Balancing Rations Using the Dynamics of Ruminal Fermentation

Charles J. Sniffen, Ph.D. & William Chalupa, Ph.D.
Fencrest, LLC, Holderness, NH
&
University of Pennsylvania
Kennett Square, PA

Introduction

Nutrition models in the world have been based on different energy systems, using static caloric values of feedstuffs and the partition of the energy, given assumed efficiencies. In the Americas there have been two energy systems used: Total Digestible Nutrients (TDN) and the Net Energy (NE) system (NRC, 2001). The NE system was initially developed at Beltsville, with the aid of respiration calorimeters to measure the energy losses from methane and heat produced from the inefficiency of metabolism in the rumen and the cow. The greatest variation is in energy losses from feces.

In the development of the NE system the need to provide NE values for feedstuffs was needed. Only limited measurements were made on different feedstuffs. Regression equations were developed from the TDN values that were published in previous NRC releases.

TDN values were derived on many feeds over many years, with digestion trials, usually using steers, being fed at maintenance. TDN is the summation of the digestion of protein, crude fiber, nitrogen free extract (we now call this non fiber carbohydrate with the replacement of crude fiber with NDF) and ether extract * 2.24 to put the fat on a carbohydrate basis. The net energy of the feedstuffs was discounted for the level of maintenance. NE_L for feedstuffs was tabulated at 3 times maintenance discounting 4% per multiple of maintenance. Dr. Van Soest (1994) recognized the differences among feedstuffs and suggested variable discounts depending on the feedstuff.

Mertens (1997) recognized that forages ranged in digestibility and that we needed a method to predict the energy of forages. He developed regression equations for each forage type to predict the energy value of forages based on the % ADF in the forage. This was a step forward from using book values. Weiss and colleagues at Ohio State (NRC, 2001) improved this with a summative equation approach that is used by our labs, using an improved prediction of fiber digestion and digestion of the other components. This approach is now incorporated into the improved energy system of NRC.

With the development of the CNCPS system, it was recognized that we needed to move beyond the Mertens prediction system and divide the carbohydrate into its different components. This started with NDF and NFC. We knew that we needed to further divide the NFC, which is a mix of several carbohydrate sources. With CNCPS 3.0, we have made a significant step toward improving the definition of carbohydrate fractions.

Carbohydrate partition

Carbohydrates in feedstuffs can be partitioned in many different ways. Van Soest (1997) developed a CHO partition system based on detergents used to analyze the fractions in forages and their use in the ruminant. Abe et al. (1997) in Japan also developed a CHO system, using enzymes rather than detergents. There are interesting differences between the two systems.

Another approach is based on chemical uniformity or identity. The advantage of this approach is that the carbohydrate sub fractions can be identified in terms of potential reactivity and the unique dynamics in the rumen and digestibility in the small intestine and hindgut (Figure 1).

Researchers in the carbohydrate area now define total carbohydrates and are beginning to think in terms of total dietary fiber. Van Soest, Hall and Van Amburgh have been restructuring the approach to the measurement of the carbohydrate fractions. Hall et al. (1997) correctly do not depict lignin in diagrams because it is not a carbohydrate. However, it is a part of the carbohydrate complex and intimately affects the availability of the potentially fermentable fiber through the ether/ester bonds to the hemicellulose in the fiber matrix. The soluble fiber is a part of the fiber but in the detergent assay, it is removed. In the assay of Abe et al. and of the human nutritionists, it is considered a part of the fiber, because it is not digested by mammalian enzymes and is a part of the cell wall complex. Soluble fiber is now considered a part of the modified carbohydrate analytical scheme. It ferments in the rumen very rapidly, with 80 to 90% disappearing in the rumen.

Starch, sugars and silage acids are now directly measured in our commercial forage labs. There is considerable work needed to bring uniformity to the assay methodology. Dr. Scott Martin, Georgia has focused our attention on the importance of the natural or metabolic forage acids in plants in terms of their amount and their impact on ruminal fermentation (Martin et al., 2000; Callaway et al., 1997). There were several papers/posters at the 2004 ADSA meetings in this area. Grant et al. (2004) presented data on continuous culture work and cow performance that looked very interesting.

CPM Dairy CHO system

The detergent system is still used in all of the laboratories. It was decided that it was necessary to continue to use the detergent system as the core to our nutrition models, recognizing that down the road there may very well be modifications to this approach.

Below is the approach as it is currently being implemented in CPM Dairy 3.0. It is critical that NDF still be analyzed without sodium sulfite. This is important because the fiber is corrected for the protein in the NDF residue. Also this protein fraction is still being used to calculate the B2 and B3 protein pools.

B3 = Available Fiber = NDF – NDIP – Lignin*2.4

Note that we are subtracting two entities. The lignin * 2.4 can be large either because it is or because there is an error in the lignin assay (lignin is a relatively difficult assay). When selecting forage from master feed dictionaries, it is critical to select as close to what you understand the forage to be. It is important to look at the lignin as a % of the NDF. If this value is quite different, either you have selected the wrong forage from the dictionary or there is an assay mistake. This is a critical number in that it affects the amount of fiber digested and your ability to predict performance. Van Amburgh and colleagues have recently reaffirmed in a series of experiments that unavailable fiber in forages is well defined by lignin*2.4.

In CPM 3.0 the starch and sugars are inputted directly. However, you may not always have those, so it is important, again to select the appropriate feed.

NFC = 100 – (Protein + (NDF – NDIP) + EE + Ash)

The important number in this calculation is the NDIP. This number makes a difference in the final calculations. It should be added that many times there are high ashes from soil contamination. This ash is insoluble in neutral detergent. An example is corn silage that usually has an ash content of around 4% DM. Many times we will see 8 or 9% DM. This can give us a negative soluble fiber, which normally is 1 to 2% DM. We input starch, sugar and the silage acids directly. Note that we can put them in as a % of DM or as a % of the NFC. It is wise for you to go to the master feed dictionary and click on forage then carbohydrates. Look at the differences in the various carbohydrate fractions (see example in Table 1). Legumes are high in sugar and soluble fiber. When forages are ensiled they lose a lot of their sugars. The carbohydrate fractions now have different symbols:

A1 = Silage acids

A2 = Sugars

B1 = Starch

B2 = Soluble fiber + plant acids

B3 = Available fiber

C = Unavailable fiber

Note that NFC is not an input (gray area) value in Table 1, but is calculated as described above. The soluble fiber is also calculated and in reality is soluble fiber + plant acids.

B2 = NFC – (Sugars + Starch + Silage acids)

We can determine soluble fiber directly but it is a difficult assay and if we do a reasonable job on the other assays, the soluble fiber estimate will be reasonably close. It needs to be pointed out that we call B2 soluble fiber but, given that it is calculated by difference there can be considerable metabolic acids such as malic, especially in immature plants.

The rates need to be discussed. There are four labs now in North America estimating rates of fermentation on fiber, two using the Ankom system, one using gas production, one using traditional in vitro and the other by in situ methodology. There is concern that the rates estimated by these labs may not be correct, due to too few points to describe a curve properly and the length of time of the fermentation may not be adequate. There is, however a reality in the expense of obtaining a proper rate. Van Soest, Van Amburgh and their colleagues (Van Amburgh et al., 2003) have developed equations to predict the rates from 24-h or 30-h NDFd, knowing the lignin and NDF in addition to the NDF digestibility and its lag time. They have recently determined that having a 24-h improved the

prediction of the Kd significantly. They also noted that the there was a fast and slow pool of fiber in forages. Dr. Abe observed this many years ago. Knowing this increases the importance of doing more points rather than fewer, if prediction equations are not going to be used. A spreadsheet (B test model) has been released and early indications from the field have been positive. The Cornell group continues to work on refinements.

Dr. Tom Tulutki, Cornell, observed through farm data analysis and using the model that the prediction of milk was most sensitive to the rate of fermentation of the starch in feeds. At this point we do not have a standardized method for measuring the rate of fermentation of starch in feeds. Two of the labs have been providing consultants and farmers in the Northeast with estimates of rates. There is concern that they have not standardized the approach and wrong rates are being provided. However, these labs are to be applauded for trying to respond to a need. There is now an intensive effort by several labs to refine a method. The values in the dictionary are now their best estimates of the relative rates of fermentation of the starch as affected by type and processing. This will be refined as quickly as we have a proper system of analysis.

It will be noted that the soluble fiber has the same rate as the starch. This is an acknowledgement that they do not have data or methods to measure the rates now. It was decided to use the same rates when the two fractions were combined. In that the organic plant acids are now a part of this fraction, this will complicate things for some of the forages; again, with time, they will refine this.

They currently have kept the sugars at the same fermentation rate as in the previous model. Again, there is an increasing body of unpublished data strongly suggesting that fermentation rates are in the 30 to 60%/h rather than in the 300% to 500%/h that is currently in the library. It is hoped that with published data, these rates will be refined.

There is research that demonstrates that the fermentation acids effectively provide limited substrate for fermentation. We decided to be conservative and use a zero Kd, with 100% digestibility. It was argued at a recent meeting that this might be too harsh. The argument was that the lactic acid in the silage would produce half the energy to the microbes that glucose would. We may change this with more research. Cornell in the next release of CNCPS will incorporate this dynamic.

Dynamic Formulation

With the new awareness of the need to optimize fermentation in the rumen and with the improved CHO assays there has been an increased demand for guidelines in CHO formulation.

Dr. Chalupa developed a beginning guideline based on a the studies that Dr. Hoover and Tammy Webster have done at West Virginia as well as the field experiences and the excellent studies of Mary Beth Hall, now from the Forage Lab in Wisconsin. These guidelines (Table 2) are very tentative. Some of Mary Beth's work would suggest that there needs to be caution in the application of these guidelines.

The guidelines emphasize the fermentable CHO. Unfortunately, at this point it is not possible to use the optimizer to formulate for the fermentable components. This is a whole new level in the use of the non linear optimizer within CPM. The best that can be done for now is to optimize for the total starch and sugar in the ration.

Note in the example in Table 3 that there is a min of 5% on sugar and a max of 8%. The starch min is 25%. The starch plus sugar is 30% DM. If the sugar is moved to 8%, then the starch can be reduced by 3%, or, as is done in the Southwest where a lot of steam flaked corn or milo is used, in the summer the starch is reduced by 5% and the soluble fiber will go up to 8%. It is interesting that in the Northwest, the starch content is low (most times barley starch), and the soluble fiber and sugar are both over 8%. It is noted that the low NDF alfalfas used in the Northwest probably have significant organic acids (malic being a major one) – it may be possible that this is contributing to improved microbial efficiency, and it has been determined that the available NDF digestibilities are very high. The answers are not all available yet.

It is suggested that there is an opportunity to vary the mixture of the NFC carbohydrates based on the environment that the cows in. During the summer, it becomes more important to control the starch being fermented in the rumen, especially if the cows are slug feeding. The starch can be reduced and the soluble fiber can be increased, leaving the sugar the same. The cows can be fed more times a day and the times of day that the cows are fed can be modified. There are times when the stalls, floors or time in the holding area is not good, compromising the cows' time budgets. This is a time to consider altering the NFC mix. It should be added that it might be wise to bring the total NFC content down to the 35 to 36% DM range and manipulate the NFC mix within that.

If the forage is high quality and feeding conditions are excellent, then the total NFC content of the ration can move up and the starch as a part of the NFC can be high with an excellent fermentability.

Up to this point microbial efficiency, has not been discussed. There are two key points in considering microbial efficiency. The first is the grams of bacterial protein produced per kg of fermented CHO. The second is the degree of coupling or uncoupling of the fermentation.

It has been found that when there is improved fermentation in the rumen there is an increase in microbial efficiency. There are products on the market that can be added to the ration that will increase microbial efficiency. An example of such a product is Fermenten. There has been a consistent increase of 10% in efficiency with this product. This translates into more microbial protein flowing to the small intestine. A part of the success of this product has been in the proper manipulation of the NFC mix and the rumen degradable protein (RDP) as suggested in the table above. This brings us to a whole new level of ration formulation; the manipulation of microbial efficiency. The bottom line is improving the digestion of the carbohydrates, providing more ME to the cow, increasing the flow of high quality protein from microbes (reducing the need for higher priced bypass proteins), and decreasing the risk of acidosis through a more coupled fermentation.

This is the second component. Microbes use carbohydrate to make new microbes. There is, like any organism, an inefficiency. This is easily seen in cows in the amount of feces the cow produces. The VFA that bacteria produce is a waste product. When bacteria produce a lot of VFA and do not grow much it is called an uncoupled fermentation. Fermenten is a product that will significantly reduce uncoupling. This is an exciting discovery. It is felt that scientists are on the "tip of the iceberg" of discoveries in exploring the opportunities for manipulating rumen fermentation. Fermenten is one good example and with time there will be more.

Summary

It is suggested that the carbohydrate sub model is a strong step forward. With improvements in analytical methods both for the pools and for the rates as well as lower tract digestibility, it will be possible to better predict the microbial yield and the energy value of feeds. There should also be better control of the acid load in the rumen and control of acidosis in cattle through manipulation of the fermentation pools and the sources. This will result in improved cow productivity and efficiency. There is just a beginning appreciation that the manipulation of the NFC mix will optimize microbial yields and ME availability for the cow. There is a beginning understanding that it is also possible with additives such as Fermenten to improve CHO digestion and microbial flow to the small intestine. There is much more to do. It is now possible to monitor the CHO fractions in the rations that are being fed and relate this to performance. There is now a significant research effort in the CHO area and this combined with field experience will move us ahead significantly in the next couple of years.

Key references

Abe, A., S. Horii, and K. Kameoka. 1979. Application of enzymatic analysis with glucoamylase, pronase and cellulase to various feeds for cattle. J. Anim. Sci. 48:1483.

Callaway, T. R., S. A. Martin, J. L. Wampler, N. S. Hill, and G. M. Hill. 1997. Malate content of forage varieties commonly fed to cattle. J. Dairy Sci. 80:1651.

Grant, R. J., C. S. Ballard, M. P. Carter, K. W. Cotanch, P. Mandebvu, C. J. Sniffen, M. Suekawa, S. A. Martin, T. K. Miller-Webster, and W. H. Hoover. 2004. Effect of feeding malic acid on performance of lactating Holstein cows. J. Dairy Sci. 87(Suppl. 1):306.

Hall, M. B., B. A. Lewis, P. J. Van Soest, and L. E. Chase. 1997. A simple method for estimation of neutral detergent-soluble fibre. J. Sci. Food Agric. 74:441.

Martin, S. A., H. M. Sullivan, and J. D. Evans. 2000. Effect of Sugars and Malate on Ruminal Microorganisms. J. Dairy Sci. 83:2574.

Mertens, D. R. 1997. Creating a system for meeting the fiber requirements of dairy cows. J. Dairy Sci. 80:1463.

National Research Council. 2001. Nutrient Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Press, Washington, D.C.

Sniffen, C. J., W. Chalupa, and S. Emanuele. 2004. Formulating rations for different carbohydrate fractions. Proc. of the Canadian Western Feed Nutrition Conf.

Van Amburgh, M. E., P. J. Van Soest, J. B. Robertson, and W. F. Knaus. 2003. Corn silage neutral detergent fiber: refining a mathematical approach for In Vitro rates of digestion. Proc. Cornell Nutr. Conf.

Van Soest, P. J. 1994. Nutritional Ecology of the Ruminant, 2nd ed. Cornell Univ. Press, Ithaca, NY.

Prepared August 2004

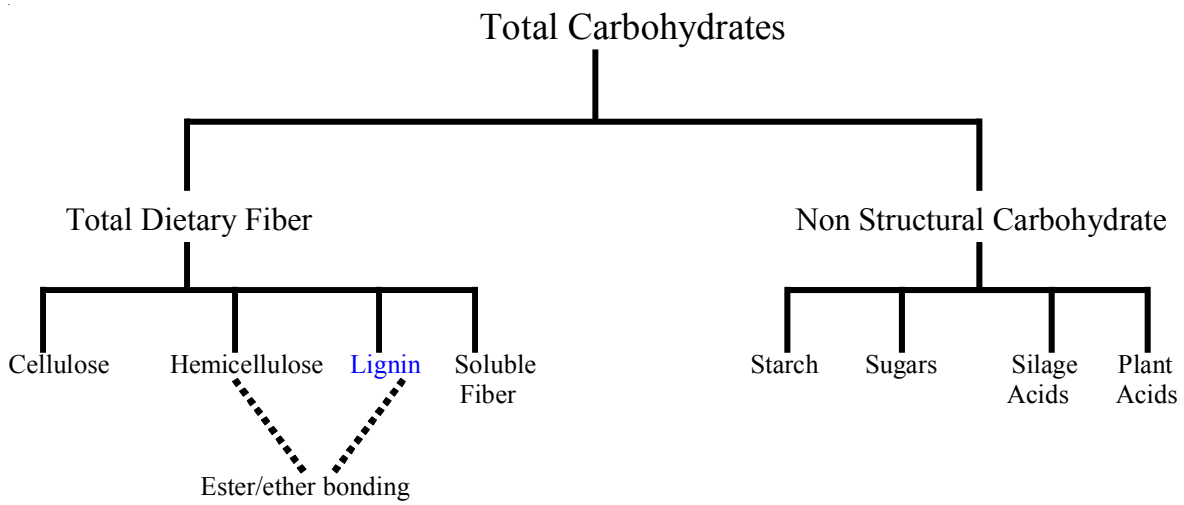

Figure 1. Carbohydrate sub fractions.

Table 1. Carbohydrate analysis for alfalfa from feed library.

Alfalfa Carbohydrate Analysis					
Feed Name		Cost	DM	Date	
AlfSil17Cp46Ndf20LNd		45.00	35.000	00-00-0000	Forage
	Nutrient Fraction	%DM	%NDF	Rates	Intest Digest
	ADF	41.000		%/h	%Escape
	NDF	46.000			
	peNDF	36.800	80.000		
	Lignin	9.200	20.000		
ChoB3	Avail NDF	23.920	52.000	5.000	20.000
ChoC	Unavail NDF	22.080	48.000		
	Ash	10.000			
	Ether Extract	3.300			
			%NFC		
	NFC	27.780			
ChoA1	Silage Acids	6.945	25.000	0.000	100.000
ChoA2	Sugar	2.778	10.000	300.000	100.000
ChoB1	Starch	1.389	5.000	30.000	75.000
ChoB2	Soluble Fiber	16.668	60.000	30.000	75.000

Table 2. Tentative Carbohydrate Guidelines for the Early Lactation Cow.[1]

Nutrient	Lbs	Kg	% Fraction	% DM	Min, % DM	Max, % DM
Dry Matter[2]	54	24.5				
Ferm Dry matter	23.2	10.5	43	43	41	44
Total NDF	16.2	7.4		30	28	33
peNDF	12.4	5.6	76.6	23	22	24
Lignin	1.89	0.9	11.7	3.5	3	4
Fermentable NDF	5.67	2.6	>35	10.5	10.5	12
Fermentation Acids		0.0		<5		
Sugar[3]	2.7	1.2		5	4	6
Ferm Sugar			98	4.9	4.8	5
Enhanced Sugar	4.3	2.0		8	7	9
Ferm Enhanced Sugar	4.2	1.9	98	7.8	6.9	8.8
Starch	13.5	6.1		25	21	27
Fermentable starch[4]	11.3	5.1	84	21	20	22
Starch + Sugar	16.2	7.4		30	27	33
Ferm St + Sugar	16.2	7.4	86.6	26	24	28
Soluble Fiber[5]	3.2	1.5		6	4	8
Ferm. SolF	2.7	1.2	84	5	3	7

1. Based on a proposal by Chalupa, based on a conference discussion with Sniffen and Hoover. This does not adequately provide for Western and Northwestern rations where sugar and soluble fiber are high.
2. These recommendations are for a cow consuming 54 lbs of DM in early lactation, making 100 lbs of milk. For other groups at less or more dry matter intake the recommendations can change.
3. Sugar needs to be at 8 to 10% DM to see a response to sugar per se; reduce starch accordingly.
4. It appears critical that there is a minimum amount of fermentable starch – the guidelines say 20%. It would appear that we need at least 18% DM and it is highly suggested that the sugar content be above 5%DM.
5. The soluble fiber recommendations are very preliminary based on Western field experience. The high sugar recommendations are based, in part on Hoover's work. Starch and soluble fiber will go down, with the total starch plus sugar being in the 28% DM range.
6. Protein recommendations are to meet the rumen degradable protein fractions. RDP needs to be 11 to 12% DM (Hoover).
7. Peptide N at 110% requirement.
8. NH_3 needs to be 110% of requirement and in excess of peptide N requirement. When subtract Peptide N from NH_3-N, NH_3-N is still positive.
9. Check soluble protein to see if in the 30 to 35% CP. (May be up to 37%).
10. Amino acid recommendations are to meet the MP and then the AA requirement.
11. Be sure that the Lys:Met ratio exceeds 3.0:1 – this will rise closer to 3.1:1 as microbial efficiency increases.
12. Be sure that the Trans 18:1 duodenal FA is below 100g.

Table 3. Nutrient optimization constraints for starch and sugar.

Nutrient	Requirement	Minimum %	Maximum %
DMI (% Rqd)	54.07 lb/d	100.000	100.000
ME (% Rqd)	66.77 mCal/d	100.000	110.000
MP (% Rqd)	6.36 lb/d	100.000	110.000
NDF (% DM)		30.000	37.000
peNDF (% DM)		22.000	28.000
NFC (% DM)		35.000	40.000
Starch (% DM)		25.000	30.000
Sugar (% DM)		5.000	8.000
Forage (% DM)		40.000	50.000
LCFA (% DM)		0.000	7.000
Pept (% Rqd)		110.000	150.000
NH3 (% Rqd)		110.000	150.000
P (% Rqd)	66.58 g/d	90.000	110.000
	Expressed by:	Percentage	
	Ratio:	Rulquin	
Met (% Rqd)		88.000	120.000
Lys (% Rqd)		93.000	120.000