Characterising Forages for Ruminant Feeding**

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ABSTRACT : Forages are the most important feed resource for ruminants worldwide, whether fed as pastures, forage crops or conserved hay, silage or haylage. There is large variability in the quality of forages so measurement and prediction of feeding value and nutritive value are essential for high levels of production. Within a commercial animal production system, methods of prediction must be inexpensive and rapid. At least 50% of the variation in feeding value of forages is due to variation in voluntary feed intake. Identification of the factors that constrain voluntary feed intake allows these differences to be managed and exploited in forage selection. Constraints to intake have been predicted using combinations of metabolic and physical factors within the animal while simple measurements such as the energy required to shear the plant material are related to constraints to intake with some plant material. Animals respond to both pre- and post-ingestive feedback signals from forages. Pre-ingestive signals may play a role in intake with signals including taste, odour and texture together with learned aversions to nutrients or toxins (post-ingestive feedback signals). The challenge to forage evaluation is identification of the factors which are most important contributors to these feedback signals. Empirical models incorporating chemical composition are also widely used. The models tend to be useful within the ranges of the datasets used in their development but none can claim to have universal application. Mechanistic models are becoming increasingly complex and sophisticated and incorporate both feed characteristics and use of biochemical pathways within the animal. Improvement in utilisation through the deliberate selection of pasture plants for high feeding value appears to have potential and has been poorly exploited. Use of Near Infrared Reflectance Spectroscopy is a simple method that offers significant potential for the preliminary screening of plants with genetic differences in feeding value. Near Infrared Reflectance Spectroscopy will only be as reliable as the calibration sets from which the equations are generated. ***(Asian-Aust. J. Anim. Sci. 2003. Vol. 16, No. 1 : 116-123)***

Key Words : Forage Evaluation, Feeding Value, Nutritive Value, Sheep, Near Infrared Reflectance Spectroscopy

INTRODUCTION

Forages are the single most important feed source for ruminants worldwide. Forages are edible parts of plants, other than separated grain, usually with substantial contents of cell walls. They are suited to utilisation by herbivores that have a capacity for microbial digestion of cell wall constituents (Wilkins, 2000).

Forages may be fed *in situ* as pastures or forage crops or be conserved as hay, silage or haylage. Within Australia, 3 distinct climatic zones determine the nature and range of forages fed to ruminants. These range from the tropical (4) pastures of northern Australia, through the temperate (c3) permanent pasture systems of south east Australia, to the Mediterranean climate of southern and Western Australia that is based on annual pasture systems. There is immense variability in the ability of these forages to meet the requirements of ruminants for maintenance and production of meat, milk, wool and fibre. The challenge is to optimise utilisation of these forages particularly when fed as the sole diet.

The move to intensive feeding of ruminants in dairy and meat feedlots and 'precision farming' of traditional extensive farming systems increases the need to define the value of forages for ruminants to better predict the quantity and quality of the product being turned-off. The rapidly expanding market for cereal hays in south east Asia is increasingly demanding objective measurement of forages, linked to animal performance.

MARKET REQUIREMENTS

Profitability of both extensive and intensive animal industries is determined by the value of the output of meat, milk and wool per unit of feed. Traditionally, the key driver of profit has focused on the quantity produced per hectare or per head. However, farming systems are undergoing significant change due to climate (e.g. global warming), environmental stresses (e.g. acidity, salinity) and social drivers (fewer, bigger farms). Agribusiness must increasingly deliver products to greater specification in terms of safety, health and consistent quality within increasing constraints being placed on them by the market, the community and by government to achieve a financial benefit within social and environmental limits.

In order to meet these goals, producers must know the quantity and quality of the inputs into their feeding systems, be able to reliably predict the products and by-products being generated, and have the skills to be able to manage their business accordingly. Easy access to accurate and objective evaluation of forage is the first key component to meeting these objectives.

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FORAGE QUALITY

Forage value is a function of its contribution to animal performance (reproduction, meat, wool and milk). For grazing animals, the challenge is to exploit forages to optimise forage utilisation and/or to maximise the genetic potential of the individual animal to grow products of economic value. The majority of Australian forage is utilised in this 'extensive' grazing system. For feedlot animals, the challenge is to optimise intake of the forage on offer to maximise the genetic potential of the animal. This latter use of forages is increasing in Australia in response to demands from feedlot beef, intensive dairy industries and export fodder markets.

Forages fed *in situ* ideally supply all essential nutrients for the grazing animal while forages fed in intensive industries are usually in the ration to supply fibre for the rumen. It is critical this distinction between feeding systems and the objective of using the forage is considered when evaluating forage quality.

Feeding value and nutritive value are two terms commonly used to describe the quality or value of a forage for animal production (Ulyatt, 1973). Feeding value refers to animal production responses when feed available does not limit voluntary feed intake and is a function of voluntary feed intake and nutritive value. Nutritive value refers to the responses in animal production per unit of intake and is a function of digestibility of nutrients and the efficiency with which the nutrients are used for maintenance or production. The distinction between nutritive value and feeding value is an important one and Ulyatt has estimated that variation in voluntary feed intake accounts for at least 50% of the variation that is observed in feeding value of forages. Frequently the availability of a forage will limit voluntary feed intake in both extensive and intensive systems.

Constraints to intake

Ruminants grazing forage or fed in pen experiments usually fail to consume sufficient nutrients to meet the needs for maximum production and hence achieve their full genetic potential. It follows that identifying constraints to intake of forages will allow us to manage or overcome the limitation. Weston (1982, 1985, 1996) proposed that voluntary feed intake of forages was regulated by an interplay between the rate of clearance of dry matter from the rumen and the amount of useful energy that is available to the animal, relative to the animals capacity to use the energy. In this conceptual model, forage diets generally fail to provide sufficient energy to meet the capacity of the animal to use energy due to a number of constraints, including the resistance of forage organic matter to removal from the rumen, low diet palatability, difficulty in forage harvesting and prehension, and environmental stress. Consequently, an energy deficit relative to the capacity to use energy exists, which Weston quantified as the forage consumption constraint (FCC). FCC can be calculated as the difference between the quantity of forage that the animal actually consumes and the amount of that forage that the animal needs to consume to meet its capacity to use energy when any constraints are absent. In general, for both weaner sheep (Weston, 1996) and adult sheep (Weston and Davis, 1991), the forage consumption constraint tends to decrease as the energy content of the diet increases. Similarly, Forbes and Provenza (2000) recently proposed a minimal total discomfort model. Briefly, signals from various families of visceral receptors interacting at organs sensitive to metabolic fluxes, together with adipose tissue, social stimuli and environmental factors are integrated at the central nervous system in an approximately additive manner to generate a total signal of discomfort. The key factors in both models are potential for clearance of organic matter from the rumen and availability of essential nutrients. Crude protein, organic matter digestibility and metabolisable energy represent important classes of nutrients while neutral detergent fibre (NDF) indicates an index of bulk. Both models can provide a framework to assess the extent to which different factors constrain intake.

In focusing on factors which constrain voluntary feed intake we have utilised the relationship between energy required to shear plant material and FCC to identify factors limiting voluntary feed intake. For example, forage consumption constraint was predicted from energy required to shear plant material (Baker and Dynes, 1999) for penned sheep fed different genotypes of dry mature subterranean clover (from Taylor et al., 1989) (Table 1). Energy required to shear plant material increased as voluntary feed intake decreased. However, constraint to intake for sheep fed Mt Barker and Mt Helena subterranean clover was significantly under that predicted from shear suggesting, some factor(s) other than resistance of the plant material to shear constrained intake of these cultivars.

The maturity of forages significantly affects the energy required to shear material. For example, the energy required to shear subterranean clover, annual grasses and broadleaf weeds was between 6 and 10 KJ/m^2 and increased as the plants matured (Dynes and Henry, 2002). Pasture species and time of sampling significantly affected energy required to shear the plant material however surprisingly there was no effect of level of feed on offer in the range 600 to 2500 kg dry matter per hectare, despite visual differences in sward structure. Predicted FCC was low (9 and 20 g OM/kg $W^{0.75}$) and requires validation with measures of intake in grazing animals to permit the comparisons presented in Table 1.

Table 1. Voluntary feed intake, dry matter digestibility and constraint to forage intake (FCC) for dry, mature subterranean clovers, (*T. subterraneum*), fed to adult wether sheep in pens

Subterranean clover	Dry matter intake (g/d)	Digestibility of dry matter (%)	Energy required to shear (KJ/m^2)	Constraint to forage intake (FCC) (g OM/kg BW$^{0.75}$.d)	Predicted constraint to forage intake (FCC) (g OM/kg BW$^{0.75}$.d)
Spencers Brook	381	48.6	23.8	96	105
Collie A	499	49.9	22.8	88	100
Mt Helena A	605	52.3	14.5	77	54
69S30.5.4.1	600	55.6	15.9	70	62
Mt Barker	732	58.0	12.3	61	42
Standard error	46.6	1.73	0.54	2.4	-

(Baker and Dynes, 1999)

Despite the importance of selection to nutrient intake by grazing animals, the mechanisms by which animals show discrimination among forages in their feeding behaviour are not well understood. Diet composition of sheep grazing forages *in situ*, commonly matches the botanical composition of the sward (Dynes et al., 1999). However, sheep will demonstrate strong selection pressure. Animals grazing an annual sward similar to those above but including saltbush (*Atriplex spp.*) will largely avoid the saltbush while any alternative forages are available (Norman et al., 2002). Further, sheep show preference within a single species of saltbush for some individual plants over others and this cannot be explained simply by soluble ash content or other nutritive value traits (H. Norman, unpublished).

Palatability is a term defined as any characteristics of the feed which inhibits intake of forage whether the forage is offered alone or as a choice. If an animal rejects a forage then clearly that forage will be of reduced feeding value even if its nutritive value is high.

We suggest the current use of palatability is too broad and may in part reflect the need to better understand factors which drive selection in animals and how components of the forage stimulate feedback signals. If we consider palatability within the conceptual model framework then feedback signals to the central nervous system can be grouped into pre-ingestive and post-ingestive feedback signals. Pre-ingestive feedback signals include taste, odour, and texture of forages, and in the long term also reflects social learning and learning developed through an aversion to post-ingestive responses to a nutrient or toxin (Provenza and Pfister, 1991). Post-ingestive signals incorporate those proposed by Weston (1996) and Forbes and Provenza (2000) and including tissue capacity to utilise energy and signals relating to rumen load and organic matter clearance from the rumen. In the case of saltbush, post-ingestive feedback from salt load would be expected but other factors influencing avoidance/selection of saltbush require identification (Masters et al., 2001).

Pre-ingestive feedback may constrain intake of some forages. The magnitude of constraint may vary between and within plant species depending on the physiological state of the animal. For example, weaner sheep fed spring harvested, dried subterranean clover (Dynes, 1996) appeared to be constrained by pre-ingestive feedback signals. Intake of the subterranean clover was lower (Table 2) than animals fed optimal or energy limiting diets, despite there being no apparent limitation to gut load on the subterranean clover diet. Over several weeks intake increased gradually and did not respond to additional protein or energy supplements, suggesting individuals were 'used to' the negative signals.

Our ability to predict the role of both pre and post-ingestive feedback signals in feeding value of forages is critical for high producing dairy cows. Here there are very high demands for maximum productivity and high dry matter intake. Similarly the introduction of novel forage species into farming systems requires careful evaluation for negative pre- and post-ingestive feedback signals.

Predicting performance

Forage evaluation evolved through the 20th century in parallel with increasing understanding of the factors, which drive animal performance (Reid, 1994). Research on voluntary feed intake, digestion and utilisation in the 1950-1970's (Crampton, 1957; Blaxter, 1962) together with the development of routine *in vitro* digestibility (Tilley and Terry, 1963), and fibre analysis methods (Van Soest and Wine, 1967) were fundamental cornerstones of modern forage evaluation.

Mathematical modeling together with laboratory

Table 2. Daily organic matter intake (g/kg metabolic liveweight W$^{0.75}$) and gut load (g OM/kg reticulo-rumen fleece free weight) of weaner sheep offered an optimal or energy limiting diet or spring harvested subterranean clover

	Optimal diet	Energy limiting	Sub clover
Voluntary feed intake	67.5±0.75^{a}	40±1.20^{b}	31±0.75^{c}
Digesta OM/kg RFW	25±1.5^{a}	39±2.4^{b}	26±1.3^{a}

[a] Within a row, means significantly different p<0.001. (Dynes, 1996)

analysis of forages currently underpins ruminant feeding systems. Many systems are based on a general positive correlation between voluntary feed intake and digestibility (Minson et al., 1964; Blaxter et al., 1966). However, this relationship is empirical and digestibility accounts for only about 60% of the variation in voluntary feed intake. Forages of similar digestibility can differ in voluntary feed intake and nutritive value, and forages of similar nutritive value can differ in feeding value. Further, the digestibility and nutritive value of forage can be altered by changing particle size (see Minson, 1990 for examples).

Globally, three main systems are in common use for predicting requirements of ruminants, all are based on relationships between intake and digestibility: Australia (SCA, 1990) and the associated computer package (GrazFeed, Freer et al., 1997), United Kingdom (ARC, 1980; AFRC, 1990), USA (NRC, 1984, 1987). The NRC equations are built on a very large number of data sets while both ARC and SCA are developed from smaller data sets. In general, animal performance is well predicted within the digestibility range these equations were developed from, but no one system can claim universal application because of the empirical way in which they were established. Consequently, if the characteristics of a forage fall outside the range for forages used in the equation development then predictions will not be accurate. For example, Poppi (1996) used equations from AFRC, NRC and SCA to predict dry matter intake where animal weight or dry matter digestibility were varied for growing cattle fed tropical diets. He found that the accuracy of the predictions depended upon the liveweight of the animal, it's body condition, and the diet being fed. SCA based on roughages predicted higher intakes at increasingly high digestibility whereas the ARC and NRC equations yielded similar intakes once the digestibility reached approx. 0.8, again reflecting the digestibility range from which they were developed.

The use of plant characteristics that predict 'constraints to intake' of forages requires consideration. Weston and Davis (1991) in a study of 14 forages showed the relationship of FCC with either the biomechanical characters or the fibre composition of the forages were better than the relationships between voluntary feed intake and biomechanical characters or fibre. Energy required to comminute was positively correlated with FCC (R=0.96, Weston and Davis, 1991) as was energy required to shear (R=0.94, S. Baker, unpublished). These biomechanical characters are good predictors of FCC when other factors such as limiting amino acids do not constrain intake. In an extensive study of oaten hays fed to sheep, energy required to shear together with crude protein and NDF content of the hay were the best predictors of animal performance (Baker et al., 1998).

In the USA, a hay grading system based on laboratory analyses was proposed to get around the costly and lengthy requirement of *in vivo* digestion trials, and the standardization issues related to *in vitro* digestibility techniques (Rohweder et al., 1978). The relative feed value index (RFV) was developed to rank cool season legumes, grasses and mixtures by an estimate of potential digestible dry matter intake, calculated from digestible dry matter and dry matter intake. The acid-detergent fibre (ADF) and NDF analyses described by Goering and Van Soest (1970) were the chemical assays of choice to estimate *in vivo* dry matter digestibility and dry matter intake respectively.

Subsequent analyses have shown the relationship between dry matter digestibility and ADF to be variable even within tropical and temperate grass species, and NDF concentration to be unsatisfactorily variable for predicting dry matter intake in grasses (Moore et al., 1996; Moore and Kunkle, 1999). These conclusions are likely to reflect the requirement for different regression equations for different plant species and possibly even locations (Rohweder et al., 1978, see Table 3). Surprisingly, when 24 alfalfa hays were grown under irrigation at one location and fed to lambs, only 1% of the variation in actual intake was accounted for by the prediction of intake from NDF. Further, only 20% of the variation in measured digestible dry matter (DDM) was accounted for by the equation predicting DDM from ADF.

Hay grading systems are evolving in Australia and a standard grading system now operates. Forage exports are dominated by long chop oaten hay, with 500,000 tonnes exported in the 2000 season (RIRDC, 2000). Japan is the largest export market followed by Korea, Singapore, Taiwan, Malaysia and UAE accounting for the balance (RIRDC, 2000). Hays are commonly selected for export using subjective criteria of colour, texture and taste. Oaten hays differ significantly in nutritional parameters and vary due to a number of factors including season, growing location, drying time and weather damage. Oaten hays from a single processor in eastern Australia selected for export based on similar colour and texture were highly variable in all characteristics measured (Table 4). Expansion of Australia's market share requires the development of objective standards for oaten hays that will predict the value of the forage in the mixed ration.

These apparent weaknesses in the existing systems reflect gaps in our understanding of the interactions between the physiology, biochemistry and nutrition of the animal rather than a failure of forage evaluation.

Table 3. Variation in linear correlations (R) for ADF with DDM and for NDF with DMI

Sample origin	ADF:DDM	NDF:DMI
Alfalfa-3 locations	0.83 - 0.91	0.44 - 0.75
Various grasses, various locations	0.73 - 0.92	0.43 - 0.94

(Rohweder et al., 1978)

Table 4. Average, range and coefficient of variation (CV) moisture content, energy required to shear (Shear energy kJ/m^2) plant material, *in vitro* digestibility (IVD), acid detergent fibre content (ADF), neutral detergent fibre content (NDF), soluble carbohydrate (SC) and crude protein (CP) of export oaten hay produced in New South Wales, Australia in 1999/2000 growing season

	Moisture content (%)	Shear energy (kJ/m^2)	IVD (% DM)	ADF (% DM)	NDF (% DM)	SC (% DM)	CP (% DM)
Mean	9	14	57	36	59	18	6
Range	3-15	10-19	46-63	28-46	52-72	1-30	3-9
CV	22.1	12.9	4.8	9.2	7.2	31.2	16.5

Mechanistic models

Mechanistic models may play an increasing role in predicting performance of ruminants. Mechanistic models are based on theory and relate processes and responses at different hierarchical levels that include whole animal and tissue biochemistry (Beever et al., 2000). Mechanistic models analyse the whole system in terms of key components and their interactions with each other (Beever et al., 2000). The models commonly have a complex range of inputs for forage and digestive parameters such that they remain principally a research tool. At least 4 distinct areas must be considered in reviewing mechanistic modelling of nutrient intake, digestion, utilisation and output of meat, wool or milk. These include, intake regulation (Poppi et al., 1994), rumen function (for example Baldwin et al., 1987; Dijkstra et al., 1992), metabolism in the lactating cow (Baldwin et al., 1987b) and metabolism in the growing animal (Gerrits et al., 1997a,b).

The success of mechanistic models in industry will depend both on the accuracy of prediction of animal performance and the inputs being measured (predicted) accurately, rapidly and inexpensively. The prediction of shear from Near Infrared Spectroscopy (NIRS) has the potential as a plant characteristic to predict animal performance directly (Baker et al., 1998) or as an input into mechanistic models if ongoing research supports its role as a predictor of ease of particle size reduction in the rumen.

Plant selection and breeding

The major criteria for selection of improved forage varieties have been optimisation of yield and digestibility along with the need to minimise disease susceptibility and maintain other agronomic traits (Beever, 1993). Relatively little regard has been given to the deliberate selection and breeding of plants for other components of feeding value for ruminants including potentially problematic secondary compounds. This is despite pasture and fodder plants ultimately being required to fit within a grazing or fodder conservation system where the final 'consumer' is the animal.

Further, because of the risk of litigation, duty-of-care issues are now considered extremely important prior to the release of new varieties. This is particularly important where new varieties are developed from germplasm with little background information on feed quality and the presence of secondary compounds is possible. However selecting 'safe' varieties is not necessarily selecting highly productive varieties. Collaboration between plant breeders and animal scientists is essential to ensure the 'best' species are selected.

There is an opportunity to develop new forage varieties with vastly improved (and known) feed quality characteristics, and to lessen the risk of litigation by developing rapid, accurate and inexpensive screening methodologies that can be utilised in the selection and breeding processes. Accessions from a novel breeding program for perennial legumes in Western Australia (Table 5) reflects the substantial variation in some nutritive traits that may be exploited in conventional plant breeding and selection programs. Obviously before such traits can be incorporated into a program, correlations with other agronomic and morphological characteristics must be established. The range in both *in vitro* digestibility of dry matter (IVDMD) and tannin content are important since some accessions have IVDMD and tannin contents which would significantly limit voluntary feed intake and/or rumen function and constrain animal performance. Our challenge in forage evaluation is to identify plant characteristics which can be used alone or as inputs to models to predict the value of a forage for animal feed.

NIRS offers significant potential to be used in selection and breeding programs. It is inexpensive, rapid and requires only small amounts of plant material. However given the potential novelty and diversity of some 'new' plant genotypes, extreme care is necessary to ensure that samples are adequately represented in the calibration set. Not only is the validity of the calibration set important but also the suitability of laboratory methods to provide accurate measures. Extreme caution is required in use of *in vitro* derived predictions of biologically important components for example fermentable metabolisable energy, where little validation with *in vivo* measurements exists (Beever and Moulds, 2000). Further, it is unlikely that some specific secondary compounds such as betaines, coumerins, oxalates and nitrates will be able to be measured using NIRS and traditional wet chemistry laboratory techniques will be

Table 5. Average (*and range*) in *in vitro* dry matter digestibility (IVDMD), crude protein (CP) and total tannin content of some alternative perennial pasture legumes harvested in June and October 2000

Species name	Common name	June IVDMD (%)	June CP (%)	June Tannin content (%)	October IVDMD (%)	October CP (%)
Dorycnium hirsutum	Hairy canary clover	52.3	12.9	3.87	55.4	13.6
		(47 - 55)	(11 - 14)	(1.8 - 6.7)	(49 - 61)	(6 - 19)
Hedysarum coronarium	Sulla	69.8	17.3	3.02	68.7	15.3
		(65 - 74)	(17 - 18)	(1.3 - 4.7)	(66 - 70)	(13 - 18)
Lotus corniculatus	Birdsfoot trefoil	67.1	15.7	1.80	66.7	16.5
		(50 - 75)	(7 - 20)	(0[a] - 6.1)	(51 - 77)	(6 - 21)
Lotus tenuis	Narrow-leaf trefoil	72.8	17.5	0.26	69.4	18.1
		(67 - 77)	(12 - 20)	(0[a] - 0.7)	(55 - 77)	(11 - 24)
Melilotus officinalis	Yellow sweet clover	72.9	14.5	0.07	75.8	19.6
		(69 - 76)	(11 - 17)	(0.02 - 0.15)	(74 - 79)	(7 - 29)
Trifolium fragiferum	Strawberry clover	74.9	21.7	0.15	76.2	17.9
		(72 - 79)	(19 - 25)	(0.05 - 0.25)	(75 - 78)	(17 - 19)
Trifolium hybridum	Alsike clover	77.8	18.8	0.08	75.5	19.4
		(74 - 82)	(15 - 21)	(0.05 - 0.11)	(76 - 80)	(12 - 27)

[a] Tannin content undetectable (less than approx 0.01 %). (Henry et al., 2002)

required, with final selection supported by animal grazing studies.

THE FUTURE

Forage evaluation will be increasingly a component of both intensive and extensive farming systems. Improving characterisation of forages must maintain focus on identifying the factors that are important for animal production and the levels of precision needed for practical application. Dewhurst and Webster's (1989) summary remains highly relevant: robust measurements suitable for routine use, adequate description of processes of metabolism and digestion. Finally we must provide a better prediction of nutritive value and ultimately animal performance than is currently available.

The challenge in intensive systems is to deliver nutrient based systems of feed characterisation. This requires comprehensive carbohydrate and protein characterisation with due recognition to all significant nutritional entities which are likely to have different metabolic fates (Beever et al., 2000). While sugar could be described adequately as one entity, descriptions of starch and fibre would need to represent potential ruminal degradability (both rate and maximal extent). Crude protein would need to be accounted for by content of true protein, peptides and amino acids and ammonia. Extensive farming systems will demand inputs for precision farming systems. Opportunities now exist to measure forage quality remotely, whether by vehicle mounted NIRS-type instruments or by airborne and satellite-borne sensors. Research is now underway to develop hyperspectral imagery for the measurement of protein content and digestibility in forages. Ultimately these will require integration into models of ruminant requirements for allocation of forage resources.

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