ECONOMICS OF REPLACING CORN WITH OTHER ENERGY SOURCES IN RUMINANT DIETS

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Summary

Many dairy producers have reduced 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. Maximize forage quality and optimize forage allocation.
2. Periodically question the need of every feed ingredient in your dairy rations. Cows do not have requirements for feeds (i.e., corn) but for nutrients.
3. Question narrow nutrient constraints when formulating dairy rations. Many such constraints are not well supported by *in vivo* data (i.e., cows can do quite well with diets that do not contain 25% starch).
4. Alter diet specifications based on price of milk and feed inputs.
5. Maximize the use of bargain feedstuffs; minimize the use of over-priced feedstuffs.

Introduction

Historically, attractive corn prices coupled with its wide availability have led to heavy corn utilization as the main source of energy in dairy feeding programs in the United States. In practical dairy nutrition, this has resulted 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 many by-products, questions have been raised regarding corn use in dairy diets, and alternative feeding and ration balancing strategies with better economic outcomes. The economic need forces the necessity to re-evaluate the role and value of carbohydrates in dairy rations and ration formulation strategies to reduce feed costs. In this paper, we analyze the need for corn in dairy diets, challenge the dogma of a narrow optimal range for dietary starch and non-fiber carbohydrates (NFC) in dairy rations, compare current feed and production economics to those that prevailed a few years ago, and explain how maximum economic feed efficiency can be attained.

Cows do not Require Corn

Some have mistakenly equated the wide use of corn in dairy rations to a requirement for corn by the animals. This is incorrect both nutritionally and economically. Table 1 summarizes the results of two experiments where barley substituted for corn in lactating cow rations. None of the production, composition, intake and feed efficiency parameters were significantly affected by the type of grain used. Although some small numerical differences would seem to favor corn, it is important to remember that these studies were designed to maximize production differences between diets. For example, in the experiment of Bilodeau et al. (1989) the substitution was entirely on an ingredient basis. That is, 43.7% of the diet was either corn or barley without any other dietary adjustments to make the diets isocaloric. Thus, the barley diet had only 97% of the caloric density of the corn diet.

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Little Evidence for Narrow Optimum Levels of Starch and NSC

Many nutritional rules of thumbs were derived during times when corn was a very inexpensive feed ingredient. Some of these rules lead to good working rations that were economically efficient when corn was cheap. For example, some have recommended constraining dairy diets to 25 to 30% starch and 35 to 40% non-fiber carbohydrates (NFC). The experimental evidence to substantiate these recommendations is very thin. What has been lost is that rumen microbes do not have a requirement for starch per se; the energy requirement can be satisfied by fermentable carbohydrate derived from the hydrolysis of either NFC or NDF. Thus, significant amounts of by-product feeds can be used in replacement for corn without much effect on animal productivity.

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 soy hulls to replace forage (Boddugari et al., 2000; Clark & Armentano, 1997; Ipharraguerre & Clark, 2003). Alternatively, and more importantly in this era of ethanol euphoria, by-products can also be used to replace grains (Beckman & Weiss, 2005; Boddugari et al., 2000; Ipharraguerre et al., 2002; Voelker & Allen, 2003a). By-products are generally much lower in starch than grains but contain significant quantities of other NFC, including sugars, organic acids, fructans, glucans, and pectins. These sources of NFC are generally very degradable in the rumen and can provide energy to both the rumen microbes and to the cow. Several research studies have shown no decrease in rumen microbial flow to the small intestine, total tract NFC and neutral detergent fiber (NDF) digestibilities, dry matter intake, and milk yield and milk components when by-product feeds are substituted for corn grain in dairy rations (Table 2). Starch contents of the diets ranged from 9.2 to 38.3% DM, with corresponding NFC levels ranging from 27.2 to 50.7% of DM and NDF levels inversely ranging from 49.4 to 24.3% of DM. In all of these studies forage NDF levels were maintained within or above current NRC recommendations for forage NDF.

A quadratic response function of milk yield to dietary starch was fitted for each study reported in Table 2. The point of maximum production was estimated by equating the first derivative of this function to zero and solving for starch. Maximum milk production was achieved at starch levels of 24.4, 33.3, 28.0 and 40.7% of DM for each of the four studies. Clearly, this is a very wide range of optima. In addition, the response functions of milk to dietary starch are very flat, indicating that milk production does not respond very much to dietary starch over a range of 15 to 40% of DM. The recommended 25 to 30% range for dietary starch may have resulted in good working rations in the past, but the economic penalty for this myopic view is now, as we shall see, excessive.

A similar method was used to estimate the optimum NFC level in each of the four studies listed in Table 2. Maximum milk production was achieved at NFC levels of 37.9, 33.3, 42.4, and 49.7% of DM across the four studies. As for dietary starch, it appears that the optimal NFC level for milk production is poorly defined, and that milk production is not very responsive to NFC level in the diet. Again, a recommendation of 35 to 40% NFC in dairy rations may have resulted in good, practical rations in the era of cheap feedstuffs, but constraining diets within this narrow range is likely no longer economically optimal.

Why Dairy Cows Express a Small Response to Starch

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 from each other 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 here. 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 vs. Diet B). The FC pool is rapidly fermented by the rumen microbes, providing energy for their maintenance and growth, and VFA 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 is varied (Voelker & 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 levels 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 (19h to 7h). Replacing the starch in corn grain with equal amounts of other NFC or digestible NDF in byproduct feedstuffs does not change energy availability, despite differences in rumen degradation rates between carbohydrate fractions.

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 TDN or NE_L. Traditionally, prices per unit of energy and crude protein were based on the cost of corn and soybean meal, respectively. This approach, first proposed by Petersen (1932) and found in most applied nutrition books such as that of Morrison (1956) assumes that these two feeds are perfectly priced. That is, the assumption here is that their selling prices are always equal to the economic value of their nutrients. This assumption doesn't make much economic sense as it would imply perfect and efficient markets. That this doesn't hold has been very evident with this year's erratic grain and protein prices. The simple energy/protein approach also ignores other nutrients that are important in ruminant nutrition.

Additional approaches have been developed to include consideration of multiple nutrients. Increasing nutritional costs are captured in FEEDVAL (Howard & Shaver, 1997), which evaluates feedstuffs based on CP, TDN, calcium and phosphorus using four 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. Fundamentally, the approach is nothing more than an expansion of the Petersen method for more than two nutrients and, thus, suffers the same limitations as the Petersen method.

A method that uses prices and nutritional composition from all feedstuffs traded in a given market has been proposed by St-Pierre and Glamocic (2000). The method uses a multiple regression approach to set as many equations as there are feedstuffs. Estimates of unit costs for each important nutrient are obtained by least-squares. The resulting software, *Sesame III* is a Windows-based program and is available at www.sesamesoft.com. This program uses a multiple regression approach to estimate break-even prices of a set of feedstuffs based on their nutrient contents and market prices. Consequently, it can be used to determine the relative price of individual feedstuffs within a defined market area. The cost of a unit of a given nutrient, e.g., NE_L or RUP, is also estimated.

Using this method, we can compare the nutrient costs prevailing in 2004 when grains and protein prices were relatively in equilibrium to those prevailing during the summer of 2007 after the onset of the corn ethanol euphoria (Table 3). The cost per Mcal of NE_L has increased by 70% during the three year period, going from \$0.087 to nearly \$0.15 per Mcal. To put this substantial increase in an even better perspective, unit cost of NE_L averaged \$0.07/Mcal during the 15-yr period that extended from 1982 to 1997 and never even exceeded \$0.10/Mcal during this same 15-yr period (St-Pierre and Thraen, 1999). Thus, the current price for dietary energy resides in a completely unchartered territory. Meanwhile, the cost per unit of rumen degradable protein (RDP), digestible rumen undegradable protein (d-RUP), non-effective NDF (ne-NDF) and effective NDF (e-NDF) dropped by \$0.186, \$0.173, \$0.037, and \$ \$0.01/lb, respectively, between summer 2004 and summer 2007. Thus, although the price of soybean meal appears to be high from a historical perspective, this doesn't imply that the prices of protein fractions (RDP and d-RUP) are also high. In fact, once we account for the increased economic value of the dietary energy contained in the protein feeds, many of them, such as expeller soybean meal are currently slightly under-priced (Table 4).

The comparison of the economic value of different commodities being traded in the Midwest yields some interesting and even surprising results. Most people would think that \$3.95/bu corn implies that corn is relatively expensive. It may be so from a historical standpoint, but corn is currently a bargain feed compared to all other commodities (Table 4). What is easily overlooked is the drastic rise in the price of many other "energy" feeds in the last 3 years, such as tallow which is now trading at nearly twice its 2004 price. During this period, however, some feeds, mostly corn by-product feeds, have remained or have become extremely well priced.

Making Better Use of By-product Feeds

Strategically, one should benefit from maximizing the use of feeds deemed bargains in our prior analysis. As an example of how this can be accomplished, we balanced a ration for a 1400 lb cow producing 80 lbs of milk per day at 3.7% fat and 3.0% protein using prices that prevailed in central Ohio during summer 2004. In doing so, we did not use a least-cost programming algorithm but used ingredients that have traditionally formed the basis of a traditional Midwestern diet (Table 5). Using the information from Table 4, we modified the selection of ingredients to reflect the market conditions in summer 2007. In doing so, we reduced the amount of corn fed by 25% and whole cottonseed by 50%, eliminated wet brewers grains, 44% solvent extracted soybean meal, and tallow, and incorporated some distillers dried grains with solubles, corn hominy, corn gluten feed, and wheat middlings (Table 5, 2007). The resulting diet is nutritionally nearly identical to the traditional Midwest dairy diet. Its cost, however, is \$0.57/cow per day less, resulting in estimated savings in feed costs of more than \$200/lactation. Although by-products are nutritionally much more variables than grains and oilseed meals (NRC, 2001), their contribution to the nutritional variance of the whole diet is approximately proportional to the square of their inclusion rates (St-Pierre and Harvey, 1986). Because the '2007' diet uses relatively small amounts of each of the by-products, the resulting diet in fact has a lower expected nutritional variance for all major nutrients than the traditional diet (St-Pierre and Weiss, 2006).

Other Feeding Strategies to Optimize Profits with High Feed Prices

Two other strategies to profit optimization will be briefly discussed: 1) altering nutrient specification of diets based on feeds and milk prices, 2) increasing forage inclusion, and 3) increasing forage quality. These three approaches may be best used in combination.

Dairy producers should always target less than maximum milk yield in order to optimize income over feed costs and profits (St-Pierre, 1998). When milk price is relatively high and feed costs are relatively low, such as in the late 1990's, the optimum nutritional levels (i.e., nutrient concentrations in the diet) are very near those required for maximum milk production. But when milk price is low or feed prices are high the optimal levels can be significantly less than those required to support maximum milk production. The exact mathematical optimization requires a known response function to nutritional inputs. Work has been done in this area (Bath and Bennett, 1980; St-Pierre and Thraen, 1999) but the suggested approaches lack the required precision to make them useful in practice. For the time being, different strategies can be evaluated using available ration balancing software (NRC, CPM Dairy, CNCPS, etc.) and the expert help of a professional nutritionist.

Generally, forages are a cost-effective way to deliver nutrients to ruminants. Increasing inclusion of forages in place of concentrates can affect NDF, CP, RUP, NFC, and NE_L levels 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, 1997; Mertens, 1994). Maximum NDF levels are determined by NE_L requirements (NRC, 2001; Mertens, 1994), and are affected by NDF digestibility.

Over the past 18 months in Ohio, corn silage, and alfalfa silage have been at break-even or lower-than-predicted values as determined using Sesame III. However, many Ohio dairy producers were not maximizing forage 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.

Better quality forages can be utilized more extensively in dairy rations than poorer ones. Quality is defined as the ability of the forage to deliver digestible nutrients (energy, protein, etc.) to the cow. 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 6) as well as the economic return from milk production

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Table 1. Effects of feeding corn or barley on milk production, composition, dry matter intake and feed efficiency.

	DePeters and Taylor, 1985			Bilodeau et al., 1989		
	Corn	Barley	*P*	Corn	Barley	*P*
Yield (kg/d)						
Milk	28.0	27.4	n.s.	29.2	28.9	n.s.
Fat	0.835	0.761	n.s.	-	-	n.s.
Protein	0.893	0.884	n.s.	-	-	n.s.
Composition (%)						
Fat	3.01	2.81	n.s.	3.98	3.96	n.s.
Protein	3.21	3.23	n.s.	3.36	3.34	n.s.
Dry matter intake (kg/d)	18.5	18.3	n.s.			n.s.
Gross Feed efficiency	1.51	1.50	-	1.33	1.31	-

Table 2. 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. Nutrients are reported on a DM basis. Abbreviations used: WCGF-wet corn gluten feed, SBM-soybean meal, SH-soy hulls, CSH-cottonseed hulls, HMC-high moisture corn.

Reference	**Diet as described in reference**	**Forage NDF**	**Total NDF**	**NFC**	**Starch**	**Milk yield (lbs)**	**DMI (lbs)**
Boddugari et al., 2001	0	22.8	28.2	43.2	30.3	66.9	54.3
WCGF vs. corn + SBM	50	22.8	35.4	36.5	23.3	67.1	49.5
(% WCGF)	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 & Weiss, 2005	35	18.2	24.7	48.3	33.3	71.1	44.7
SH+CSH vs. corn	29	18.2	28.6	43.7	30.1	69.7	46.2
(% corn)	23	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 vs. corn	10	19.1	34.4	44.8	31.1	64.5	54.6
(% SH)	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 & Allen, 2003a	0	17.1	24.3	47.0	34.6	80.1	54.6
beet pulp vs. HMC	6	17.1	26.2	45.0	30.5	80.5	55.0
(% beet pulp)	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

Table 3. Estimates of nutrient unit costs, central Ohio, for July 2004 and July 2007.

Nutrients	July 2004	July 2007
	$/unit[1]	
Net energy lactation	$ 0.087	$ 0.148
Rumen degradable protein	$ 0.023	$ -0.163
Digestible-rumen undegradable protein	$ 0.342	$ 0.169
Non-effective NDF	$ -0.058	$ -0.095
Effective NDF	$ 0.054	$0.044

[1] Units are Mcal for NE_L, and lb for all other nutrients.

Table 4. Actual and break-even feed prices for Central Ohio, July 2004 vs. July 2007, using Sesame III. Break-even prices were based on net energy lactation (NE_L), rumen degradable protein (RDP), digestible rumen undegradable protein (d-RUP), effective NDF (e-NDF), and non-effective NDF (ne-NDF).

	2004		2007	
Feedstuffs	Actual	Break-even	Actual	Break-even
	$/ton			
Alfalfa hay, 44% NDF, 20% CP	130	150	140	132
Bakery by-product meal	127	154	185	211
Beet pulp, dried	160	122	200	146
Blood meal, ring dried	600	540	745	400
Brewers grains, wet	35	36	39	29
Canola meal	189	181	192	139
Citrus pulp, dried	126	122	214	173
Corn grain, ground	110	156	151	220
Corn silage, 35% DM	40	53	50	65
Cottonseed, whole w lint	208	221	220	234
Distillers dried grains w solubles	156	184	116	170
Feathers, hydrolyzed meal	330	422	260	295
Gluten feed, dry	102	155	104	149
Gluten meal, dry	369	430	383	351
Hominy	132	137	140	179
Meat meal	280	317	285	255
Molasses	105	107	154	161
Soybean hulls	112	74	115	68
Soybean meal, expeller	380	344	275	310
Soybean meal, solvent 44%	336	253	235	192
Soybean meal, solvent 48%	345	294	244	229
Soybean seeds, roasted	380	318	299	317
Tallow	370	358	645	607
Wheat bran	79	93	77	91
Wheat middlings	71	112	70	111

Table 5. Comparison of a dairy diet optimized for prevailing feed prices in summer 2004 vs. summer 2007.[a]

Ingredients	2004	2007
	---- lbs as fed per day ----	
Legume hay	4.2	4.2
Legume silage	19.5	19.5
Corn silage	37.0	37.0
Wet brewers grains	13.8	0.0
Cottonseed, whole	5.0	2.75
Corn grain	15.0	11.25
Soybean meal, solvent, 44%	2.25	0.0
Soybean meal, expeller	2.25	2.75
Dried distillers grains with solubles	0.0	3.33
Hominy	0.0	2.25
Corn gluten feed	0.0	2.75
Wheat middlings	0.0	2.75
Tallow	0.5	0.0
Minerals and vitamins	1.5	1.5
Composition		
Dry matter (lbs)	51.3	51.3
NE_L (Mcal/lb)	0.74	0.73
	-------- % of DM --------	
CP	17.0	16.7
RDP	11.3	10.8
RUP	5.6	5.8
MP	10.6	10.6
NDF	32.2	33.3
NFC	42.5	42.8
Ether extracts	5.7	4.6
Cost ($/cow per day)[b]	4.62	4.05

[a] Rations balanced for a 1400 lb cow producing 80 lbs of milk per day at 3.7% fat and 3.0% true protein.
[b] Prices used are those reported in Table 4 for central Ohio.

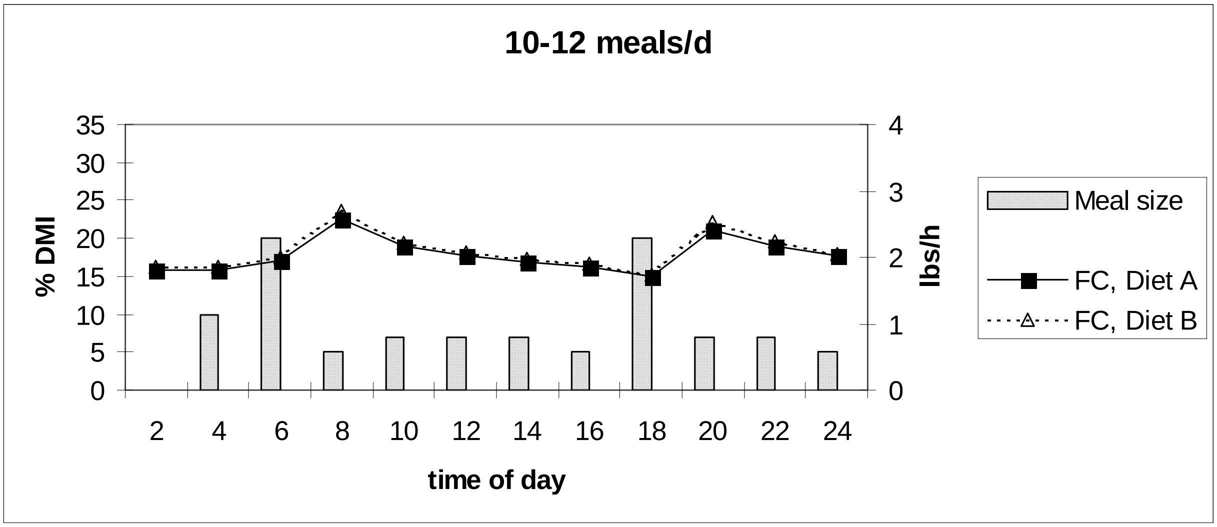
Table 6. NDF digestibility and starch content of corn silage is important in determining feeding value[a].

Quality	Moisture (%)	NDF (%)	CWD[b] (%)	Starch (%)	Net Energy Lactation (Mcal/lb)	Partial Milk, (lbs/cow)[c]	Partial Milk Income ($/cow)[d]	IOFC per 1000 cows ($/d)[e]
Poor	69.3	53.5	42.4	15.5	.453	13.1	$1.64	$1070
Fair	69.1	46.4	48.0	25.5	.526	15.3	$1.91	$1340
Medium	67.3	41.9	51.0	30.9	.561	17.3	$2.16	$1590
Good	63.3	39.7	53.8	35.2	.590	20.4	$2.55	$1980
Average	68.7	45.4	48.7	26.7	.533	15.7	$1.96	$1390

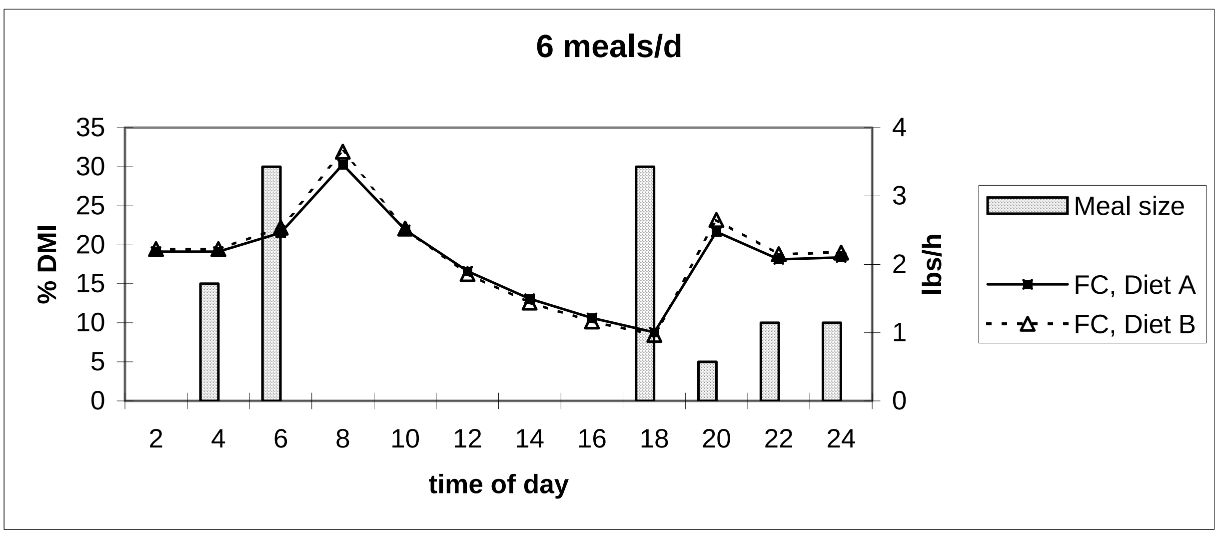
[a] Data on more than 700 samples from California kindly provided by Agri-King, Inc.
[b] CWD = Cell wall (NDF) digestibility.
[c] Predicted milk yield (lbs/cow/day) from 30 lbs of corn silage based on forage energy content and milk fat at 3.5%.
[d] Milk income ($/cow per day) with milk price at $12.50/cwt.
[e] IOFC = Daily income over feed cost per 1000 cows with corn silage priced at $38/Ton

Figure 1. Energy availability to rumen microbes is not altered by varying starch content while maintaining NFC with other sources of fermentable carbohydrate under either semi-steady state (10-12 meals/d, panel A) or non-steady state (6 meals/d, panel B) feeding conditions. Diet A contains 30% NDF, 40% NFC, 25% starch, and Diet B contains 30% NDF, 40% NFC, 15% starch.

A



B



NOTES: