ESTIMATING THE ENERGY VALUE OF CORN SILAGE AND OTHER FORAGES

P.H. Robinson[1]

ABSTRACT

It is possible to estimate the energy value of ruminant feeds if some chemical assays of the feedstuffs, and the estimated *in vitro* digestibility of its NDF, are determined. These assays are all available commercially from several laboratories. While the actual accuracy of the resulting energy values cannot be evaluated absolutely, it provides the best approach when forages of mixed, or unknown, botanical descriptions make up a portion of the feeds in the ration.

Corn silage is commonly classed as a forage even though its actual botanical description means that it is really a combination between a forage and a grain, and this becomes more pronounced as it matures. The possibility of using a single assay, such as NDF, to accurately and inexpensively predict the energy value of corn silage is very very unlikely. However use of a package of several chemical assays can provide accurate estimates of the energy value of any corn silage, albeit at a higher cost.

INTRODUCTION

Feedstuffs can be chemically assayed for a number of constituents that define nutritive value. However the energy value of a feedstuff, which is the nutritive characteristic that defines much of its economic value, is not a chemical constituent and cannot be chemically assayed. This situation has challenged agronomists and ruminant nutritionists for decades, and provided the impetus for development of numerous equations and systems that purport to estimate the energy value of feedstuffs from one or more chemical constituents. These equations and systems may have worked well, or not so well, although it is virtually impossible to critically evaluate them, since energy values of feedstuffs have not been regularly measured in animals since the late 1960's. Thus there are no 'standards' to which predicted energy values of feeds can be critically compared.

It has long been recognized that the two key factors that determine the energy value of a feedstuff are its content of fat, due to its high energy value, and the digestibility of its structural fiber (i.e., neutral detergent fiber; NDF), due to its generally high content in forages. The former can be dealt with by chemical analysis, although the latter has proven to be more difficult to estimate. In North America the tendency has been to rely upon the basic similarity of fiber, within a forage type, to develop unique energy prediction equations for each forage type. This is also the logic behind the equation used in California to estimate the total digestible nutrients (TDN) and net energy for lactation (NE_l) content of alfalfa hay from its content of acid detergent fiber (ADF). This approach has also been used by the National Forage Testing Association

---

[1] Peter Robinson, Cooperative Extension Specialist, University of California, Davis, CA 95616-8521. **In**: Proceedings, 31st California Alfalfa and Forage Symposium, 12-13 December, 2001, Modesto, CA, UC Cooperative Extension, University of California, Davis 95616. (See http://alfalfa.ucdavis.edu).

(NFTA), which lists numerous equations at its web site to predict the total digestible nutrient (TDN) value of specific forages.

The big problem with this approach is that the botanical description of the forages, and time of year that the forage was harvested, must be known in order to decide which equation to use. This provides intractable problems for unknown and mixed forages. In addition, these equations tend to be region specific. This can be a problem for forages, such as alfalfa hay, that are transported to markets outside their region of origin and forages, such as corn silage, that are grown from numerous cultivars selected for different characteristics. In contrast, European countries have tended towards use of *in vitro* fiber digestibility (i.e., small samples of the forage are 'digested' in a small container with rumen fluid from a cow or sheep) to estimate actual fiber digestibility. This approach eliminates concerns about accurate botanical description of the test feedstuff, but introduces the complexity, cost and uncertainty of the *in vitro* procedure itself. However new *in vitro* procedures, and their wide commercial availability in the USA, have overcome many concerns about its use to estimate the energy value of forages for cattle.

ENERGY CALCULATIONS IN THEORY

The traditional, and still most common, approach to estimating the energy value of feedstuffs has been to calculate its total digestible nutrient (TDN) level using a summative equation based upon analyzable components of feedstuffs. Although the exact TDN equation has changed over the past 100 years, as feedstuff analyses have improved, the principles have remained unchanged. Currently accepted equations calculate TDN as the sum of digestible crude protein (CP), digestible fat (multiplied by 2.25), digestible neutral detergent fiber (NDF), and digestible non-structural carbohydrate (NSC) all corrected for a metabolic cost of digestion by the animal. The TDN value, calculated in this manner, can then be used to estimate the digestible energy (DE), metabolizable energy (ME), and/or NE_l values of individual feedstuffs.

One major problem with this approach is that the digestibility of NDF varies widely among and within feedstuffs. Analytical procedures, such as lignin (the truly indigestible portion of NDF), have been used to estimate the actual digestibility of NDF in specific feedstuffs, but these are highly inaccurate due to analytical error of the lignin procedure (it is often present in feeds at very low levels) and the poor relationship between lignin levels of feedstuffs and their actual digestibility by cows. The only reliable, and relatively laboratory friendly, method currently available to accurately estimate actual ruminal digestibility of NDF is the *in vitro* rumen digestion procedure. In this procedure, small samples of the feeds are incubated with rumen fluid from cows for a specific period of time to estimate the actual digestibility of the NDF by cows.

The following equations define estimates of the TDN and NE_l values of feedstuffs for cattle fed at a low level of intake (i.e., a level of intake sufficient only to maintain the body weight of the animal, referred to as the maintenance level of intake (1xM)), as well as how to modify that energy value for animals fed at higher or lower levels of intake.

Estimation of the TDN and NE_l (1xM) in Mcal/kg of Dry Matter

$$TDN_{(1xM)} = ((CP-ADICP)*(FT/5)*.98) + ((CP-ADICP)*(1-(FT/5))*.8) + ((EE-1)*.98*2.25) + (NDF*dNDF) + (.98*(100-ASH-EE-NDF-CP)))$$

$$NE_{l\,(1xM)} = ((TDN_{(1xM)})*.0266) - .12$$

Where:	CP	=	crude protein (% of DM)
	ADICP	=	acid detergent insoluble CP (% of DM)
	FT	=	feed type (silages = 1, wet by-products = 2, others = 3)
	EE	=	ether extract (% of DM)
	NDF	=	ash-free NDF assayed with sodium sulfite & amylase (% of DM)
	dNDF	=	*in vitro* NDF digestibility at 30 hrs (% of NDF)
	ASH	=	ash (% of DM)

However, the energy content of a feedstuff is not a constant value. As its intake by the animal increases, its energy content tends to decline since it passes through the intestine faster allowing rumen microorganisms and intestinal enzymes less time to digest the available nutrients. The extent of the change, referred to as the energy discount value or simply discount, quantifies the extent of this change. The discount is a reflection of the NDF and NSC content of the feedstuff, and it can be calculated as '% per unit of energy intake' (as a % of maintenance energy requirements of the ruminant in question) as:

$$Discount = ((.033 + (.132*NDF_{(\% DM)})) - (.033*NE_{l\,(1xM,\ Mcal/kg)})) + (NSC_{(\% DM)}*.05)$$

Where:	NDF	=	ash-free NDF assayed with sodium sulfite & amylase (% of DM)
	NE_l	=	energy value at 1xM intake
	NSC	=	non-fiber carbohydrate calculated as: 100-ASH-EE-NDF-CP

The energy discount is important as it defines the rate of change in the energy value of a feedstuff as the energy intake of the target ruminant changes relative to its energy requirements for maintenance.

Estimation of NE_l (3xM) in Mcal/kg of Dry Matter

The NE_l values reported by the National Research Council (NRC) in its 2001 booklet outlining the nutrient requirements of dairy cattle are expressed at both three and four times maintenance energy requirements (i.e., 3xM or 4xM) as these are considered to represent the energy intake of average high producing dairy cows. However the NE_l value at 4xM is new to this publication and it is the NE_l value at 3xM that we are familiar with as it has been the value used since the NRC (1978) publication. NE_l (3xM) is calculated from the value at 1xM and the energy discount as:

$$NE_{l\,(3xM)} = NE_{l\,(1xM)} - (NE_{l\,(1xM)} * (Discount*2/100))$$

The same approach can be used to estimate the NE_l value of virtually any feedstuff at any known level of energy intake relative to maintenance energy requirements of the cows. These equations, which rely upon chemical analysis and *in vitro* determinations of the digestibility of NDF are applicable to virtually all potential ruminant feedstuffs.

ENERGY CALCULATIONS IN PRACTICE

The equations outlined in the previous section, while descriptive of an approach to estimating the energy value of virtually any potential feed for ruminants, are too esoteric and complex to be used by most people. In practice, there are two methods available to estimate the energy value of feedstuffs using this approach.

Request an *In vitro* Digestibility Estimate of NDF

Commercial laboratories, such as Dairy One, Ithaca (NY) and Cumberland Valley Laboratories, Maugensville (MD) provide this assay. The *in vitro* NDF assay that has essentially become an industry standard is the '30 h in vitro NDF', which simply means that the sample of feed was incubated with rumen fluid for 30 h. The 30 h period was selected since it best represents digestion of feeds in dairy cows. Once in hand, this value can be entered into a simple spreadsheet to estimate the energy value of the feed. The spreadsheet, downloadable from:

http://animalscience.ucdavis.edu/faculty/robinson

is shown in Table 1. The user enters only the analytical information highlighted and the program estimates the various energy values, which can then be used for feed evaluation, feed pricing and ration formulation.

Request an *In vitro* Digestibility Based Energy Estimate

One commercial California laboratory (JL Analytical, Modesto) provides this assay. Based on the same 30 h *in vitro* NDF assay, the analytical report (Table 2) lists several analyzed fractions and the various energy values, which can then be used for feed evaluation and ration formulation.

CORN SILAGE

As most forages mature, the proportion of NDF increases as its digestibility declines. Since NDF is generally the slowest fermenting portion of the plant in the rumen of the cow (i.e., has the lowest energy value) the impact of the increasing NDF and declining digestibility of NDF tends to drive down the energy value of the entire plant. Generally the small contribution of the higher energy parts of the plant, such as starch and fat in the seed head, with advancing maturity are relatively small and so, in general, as the plant matures its energy value declines. Indeed this principle drives the California system (i.e., the Western States Equation), which is widely used in California to estimate the TDN and NE_l value of alfalfa hay from ADF. Based upon actual feeding studies completed at UC Davis in the 1970's with alfalfa hays, the Western States Equation relies upon the high correlation of ADF with NDF in alfalfa hay. Thus as the ADF goes up, so does the NDF while its digestibility decreases. All of this means that a relatively inexpensive assay, ADF, can be used to estimate the TDN or NE_l value of alfalfa hay with accuracy. So why can't the same approach work for corn silage?

Corn silage is generally classed as a forage, even though it can contain up to 40% grain by weight. Thus, unlike most forages, the contribution of higher energy parts of the plant (i.e., starch and fat in the seed head), with advancing maturity are very large and prevent, or actually reverse, the decline in whole plant energy value with maturity. Corn silage really has two distinct portions; the plant itself and the grain. As the corn plant (exclusive of the grain) matures, its energy value declines for all the reasons noted above for alfalfa hay (i.e., increasing levels of less fermentable NDF). However the increase, by weight, of the highly fermentable seeds can overwhelm this decline in energy value of the corn plant. In other words the energy value of the whole harvested corn crop (inclusive of the grain) can increase, even as the energy value of the corn plant (exclusive of the grain) is declining.

Other difficulties with corn silage that make its energy estimation difficult, are the multiplicity of cultivars grown in California that have been selected for various agronomic and nutritional (to cows) characteristics that interact to change both grain to whole plant ratios as well as fermentability of the NDF in the rumen. The best known varieties that accomplish the latter are the 'brown midrib' corn silages, specifically selected over decades for NDF that ferments faster in the rumen of the cow, thereby increasing its energy value. Finally, corn silage is harvested over a very wide maturity range, relative to other forages, since its energy value is less impacted by maturity than other forages. This harvest range is increasing due to introduction of the so-called 'stay green' varieties that visually appear to not be maturing based upon color change while, in fact, they are maturing.

The poor relationship between the NDF level of corn silage and its estimated digestibility in the cow is illustrated in commercially grown California corn silages in Figure 1, and the lack of any relationship between the NDF level of corn silage and its estimated NE_l value is in Figure 2. These ranges in the NE_l value of corn silage within an NDF level are huge, and would impact the performance of the cows to which they are fed. Overall, the message is that no single assay, such as is the case with alfalfa hay, will accurately estimate the energy value of corn silage since it is a more complex forage than alfalfa hay. Thus a larger, and more expensive, analytical package (as discussed above) is required, that is if you really want to know the energy value of a sample of corn silage.

J L ANALYTICAL SERVICES, INC.

217 Primo Way • Modesto, California 95358 • Office (209) 538-8111 • FAX (209) 538-3966

Sample Description: Date: 9/1/2000

Study #1, Sample #1, QC 97.20, Alfalfa Hay, 1-13-2000

JL Lab # 00101156

Results of Analysis:	as received	100% dry basis		Method reference
Dry Matter	90.0			AOACI 930.15
Ash	9.0	10.0	% of DM	AOAC 942.05
Organic Matter	81.0	90.0	% of DM	
Crude Fat (Ether Extract)	1.6	1.8	% of DM	AOACI 930.39
Crude Protein (N x 6.25)	17.3	19.2	% of DM	AOACI 990.03
Acid Detergent Insoluble Protein		5.2	% of CP	NFTA 6
Available Protein		94.8	% of CP	NFTA 6
Acid Detergent Fiber	31.6	35.1	% of DM	AOAC 973.18
Neutral Detergent Fiber	41.8	46.4	% of DM	NFTA 5.1
30 hr in vitro NDF Digestibility		42.6	% of NDF	Daisy
Non Structural Carbohydrate	20.3	22.6	% of DM	
Calculated Energy Values:**				
Total Digestible Nutrients (if fed at 3 times Maintenance)		51.4	% of DM	
Net Energy for Lactation (if fed at 3 times Maintenance)		0.575	Mcal/lb of DM	
Energy Discount *		7.24	% unit M	
Net Energy for Lactation (if fed at 1 times Maintenance)		0.672	Mcal/lb of DM	
Digestible Energy (if fed at 1 times Maintenance)		1.20	Mcal/lb of DM	
Metabolizable Energy (if fed at 1 times Maintenance)		1.01	Mcal/lb of DM	
Net Energy for Maintenance (if fed at production level)		0.60	Mcal/lb of DM	
Net Energy for Gain (if fed at production level)		0.34	Mcal/lb of DM	

* The % decline in the energy value for each increase of 1 maintenance unit of intake (expressed as a % of maintenance energy value).

** Energy calculations are the UC Davis equations as described in: Robinson, P.H. 1999. Estimating the Energy Value of Ruminant Feedstuffs. May, 3 pp Available on the Web at: 'animalscience.ucdavis.edu/faculty/robinson'.

Table 2. Sample analytical Report showing several analyzed fractions and energy values.

Figure 1. Relationship between NDF level of corn silage and its digestibility in cows.

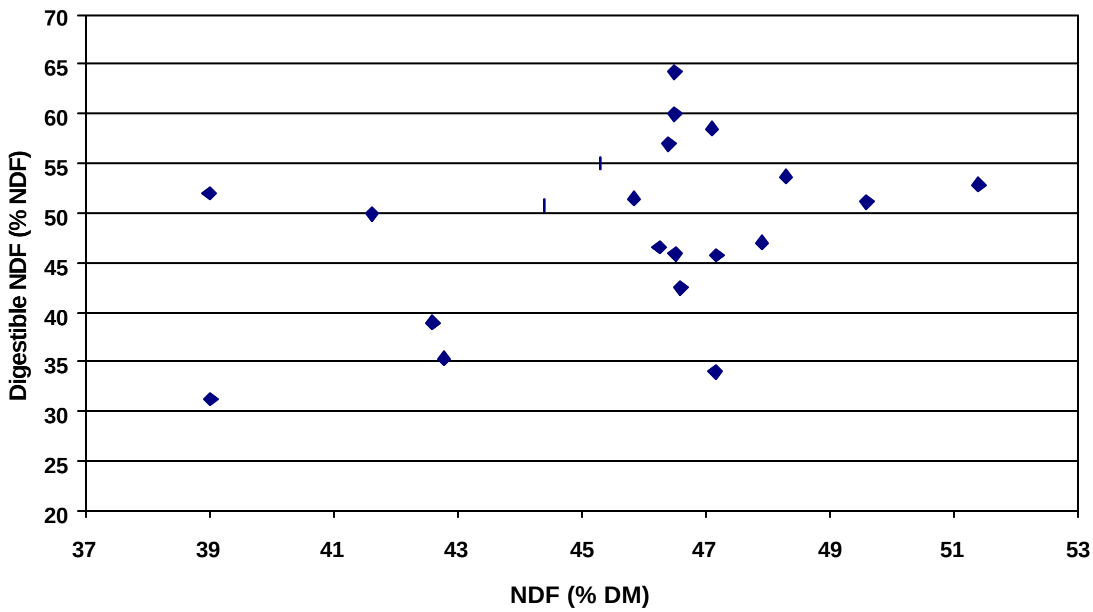

Figure 2. Relationship between NDF level of corn silage and its energy value to cows.

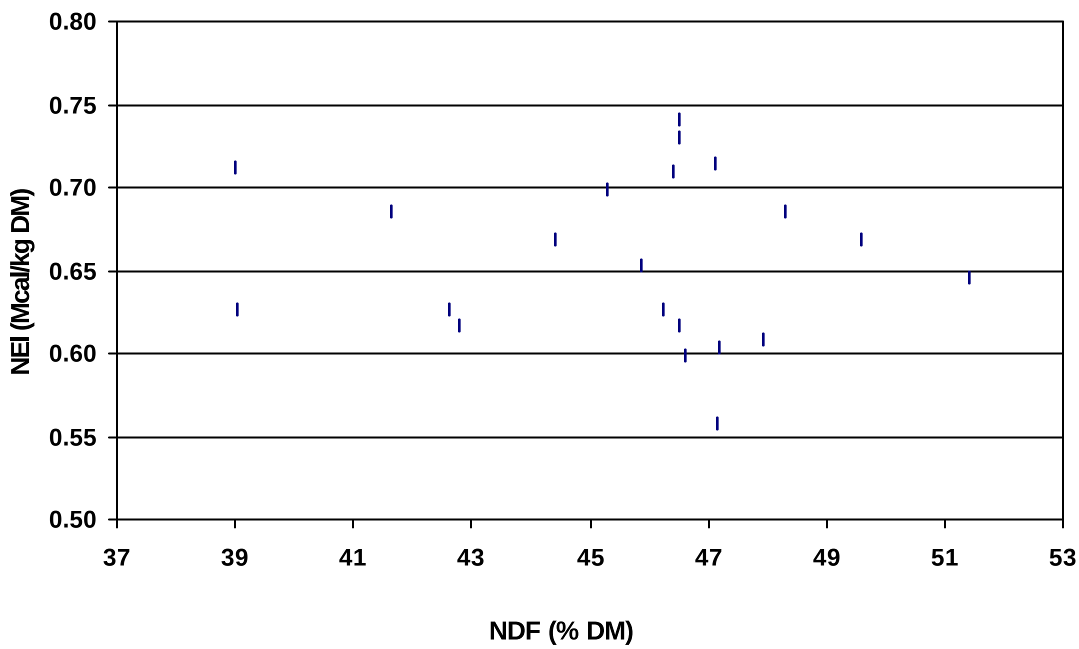

Table 1. Predicting the Energy Value of Feedstuffs from Analyses

Sample Description	--- Required assays for Energy Calculations ---								---------- Energy Calculations ----------							
	DM	OM	Fat	CP	ADICP	NDF	dNDF	Feed Type	TDN (1XM)	NEl (1XM)	Energy Discount	NEl (3XM)	DE (1XM)	ME (1XM)	NEm -- production level --	NEg
	%	----------- % DM ---- -------			% CP	% DM	% NDF		% of DM	Mcal/lb DM	% unit M	Mcal/lb DM	Mcal/lb DM	Mcal/lb DM	Mcal/lb DM	Mcal/kg DM
Feed Type 1	**24.9**	**94.4**	**4.2**	**7.8**	**11.5**	**49.6**	**51.1**	**1**	70.32	0.79	8.16	0.66	1.41	1.22	0.75	0.47
Feed Type 2	**28.2**	**96.3**	**6.5**	**24.4**	**7.4**	**31.4**	**56.9**	**2**	83.02	0.95	5.81	0.84	1.66	1.47	0.92	0.62
Feed Type 3	**92.4**	**94.7**	**6.1**	**6.1**	**13.1**	**42.2**	**53.0**	**3**	77.92	0.89	7.55	0.75	1.56	1.37	0.85	0.56

Codes

DM	Dry matter (not actually needed for the calculations)
OM	Organic matter (i.e., 100 - total ash)
Fat	Crude Fat, or fatty acids + 1
CP	Crude Protein (N x 6.25)
ADICP	CP estimated to be totally indigestible in the digestive tract
NDF	Neutral detergent fiber (ash-free with sod sulf and amylase)
dNDF	NDF estimated to be digested in the rumen at 30 h in vitro
Feed Type	Silages = 1, wet by-products = 2, others = 3.
NEl (1XM)	Net energy for lactation (1X Maintenance) calculated from the assays
Energy Discount	The % decline in the energy value for each increase of 1 unit of intake (expressed as a % of maintenance energy requirement
NEl (3XM)	Net energy for lactation (3X Maintenance) calculated from NEl (1XM) and Energy Disc (equivalent of NRC (1989) values)
DE	Digestible energy (1XM)
DE	Metabolizable energy (1XM)
NEm	Net energy for maintenance (production level)
NEg	Net energy for gain (production level)

This spreadsheet can be downloaded at : http://animalscience.ucdavis.edu/faculty/robinson