Strategies for Diet Formulation with High Corn Prices

Joanne Knapp[1]
J.D. Heiskell & Co.

Abstract

Due to unprecedented changes in grain prices during the past year, the dairy industry is re-examining how feed ingredients are used to balance rations. Because corn is no longer the cheapest source of energy, it cannot be used as the sole reference feed in evaluating nutrients supplied by other feedstuffs. Energy in dairy rations is supplied mainly by carbohydrates in the form of neutral detergent fiber **(NDF)** and non-fiber carbohydrate **(NFC)**. Strategies aimed at reducing ration costs include using more high-quality forage and/or using more by-product feedstuffs to provide highly digestible NDF and NFC. Numerous research studies have demonstrated that grain starch can be replaced by fermentable carbohydrates from other feedstuffs without compromising milk yield or milk components. The key is to optimize rumen function by maintaining adequate levels of forage NDF and providing readily fermentable carbohydrate in the form of NDF and NFC. Current National Research Council (NRC, 2001) recommendations for minimum forage NDF levels in the range of 15 to 19% of DM work well. Non-forage NDF can be varied over the range of 6 to 25% of DM with NFC inversely ranging from 27 to 50%DM. Using several approaches to providing fermentable carbohydrates and thus energy in the diet, dairy producers have been able to reduce corn grain use by 25 to 35% in lactating cow rations without compromising production.

Introduction

Historic prices have led to heavy utilization of corn species as the main source of energy in feeding programs for all species. In dairy nutrition, this has been translated into corn grain being used to maximize levels and amounts of fermentable carbohydrate that provides energy to both the rumen microbes and to the dairy cow. As a consequence, recent approaches in balancing dairy rations have focused on the optimal level of dietary starch to optimize rumen fermentation and lactation performance (Emanuele, 2005; Grant, 2005). With the advent of higher corn prices and concurrent price increases in other grains and by-products, it is time to re-evaluate the role and value of carbohydrates in dairy rations towards the goal of identifying strategies in feedstuff selection and ration formulation to reduce feed costs.

Comparing and Evaluating Feedstuffs

A simple approach to evaluating feedstuffs is to compare their cost per unit of energy and protein. Energy can be based on total digestible nutrients **(TDN)** or net energy for lactation **(NE_L)**. Cost per unit of protein can be based on a crude protein **(CP)** or rumen undegradable protein **(RUP)** basis. Traditionally, the price per unit of energy and protein were based on the cost of corn and soybean meal, respectively. This approach assumes that these feeds are the most cost effective sources of energy and protein, which probably is not true in all

[1]Contact at: P.O. Box 1379, Tulare, CA 93275, (559) 757-3135, FAX: (559) 757-3145, Email: JKnapp@heiskell.com

feed markets and has been turned upside down with this year's grain prices. The simple energy/protein approach also ignores other nutrients that are important in ruminant nutrition.

Historically, the TDN system has been very valuable across species. It focuses on energy availability for maintenance and production. However, it neither includes components that evaluate forage NDF or physically effective NDF, which is important to maintaining optimal rumen function, nor does it include the concept of metabolizable amino acid delivery to the animal. Relative feed value **(RFV)** uses NDF and ADF concentrations to predict digestibility and dry matter **(DM)** intake of forages. It works well for comparison of alfalfa hays but does not work well across other hay species. Relative feed quality **(RFQ)** uses *in vitro* NDF digestibility and TDN to predict the available nutrients in forages and allows better comparisons across all hay types than does RFV.

Additional approaches have been developed to include consideration of multiple nutrients. Increasing nutritional costs are captured in FEEDVAL (Howard and Shaver, 1997), which evaluates feedstuffs based on CP, TDN, calcium, and phosphorus using 4 reference feedstuffs. Earlier versions have also allowed evaluations based on RUP. Because the reference feedstuff for energy is shelled corn, the value of energy predicted by this program will be high when corn prices are high. A program that allows nutrient pricing comparisons across a larger set of feedstuffs and user-selected nutrients is Sesame III (St. Pierre & Glamocic, 2000). This program uses a multiple regression approach to predict the prices of a set of feedstuffs based on their nutrient contents, and it consequently can be used to determine the relative price of individual feedstuffs within a defined market area (Table 1). The cost of a unit of a given nutrient, i.e. NE_L or CP, is also predicted (not shown). As an example, two major sources of starch and thus NE_L, rolled corn and rolled barley, were under-valued in July 2006. In March 2007, the price of rolled corn was at the high end of its predicted value, and rolled barley was very over-valued.

Feeding Strategies to Minimize High Grain Prices

Three strategies to reduce inclusion rates of grain will be discussed: 1) increasing forage inclusion, 2) increasing forage quality, and 3) more extensive use of by-product feeds. These 3 approaches may be best used in combination. In considering different strategies, performance goals need to be identified. Dairy producers may choose less than maximum milk yield in order to optimize income over feed costs or to minimize purchased feed costs. Different strategies can be evaluated using available ration balancing software that predicts lactation performance [National Research Council **(NRC)**, Cornell-Penn-Minor **(CPM)** Dairy, Cornell Net Carbohydrate and Protein System **(CNCPS)**, etc.].

Generally, forages are a cost-effective way to deliver nutrients to ruminants, although seasonal price variations may occur. Increasing inclusion of forages in place of concentrates can affect NDF, CP, RUP, NFC, and NE_L concentrations in a ration, as well as increasing forage NDF and physically effective NDF **(peNDF)**. Significant attention has been given to minimum levels of forage NDF or peNDF to ensure adequate rumination and prevent rumen acidosis and milk fat depression (Shaver, 2000; Mertens, 1994). Maximum NDF levels are determined by NE_L requirements (Mertens, 1994; NRC, 2001) and are affected by NDF digestibility. The current recommendations for NDF content from the NRC (2001) work well over the range of typical dairy cattle rations used in the U.S. (Table 2).

Over the past 18 months in California, small grain silages, corn silage, and alfalfa hay have all been at break-even or lower-than-predicted values as determined using Sesame III (Table 1). However, many CA dairy producers were not maximizing forage concentrations in rations until recently, with forages included only at 40 to 45% DM. As grain prices have increased since the 2006 harvest, significant increases in forage utilization have occurred, often with little or no decrease in milk yield. To determine cost effectiveness of forages, harvest, storage, and shrink costs must be included in the forage price.

Better quality forages, than poor ones, can be utilized more extensively in dairy rations. Quality is defined as the ability of the forage to deliver digestible nutrients (energy, protein, and NDF) to the cow. The use of the RFV and TDN systems to rank quality of alfalfa hays adequately captures their nutritional value (Table 3). Similar evaluations should be considered for grass hays, all haylages, small grain silages, and corn silage. While *in vitro* and *in situ* NDF digestibility assays are available, the poor correlation between these measures and *in vivo* NDF digestibility limits their value in predicting energy availability and lactation performance. Maturity and DM content at harvest have large impacts on forage quality, as do harvesting and storage procedures. Grain content of the small grain silages and corn silage also has a large impact on forage quality and the potential to increase forage proportions in a ration (Table 4). Continued focus on producing high quality forages is very important in dairy cattle nutrition.

By-product feeds can be used to replace both forages and grain in dairy cattle diets. Several research articles have been published on the ability of by-products, such as corn gluten feed, beet pulp, and soyhulls to replace forage (Clark and Armentano, 1997; Boddugari et al., 2000; Ipharraguerre, et al., 2002). Alternatively, by-products can also be used to replace more expensive grains (Boddugari et al., 2001; Ipharraguerre et al., 2002; Voelker and Allen, 2003a; Beckman and Weiss, 2005). By-products are lower in starch than grains, but they contain significant quantities of other NFC, including sugars, organic acids, fructans, glucans, and pectins. These sources of NFC are very degradable in the rumen and can provide energy to both the rumen microbes and to the cow. Rumen microbes do not have a requirement for starch per se; the energy requirement can be satisfied by fermentable carbohydrates derived from the hydrolysis of either NFC or NDF. Several research studies have shown no decrease in rumen microbial flow to the small intestine, total tract NFC and NDF digestibilities, DM intake, and milk yield and milk components when by-product feeds are substituted for corn grain in dairy rations (Table 5). Starch concentrations of the diets ranged from 9.2 to 38.3% of DM, with corresponding NFC concentrations ranging from 27.2 to 50.7% of DM, and NDF concentrations inversely ranging from 49.4 to 24.3% of DM. These studies maintained forage NDF concentrations within or above current NRC (2001) recommendations.

Steady-State Versus Non-Steady-State Kinetics in Rumen Fermentation

Significant attention has been given to rumen degradation rates of dietary carbohydrate fractions and synchronization of rumen degradable protein with carbohydrates. This has culminated in an emphasis on these rates in static nutrition models currently used in the field. Static models estimate nutrient availability at a single time point; they do not integrate over time as dynamic models do.

While the carbohydrates in NFC (sugars, organic acids, fructans, glucans, pectins, and starch) and in NDF (hemicellulose and cellulose) have different degradation rates, which can vary under different conditions, the degradation products of all of these supply a single rumen carbohydrate pool that is potentially fermentable by microbes, designated as the fermentable carbohydrate **(FC)** pool. Because cows eat multiple meals per day and there are multiple carbohydrate fractions that contribute to the FC pool, this pool approaches steady-state kinetics under common dairy management practices (Figure 5A). Altering the proportion of starch vs. other carbohydrates does not change the flow into the FC pool (Diet A versus Diet B). The FC pool is rapidly fermented by the rumen microbes, providing energy for their maintenance and growth, and volatile fatty acids to the cow for energy and milk precursors. Consequently, varying dietary starch content does not change the energy availability to the microbes or the cow, given that total NFC is maintained and that the carbohydrate fractions are degradable. This conclusion is supported by experimental evidence that demonstrates no change in microbial protein flow to the small intestine when dietary starch content was varied (Voelker and Allen, 2003b; Ipharraguerre et al., 2005).

This lack of difference between diets with altered NFC components also holds true under non-steady-state conditions (Figure 5B), such as slug feeding during heat stress situations. The pool of each carbohydrate will vary over the course of the day as a function of meal size and meal intervals, but as long as the total NFC and NDF concentrations are maintained, there is no difference in replacing starch with other NFC. The model assumes that passage of the carbohydrate fractions out of the rumen is not affected by the meal feeding pattern. Note that during the 12-hour period when the cow is eating, the FC pool approaches steady-state (19 to 7 hours). Replacing the starch in corn grain with equal amounts of other NFC or digestible NDF in by-product feedstuffs does not change energy availability, despite differences in rumen degradation rates between carbohydrate fractions.

Summary

Many dairy producers have been able to reduce corn inclusion in rations for lactating dairy cows by 25 to 35% by increasing forage and by-product utilization without sacrificing milk yield or milk components. The keys to success are:

1. Optimizing forage use by using more digestible forages at higher inclusion rates,
2. Utilizing cost-effective by-products that provide energy in the form of NFC and/or digestible NDF, and
3. Maintaining optimal rumen function by balancing rations for forage NDF or physically effective NDF.

As dairy nutritionists, we are very fortunate to work with a biological system that was designed to be flexible in terms of dietary inputs. Let's take advantage of the rumen ecology to optimize feed utilization for dairy production!

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Table 1. Actual and predicted feed prices ($/ton) for the San Joaquin Valley, July 2006 versus January 2007, using Sesame III (St-Pierre and Glamocic, 2000). Predictions were based on net energy lactation (NE_L), effective neutral detergent fiber (eNDF), and crude protein (CP).

Feedstuff	Actual 2006	2006 Predicted	2007 Actual	2007 Predicted
Corn silage	38	52	38	55
Alfalfa hay, 40 to 45% NDF	180	132	155	146
Alfalfa hay, <40% NDF	200	167	170	176
Rolled corn	131	156	178	164
Rolled barley	144	155	202	159
Bakery by-product	105	164	155	167
Wheat mill run	111	153	163	145
Rice bran	85	168	120	171
Soybean meal	217	212	229	228
Canola	184	183	196	189
Distillers grains, dry	125	193	178	188
Corn gluten feed	124	166	161	169
Cottonseed meal	189	189	197	200
Whole cottonseed	225	189	222	212
Almond hulls	93	103	130	110
Soyhulls	119	125	169	127

Table 2. The NRC Recommended minimum concentrations of forage and total neutral detergent fiber (NDF) and maximum concentrations of nonfiber carbohydrates (NFC) for lactating cows (adapted from Table 4-3, p. 37; NRC 2001).

Minimum Forage NDF (% of DM)	Minimum Dietary NDF (% of DM)	Maximum Dietary NFC (% of DM)
19	25	44
18	27	42
17	29	40
16	31	38
15	33	36

Table 3. The relative feed value (RFV) and total digestible nutrient (TDN) systems capture nutritional value of alfalfa hay[1,2].

Quality	CP (%)	NDF (%)	TDN (%; 90% DM)	RFV	Cost ($/ton)	IVDMD (%)	NE_L (Mcal/lb)	Partial milk[3] (lb)	Milk[4] ($/cow)	IOFC[5] ($/1000 cows)
Utility	18.1	51.7	50	<130	130	65.7	0.444	12.3	$1.54	$887
Fair	21.3	42.3	52	140	145	72.4	0.483	13.4	$1.67	$950
Good	23.2	35.4	54	160	160	76.9	0.512	14.2	$1.77	$975
Premium/Supreme	24.9	29.2	>56	>180	200	81.4	0.540	14.9	$1.86	$862

[1]Data on more than 40,000 U.S. hay samples kindly provided by Agri-King, Inc., Fulton, IL.
[2]CP = Crude protein, NDF = neutral detergent fiber, TDN = total digestible nutrients, RFV = relative feed value, IVDMD = In vitro dry matter digestibility, and NE_L = net energy for lactation.
[3]Predicted milk yield (lb/cow/day) from 10 lb of alfalfa hay based on forage energy content and milk fat = 3.5%.
[4]Milk income ($/cow/day) at $12.50/cwt.
[5]IOFC = Income over feed cost (1000 cows/day) with alfalfa hay at prices listed in this table.

Table 4. The NDF digestibility and starch content of corn silage is important in determining feeding value[1,2].

Quality	Moisture (%)	NDF (% of DM)	CWD (%)	Starch (%)	NE_L (Mcal/lb)	Partial Milk[3] (lb)	Milk[4] ($/cow)	IOFC[5] ($/1000 cows)
Poor	69.3	53.5	42.4	15.5	0.453	13.1	$1.64	$1070
Fair	69.1	46.4	48.0	25.5	0.526	15.3	$1.91	$1340
Medium	67.3	41.9	51.0	30.9	0.561	17.3	$2.16	$1590
Good	63.3	39.7	53.8	35.2	0.590	20.4	$2.55	$1980
Average	68.7	45.4	48.7	26.7	0.533	15.7	$1.96	$1390

[1]Data on more than 700 samples from California kindly provided by Agri-King, Inc., Fulton, IL.
[2]NDF = Neutral detergent fiber, CWD = Cell wall (NDF) digestibility, and NE_L = net energy for lactation.
[3]Predicted milk yield (lb/cow/day) from 30 lb of corn silage based on forage energy content and milk fat = 3.5%.
[4]Milk income ($/cow/day) at $12.50/cwt.
[5]IOFC=Income over feed cost (1000 cows/day) with corn silage at $38/ton.

Table 5. Summary of selected published research demonstrating that replacement of corn grain in lactating cow diets with other sources of fermentable carbohydrate does not impact milk production and can increase feed efficiency.[1]

Reference	Diet as described in reference	Forage NDF	Total NDF	NFC	Starch	Milk yield (lb/day)	DMI (lb/day)
		-------------- % of DM			------------		
Boddugari et al., 2001	0	22.8	28.2	43.2	30.3	66.9	54.3
WCGF versus corn + SBM	50	22.8	35.4	36.5	23.3	67.1	49.5
	75	22.8	38.2	32.9	18.9	67.8	50.8
	100	22.8	41.6	29.4	15.1	64.9	48.0
Beckman and Weiss, 2005	0.74	18.2	24.7	48.3	33.3	71.1	44.7
SH+CSH versus corn	0.95	18.2	28.6	43.7	30.1	69.7	46.2
	1.27	18.2	32.2	40.4	25.4	69.5	47.7
Ipharraguerre et al., 2002	0	19.1	29.4	50.7	38.3	64.9	52.4
SH versus corn	10	19.1	34.4	44.8	31.1	64.5	54.6
	20	19.1	39.9	39.0	23.8	65.8	53.7
	30	19.1	44.8	33.1	16.5	64.5	50.4
	40	19.1	49.4	27.2	9.2	62.3	49.9
Voelker and Allen, 2003a	0	17.1	24.3	47.0	34.6	80.1	54.6
beet pulp versus HMC	6	17.1	26.2	45.0	.30.5	80.5	55.0
	12	17.1	28.0	43.0	26.5	79.0	55.2
	24	17.1	31.6	39.1	18.4	77.9	50.4

[1]WCGF = wet corn gluten feed, SBM = soybean meal, SH = soyhulls, CSH = cottonseed hulls, HMC = high moisture corn, NDF = neutral detergent fiber, NFC = nonfiber carbohydrates, and DMI = dry matter intake.

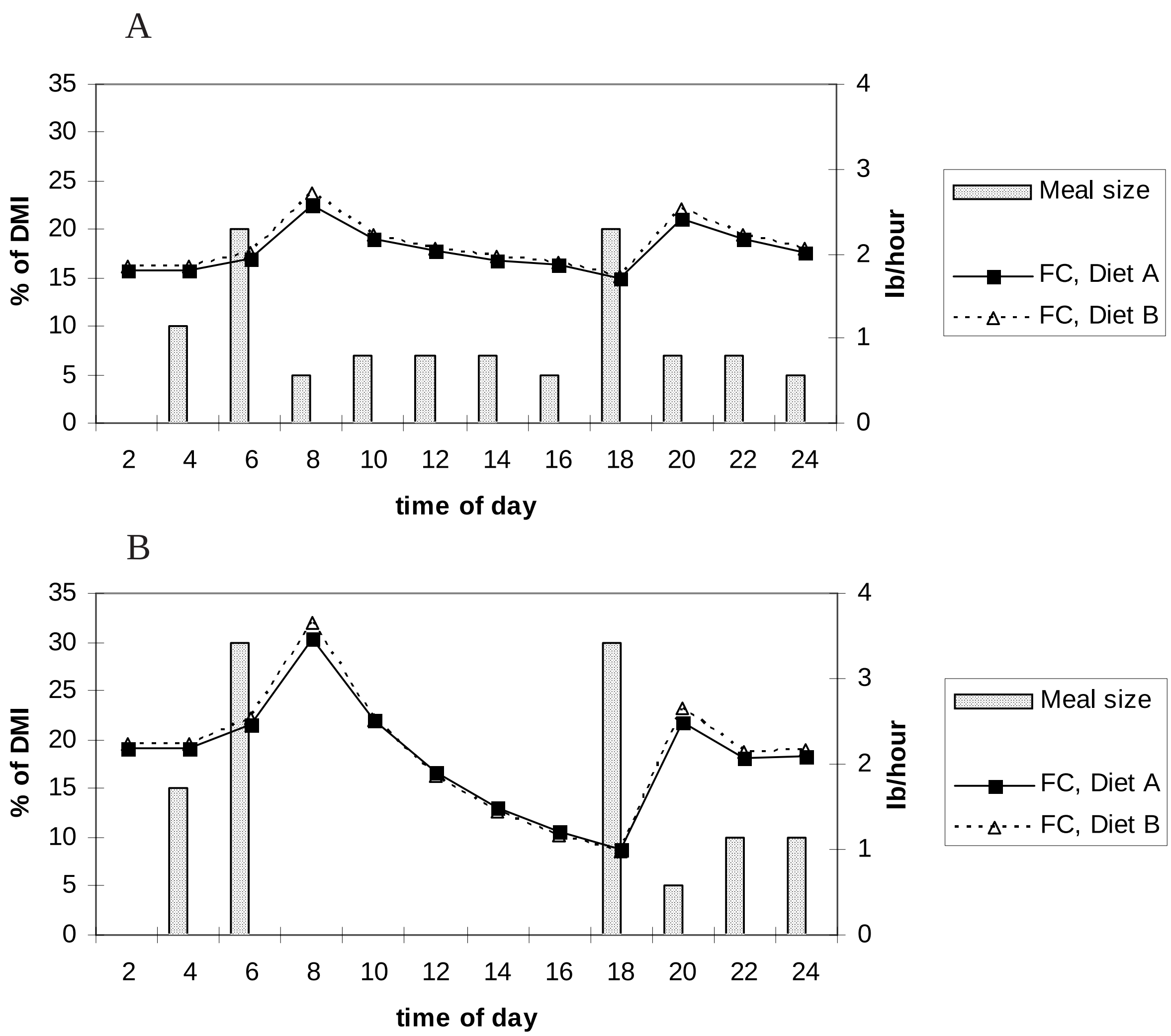

Figure 1. Energy availability to rumen microbes is not altered by varying starch content while maintaining nonfiber carbohydrate (NFC) with other sources of fermentable carbohydrate (FC) under either semi-steady state (10 to 12 meals/day, panel A) or non-steady state (6 meals/day, panel B) feeding conditions. Diet A contained 30% NDF, 40% NFC, and 25% starch, and Diet B contained 30% NDF, 40% NFC, and 15% starch. Meal size is expressed as a percentage of dry matter intake and FC is expressed as pounds per