Proceedings 13th Annual Florida Ruminant Nutrition Symposium, pp 16-32

Relative Forage Quality: An Alternative to Relative Feed Value and Quality Index

John E. Moore[1] and Daniel J. Undersander[2]
[1]Professor Emeritus, University of Florida, Gainesville
[2]Research and Extension Agronomist, University of Wisconsin, Madison

Introduction

Several indices of forage quality have been developed over the history of forage quality evaluation research, e.g., Nutritive Value Index, Digestible Energy Intake, Relative Feed Value, and Quality Index (Moore, 1994). Each index included both voluntary intake of forage when fed as the sole source of energy and protein, and some measure of available energy, such as energy digestibility, digestible energy, digestible dry matter (DDM), or total digestible nutrients (TDN), respectively. Intake of available energy is a major factor affecting animal performance.

Relative Feed Value

Relative Feed Value (RFV) is the only forage quality index used widely in the United States. It was developed by the Hay Marketing Task Force of the American Forage and Grassland Council (Rohweder et al., 1978). Currently, RFV is an important tool in the marketing of forage, and in forage quality education. National Forage Testing Association (NFTA) laboratories report RFV values. Hay producers and purchasers use RFV in price discovery, especially in midwestern hay auctions (Undersander, 2001). Forage seed producers use RFV to indicate variety improvement. Reference to RFV and the equations used to predict it appear in extension documents and textbooks (e.g., Kellems and Church, 2002).

The basis of RFV is voluntary intake of DDM. Intake of DDM by animals, and thus observed RFV, is determined by two animal responses, DM intake (DMI, % of BW) and DDM concentration (% of DM) that are often not correlated greatly (Moore and Coleman, 2001). Therefore, RFV is calculated from predicted values for both DMI and DDM based on laboratory analyses for neutral-detergent fiber (NDF) and acid-detergent fiber (ADF), respectively. The current equations used by NFTA are:

DMI, % of BW = 120 / (NDF, % of DM)
DDM, % of DM = 88.9 - .779 * (ADF, % of DM)
RFV = DMI * DDM / 1.29

The divisor, 1.29, was chosen so that the RFV of full bloom alfalfa has a value of 100. Larger RFV values indicate greater overall quality relative to the base of 100. It is impossible to separate RFV from the two equations used to predict DMI and DDM.

Quality Index

Quality Index (QI) and TDN were reported by the Florida Extension Forage Testing Program from 1982 to 2001 (Moore et al., 1984). The working definition of QI is voluntary TDN intake as a multiple of the TDN requirement for maintenance. It is assumed that TDN is equivalent to digestible organic matter (DOM); this is true if digestible ether extract is negligible as it is in most forages. The animal data used to calculate QI and RFV are similar, except that for QI, OM digestibility rather than DM digestibility is required. Selection of TDN as the available energy expression made it possible to use QI both for relative comparisons among forages and for predicting animal performance in computer models.

The major difference between QI and RFV is that, for QI, the reference base is a defined animal requirement for energy rather than the quality of a particular forage chosen arbitrarily. The base QI was set to 1.0 rather than 100 in order to avoid confusion with RFV. When QI is less than 1.0 (low-quality), weight loss would be expected. When QI equals 1.0, animals would neither gain nor lose weight. When QI equals 1.8 (medium-quality), growing cattle would gain 0.6 kg/day and lactating cows would produce 10 kg milk/day assuming no weight change. Another difference is that intake is expressed as grams per kilogram of metabolic weight (MW = $W_{kg}^{.75}$) rather than as percentage of BW. The equations for calculating QI from animal data are:

TDN, % of DM = OM, % of DM * OM digestibility, % / 100
TDN intake, g/MW = DM intake, g/MW * TDN, % of DM / 100
QI = TDN intake, g/MW / 29

The divisor 29 is the maintenance TDN requirement for sheep (29 g/MW). The sheep maintenance value was used because the equations used to predict DM intake were derived from sheep data. A comparable value for cattle is 36 g/MW (derived from data on growing cattle in NRC, 1984).

As with RFV, forage NDF was used to predict DM intake in the Florida QI program. Rather than using ADF to estimate forage OM digestibility, however, in vitro OM digestion was used. The following equations used to estimate OM digestibility and DM intake were derived from a database of tropical grasses fed to sheep in Florida:

OM digestibility, % = 32.2 + .49 * in vitro OM digestion, %
DM intake, g/MW = 120.7 - .83 * NDF, % of DM

Objectives

While RFV and QI have served the forage-livestock industries well, new information is now available about predicting forage quality, and about using Near

Infrared Reflectance Spectroscopy (NIRS) and in vitro digestion in forage testing. The objectives of this paper are to evaluate the acceptability of RFV and QI, and to describe a new index, Relative Forage Quality (RFQ), which makes it possible to incorporate these newer concepts and provide more accurate prediction of the performance of forage-fed animals.

Acceptability of Current Prediction Equations

No matter how sound RFV and QI are in concept, the accuracy of predicted RFV or QI values is dependent on the equations used to predict DMI, DDM, and OMD from NDF, ADF, and in vitro OM digestion, respectively. Relationships between NDF and DMI, and ADF and DDM reported in the literature have often been quite small (Moore and Coleman, 2001). Van Soest et al. (1978) reported that NDF and ADF accounted for only 58 and 56% of the variability in DMI and DDM, respectively, in a diverse data set (n = 187). Further, they noted that neither ADF nor NDF were related to DDM in aftermath cuttings (r = -.20). Abrams (1988) found that more than half the error in predicting forage digestibility from ADF was associated with selection of an unacceptable equation. Current NFTA equations used to predict RFV often underestimate RFV of higher-quality grasses, and give unacceptable estimates in many cases (Figure 1; Moore et al., 1996, 1999b).

Voluntary Forage Intake

The RFV of high-quality grasses is underestimated because DMI is underestimated (Figure 2). The NFTA intake prediction equation is based on the assumption that NDF intake is a constant 1.2% of body weight. Intake of NDF is not, however, a constant 1.2% of body weight (Figure 3), and NDF is not correlated closely with DMI (Figure 2). Others have found NDF intake to be variable for grasses and legumes fed alone (Beauchemin, 1996) and for mixed diets for lactating cows (Rayburn and Fox, 1993). With alfalfa, Sanson and Kercher (1996) found a very small correlation between observed DMI and DMI predicted from NDF using the NFTA equation.

The concept of constant NDF intake seems to be based on studies by Mertens (1987) who found Athat daily NDF intake was 1.2 ± .1% of body weight per day in diets that produced maximum daily 4% fat-corrected milk yields.@ Extrapolation of data on high-concentrate mixed diets (where associative effects decrease forage intake) to forages fed alone does not seem to be rational or justified.

The Florida QI intake prediction equation was evaluated using animal and laboratory data on cool and warm season grasses from Southern Regional Project S-45 (Moore et al., 1996). The regression of observed DM intake (g/MW) on DM intake predicted from NDF gave the following equation:

Observed DMI = 1.75 * predicted DMI B 18.9; n = 40, r^2 = .39

The mean predicted DMI (60.4 ± 4.8 g/MW) was much smaller and less variable than the observed DMI (87.1 ± 13.3 g/MW). Some of this discrepancy is due to the use of an equation derived from sheep intake data to predict cattle intake data. Nevertheless, the small r^2 values show that NDF is not an acceptable predictor of the intake of forages fed alone.

DDM and TDN

Although the NFTA equation used to predict DDM from ADF was similar to the fitted equation, differences between observed and predicted values were large in many cases (Figure 4). The forages in the S-45 project were analyzed using the Florida in vitro procedure. The regression of TDN (% of DM) calculated from observed in vivo OM digestibility on TDN (% of DM) calculated from in vitro prediction of OM digestibility gave the following equation:

Observed TDN = 1.22 * predicted TDN B 12.2; n = 52, r^2 = .71

The mean predicted TDN (55.0 ± 3.7%) was similar to the observed TDN (55.0 ± 5.4%) but the variation was slightly less. Although the relationship between observed TDN and TDN predicted from in vitro OM digestion shown here was stronger than that between observed DDM and ADF (Figure 4), differences between observed and predicted TDN values were large in several cases.

Need for an Alternative Index

Although used widely in marketing and educational programs, RFV has not been incorporated into nutritional models. The lack of use of RFV by nutritionists may be because DDM is not a conventional measure of available energy requirements and feed energy concentration. Total digestible nutrients may have been the first measure of available energy to be adopted for routine use by animal nutritionists, and TDN is used in QI. Even though modern energy systems use net energy (NE) for maintenance, growth, or lactation, each of the NE measures may be calculated from TDN (NRC, 1996, 2001). Therefore, nutritionists would more likely use an index of forage quality if TDN were used to express available energy. A forage quality index using both DM intake and TDN would be compatible with most models.

Our evaluations of current intake and available energy prediction equations suggest that errors may be unacceptable for both relative ranking of forages, and for providing inputs of intake and available energy for computer models. Furthermore, lack of fit of equations to data sets different from the one on which they were developed suggests that prediction equations should be specific for different types of forages or forage mixtures. Therefore, new approaches for predicting voluntary intake and available energy of forages fed alone must be considered.

Because RFV and QI are tied so closely to the equations used to predict them, it would be unwise to substitute other prediction equations even though they might provide more acceptable estimates. An alternative index must, therefore, have the flexibility to incorporate the most appropriate prediction equations for the type of forage being tested.

Proposed Alternative Index

We propose RFQ as an alternative to RFV and QI as an overall index of forage quality. Like RFV and QI, 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 DMI as a percentage of BW, as in RFV, and the available energy component is TDN (% of DM), as in QI. The calculation of RFQ is as follows:

RFQ = (DMI, % of BW) * (TDN, % of DM) / 1.23

The divisor, 1.23, was developed from data on 29 forages having animal observations on intake of both DDM and TDN by cattle (Table 1, set A). The data were from the S-45 project (Moore et al. 1996), and a variety of sources (Moore, et al., 1999a). The correlation between DDM intake and TDN intake was .99 (n = 29). As expected, TDN intake was smaller than DDM intake because TDN was smaller than DDM. The no-intercept regression of TDN intake on DDM intake gave a slope of .950. Therefore, multiplying the RFV divisor, 1.29, by .95 gave the RFQ divisor, 1.23.

The divisor 1.23 was used to calculate RFQ, and RFQ was compared to RFV and QI in sub sets of the data (Table 1). Data in Table 1, Set B included observations having animal data on TDN. To expand the data to a wider range of forage qualities, set C included estimates of missing TDN and DDM values calculated using regression equations derived from balanced set A. The cattle QI divisor, 36 g/MW, was used.

The means and ranges of RFV and RFQ were similar (Table 1, sets A and C) and RFV and RFQ were highly correlated (n = 29, r = .99, Set A). We conclude, therefore, that the forage base may be considered as the same for both RFV and RFQ, i.e., full bloom alfalfa, and that RFV and RFQ values, when based on animal data, are equivalent.

Although RFQ and RFV based on animal data have similar means and ranges, predicted RFQ and RFV values for individual samples may vary greatly in practice because different prediction equations will be used. We believe that when predicted RFQ and RFV values are different for a particular forage, RFQ will give a more accurate prediction of animal performance on that forage because it will be based on more accurate prediction equations.

The correlation between observed RFQ and QI was .97 (n = 71, Set B). Set C was used to develop the following equation:

$$QI = .0125 * RFQ + .097; n = 118, r^2 = .95$$

Table 1. Characteristics of Data Sets use to Compare Relative Forage Quality (RFQ), Relative Feed Value (RFV) and Quality Index (QI) using animal data[a]

Data set[b]	No.	Item[c]	Mean	Std. Dev.	Minimum	Maximum
A	29	CP	9.3	3.7	2.9	17.2
		DDM	53.1	8.1	35.1	71.6
		OMD	55.1	7.6	38.5	72.5
		TDN	51.8	6.9	35.0	67.2
		DMI	1.93	.38	.90	2.5
		RFV	80.2	21.7	34.7	124.8
		RFQ	80.3	20.4	35.3	122.9
B	71	CP	10.4	3.9	2.3	17.5
		OMD	57.1	8.9	37.7	75.4
		TDN	52.8	7.9	34.9	68.1
		DMI	2.13	.58	.74	3.38
		QI	1.24	0.41	.37	2.24
		RFQ	92.9	32.5	25.8	182.1
C	118	CP	10.7	4.7	1.9	21.0
		DDM	55.5	9.5	32.5	76.6
		OMD	57.3	8.9	36.0	76.8
		TDN	52.9	8.1	33.4	70.6
		DMI	2.17	.57	.49	3.38
		QI	1.29	0.43	.23	2.24
		RFV	95.3	35.0	16.2	185.5
		RFQ	94.9	33.6	16.7	182.1

[a]Data from Moore et al., 1996 and Moore et al., 1999a; forages include cool and warm season grasses, native grasses, straws, and alfalfa.
[b]Set A included observations having animal data on both DMD and TDN; Set B included observations having animal data on TDN; and Set C included estimates of missing values for DDM and TDN.
[c]CP = crude protein, % of DM, DDM = digestible DM, % of DM, OMD = OM digestibility, %, TDN = total digestible nutrients, % of DM, DMI = DM intake, % of BW, QI = quality index, RFV = relative feed value, RFQ = relative forage quality.

Applications of Relative Forage Quality

The potential uses of RFQ include all the current uses of RFV and QI. In addition, RFQ has the following advantages:

1. RFQ may be translated into energy requirements for maintenance and production.

a. Multiplying RFQ by .0123 gives an estimate of TDN intake (% of BW).
b. TDN concentration may be converted to NE concentration.
c. DM intake can be calculated by dividing TDN intake by TDN concentration.
d. Both DM intake and TDN can be used as inputs for several nutritional models.
e. The TDN component has value by itself when forages are fed in restricted amounts or in mixed diets.

2. Development of a new index provides the opportunity for flexibility in choice of equations for predicting DMI and TDN; these equations should be specific for different types of forage.

3. Associative effects between forages and concentrates that influence forage intake and digestibility can be predicted from estimates of forage TDN intake when fed alone (Moore et al., 1999a).

4. Those who wish to have an estimate of QI may convert RFQ to QI:

$$QI = .0125 * RFQ + .097$$

Predicting Relative Forage Quality

Voluntary Forage Intake (DMI).

Accurate prediction of DMI is the greatest challenge in developing accurate RFQ predictions. Moore et al. (1996) demonstrated that multiple regression equations using two or more laboratory analyses provided a higher percentage of acceptable estimates of intake than did equations using a single analysis. Lippke and Herd (1990) developed a model (ForagVal) that predicted animal performance from CP and ADF.

Moore and Kunkle (1999) evaluated the intake prediction equations of NFTA and those published in NRC beef cattle bulletins (NRC 1984, 1996) on a database of grass hays fed to non-lactating cattle (data were similar to those data in Table 1). From 15 to 71% of the intake estimates from these published equations were not acceptable. Moore and Kunkle (1999) developed and evaluated multiple regression equations on separate data sets. All equations that included ADF fit the data better than did those that included NDF. A new multiple regression equation including TDN, ADF, and crude protein (CP) was developed. When evaluated on an independent data set, only 7% of the estimated DMI values were unacceptable. The new equation, recommended for grasses only, is:

$$DMI = -2.318 + .442*CP - .0100*CP^2 - .0638*TDN + .000922*TDN^2 + .180*ADF - .00196*ADF^2 - .00529*CP*ADF;\ r^2 = .76$$

Where:

DMI = DM intake, % of BW
CP = crude protein, % of DM
ADF = acid detergent fiber, % of DM
TDN = total digestible nutrients, % of DM

Intake prediction equations that include a measure of digestibility may have the potential to provide more acceptable predictions than equations based on chemical analyses alone. In vitro NDF digestibility has been suggested (Oba and Allen, 2001).

Total Digestible Nutrients (TDN)

In animal trials, TDN is the sum of digestible organic nutrients with an adjustment for the higher energy value of digestible fats. In forages, TDN is considered equal to digestible OM. Many equations for estimating TDN are available. Most of them are, however, based on empirical regressions on single variables, like crude fiber, ADF, or NDF. These equations have varying accuracy, but are generally unacceptable (Moore et al., 1998). Multiple regression equations may be more acceptable, but are still empirical and forage specific.

A promising approach to predicting TDN of forages is a Asummative equation@ that sums estimates of the digestible components. Van Soest (1967) developed the first summative equation:

DDM, % of DM = .98 * NDS + DNDF B 12.9

Where:

NDS = neutral detergent solubles (DM B NDF), % of DM
NDF = neutral detergent fiber, % of DM
DNDF = Digestible NDF, % of DM = NDF*NDF digestibility, % /100
.98 = fraction of NDS that is truly digestible
12.9 = metabolic fecal DM, % of DM

The only variables in this summative equation are NDF and NDF digestibility, and the major challenge is the estimation of NDF digestibility.

Weiss equation. The summative equation of Weiss et al. (1992) is being used successfully to estimate TDN concentrations in feeds, forages, and mixed diets. It includes estimates of truly digestible non-fiber carbohydrates, truly digestible CP, truly digestible fatty acids, truly digestible NDF, and metabolic fecal excretion. As with the Van Soest summative equation, the Weiss equation requires an estimate of NDF digestibility. The Weiss equation uses lignin concentration to predict digestibility of NDF. This equation was adopted by the NRC Dairy committee (NRC, 2001).

In vitro NDF digestion in Van Soest=s equation. We have developed a simple summative equation, based on the Van Soest equation, which uses in vitro digestible NDF (IVDNDF). Data on cool- and warm-season grasses in the S-45 project were used (Moore et al., 1996). When TDN values were not available, they were estimated from DDM.

Van Soest=s summative equation requires estimates of true digestibility and metabolic fecal excretion of ND solubles (NDS = 100 - NDF). These estimates are derived from regression of apparently digestible NDS (ADNDS, % of DM) on NDS, % of DM:

ADNDS = .953 * NDS B 13.1; n = 46, r^2 = .96

In this database, the true digestion coefficient of NDS is .953 and the metabolic fecal NDS excretion is 13.1% of DM. These values are very similar to those reported by Van Soest (1967). Therefore, the equation used to estimate summative DDM (SDDM) in this study is:

SDDM, % of DM = .953 * NDS + IVDNDF B 13.1

In the database, there were 30 observations of both in vivo DDM and TDN. Regression of TDN on DDM gave r^2 = .96 and an intercept not different from zero (P = .11). Regression with a no intercept option gave a slope = .954. Therefore, summative TDN (STDN) estimates were obtained by multiplying SDDM estimates by .954.

The IVDNDF component of the SDDM equation is estimated from analyses for NDF and in vitro NDF digestion (IVNDFD). Although no collaborating laboratory in the S-45 project conducted IVNDFD analyses, one laboratory analyzed all the forages for true in vitro DM digestibility (TIVDMD). Because estimation of TIVDMD involves recovering residual NDF, it was possible to calculate IVNDFD:

IVNDFD, % = (NDF, % of DM B Residual NDF) / NDF * 100

Where:

Residual NDF, % of DM = 100 B TIVDMD, % of DM

To adjust IVNDFD for the in vivo/in vitro relationship, in vivo NDF digestibility (NDFD) was regressed on IVNDFD:

NDFD, % = 22.2 + .664 * IVNDFD, %; r^2 = .76

This equation is consistent with expectations. Adjusted in vitro NDF digestibility (IVNDFDa) was calculated using the coefficients from the above equation. In turn, IVDNDF was calculated:

IVDNDF, % of DM = NDF, % of DM * IVNDFDa, % / 100

There was a wide range in the variables in the database, and values were considered typical for grass hays (Table 2). Digestibility of NDF was slightly higher than that of DM, as expected for grasses. In vitro NDF digestion values had a lower mean, and greater range than did in vivo NDF digestibility, but the maximum values were nearly the same. As is typical, in vitro NDF digestion was smaller than in vivo NDF digestibility for hays in the smaller end of the range.

Table 2. Description of database used in estimating TDN of grass hays (Southern Regional Project S-45; Moore et al., 1996; n = 50)

Variable	Mean	Std. Dev.	Minimum	Maximum
CP, % of DM	11.9	3.4	5.7	20.4
NDF, % of DM	70.7	6.5	56.4	82.6
In vivo DM digestibility, %	57.8	6.0	44.4	70.5
In vivo NDF digestibility, %	62.5	6.6	45.8	77.6
In vitro NDF digestion, %	60.8	8.7	39.3	77.9
In vivo TDN, % of DM	54.9	5.3	43.3	65.8
Summative TDN, % of DM	55.2	5.5	43.0	65.9

The correlation (r) between in vivo TDN and summative TDN was .89 (n = 50). Estimates of summative TDN were similar to in vivo TDN values in mean, standard deviation and range.

In vitro estimates of TDN were evaluated further by examining differences between STDN and in vivo TDN values. Acceptability of differences was based on a presumed variability in TDN values among animals fed alike equal to 5% of mean TDN. Given a mean in vivo TDN of 54.9% of DM, the absolute acceptability limit was 2.745 % of DM. Differences greater than twice the limit, 5.49% of DM, were considered unacceptable, and differences falling between 2.745 and 5.49% were considered marginal. The expected optimum percentage distribution of differences using these criteria would be 67% acceptable, 28% marginal, and 5% unacceptable. In this case the percentage distribution of differences between TDN and STDN was 70% acceptable, 28% marginal, and 2% unacceptable. The large percentage of acceptable estimates is not unexpected because the evaluation of the equation was done on the same data set as that used to develop the adjusted IVNDFD equation. Further evaluation should be done on independent data sets.

We conclude that the use of in vitro NDF digestion to estimate the digestible NDF component of summative equations is a viable and potentially accurate approach to the estimation of TDN concentrations of forages fed alone. It is necessary, however, that the equations used to adjust in vitro NDF digestion to in vivo NDF digestibility be tested for acceptability. This test can be accomplished only with both in vivo and in vitro digestion trials on the same forages, and by developing equations on one data set and evaluating them on another.

Implementation of Relative Forage Quality

In order that forage testing laboratories use RFQ correctly, they must match the type of forage being tested to the most appropriate equations used to predict DMI and TDN. In most all cases, this will mean using equations different from the ones used to predict RFV and QI.

Use of in vitro NDF digestion may improve the accuracy of both DMI and TDN prediction. Routine use of in vitro NDF digestion will, however, require the standardization of methodology, comparisons with in vivo NDF digestibility for various types of forages, and development of Near Infrared Reflectance Spectroscopy (NIRS) calibration equations.

In addition to reporting values for predicted DMI, TDN, and RFQ, laboratories should report the equations they used to predict DMI and TDN on each sample. Clients should be informed that different equations are being used for different types of samples. Also, clients should be informed that if their sample is tested by more than one laboratory, it is critical that all laboratories use the same equations on that sample.

We recommend that a nation-wide organization take the responsibility for establishing a communication network among forage testing laboratories, extension specialists, researchers, and consultants. The main goal of this network is to encourage development of prediction equations, communication of them to laboratories, and monitoring their proper usage. This communication network is essential to the success of the RFQ program, and improvement in the accuracy of forage testing.

Take Home Messages

1. Relative Feed Value (RFV) and Quality Index (QI) are based on a sound concept: voluntary intake of available energy.

2. There is need for an alternative index because:
    a. Current equations used to predict RFV and QI often give unacceptable estimates of voluntary DM intake and TDN, and may not be applicable across a wide range of forage types.
    b. RFV is not expressed in units of available energy and is, therefore, not used in nutritional models.

3. A proposed alternative index, Relative Forage Quality (RFQ), is expressed in terms of total digestible nutrients (TDN), and provides the opportunity to use new equations for predicting voluntary DM intake

and TDN. Because of the use of new and forage-specific equations, RFQ will be applicable across a greater range of forage types than were RFV and QI.

4. Research is needed to identify forage-specific equations that will provide more acceptable predictions of voluntary DM intake and TDN. Different equations may be needed for alfalfa, cool-season grasses, warm-season grasses, grass/legume mixtures, corn silage, etc.

5. Multiple regression equations may provide more acceptable predictions of DM intake; including some estimate of digestibility as well as chemical composition may be helpful.

6. The Weiss and Van Soest summative equations are recommended for predicting TDN concentration of forage grasses. In vitro NDF digestion is an acceptable method for estimating the digestible NDF component in summative equations.

7. Efforts to standardize methods for estimating in vitro NDF digestion are needed. The potential of NIRS to estimate forage digestibility makes it possible to use in vitro NDF digestion values in routine forage testing.

8. A nation-wide communication network is needed to foster the development of new prediction equations, to assist forage testing laboratories in choosing the most appropriate equations for different types of forages, and to educate clients about the new program.

Literature Cited

Abrams, S.M. 1988. Sources of error in predicting digestible dry matter from the acid-detergent fiber content in forages. Anim. Feed Sci. Technol. 21:205-208.

Beauchemin, K.A. 1996. Using ADF and NDF in dairy cattle diet formulation - a western Canadian perspective. Anim. Feed Sci. Technol. 58:101-111.

Kellums, R.O, and D.C. Church. 2002. Livestock Feeds & Feeding, Fifth Edition. Prentice Hall, NJ.

Lippke, H. and D.B. Herd. 1990. FORAGVAL: Intake and gain estimated from acid detergent fiber and crude protein of the forage diet. Tex. Agric. Expt. Sta. MP-1708.

Mertens, D.R. 1987. Predicting intake and digestibility using mathematical models of rumen function. J. Anim. Sci. 64:1548-1558.

Moore, J.E. 1994. Forage quality indices: development and application. p. 977-998. In: G.C. Fahey, Jr. (Ed.) Forage Quality, Evaluation, and Utilization. ASA, CSSA, SSSA, Madison, WI.

Moore, J.E., and S.W. Coleman. 2001. Forage intake, digestibility, NDF and ADF: How well are they related? p. 238-242. In: T. Terrill (Ed.) Proc. Am. For. Grsld. Coun., Springdale, AR. AFGC, Georgetown, TX.

Moore, J.E., and W.E. Kunkle. 1999. Evaluation of equations for estimating voluntary intake of forages and forage-based diets. J. Animal Sci. (Suppl. 1):204.

Moore, J.E., W.E. Kunkle, K.A. Bjorndal, R.S. Sand, C.G. Chambliss, and P. Mislevy. 1984. Extension forage testing program utilizing near infrared reflectance spectroscopy. p. 41-52. In: Proc. Am. For. Grsld. Coun., Houston, TX. AFGC, Georgetown, TX.

Moore, J.E., J.C. Burns, and D.S. Fisher. 1996. Multiple regression equations for predicting Relative Feed Value of grass hays. p. 135-139. In: M.J. Williams (Ed.) Proc. Am. For. Grsld. Coun., Vancouver, BC. AFGC, Georgetown, TX.

Moore, J.E., W.F. Brown, and M.B. Hall. 1998. Evaluation of equations for estimating total digestible nutrient concentrations in forage grasses. p 117-121. In: M. Phillips (Ed.) Proc., Am. For. Grsld. Coun., Indianapolis, IN. AFGC, Georgetown, TX.

Moore, J.E., M.H. Brant, W.E. Kunkle, and D.I Hopkins. 1999a. Effects of supplementation on voluntary forage intake, diet digestibility, and animal performance. J. Anim. Sci. 77 (Suppl. 2):122-135.

Moore, J.E., W.E. Kunkle, and M.B. Hall. 1999b. Evaluation of equations for predicting relative feed value of grasses. Proc. Natl. For. Testing Assoc.Workshop, Topeka, KS.

NRC, 1984. Nutrient Requirements of Beef Cattle, Sixth Revised Edition. National Research Council, National Academy Press, Washington, DC.

NRC, 1996. Nutrient Requirements of Beef Cattle, Seventh Revised Edition. National Research Council, National Academy Press, Washington, DC.

NRC, 2001. Nutrient Requirements of Dairy Cattle, Seventh Revised Edition. National Research Council, National Academy Press, Washington, DC.

Oba, M. and M.S. Allen. 1999. Evaluation of the importance of the digestibility of neutral detergent fiber from forage: effects on dry matter intake and milk yield of dairy cows. J. Dairy Sci. 82:589-596.

Rayburn, E.B., and D.G. Fox. 1993. Variation in neutral detergent fiber intake of Holstein cows. J. Dairy Sci. 76:544-554.

Rohweder, D.A., R.F. Barnes, and N. Jorgensen. 1978. Proposed hay grading standards based on laboratory analyses for evaluating quality. J. Anim. Sci. 47:747-759.

Sanson, D.W., and C.J. Kercher. 1996. Validation of equations used to estimate Relative Feed Value of alfalfa hay. Prof. Anim. Sci. 12:162-166.

Undersander, D. 2001. Does forage quality pay? p. 120-125. In: Proc. Am. For. Grsld. Coun. April 22-25, Springdale, AR. AFGC, Georgetown, TX.

Van Soest, P.J. 1967. Development of a comprehensive system of feed analyses and its application to forages. J. Anim. Sci. 26:119-127.

Van Soest, P. J., D. R. Mertens, and B. Deinum. 1978. Preharvest factors influencing quality of conserved forage. J. Anim. Sci. 47:712-720.

Weiss, W.P., H.R. Conrad, and N.R. St-Pierre. 1992. A theoretically-based model for predicting total digestible nutrient values of forages and concentrates. Anim. Feed Sci. Technol. 39:95-110.

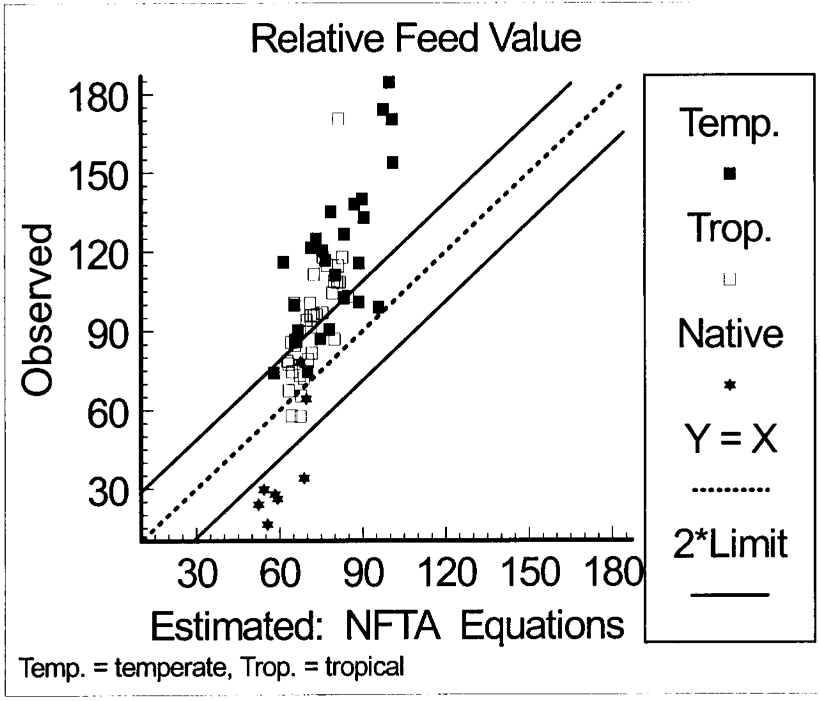

Figure 1. Observed RFV vs estimates by NFTA equations for 68 grass hays. Points outside the solid line represent differences between observed and estimated values greater than twice the acceptability limit of 9.4 (Moore et al., 1999b).

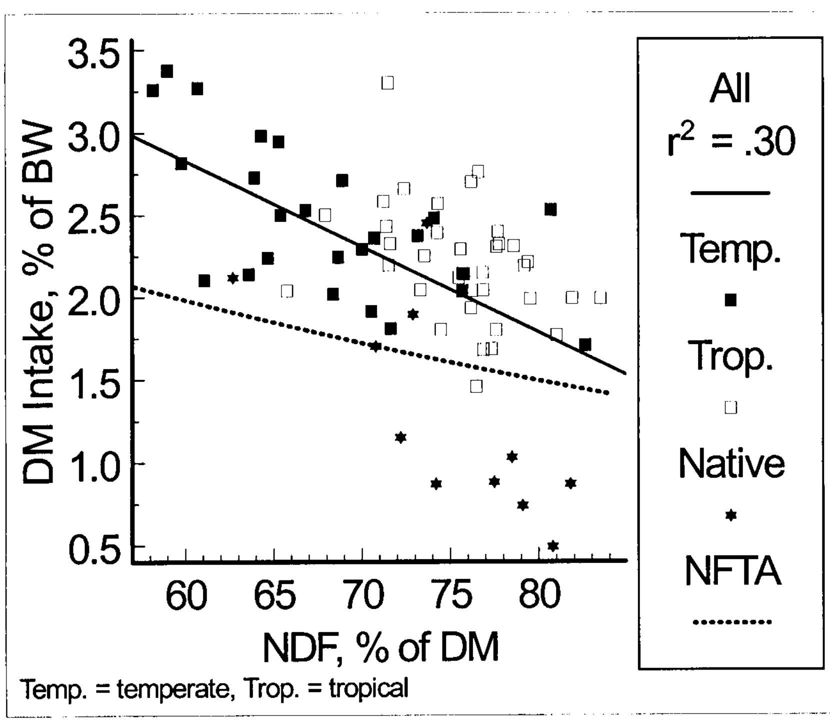

Figure 2. Observed DM intake vs NDF concentration for 73 grass hays, and NFTA estimates of DM intake (Moore et al., 1999b).

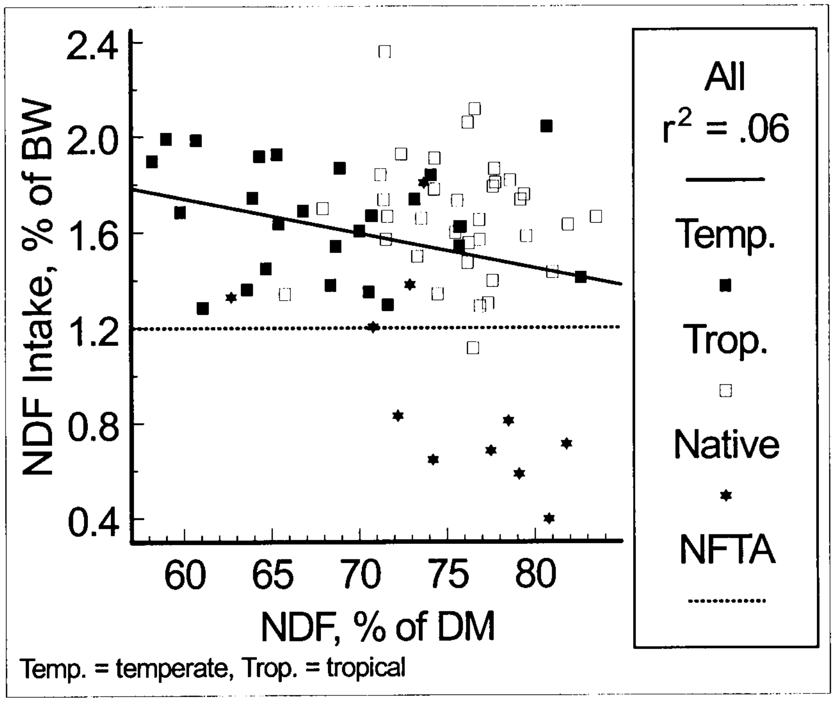

Figure 3. Observed NDF intake vs NDF concentration for 73 grass hays, and the NFTA assumption of 1.2% of BW (Moore et al., 1999b).

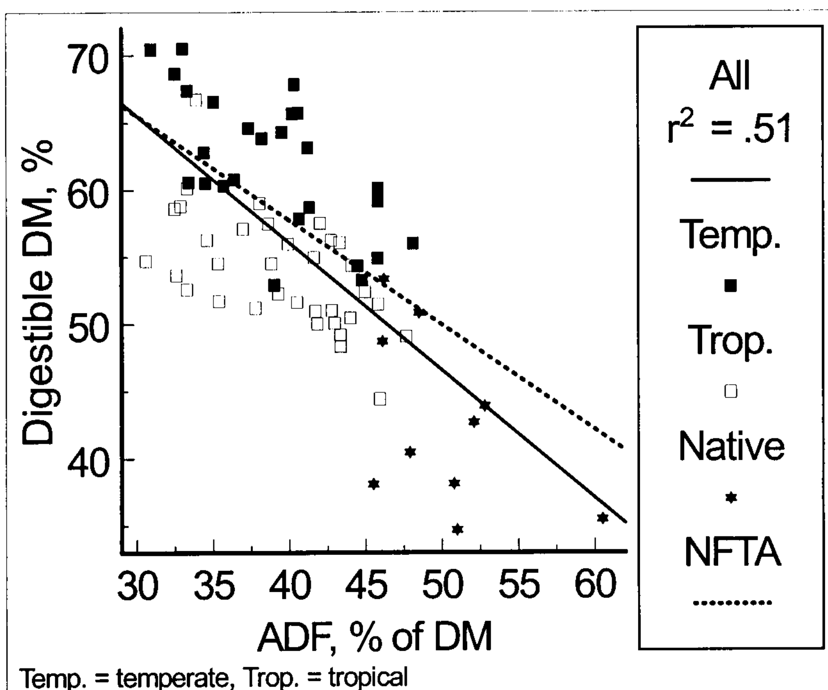

Figure 4. Observed digestible DM vs ADF concentration for 70 grass hays, and NFTA estimates of digestible DM (Moore et al., 1999b).