing validation of the necessary calibration equations is costly, specialist instrumentation and technical expertise are needed, and calibration equations are generally applicable only to the land systems, pastures, and animals for which they have been developed.

References

Archimède H, Eugène M, Marie Magdeleine C, Boval M, Martin C, Morgavi DP, Lecomte P, Doreau M (2011) Comparison of methane production between C3 and C4 grasses and legumes. *Animal Feed Science and Technology* **166-167,** 59-64.

Boval M, Ortega-Jimenez E, Fanchone A, Alexandre G (2010) Diet attributes of lactating ewes at pasture using faecal NIRS and relationship to pasture characteristics and milk production. *Journal of Agricultural Science, Cambridge* **148,** 477-485.

Coates DB, Dixon RM (2008) Development of NIRS analysis of faeces to estimate non-grass proportions in the diets selected by cattle grazing tropical pastures. *Journal of Near Infrared Spectroscopy* **16,** 471-480.

Decruyenaere V, Lecomte P, Demarquilly C, Aufrere J, Dardenne P, Stilmant D, Buldgen A (2009) Evaluation of green forage intake and digestibility in ruminants using near infrared reflectance spectroscopy (NIRS): developing a global calibration. *Animal Feed Science and Technology* **148,** 138-156.

Decruyenaere V, Froidmont E, Bartiaux-Thill N, Buldgen A, Stilmant D (2012) Faecal near infrared reflectance spectroscopy (NIRS) compared to other techniques for estimating the *in vivo* digestibility and dry matter intake of lactating grazing dairy cows. *Animal Feed Science and Technology* **173,** 220-234.

Dixon RM, Smith DR, Coates DB (2007) Using faecal NIRS to improve nutritional management of breeders in the seasonally dry tropics. *Recent Advances in Animal Nutrition in Australia* **16,** 123-134.

Dixon RM, Coates DB (2008) Diet quality and liveweight gain of steers grazing *Leucaena*- grass pasture estimated with near infrared reflectance spectroscopy (F.NIRS). *Australian Journal of Experimental Agriculture* **48**, 835-842.

Dixon RM, Coates DB (2009) NIR spectroscopy of faeces to evaluate the nutrition and physiology of herbivores. A review. *Journal of Near Infrared Spectroscopy* **17,** 1-31.

Heuzé V, Sauvant S (2011) Koronivia grass (*Brachiaria humidicola).* Feedipedia.org, INRA, CIRAD and AFZ with the support of FAO.

Peripolli V, Prates ER, Barcellos JOJ, Neto JB (2011) Fecal nitrogen to estimate intake and digestibility of grazing ruminants. *Animal Feed Science and Technology* **163,** 170-176.

Putman RJ (1984) Facts from faeces. *Mammal Review* **14,** 79-97.

Stuth J, Jama A, Tolleson D (2003) Direct and indirect means of predicting forage quality through near infrared reflectance spectroscopy. *Field Crops Res*earch **84,** 45-56.

Williams P, K Norris (eds.) 2001. Near-Infrared Technology in the Agricultural and Food Industries, 2nd Edn. American Association of Cereal Chemists, St Paul, Minnesota, USA.