The importance of near infrared spectroscopy in deciding appropriate feeding strategies for Australian livestock

P.C. Flinn and G.J. Downes

Agriculture Victoria, Pastoral and Veterinary Institute, Private Bag 105, Hamilton, Vic. 3300, Australia.

Introduction

The title of this session refers to "a time for new paradigms". The word "paradigm" is derived from the Greek *paradigma* and simply means an example or pattern, but it sounds impressive and now appears quite frequently in our modern idiom. A recent definition of "paradigm", in a business context, was "a set of rules and regulations (written or unwritten) that does two things: (i) establishes or defines boundaries and (ii) tells you how to behave inside the boundaries in order to be successful".[1] This immediately brings to mind the practice of near infrared (NIR) spectroscopy and, in particular, its increasing use in decisions about feeding strategies for grazing animals in Australia.

Grazed pasture is the cornerstone of Australia's livestock industries. In Victoria alone, 60% of agricultural production comes from grazing animals, in the form of wool, meat and milk. In all grazing enterprises, the aim is to minimize the use of expensive supplements but Australian pastures have highly fluctuating growth and quality patterns. For example, in southern Australia pasture growth can vary from 60 kg dry matter per hectare per day (DM/ha/d) in spring (October/November) to 5 kg DM/ha/d in late summer (February/March).[2] This results in seasonal limitations to animal production due to low availability or poor feeding value, or both. The feed gaps must be modified if the needs of pregnant, lactating or young growing animals are to be met, or if liveweight maintenance or even survival is to be ensured in a drought.

The development of rapid and accurate feed quality testing based on NIR allows real-time decisions to be made on appropriate feed supplements to purchase and utilise, as well as monitoring the nutritional status of grazed pastures. NIR will also be an integral part of an objective quality description system about to be introduced in the Australian fodder industry. However, much remains to be done and there are many challenges ahead. This paper seeks to place NIR in perspective, as a technology with a growing impact on decision-making in grazing and feeding management.

Models for grazing management: the role of NIR

Meeting the needs of grazing animals is a more complex problem than for housed animals, which are totally fed and where greater control of rations is possible. In the grazing situation, the huge variation in quality and quantity of pasture available and the difficulty in estimating how much pasture animals are eating, presents a real challenge to nutritionists and producers. As an

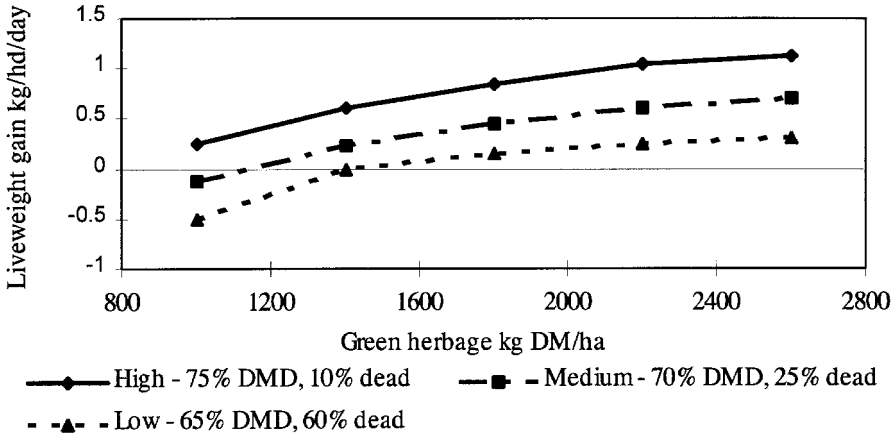

Figure 1. Effect of pasture quality and quantity on steer growth (350 kg).

example, the effect of pasture quality (dry matter digestibility, DMD) and quantity on the growth of 350 kg steers is shown in Figure 1.[3]

It is evident from Figure 1 that the steers will only gain in excess of 1 kg/head/d if the pasture DMD is at least 75%, there is less than 10% dead material present and at least 2,000 kg DM/ha of green herbage available.

This problem has led to the development of computer models to predict animal performance from pasture status. One such model is Grazfeed, developed by CSIRO researchers and now marketed commercially in Australia. It is based on a large amount of experimental data and allows informed decisions to be made on the amount and type of supplement to feed (where necessary), the optimum stocking rate, target production rates for specialised markets and pasture benchmarks for various types of animals.

The Grazfeed user is required to enter data on pasture quantity, DMD, legume content, grass species, season, latitude and weather conditions. The supplement type being considered is also entered, together with its cost (which can fluctuate wildly depending on seasonal conditions), DM, DMD, crude protein (CP) and protein degradability. Details of the animals to be fed are also required, such as type and breed, age and liveweight. The program can test the effect of different feeding levels or the user can set a target weight gain or milk yield.

Clearly, information on pasture and supplement quality is a key requirement and NIR is increasingly being used to provide it. Intensive efforts are also being made to educate producers on how to estimate the quantity of pasture available in a given paddock.

The importance of knowing the quality of the supplement to be used is illustrated in the case of hay and silage, where large variations in CP, DMD and estimated metabolisable energy are commonly observed (Table 1). This variation, now well-recognised by producers, has led to a steady increase in demand for feed testing. An example of this is Agriculture Victoria's commercial Feedtest service, which is now largely based on NIR, and has built up calibrations over several years for routine estimation of DM, CP and DMD of hays, silages, pastures, cereal grains and many mixed feeds.

Table 1. Quality of hay and silage measured by NIR (Feedtest service, Hamilton, Victoria, 1995).

Constituent	Product	Mean	Range
CP %	Hay	11.2	3.7–24.3
	Silage	14.9	6.6–22.1
IVDMD %	Hay	62.3	45.1–78.0
	Silage	66.5	46.7–78.3
ME (MJ kg^{-1} DM)	Hay	8.6	5.7–11.3
	Silage	9.3	5.9–11.3

CP = crude protein.
IVDMD = predicted *in vivo* dry matter digestibility (from pepsin–cellulase digestion).
ME = estimated metabolisable energy (from IVDMD).

Prediction of DMD and ME: nudging the boundaries

The Grazfeed program relies heavily on estimates of DMD, of both pastures and supplements, for prediction of animal performance. The DMD of a feed is one of the most important indicators of nutritive value.[4] However, DMD is a *property* of a feed rather than a *constituent* and is influenced by many different factors. At Hamilton, we have for many years estimated DMD using the pepsin–cellulase enzymatic technique[5] to measure the disappearance of dry matter and then adjusting analytical values using a linear regression (derived with every batch of unknown samples) based on similar samples of known *in vivo* DMD. The R^2 and residual standard deviation (RSD) values for these regressions typically range from 0.90 to 0.95 and 1.5 to 2.5 respectively. The predicted DMD values are then used in turn to derive NIR calibrations for DMD.

Great care is needed in the use of laboratory predictions of DMD in certain grazing or feeding situations, where the successful linking of NIR with decision-making depends on feed and animal factors as much as on appropriate calibration protocols. Some examples follow.

Pastures

Pasture samples can vary widely in ash content, particularly on heavily stocked pastures during winter in southern Australia. Soil contamination can result in pasture samples containing up to 50% ash and consequently DMD values are much lower than expected, often giving a false picture of pasture quality. Because of this, it is preferable to express digestibility on an organic matter basis (OMD) instead of as DMD, but at Hamilton relatively few of our *in vivo* standards have had OMD values and our NIR calibrations are based on DMD. Until we acquire more standards with OMD, we overcome the problem by deriving an NIR calibration for ash in pasture and using this to screen all pasture samples for ash content. If samples contain more than about 15% ash, they are analysed for OMD using a separate but more narrow-based calibration.

Pelleted sheep diets

Live sheep exported by sea from Australia to the Middle East rely on pelleted complete diets, containing both roughage and grain. NIR has been used successfully for several years as a test method to ensure pellets conform to nutritional standards. However, DMD predictions were

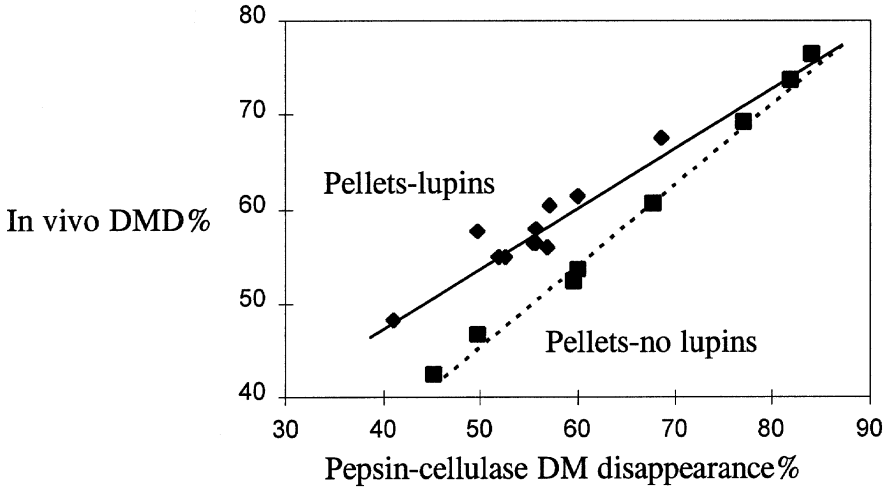

Figure 2. Effect of high lupin content on the digestibility of pelleted sheep diets.

initially based on *in vivo* standards containing only roughage and cereal grain. These were later found to be inadequate when applied to pellet samples from Western Australia which contained from 10% to 30% lupin grain. *In vivo* DMD of pellets containing lupins appear to be higher than expected (Figure 2) and use of the inappropriate regression line results in serious under-estimation of DMD by the pepsin–cellulase method. For some time, we used the "lupin line" to test high-lupin pellets separately, but our NIR calibration for DMD is now based on both types of pellets, where calibration values are obtained from either regression line, as appropriate. When the problem first occurred, NIR was blamed but as happens so often, the cause was nothing to do with NIR.

Cereal grains: whole vs processed

For logistical reasons, *in vivo* measurements of DMD are most frequently obtained using sheep rather than cattle but there is often debate on the validity of applying DMD predictions based on sheep data to cattle diets. The problem is more serious with cereal grains than with forages, as grain processing can greatly affect DMD. In a comparison between whole and cracked barley fed to either sheep or beef cattle, Clarke *et al.*[6] found that DMD of whole barley was markedly lower

Table 2. Dry matter digestibility (%) of whole and cracked barley in cattle compared to sheep (mean ± SD).[6]

	Whole barley	Cracked barley	Difference
Sheep	83.1 ± 2.5	81.8 ± 1.7	1.3 ns
Cattle	52.9 ± 3.4	82.2 ± 2.3	29.3[a]
Difference	30.2[a]	0.4 ns	

[a]denotes significance at 0.1% level ($P < 0.001$).
ns: denotes no significant difference.

for cattle than for sheep (Table 2). With cracked barley, there was no difference in DMD between sheep and cattle.

Until more *in vivo* DMD values for grains are available using cattle, laboratory estimates of DMD based on sheep data and intended for cattle can be used with confidence only when the grain is processed in some way before feeding. Further work is required to determine the effect of different grain processing methods on DMD estimation. This issue must be taken into account when using NIR analysis of feed grains.

Effect of fat content in grain on ME prediction

The ME system was adopted in Australia in 1978 and is now widely used. However, very few institutions have the facilties to measure ME and it is most often predicted from various chemical analyses or, more accurately, from DMD. At Hamilton, we use the equation ME (MJ kg^{-1} DM) = 0.17 DMD% – 2.0[7] for most feeds, but this equation does not account for fat content, which can result in underestimates of ME for feeds containing appreciable levels of fat. M. Freer[8] has suggested an alternative prediction equation which incorporates fat and thus increases predicted ME values where fat is high.

The equation is ME = 0.164 (DMD% + Fat%) – 1.6, and Freer has now included it in the Grazfeed program. Two examples illustrate the point. The predicted ME of barley (DMD 82%, fat 2%) using the SCA and Freer equations is 11.9 and 12.1 MJ kg^{-1} DM respectively. The difference here is negligible but in the case of whole cottonseed (DMD 72%, fat 25%) the respective ME predictions differ greatly (10.2 and 14.3 MJ kg^{-1} DM) and the SCA equation seriously underestimates ME. We are now in the process of deriving NIR calibrations for fat in various grains and mixed feeds and will use this information to decide which ME prediction equation is appropriate.

By-products: should we even try?

Prediction of DMD of by-product feeds represents a real challenge to feed testing laboratories. In Australia, farmers are attracted to by-products because they are often cheap (or even free), particularly if they live near the source (e.g. a fruit processing plant). Some examples of by-products submitted to the Feedtest service are: cereal straws, bagasse, brewers grain, breakfast cereal, potato waste, ensiled grape waste, almond hulls, malt combings, carrot pulp, maize gluten, pea pollard, paper pulp, peppermint residue, peanut oil, poppy pulp, licorice, chicken litter, pizza crusts, cough lollies, leek offal, sawdust, bloodmeal, pear pomace, cotton trash, biscuit meal, kiwi fruit, broccoli waste, rice hulls, sunflower hulls, mixed chocolate and dried apple. Obviously, there is little if any information on *in vivo* DMD for most of these materials, which means that any laboratory estimate of DMD must be treated with caution. In addition, there are too few of each type of by-product to enable specific NIR calibrations to be derived. The best that can be done is to group all by-products together into one diverse population and to use NIR to rank samples according to predicted DMD based on either a “roughage”, “grain” or “mixed feed” regression relating pepsin–cellulase dry matter disappearance to *in vivo* DMD. This approach has limitations, but is arguably better than using a prediction equation involving some arbitrary fibre fraction.

The question which arises in all of this is why not bypass laboratory methods used to predict DMD and calibrate NIR directly on *in vivo* measurements? This has been done successfully in the UK with grass silage.[9] However, a major limitation is the time, effort and expense required to conduct *in vivo* trials and therefore the difficulty in obtaining enough feed samples to derive robust NIR calibrations. Ideally, *in vivo* DMD values should be obtained using exactly the same protocol, i.e. with animals of the same type and physiological status and fed at the same level. At Hamilton, we have accumulated a set of forage and grain “standards” over 20 years from a wide variety of

Table 3. NIR measurement of per cent *in vivo* dry matter digestibility (DMD).

	Hay/Silage/Pasture	Cereal Grains
N	72	80
Mean	62.8	80.2
Range	43.1–77.3	62.3–92.4
SD	9.19	8.10
R^2	0.84	0.86
SECV	3.61	3.10
SECV/SD	0.39	0.38

N = no. of samples.
SD = standard deviation of population.
R^2 = coefficient of determination.
SECV = standard error of cross validation.

trials and locations, where, in most cases, the trials had been conducted for other reasons. Some were obtained with cattle, some with sheep, and at either maintenance or *ad libitum* feeding levels. In many cases, only small quantities of sample were able to be retrieved. When we attempted NIR calibrations using this data, we broke all the rules, or overstepped the "paradigm boundaries". However, as indicated in Table 3, when NIR calibrations were derived on either a combined forage or cereal grain population, the statistics were quite encouraging.

Further *in vivo* trials are now in progress to refine these relationships by increasing the number of DMD values obtained from a standard protocol.

Quality based fodder trading

A prime example of linking NIR technology with decision-making is in the rapidly growing Australian fodder (hay and silage) industry, worth around A$1 billion per year. This industry has traditionally been very fragmented, with hay being sold on an *ad hoc* basis and quality assessed by the "sniff and feel" method. However, all this is changing. Increasingly, buyers of fodder on both the domestic and export markets are demanding objective tests on the products before they purchase. A recent National Fodder Industry Forum decided that, for the first time, a national industry body would be established, together with a uniform quality description system, based on objective measurements (DM, ME and CP). Clearly, NIR is playing a pivotal role in this industry, as it is the only realistic method which can provide the market with timely estimates of fodder quality.

The biggest challenge in implementing a uniform fodder quality system is to obtain agreement on measurements and procedures between the various fodder testing laboratories in Australia, especially for digestibility and predicted ME. The procedures we use at Hamilton have already been outlined in this paper. Another laboratory estimates DMD using the equation DMD% = 83.58 – 0.824 ADF% + 2.626 N%, where ADF is acid detergent fibre and N is nitrogen.[10] ME is then estimated by the equation ME (MJ kg^{-1} DM) = 0.15 DMD%. A third laboratory uses the equation DMD% = 88.9 – (0.779 ADF%), which has been recommended for use in the USA,[11] then

calculates ME from net energy, also estimated using US equations. A major task of the new Australian Fodder Industry Association is to recommend a standard procedure for estimating DMD and ME and to institute a system of "ring tests" between laboratories to ensure uniform results, similar to those undertaken in Europe and by the US National Forage Testing Association.

Current and future challenges

The estimation of feed value and the decisions which rest upon it, require a shift in emphasis away from the 19th century "boil and stir" laboratory techniques. Whilst quite satisfactory NIR calibrations can be established for various chemical fractions in feeds, we need to escape the treadmill of eternal measurement of meaningless numbers and concentrate on improvements to measurements of *functional* properties of feeds, i.e. *in vivo* DMD, voluntary intake and animal production. NIR calibrations against these properties, whilst perhaps slightly less accurate than for chemical components, should be more useful to the end user, i.e. the producer or feed purchaser.

To summarise, the specific tasks facing us in southern Australia are as follows: improved ability to assess pasture availability, intake and selection by grazing animals; improved NIR calibrations for *in vivo* DMD; use of faecal NIR analysis to predict diet quality of grazing animals; analysis of intact feeds such as fresh pasture and silage; better procedures for dealing with unusual by-product feeds; nationally uniform laboratory procedures to boost confidence in objective fodder quality standards and easier access to NIR instruments, through a move toward networking and development of portable instruments.

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