Predicting Forage Intake by Grazing Ruminants

Sam W. Coleman[1]
USDA, ARS, STARS
Brooksville, FL

Introduction

Determination of the amount eaten and characteristics of the diet of grazing ruminants remains one of the most difficult tasks in research. While several lifetimes have been devoted to developing techniques to 'measure' intake and diet quality, they are laborious, expensive, and often lack both precision and accuracy. Hence, there has been little effort on the part of producers or consultants to attempt these determinations in commercial operations. The result has largely been a reliance on guesswork to assess the nutritional status and potential needs for supplementing grazing animals. The purpose of this paper is to examine and evaluate some of the methods used to assess and predict intake.

How the Cow Meets Her Nutrient Needs

Herbivores eat to satisfy a need and desire for nutrients, the most prominent being energy and protein (NRC, 1996; 2001). Demands for maintenance, lactation, growth, and conceptus sum to the total requirements (Fig. 1). Energy requirements may be modified by requirements for locomotion or thermal stress. Feed bulk density, ease of consumption, ease of communition, palatability, and ease of digestion and passage once in the rumen all interact with the needs and desires of the animal (Weston, 1982). Maximum or optimum

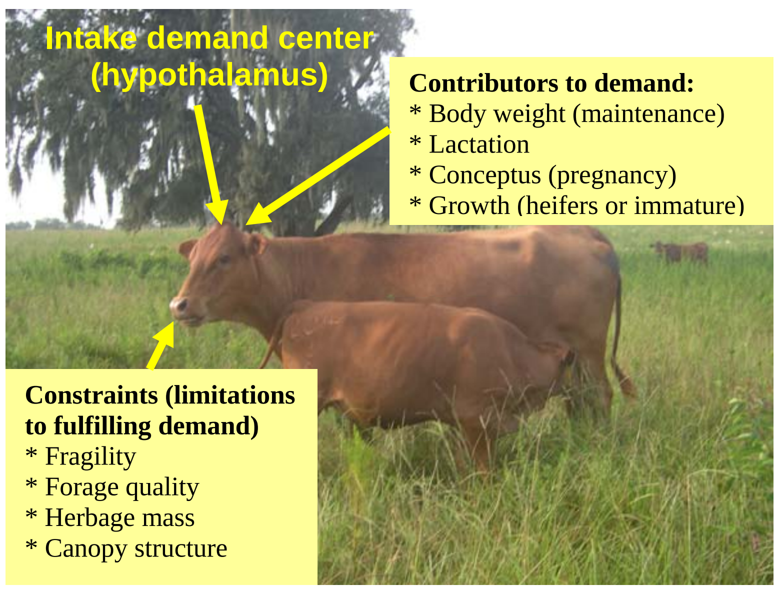

Figure 1. Illustration of the cow's demand for energy based on components which drive the desire to consume feed and constratints to ad libitum intake by the pasture characteristics.

[1] Contact at: 22271 Chinsegut Hill Road, Brooksville, FL 34601; (352) 796-3385-0ffice; (352) 796-2930-FAX; swcol@ifas.ufl.edu

nutrient intake occurs under ideal conditions and when the nutritional needs are met, anatomical sensors send a signal to the brain that satiety has occurred (Van Soest, 1994). Under many grazing situations, satiety does not occur because the animal is unable to satisfy its nutrient requirements with the forage on offer. Senft et al. (1987) suggested that diet selection by large herbivores such as cattle requires the solution of two opposing problems: obtaining adequate quantity of forage with maximal quality. Reduced dry matter (DM) intake is the major impact of inadequate nutrition of grazing animals (Hodgson, 1982a), whether constrained by deficient herbage quality or quantity.

Daily Requirements Make up Annual Demand Curve

The energy requirements are met when the animal consumes sufficient energy to meet the summative requirements. The energy consumed is a function of the amount of feed consumed and the concentration of utilizable energy in the feed. Utilization of energy is slightly different for different functions (e.g., maintenance, growth or milk). Because the largest and most variable loss of consumed energy is in the feces, digestibility may be used as a proxy for the entire process of utilization (digestion, absorption, assimilation). For most purposes, the digestibility of the energy is similar to that for the total dry matter, so dry (or preferably organic) matter digestibility (OMD) is a good proxy from which net energy can be calculated using equations from NRC (1996). There has been good agreement between the intake of digestible organic matter (DOMI) and gain (Lippke, 1980).

Measuring Intake

Ad libitum intake occurs when the feed supply is unlimited in quantity and quality so that animals are unconstrained in satisfying their hunger (Moore, 1994). Most determinations of forage intake have been conducted by feeding animals under controlled situations in which the feed is either harvested or manufactured (mixed) and provided to animals in lots or pens. Intake is measured as the difference between the feed offered and that refused when fed in excess of the amount the animal would consume. While these measurements may be quite accurate, variability among animals given the same diet, particularly a forage diet, may be quite high, ranging from 10 to 30% of the mean. This high variation may be caused by different nutrient demands among animals, by differences in the ability to consume and process feed, or the conditions under which the intake trials are conducted.

Measuring intake at pasture

There is a huge dilemma for measuring intake under grazing because weighing the feed and refusal as in pen studies is not possible. Therefore, indirect measures or estimates have been used, and generally the accuracy and precision (measure of variability) are compromised. Burns et al. (1994) reviewed several methods for estimating intake of grazing animals. All have their difficulties.

Fecal excretion. If one knows the amount of feces voided (FO) each day and the digestibility (D) of the diet consumed, then intake can be calculated by the equation:

$$\text{Intake (kg/d)} = \text{FO}/(1\text{-D}) \qquad \text{Eqa. 1}$$

However, collection of feces voided is quite difficult under grazing, although not impossible. Various kinds of collection bags have been used. A simple plastic bag can be clipped to the wool of small ruminants such as sheep. The bags are removed once or twice per day, dried and processed as in a typical digestion trial. However, with cattle, fecal bags are quite cumbersome, require moving the animal to an enclosure to remove and replace the bags, and often interferes with normal grazing, likely reducing intake. Hence, other methods have been devised to estimate fecal output.

The use of external markers has probably been most widely used to estimate fecal output of grazing, and often stall-fed, cattle. The concept is that when a known amount of an inert (indigestible) marker is fed and equilibrium is obtained (~ 7 d), the same amount should be voided in the feces. If a small grab sample of daily fecal excretion is obtained, concentration of the marker in the feces can be used to calculate the amount voided. Assumptions include: 1) the marker is quantitatively recovered (completely indigestible or the digestibility is known and constant); 2) the marker is proportionately and evenly excreted (no pattern over hours or days); and 3) the marker does not interfere with ruminal activity. Markers that have been widely used include chromium sesquioxide (Cr_2O_3), rare earth elements such as Ytterbium (Yb), and long chain alkane waxes (C_{32} and C_{36}).

Diet Quality

Even if fecal output can be measured or estimated, digestibility of the diet is also required for equation 1. Most often a hand clipped sample of the pasture herbage is evaluated by routine chemistry and *in vitro* organic matter digestibility (IVOMD) to represent nutritive value. However, IVOMD often fails to mimic *in vivo* digestibility determined with animals (Nelson et al., 1975). To avoid this error, adjustment equations relating *in vitro* to *in vivo* digestion of similar forages may be used. A greater difficulty is obtaining a sample of the diet. Many studies have shown that animals graze selectively and that hand clipping a sample from the available herbage in a pasture does not adequately characterize the diet (Weir et al., 1959). Kiesling et al. (1969) attempted to hand-pluck samples similar to that being grazed by cattle. However, esophageally-fistulated steers selected forage with more ash, protein, fat and less crude fiber than hand plucked samples.

The degree of selectivity reported in the literature is quite variable due to season, forage species, and chemical anti-quality components, such as tannins (Sollenberger and Burns, 2001). Because of animal selectivity, **most investigators in this field of research concluded that it is virtually impossible to sample a pasture by hand and have reliable representation of the animal diet**. The problems are exacerbated if the pasture contains a mixture of plant species or heterogeneity in canopy (e.g., with spot grazing, or where there is mixture of dead and green material). With modern techniques for mapping (e.g., global positioning systems), the relative proportion of grazed to the total area available could be mapped and characterized. Because of the inadequacy of hand sampling, two methods have evolved to estimate diet quality; 1) the use of esophageally- (or occasionally ruminally-) fistulated animals, and 2) the use of internal markers (as opposed to external markers mentioned above).

Cannulated animals. The use of the esophageal fistula initiated by Torell (1954) allowed the animal to collect the forage sample for the investigator. The fistula is simply an opening (~1.5 inches in diameter) through the neck into the esophagus through which the grazed forage can drop. When not being used for forage collection, the fistula is closed so that feed passes down the esophagus to the rumen. Cook et al. (1958) later developed a cannula for the fistula to facilitate opening and closing the fistula. Samples of forage collected by fistulated animals have consistently been shown to be different chemically from those collected by hand, whether by random selection of the forage to be clipped (Weir et al., 1959), or by seeking to harvest only that which the animal is eating (Kiesling et al. 1969).

While the use of animals fistulated at either the esophagus or rumen have been used for many years to collect forage samples representing the diet selected by the grazer, they are not without their problems (Coates et al., 1987). Esophageally-fistulated animals are not easy to prepare and they require constant maintenance, because if the fistula opens accidentally then severe loss of electrolytes can occur. As a sampling method, questions have arisen over incomplete collection of the eaten forage and whether the fistulated animals ingest a diet similar to that of target animals (the ones the diet is supposed to represent). Coates et al. (1987) found little relationship ($r^2 = 0.13$) between the grass or legume content of diets selected by fistulated animals and diets from resident cattle (those that had been grazing the same pasture for the entire season) determined by the $\delta^{13}C$ content of the forages and feces. Contamination by saliva can be problematic and variable. Bath et al. (1956) found that only ash was significantly different between hand-clipped and esophageal-fistula samples. However, Coleman and Barth (1973) observed differences and developed adjustments for each ash, protein and fiber components.

Incomplete recovery of the diet may also occur if some of the ingested material bypasses the opening and proceeds to the rumen. In order to alleviate the loss of ingesta, some have used animals with rumen fistulas fitted with a molded rubber cannula. Ruminally-fistulated cattle are not as likely to undergo stress due to loss of cannula or plug as those fistulated at the esophagus, and thus are easier to maintain. However, the same problems exist relating to grazing when samples are desired and whether the diet mimics resident animals.

Internal markers. The use of internal markers to estimate digestibility of the diet has been widely investigated (see reviews by Burns et al., 1994 and Dove, 1996). Internal markers are natural plant constituents that are recovered quantitatively in the feces, that is either they are indigestible or the digestibility is known and constant. Diet digestibility (D) can be calculated from the ratio of the marker in the diet (M_d) and feces (M_f):

$$D, \% = 100 - (100 * M_c / M_f) \qquad \text{Eqa. 2}$$

Markers that have been evaluated are silica, lignin, fecal N, chromogen, indigestible neutral detergent fiber, and acid insoluble ash (Burns et al., 1994). All have problems of consistent recovery. Chromogens are pigments associated with chlorophyll and xanthophylls and are specific for each forage. Thus they are more effective for lush growing forage and least effective for drought or stressed plant tissues. Calibration must occur for each set of conditions; therefore they have limited application (Weir et al. 1959). Lignin is probably the most widely used as internal marker, but suffers from variation in digestibility.

The most recent development of a marker system has been the use of the hydrocarbons (*n*-alkanes) of plant wax. By using dosed synthetic alkanes as external markers to estimate fecal output together with naturally occurring plant wax alkanes, diet selection, intake and digestibility can be determined (Dove, 1996). The technique has the advantage that determination of both internal (natural plant waxes) and external (dosed synthetic) markers are made with one process using gas chromatography. One must still collect samples of each plant part (leaf, stem, inflorescence) from each species that the animals might graze. Many plant parts and species have different proportions of alkanes that form a fingerprint for that particular tissue. By using the fingerprint information, diet composition can be determined by statistical evaluation of the pattern of waxes in the feces with that from all the available plant parts and species in the pasture. Problems with the alkane technique include variable recovery and low concentrations of natural waxes in some plants, especially tropical and subtropical species (Loredo et al., 1991).

An ideal internal marker is currently not available. Moreover, because of the labor involved and the extreme number of laboratory assessments required, the use of markers have received little or no application by producers nor routinely in large experiments from which to develop a database of samples useful for equation development and prediction of diet quality from chemical or other characteristics of harvested forage. However, such a database would be very useful on which to base prediction equations to estimate diet quality and intake from more easily obtainable determinations.

Predicting Potential Intake from Diet Characteristics

The accurate measurement of feed intake through *in vivo* feeding trials or from the use of markers to estimate intake at pasture is quite costly and laborious. Therefore, many efforts have arisen to predict intake from forage characteristics. However, actual intake can be affected by the animal (e.g., hunger intensity, health status, physiological status) and the availability of the forage on offer, especially the amount of standing forage mass. Therefore, forage characteristics can be used to predict only the potential intake, whereas the amount actually eaten may be different from the potential.

One of the more confusing problems for predicting forage quality is evaluation of the prediction equations. The usual criteria are goodness of fit (r^2) between reference (*in vivo*) values and the predicted values and the residual standard error (SE). However, the question is NOT how well they are correlated, but whether values predicted by the equations are acceptable (Moore et al., 1999). They proposed that acceptable values were within a limit based on the error associated with the animal variation in the *in vivo* trials used as reference data. Based on examination of many such trials in the literature, they proposed the limits be within 5% of the mean for digestibility and 10% for intake. This means that for a data set with a mean of 50% digestibility, the difference limit would be 2.5 percentage units (difference between measured digestibility and predicted digestibility for a single forage sample). Using this criteria, 65% of the samples from the unknown (test) population should fall within the acceptable range and 95% should fall within 2*limit (or 5% difference; marginally acceptable). For an equation to be suitable for use, only 5% of the differences should exceed 2*limit.

Simple relationships

Attempts at prediction of both intake and digestibility of the diet from chemical components of the forage are quite numerous (Moore, 1994). Digestibility is probably best estimated by the *in vitro* technique (Tilley and Terry, 1963), but for some tropical forages such as bahiagrass, IVOMD does not predict *in vivo* digestibility well. Nelson et al. (1975) showed that bahiagrass forage required incubation for 72 hr to reach typical *in vivo* digestibility as opposed to 48 hr routinely used in *in vitro* systems. Some have suggested that digestibility could be used to predict intake (Freer and Jones, 1984), yet Minson (1990) and Moore and Coleman (2001) reported correlations between intake and digestibility from the literature ranging from -.30 to 0.78. Therefore, potential intake cannot be reliably predicted from estimates of digestibility.

Routine forage analyses usually include determinations of CP, neutral detergent fiber (NDF), and acid detergent fiber (ADF). Within forage species these values vary in a consistent manner, usually with increasing maturity, and may be used to rank quality. Probably the greatest and most uniform relationship of forage chemistry to intake occurs when crude protein (CP) concentration is below ~8% (Fig. 2) or the ratio of DOM:CP exceeds 10 to 12 (Moore et al., 1999). Under these conditions, ruminal microbes may be N limited relative to energy available, and forage intake increases with supplemental N.

Cell walls and their derivatives, ADF and hemicellulose, have been used either alone or with other chemical entities to predict both intake (Table 1) and digestibility (Minson, 1990; Moore et al., 1996). Mertens (1987) proposed that daily NDF intake was ~1.2% of body weight per day in diets that produced maximum daily 4% fat corrected milk. The concept based on 1.2/NDF has come to be used as a predictor of the potential intake of forage and used in hay marketing. The limitation of this theory, and the resulting predicting equation, is that when forages are the sole component of the diet, NDF is a poor predictor of intake across many forage types, particularly C_4 perennials (Moore et al., 1996). Extrapolation of data obtained from high-concentrate mixed diets to diets where forages are fed alone is not wise because associative effects decrease intake. Rohweder et al. (1978) found that correlations between intake and NDF content lacked consistency and were generally low for subtropical species. Different equations relating intake to NDF were proposed for legumes and grasses. Moore et al. (1996) concluded that simple prediction equations must be different for temperate and tropical grasses. They found that at the same digestibility, intake of tropical grasses were higher than that for temperate grasses.

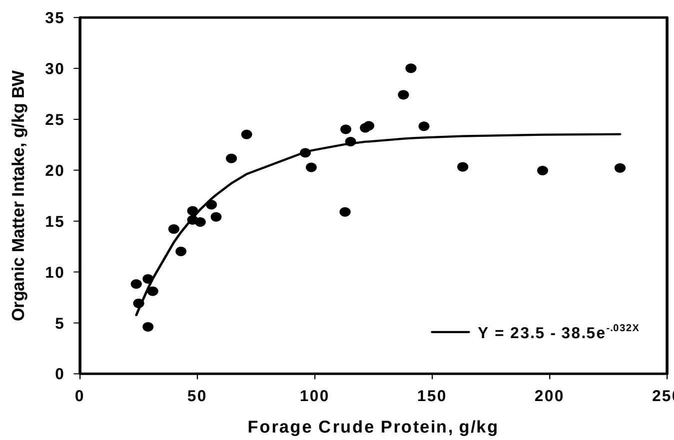

Figure 2. Response of intake to increasing concentrations of crude protein in forages fed alone (Adapted from the data of Moore et al., 1999a).

Multiple Regression

To overcome the limitations of simple relationships and the interactions of undefined factors, Moore et al. (1996) and Moore et al. (1999b) developed and tested multiple regression equations using CP, ADF, and *in vitro* digestibility to predict intake and *in vivo* digestibility. The database was developed from published studies and included a diverse group of both temperate and tropical forage species. The equations were then tested with an unrelated group of samples as described above. When *in vivo* DMI of the test samples were compared to the predicted DMI from the equations, 54% produced differences within 10% of the mean DMI (one standard deviation (Sd) or acceptable), and an additional 39% between 10 and 20% of the mean (2 Sd or marginal). Only 7% were unacceptable (> 2 Sd).

Indices of Forage Quality

It has long been recognized that productivity (milk or growth) is related intake of digestible energy (Holmes et al., 1966; Lippke, 1980), often described as DOMI or TDN intake. The combination of intake and digestibility into indices of forage quality have been proposed [e.g., digestible energy intake (Heaney, 1970); relative feed value (Roweder et al., 1978); fill unit (Jarrige et al.,1986)]. Relative feed value (RFV) was adapted by the National Forage testing Association (NFTA) base on prediction of intake from NDF and digestibility from ADF. Moore and Undersander (2002) proposed Relative Forage Quality (RFQ) as an alternative to RFV as an overall index of forage quality. Like RFV, RFQ is an estimate of voluntary intake of available energy when forage is fed as the sole source of energy and protein. The intake component is called voluntary forage intake (VFI), expressed as DM intake as a percentage of BW. The available energy component is TDN (% of DM).

The main reason for changing to RFQ was to move from the inadequacies of the equations used to estimate RFV and from the varied formulas used to calculate RFV among laboratories. Nevertheless, it is critical that accurate and appropriate equations be used to predict RFQ. Moore and Undersander (2002) proposed two sets of equations, one for legumes and one for grasses. The need for accuracy in predicting intake and digestibility is illustrated in Figure 3 where the potential net energy intake of bahiagrass calculated by three different equations are plotted for each month (graphed as lines). The samples were hand harvested (Chet Fields, unpublished data) so the effects of herbage mass or selective grazing are not included. The monthly requirements of a January-calving cow (1035 lbs) with a peak production of 13 lbs of milk are represented by the bars. The calculated requirements are for a rather small, low producing cow, but illustrate the nutritional problems in Florida. Two of the three equations predict a positive energy balance only from July to September, where as the NRC (2001) equation predicts the cow to continually be in energy deficit.

While these evaluations indicate that bahiagrass pasture seldom meets the requirements of grazing cows, we have demonstrated in Brooksville that while cows lose weight and condition due to calving and lactation during winter, they recover most before breeding (May 20) even though the quantity of forage is quite low due to the drought (Coleman et al., 2004). Bahiagrass hay and molasses (16%) were used as a supplement from frost to the end of the breeding season. Therefore, all equations predicted inadequate energy intake based on analysis of hand-clipped samples whereas the animals were apparently doing much better than predicted.

Physico-Chemical Methods

Biomechanical. Voluntary intake below the energy demand of the animal often occurs because the forage is resistant to breakdown during chewing and to degradation by ruminal microbes. Slow rate of particle communition, long retention times of residues in the rumen (Balch, 1969), and potentially extended ruminating time are consequences. This resistance to breakdown by chewing has been attributed to the physical strength of the material (Mackinnon et al., 1988). An early study by Troelsen and Bigsby (1964) demonstrated that intake was highly correlated ($r = 0.94$) with the particle size index obtained from an artificial masticator. Subsequent measures of ‘resistance’ included grinding energy ($r = 0.90$; Chenost, 1966), tensile strength ($r = -0.47$; Henry et al., 1996), and shear strength (Mackinnon et al., 1988). These estimates of the resistance of plant material to breakdown not only directly have an impact upon particle size reduction and passage from the rumen, but influence the surface area available for microbial enzymes to attack the residual lignified cellulose tissues. Retention time was more useful for predicting intake of hay by goats than forage chemistry (Coleman et al., 2003). However, these methods have not caught on as routine measures to predict intake.

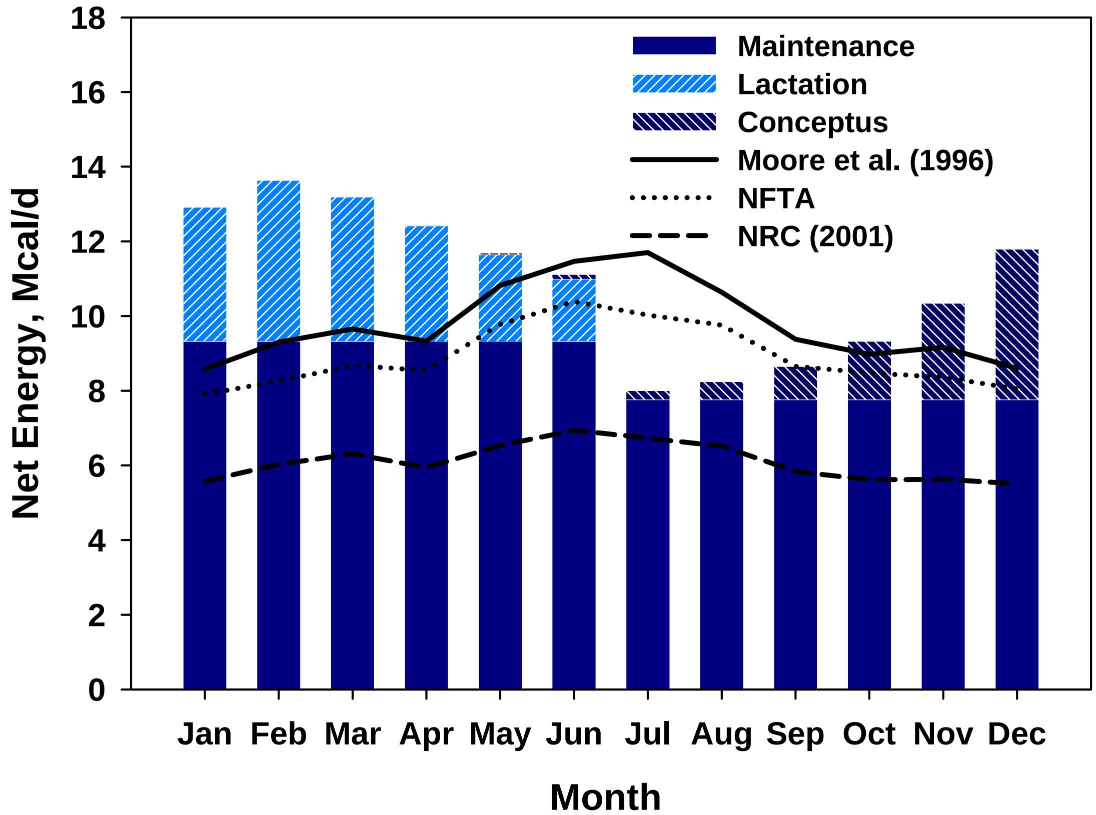

Figure 3. Monthly requirements for a 1040 lb cow giving 13 lb milk at peak with predicted potential NE intake from bahiagrass pastures. Predicted intake is not adjusted for herbage available or selectivity by the cow, both of which would influence the results.

<u>Near-infrared reflectance spectroscopy.</u> The NIRS is an instrumental technique that measures the absorbance of monochromatic light in the near-infrared region of the magnetic spectrum by a substrate. The primary use of NIRS has been to assess chemical composition and in vitro digestibility of forages. Routine nutritional assessment usually includes predicting the chemical composition of forage samples by NIRS, and then predicting forage quality (intake and digestibility) from the chemistry. The early work of Norris et al. (1976) demonstrated that NIRS not only could be used to estimate chemical composition of forages, but could also directly estimate animal intake and digestibility. Following

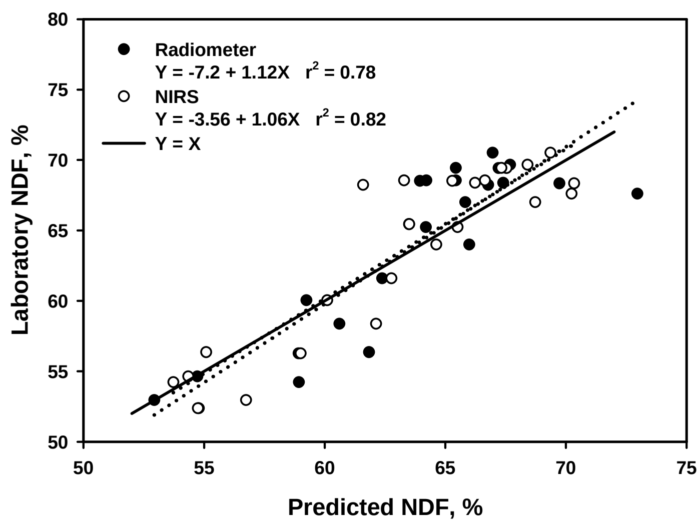

Figure 4. Prediction of neutral detergent fiber with bench-top NIR spectrometer or hand held radiometer (from Starks et al., 2004).

this work, several researchers reported direct calibrations for digestibility and recent reviews by Givens et al. (1997) and Coleman et al. (1999) discuss its use for predicting both intake and digestibility.

Poppi (1996) argued that NIRS was the method of the future for predicting intake, and that large databases could be established by collection of spectra and intake values as intake trials were conducted. Recently Starks et al. (2004) demonstrated that small hand-held radiometers provide chemistry results comparable to expensive bench-top units (Fig 4). The greatest advantage of the radiometer is that forage can be assessed *in situ* with no hand harvesting, drying, processing, and analyzing. The results are predicted immediately.

Equation Validation and Database Development

The problem with predicting *in vivo* measurements with routine chemistry or NIRS has been in obtaining sufficient numbers of samples for which reference data were obtained under carefully defined conditions. More rigorous statistical procedures and larger sample sets may help overcome problems of developing broadly-based robust equations.

How Then Might We Determine Intake of Grazing Animals?

Harvest Before and After Grazing

Macoon et al. (2003) certainly were not the first to suggest the simple procedure of harvesting forage before and after grazing to determine intake and diet quality. However, they were the first that I know of to compare this method with marker. They found that intake estimates from before-and-after clipping more nearly reflected calculated requirements for the level of production observed than those from a pulse-dosed marker. However, the procedure can only be successful under a very intensive and short duration rotation grazing. Under these conditions, diet quality is similar to the 'before' sample since the animals are required to graze most of the forage before being moved.

Feces is an Integrator of Diet Components

Since feces is the product of eroding and synthesizing digestive processes and consists of residues of feed and plant tissue, and components of microbial and animal origin, feces should contain information about the amount and characteristics of the diet. One could argue that the combination of intact feed residues (undigested fiber), microbial biomass, and sloughed animal tissue should provide information on the ingested diet and its digestion by the animal. Due to difficulties sampling the diet of grazing animals, several attempts have been undertaken to use feces as an integrator of feeding over several days. The alkane wax marker method in part relies on this concept, but Holloway et al. (1981), Coleman et al. (1989), and Leite and Stuth (1990) advocated using indices developed from only feces to measure intake and various aspects of diet quality.

The fecal index method for determination of intake and (or) digestibility does not require forage sampling but is based on a predictive method requiring calibration with *in vivo* data. This means intake must be determined by one of the methods described above to serve as the reference method and dependent variable for regression, even though they are quite laborious. Fecal indices can be implemented by producers since only a grab sample of fresh feces need be taken from the pasture where the animals are grazing. Thus, perhaps this is the most plausible way to move intake estimates to the world of the producer.

Fecal indices based on chemistry. Crampton and Harris (1969) described the fecal index for estimating digestibility of diets by free-grazing animals. Holloway et al. (1981) and Leite and Stuth (1990) enlarged upon the idea to estimate intake by using a variety of chemical and bioassay as a multivariate index with mixed results. In general the relationships were not strong enough to pursue using the system to predict intake.

Fecal Indices based on NIRS. We proposed a multivariate index based upon the spectral properties of feces scanned by NIRS (Coleman et al., 1989), based on the premise that the infrared spectrum of a sample contains much more information than a discrete set of chemical constituents. The calibration results from six data sets were quite good, but developing equations that were sufficiently broad for routine prediction of intake were less promising. While good agreement could be obtained from NIRS-predicted intake and digestibility within an experiment, extrapolation to different data sets collected from different regions of the country produced both bias and random error. Lyons and Stuth (1992) reported excellent results for estimating diet crude protein and digestibility of grazing animals using NIRS. Boval et al. (2004) extended the concept to directly predict intake based on trials in which forage was harvested and fed to steers in confinement with excellent results. They are moving the concept to predict intake and digestibility of cattle on commercial operations.

Decision Support Systems

The problems we have addressed for accurately predicting intake of grazing animals include: 1) accurately representing the diet and its quality (chemical composition and digestibility); 2) developing an equation to predict potential intake from diet quality; and 3) modeling the constraints to ad libitum intake. Considerable research has been conducted on #2 and the RFQ equations and procedures suggested by Moore and Undersander (2002) are suitable for routine use by laboratories to estimate potential intake from a small sample collected from the pastures. Now we need to put a system together by solving the remaining parts of the puzzle.

Selectivity index. We have noted above that selective grazing occurs and that mimicking the diet with hand harvested pasture samples is difficult if not impossible. A few studies have been conducted in which a selection index was calculated. A selection index is an attempt to calculate the relative degree of intensity for which the grazer attempts to select a particular plant species, plant part, or perhaps a chemical component. Lorimer (1978) with sheep and Coates et al. (1987) with cattle found that selection for various forage species in Northwest Queensland varied across the grazing season. Milne et al. (1979) observed similar results in Scotland, but also found that grazing pressure (or relative amount of herbage available) also influenced the degree of selectivity. Njwe et al. (1995) found the selection index for Stylosanthes by goats ranged from <0 to 4.29 depending on stocking rate. However, stocking rate could not be used to predict the selection index.

Coleman and Barth (1973) tried to predict diet quality from chemical composition, legume proportion, and height of the forage in two different grass/legume mixtures. The resulting equations ranged in r^2 from 0.55 for diet ADF to 0.95 for *in vitro* digestibility (IVDMD). However, the equations were different for fescue-lespedeza pastures as compared to orchardgrass-clover pastures. Equations to predict selection index for tropical pastures will also likely be species specific.

It should be feasible to predict adjustments of chemical composition (and quality) of a hand clipped sample using pasture conditions (species, canopy height and character, chemical composition etc…) so that the sample closely represents the diet. For instance, a producer could hand harvest samples from the pastures that represent the available forage and send them to a laboratory for analyses. From the laboratory analysis potential intake and RFQ could be predicted using equations of Moore and Undersander (2002). Visual assessment and some simple measures such as height of canopy could then be used to formulate a selectivity index for correcting potential RFQ to actual RFQ similar to the method used by Coleman and Barth (1973). This procedure is best applied to a monoculture sward or one with few components.

Based on the scarce reports available, this part of the puzzle appears to be solvable, but the data for predicting the selectivity index for Florida pastures is currently not available. This would be a worthy research problem for the major forage species used in Florida.

<u>Herbage Mass or Available Forage.</u> Provided we could obtain a sample of the diet and could from that sample predict potential intake, the canopy structure of the forage on offer often constrains actual intake. According to Hodgson (1982), daily herbage intake of grazing animals is a function of feeding time (FT) and intake rate. Intake rate is a function of intake per bite (IB) and rate of biting (RB). Therefore:

$$\text{Intake (kg/d)} = IB * RB * FT \qquad \text{(Eqa. 3)}$$

Short-term intake can be estimated by recording each of the components. However, amount of IB requires the use of an esophageal cannulated animal for the collection of weight of herbage ingested over a period of time, usually ~30 minutes and have all the problems discussed under estimating diet quality above. The method is extremely laborious and has not found widespread use for routine measurement of grazing animals.

Because of sward architecture, tropical and subtropical forage grasses may limit intake rate by grazing animals because leaf density is insufficient to support adequate intake per bite (Stobbs, 1973). The majority of work on the relationship of the sward canopy to grazing behavior has been conducted with perennial ryegrass (*Lolium perenne* L.), a C_3 species for which bulk density appears to be less important than herbage height or total herbage mass (Hodgson, 1982). Rayburn (1986) summarized a group of experiments and developed a more general relationship of relative intake (a proportion of maximum or potential intake) to herbage mass (Fig. 5). Forbes and Coleman (1993) reported that the best sward variable for predicting bite weight and intake of old world bluestem, a C_4 bunchgrass, was green leaf mass. The quantity necessary for maximum intake pre bite was 1.1 Mg/ha, very similar to the asymptote for intake based on Rayburn (1986; Fig. 5). From the data available, it appears that the effect of forage standing crop is predictable and can be used in a decision support system to predict constraints to potential intake.

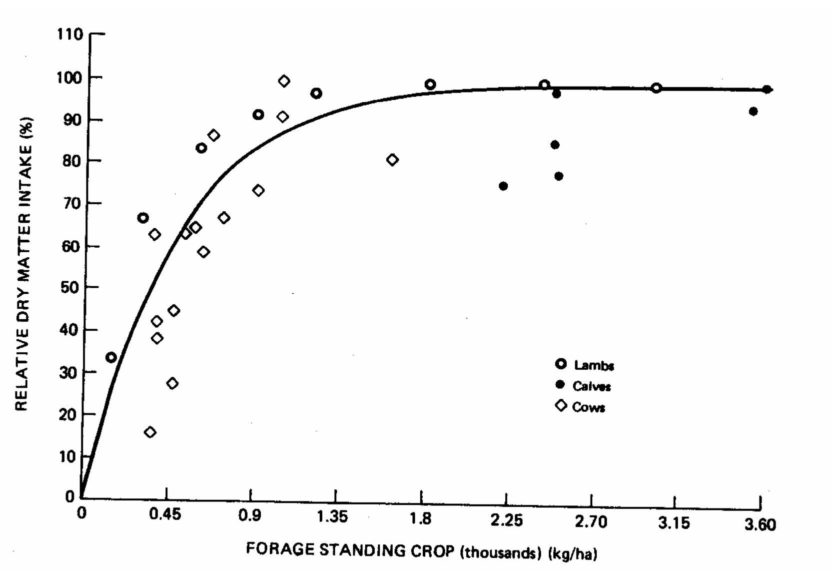

Figure 5. Constraint to ad libitum intake by forage standing crop of different classes of livestock grazing under continuous grazing management (Rayburn, 1986).

The Solution

The process would include collecting pasture forage with a standardized procedure (e.g. standard clipping height), analyzing the pasture sample for chemistry and IVOMD, estimating the amount of forage on offer (probably with canopy height), and predicting diet nutritive value by adjusting clipped samples for selectivity, predicting potential intake from diet nutritive value, and finally adjusting potential intake to actual intake based on pasture constraints.

The fecal index method could be adapted more easily by producers and a broad-based decision support system called NUTBAL (Stuth et al., 1997) has already been developed by the Texas A&M group. The system has achieved wide application throughout the world with support in the USA from NRCS. One ingredient to its success is rapid turn-around time that has been recently enhanced by posting results on the internet. The main use of the NIRS-NUTBAL system by producers is to determine when and with how much to supplement cattle. However, extrapolation beyond the conditions represented in the calibration samples is risky and it is difficult to validate whether the analyses are accurate.

Starks, Phillips, and Coleman (2004, unpublished data) compared the hand held radiometer and NUTBAL with a standard time based supplementation (Oklahoma Gold) of steers grazing bermudagrass in Oklahoma. Steers supplemented according the recommendations of NUTBAL made the fastest and most efficient gains. Steers based on forage analyses from the radiometer and adjusted for selectivity using the equations of Coleman and Barth (1973) also gained faster and more efficiently than those supplemented under the more traditional time-based system. More evaluations are needed and the databases need to be expanded to include more conditions.

Conclusion

The great difficulty in the subtropics, and Florida in particular, is that the spring dry season limits forage growth at the time when quality is highest, and in most parts of the USA, growth rate is fastest. If the calving season is delayed to avoid peak lactation during the spring drought, then the older calf (> 3 mo) must rely on forage that is low in quality during mid-summer. This illustrates how producers need on-site information and tools for managing and supplementing their cattle. Building a database with sufficient numbers of animals, forage types, climatic conditions, etc… will be difficult. We are currently including the data collected from the Buck Island project to develop local equations to predict intake and diet quality from NIRS analysis of feces. The theory and for the most part, the data pieces, are in place to develop a decision support system. Once developed, the data can be fed into animal production decision support systems such as DECI (Williams and Jenkins, 1996) or the NRC (1996) program.

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Table 1. Relationship of voluntary intake with various conventional chemistry methods, fragility (retention time) or NIR spectroscopy.

Forage type and measure	Species	Method	Calibration N	Calibration R^2	Calibration SEC[a]	Validation N	Validation R^2	Validation SEV[a]	Reference
Mixed hay and diets g kg BW^{-1}	Sheep	CP, ADF, DOM[b]	85	0.72	3.1	46	0.76	2.8	Moore et al. (1999)
Mixed grass and legume G kg BW^{-1}	Goats	NDF, Lignin	20	0.56	2.1	--	--	--	Coleman et al. (2003)[c]
		Retention time	20	0.70	1.6	--	--	--	
Mixed grass and forbs g MBS^{-1d}	Cattle	NIRS	21	0.72	9.6	--	- -	- -	Ward et al. (1982)[e]
Mixed grass and legume g kg BW^{-1}	Cattle	NIRS	53	0.70	1.7	17	0.73	1.7	Redshaw et al. (1986)
	Sheep	NIRS	44	0.60	3.1	15	0.71	2.8	

[a] SEC: Standard error of calibration; SEV: Standard error of validation with random subset.
[b] DOM = in vivo organic matter digestibility.
[c] Adapted from the data.
[d] MBS = animal weight$^{0.75}$.
[e] Intake measured with grazing animals.