THE CHANGING ROLE OF FORAGE FIBER IN DAIRY RATIONS

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ABSTRACT

The 'big three' forages in California, alfalfa hay, corn silage and small grain silage, are quantitatively the most important feed group on California dairy farms, as they comprise about 45% of all feeds consumed by California dairy animals. Thus, accurate estimation of their energy content is central to feed formulation that allows maximum animal performance and minimum environmental impact. While new methods are available to accurately estimate the energy value of feeds, they are relatively expensive and slow. However research completed at UC Davis has identified rapid, inexpensive and practical 'shortcuts' that accurately estimate the energy value of these forages with acceptable accuracy.

Key Words: Alfalfa, corn silage, grain silage, NDF, ADF

INTRODUCTION

The California dairy industry continues to expand at a rapid rate. Since 1997, the number of lactating dairy cows has increased approximately 75%, to about 1.75 million, and there seems little doubt that this increase will continue. Such expansion has put pressure on all potential animal feed supplies as dairy producers look to alternates to keep dairy ration costs as low as possible. A list of feeds found in rations of dairy cows in California quickly reaches into the 100's and ranges, pretty much literally, from soup to nuts.

However the 'big three' forages, alfalfa hay, corn silage and small grain silage, are quantitatively the most important feed group as they comprise about 45% of all feeds consumed by California dairy animals, and deliver the fiber that maintains healthy rumen function. In the past, forage fiber has often been generally considered to be a negative component of forages, and feeds in general, being associated with reduced energy content of the forage, reduced intake potential and reduced milk output. However it is now widely recognized that the nutritional quality of forage fiber varies both within and among these 'big three' forages and that it is possible to select for fibers that both maintain rumen function, by stimulating chewing, while having faster rates of digestion in the rumen, thus giving them a higher energy value (and intake potential) to the cows.

The purpose of this article is to discuss current practical approaches to estimate the true energy value of California alfalfa hay, corn silage and small grain silages, why these methods should be adopted in California, and why forage growers have the most to gain.

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WHY WORRY ABOUT THE ENERGY VALUE OF A FORAGE?

The fundamental characteristic of rations for dairy cattle, around which all other nutrients are structured, is its energy content. Expressed variably as TDN (total digestible nutrients) or NE_l (net energy for lactation), the level of energy in a ration is the sum of the energies of its component feeds. And therein lies the rub since, unlike chemical components such as crude protein (CP) and acid detergent fiber (ADF), the energy content of a feedstuff cannot be chemically analyzed, as energy only represents the potential of a feed's chemical components to do work as biological products, such as meat or milk, or as heat. Nevertheless, an accurate knowledge of the energy content of feeds is central to formulating cattle rations that maximize animal output of usable products, and minimize output of unused nutrients (i.e., wastes).

THE SPECIAL CASE OF CALIFORNIA ALFALFA HAY

Alfalfa hay continues to be the key forage for dairy cattle in California. It is prized by dairy nutritionists and dairy ranchers for its slowly rumen degraded CP, rapidly rumen fermented non-structural carbohydrates, as well as its high energy value for lactating dairy cows. This latter characteristic is a result of its relatively, for a forage, low levels of structural carbohydrate (i.e., neutral detergent fiber; NDF) that is relatively, for a forage fiber, rapidly degraded by microbes in the rumen of dairy cows.

The current California method to predict the energy (as total digestible nutrients; TDN) content of California alfalfa hay is based upon a publication of Dr.'s Don Bath and Vern Marble of UC Davis (Testing Alfalfa for its Feeding Value, Leaflet 21457 – WREP 109, 1989; available through any UCCE Office). Bath and Marble noted, as had others before them, that because ADF contained a high proportion of the indigestible fiber components lignin and cutin, that there was a good relationship between the ADF level of a hay and its TDN value. Combined with the speed and low cost of the ADF assay, Bath and Marble felt that ADF was an excellent assay to choose as a predictor of the TDN value of California alfalfa hay which, in contrast to 'alfalfa hays' from many other parts of the country, was in fact almost always pure alfalfa hay. Indeed, the problem of grass contamination of 'alfalfa hays' in much of the Midwestern US largely explains why RFV (Relative Feed Value) was adopted in that part of the country, as RFV at least partly deals with impure alfalfa hays, which is not a significant problem in California.

Based on UC Davis research with cattle and sheep (completed mostly by Dr. Bill Garrett) in the late 1960's and early 1970's, Bath and Marble determined that the best ADF based equation to predict the TDN value of California alfalfa hay was:

$$\text{TDN (\% of hay DM)} = 82.38 - (.7515 * \text{ADF \%})$$

This equation, referred to as the 'Western States Equation' (WSE), has been adopted by virtually all California hay testing laboratories, and has served the industry well as a quick, inexpensive, precise and robust method to predict the TDN of alfalfa hays.

The strength of the WSE is that increases in the ADF content of alfalfa hay are associated with changes in other nutrients in the hay, and all of them are negative relative to the overall energy value of the hay. The most obvious change is that as the ADF level increases, so does the NDF

(Figure 1). Since NDF captures all of the structural fiber (unlike ADF that only captures about 70 to 85% of it in alfalfa hay) and because NDF is the slowest digesting portion of the plant that is in fact digestible, its increase in hay reduces the energy level of the hay.

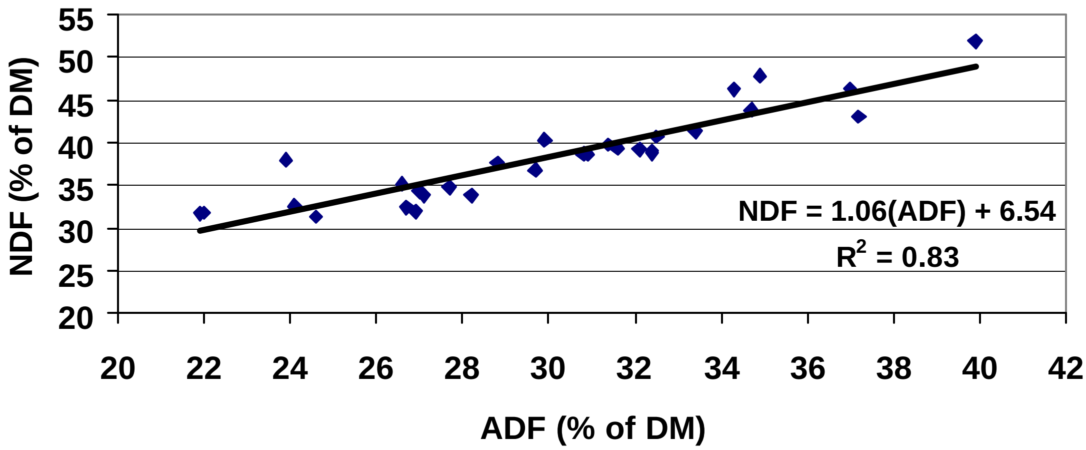

Figure 1. Relationship between ADF and NDF in California Alfalfa Hays.

However as ADF increases it is not just the NDF that is increasing, but the digestibility of that NDF is decreasing (Figure 2), which means that on a unit NDF basis, there is less energy from the NDF that is in the hay. Thus the double negative whammy on TDN – more slowly digestible NDF in the hay and more of that NDF which is not digested.

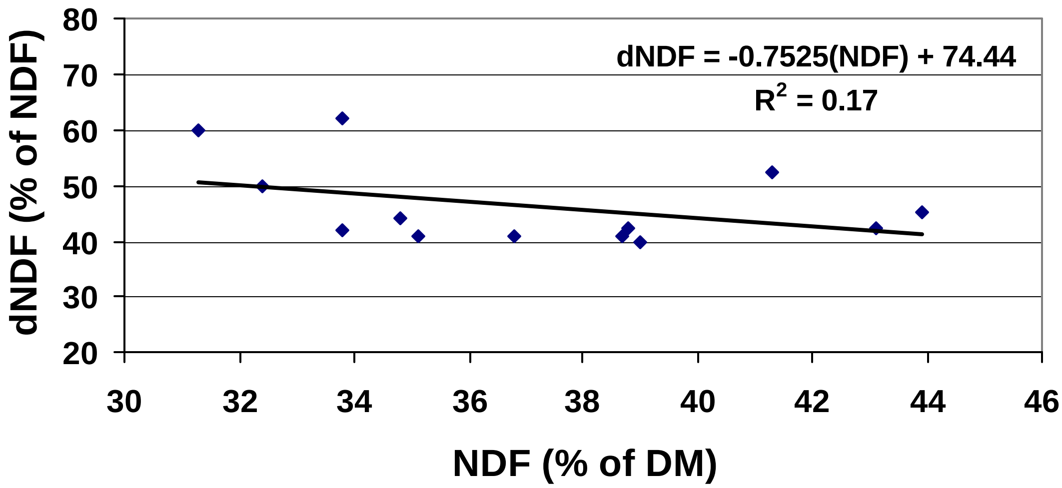

Figure 2. Relationship of NDF and digestible NDF (dNDF) in California Alfalfa Hays.

The relationship of NDF and dNDF (i.e., Figure 2) is certainly not as strong as that between ADF and NDF (i.e., Figure 1), reflecting the biological reality that there are numerous agronomic factors that impact the resistance of NDF to digestion in the rumen of cows, but the overall relationship is clear. Thus, overall, as the ADF level of hay increases, the NDF level increases, and its digestibility decreases, and these changes depress the energy (i.e., TDN) level of the hay.

Clearly this is one of the major strengths of the WSE, as it is not the increasing ADF *per se* which drives down the TDN of hay, but that ADF levels are tightly correlated to other hay components that impact the energy level of the hay. So, in a sense, the WSE equation is an energy 'shortcut', since it is not necessary to analyze for the other hay components since they are well correlated to ADF.

However the alfalfa hays upon which the WSE was based were grown from 30 to 40 years ago. Alfalfa cultivars and fertilization practices have changed dramatically during this time and it seems likely that the ADF:NDF:dNDF ratios in current cultivars differ from those of cultivars grown in the 1960's and 1970's. In other words, the WSE was almost certainly an excellent energy (TDN) shortcut in 1975, but may not be so good in 2005. In addition, these correlations between ADF and the NDF (and dNDF) levels of feeds, that actually impact their energy levels, do not hold ***among*** feeds because of chemical differences among feed fibers. Thus it would be necessary to use similar approaches to develop equivalents of the WSE equation for corn silages and small grain silages (and re-develop the WSE equation), and there are no resources available for such a long term series of digestion studies with cattle.

SO HOW SHOULD WE ESTIMATE THE ENERGY VALUE OF A FORAGE?

It has long been recognized that the two key factors that determine the energy value of a forage for cattle are its content of fat, due to its high energy value, and the digestibility of its total structural fiber (i.e., NDF), due to its high level in forages. The former can be dealt with by chemical analysis, although the latter has proven to be more difficult. The most common approach to estimate the energy value of feedstuffs has been to calculate its TDN value using an equation based on analyzable components of feedstuffs. Although the TDN equation has changed over the past 120 years, as feedstuff analyses have improved, the principles have remained unchanged. TDN is calculated based on digestible CP, digestible fat, digestible NDF, and digestible non-fiber carbohydrate (NFC), all corrected for a metabolic cost of digestion by the animal. The TDN value can then be used to estimate the net energy for lactation (NE_l) value of individual feedstuffs.

UC DAVIS APPROACH TO ESTIMATE FEED ENERGY LEVELS

The following equations define ways to estimate the TDN 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 or 1xM), as well as ways to estimate the NE_l values of feedstuffs for cattle fed at a higher level of intake (i.e., a level of intake sufficient to maintain the body weight of the animal and produce about 60 lbs/d of milk, referred to as the production level of intake or 3xM).

Estimation of the TDN (1xM) in % Dry Matter

TDN (1xM) = ((CP-SCP-ADICP)*.98) + (SCP*.80) + ((EE-1)*.98*2.25) + (NDF*dNDF)

+ (.98*(100-ASH-EE-NDF-CP)))

Where:	CP	= crude protein (% of DM)
	SCP	= soluble CP (% of DM)
	ADICP	= acid detergent insoluble CP (% of DM)
	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)

The estimation of the NE_l value at 3xM is calculated from the TDN value at 1xM and the energy 'discount' which is estimated from some of the same components used to estimate TDN value at 1xM. These equations, while allowing estimation of the energy value of virtually any feed for ruminants to be estimated, are rather complicated, and so a spreadsheet is available to make the calculations (Table 1), which can be downloaded from the author's website.

Many commercial laboratories now provide the assays required in the equation above (and in the spreadsheet in Table 1). The *in vitro* NDF assay that has essentially become an industry standard is the '30 h *in vitro* NDF', which simply means that the forage sample was incubated with rumen fluid for 30 h (the 30 h period was selected since it best correlates to digestion of dried and ground feeds in dairy cows fed at 1xM). Once in hand, this value can be entered into a simple spreadsheet to estimate the energy value of the feed. The user enters only the analytical information in bold and the program estimates the various energy values, which can then be used for feed evaluation, feed pricing and ration formulation.

Table 1. A program to predict the energy value of any feedstuff.

PREDICTING THE ENERGY VALUE OF FEEDSTUFFS FROM ANALYSES

	------ Required assays for Energy Calculations ------								--------- Energy Calculations (DM basis) --------					
									TDN	DE	ME	NEl	Energy	NEl
Sample	DM	OM	Fat	CP	SCP	ICP	NDF	dNDF	(1XM)	(1XM)	(1XM)	(1XM)	Discount	(3XM)
Description	%	-------- % DM	--------		% CP	% CP	% DM	% NDF	%	Mcal/kg	Mcal/kg	Mcal/kg	% unit M	Mcal/kg
Feed 1	**24.9**	**88.6**	**1.1**	**8.2**	**55.0**	**13.4**	**49.8**	**46.6**	58.27	2.57	2.14	1.43	8.03	1.20
Feed 2	**28.2**	**96.3**	**6.5**	**24.4**	**62.0**	**7.4**	**31.4**	**56.9**	83.02	3.66	3.25	2.09	5.81	1.85
Feed 3	**92.4**	**95.0**	**3.7**	**19.5**	**19.0**	**7.0**	**41.2**	**27.8**	63.86	2.82	2.39	1.58	6.95	1.36

http://animalscience.ucdavis.edu/faculty/robinson (can be downloaded for free)

However the package of chemical and biological characteristics of feeds that is required to calculate TDN, and/or NE_l, in this way costs up to $70 with a turnaround time of 3 to 14 days. Forage growers and cattle feeders require faster response times and lower costs, and this approach is too complex for routine field application. A practical alternative is needed.

UC DAVIS RECOMMENDED FORAGE ENERGY PREDICTIONS

Over the past 3 to 4 years a number of California alfalfa hays, corn silages and small grain cereals have had their TDN and NE_l values estimated at UC Davis by this expensive, and time consuming, approach that includes numerous analyses on each sample. Fortunately, the number of forage samples with these analyses is now sufficiently large to allow simpler 'shortcut' equations to estimate the TDN and NE_l values, based upon a much smaller number of chemical assays, to be recommended. This simpler predictive approach (i.e., the 'shortcuts') rely upon the basic similarity in the chemical and biological structure of these forages within California, and surrounding areas with similar climates, to allow the actual TDN and/or NE_l, calculated from the complete set of chemical and biological assays, to be estimated from a much smaller number of assays.

All of the following equations, within forage, are recommended, even though their predictive accuracy varies somewhat both within and among forages (which can be evaluated based upon the 'r^2' value listed for equation; where '1.00' is perfect and '0.00' is no relationship at all). However as samples arriving in commercial California forage testing laboratories vary in terms of requested assays, the laboratories require the ability to predict TDN and/or NE_l from assays such as ADF, NDF, OM (i.e., ash) and/or CP. Thus it is the decision of each laboratory to decide which equation to use, based upon available assays and the relative accuracy (i.e., the r^2 value) of the equations, since, within forage, each of the TDN or NE_l equations predict TDN or NE_l.

All values of NDF, ADF, CP, OM, as well as TDN, are as a % of DM, whereas NE_l is expressed in Mcal/lb of DM. Both NDF and ADF are expressed with residual ash, and NDF is assayed with the inclusion of sodium sulfite in the ND and the use of a heat stable alpha amylase during ND extraction. Although wet chemical analysis is very popular in California, values based upon near infrared (NIR) procedures are acceptable if they have been calibrated based upon appropriate wet chemical assay sets. TDN is estimated at 1xM (i.e., low feed intake), as this is the most common usage of TDN when we use it amongst ourselves, whereas NE_l is estimated at 3xM (i.e., high feed intake), as this is the most common usage of NE_l when we use it amongst ourselves.

Alfalfa Hay

Recommended equations to predict the TDN value of California alfalfa hays are:

$$TDN = 97.36 - (0.68627 * NDF) - (0.27333 * CP) \qquad r^2 = 0.75$$
$$TDN = 90.21 - (0.69137 * ADF) - (0.16483 * CP) \qquad r^2 = 0.73$$
$$TDN = 85.37 - (0.52179 * NDF) \qquad r^2 = 0.71$$
$$TDN = 83.49 - (0.58531 * ADF) \qquad r^2 = 0.70$$

Recommended equations to predict the NE_l value of California alfalfa hays are:

$$NE_l = 1.049 – (0.00939 * NDF) – (0.00289 * CP) \qquad r^2 = 0.74$$
$$NE_l = 0.960 – (0.00965 * ADF) – (0.00158 * CP) \qquad r^2 = 0.73$$
$$NE_l = 0.922 – (0.00765 * NDF) \qquad r^2 = 0.72$$
$$NE_l = 0.896 – (0.00863 * ADF) \qquad r^2 = 0.71$$

Within alfalfa hay, there is very little difference in the predictive accuracy of NDF vs. ADF due to the very high inter-correlation between them. Addition of CP to the equations to predict TDN or NE_l provides only a slight increase in predictive accuracy.

Corn Silage

Recommended equations to predict the TDN value of California corn silages are:

$$TDN = -40.58 – (0.99417 * NDF) + (1.66003 * OM) \qquad r^2 = 0.71$$
$$TDN = 119.07 – (1.06677 * NDF) \qquad r^2 = 0.63$$
$$TDN = -31.91 – (1.05137 * ADF) + (1.39908 * OM) \qquad r^2 = 0.56$$
$$TDN = 103.32 – (1.16829 * ADF) \qquad r^2 = 0.50$$

Recommended equations to predict the NE_l value of California corn silages are:

$$NE_l = -0.306 – (0.01169 * NDF) + (0.01611 * OM) \qquad r^2 = 0.78$$
$$NE_l = 1.243 – (0.01239 * NDF) \qquad r^2 = 0.71$$
$$NE_l = -0.169 – (0.01265 * ADF) + (0.01277 * OM) \qquad r^2 = 0.62$$
$$NE_l = 1.065 – (0.01371 * ADF) \qquad r^2 = 0.58$$

Within corn silage, the predictive accuracy of NDF is higher than ADF, and the increase in predictive accuracy with the addition of OM is significant for both NDF and ADF.

Small Grain Cereals (Barley, Oats, Triticale, Wheat)

Recommended equations to predict the TDN value of California small grain cereals are:

$$TDN = 80.54 – (0.52858 * NDF) + (0.43147 * CP) \qquad r^2 = 0.66$$
$$TDN = 70.47 – (0.56338 * ADF) + (0.48811 * CP) \qquad r^2 = 0.61$$
$$TDN = 105.79 – (0.88447 * NDF) \qquad r^2 = 0.56$$
$$TDN = 97.32 – (1.17585* ADF) \qquad r^2 = 0.50$$

Recommended equations to predict the NE_l value of California small grain cereals are:

$$NE_l = 0.820 – (0.00661 * NDF) + (0.00557 * CP) \qquad r^2 = 0.74$$
$$NE_l = 0.689 – (0.00690 * ADF) + (0.00635 * CP) \qquad r^2 = 0.68$$
$$NE_l = 1.146 – (0.01121 * NDF) \qquad r^2 = 0.63$$
$$NE_l = 1.038 – (0.01487 * ADF) \qquad r^2 = 0.55$$

Within small grain cereals, the predictive accuracy of NDF is higher than ADF, and the increase in predictive accuracy with addition of CP is substantive for both the NDF and ADF based equations.

As in all cases where corners are cut to save time and money, some predictive accuracy is lost. Thus the equations, within forage, are presented from best to worst with the r^2 value indicated, where r^2 is a statistical value that describes the ability of the equation to predict the calculated energy values (where an r^2 of 1.00 is perfect prediction and 0.00 is no prediction at all). Since both NDF and ADF are used extensively in the California hay industry, equations are presented based upon both, with or without the addition of CP or organic matter (OM; which is all the DM except ash), but only if they provide substantive improvements in predictability over NDF or ADF alone.

BACK TO THE PAST – THE WESTERN STATES EQUATION REVISITED

As the WSE was developed based upon alfalfa hays that were grown in the late 1960's and early 1970's and as, since about 1980, alfalfa seed companies have been including dNDF values (of some type) of cultivars in their selection criteria, it the reasonable to expect that NDF and ADF characteristics have changed in alfalfa cultivars with time. If this resulted in more digestible fiber (which has been one of the selection criteria), then the WSE may be underestimating the energy value of current California alfalfa hays. The difference between the WSE equation and the UC Davis recommended equation based upon ADF demonstrate that this is the case:

WSE equation:	TDN (% of hay DM) = 82.38 – (.7515 * ADF %)
UC Davis recommended:	TDN (% of hay DM) = 83.49 – (.5853 * ADF %)

These direct comparisons show that the intercepts are not different (i.e., the energy value of NSC and CP and fat is unchanged between 1970 and 2005, as would be expected) but that **the WSE is undervaluing the energy value of alfalfa hay** and so the new equation will more accurately represent the true feeding value of alfalfa hay relative to other hays and feedstuffs. Thus the equations listed above to predict the TDN value of alfalfa hay from ADF **will result in higher estimates of TDN than those predicted by the Western States Equation** (WSE) published by Bath and Marble (1989) in 'Testing Alfalfa for its Feeding Value'. [For example a hay with 27% ADF on a DM basis would increase from 55.9% TDN (90% as fed basis) to 60.9% TDN (90% as fed basis)].

However since the WSE remains the official equation to estimate the TDN value that is used to value alfalfa hay for trading purposes, its continued use will perpetuate a ***consistent underestimation of the true energy value of alfalfa hay relative to other forages and feeds in general***.

CONCLUSIONS

The TDN and NE_l contents of California alfalfa hay, corn silage and small grain cereals can be estimated based upon their NDF or ADF content alone. However in several cases the addition of CP or OM increases predictive accuracy sufficiently to justify its analysis and inclusion. California forage testing laboratories can use these predictive equations to provide the most accurate cost effective estimates possible of the energy value of these types of California forages.

However it is time to update the Western States Equation as the official equation to estimate the energy (i.e., TDN) level of California alfalfa hay, since is was developed based upon the feeding value of alfalfa hays grown over 30 years ago that are not reflective of the chemical characteristics of contemporary alfalfa cultivars. Indeed, it is clear that:

> *the group that has the most to gain by changing the current WSE equation for alfalfa, as the official California method to estimate the TDN value of California alfalfa hay, to one or more of the equations listed in this article is the California alfalfa hay growing industry as the WSE equation is* ***consistently underestimating of the true energy value of alfalfa hay relative to other forages and feeds in general*** .