Protein and Carbohydrate Utilization by Lactating Dairy Cows[1]

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Milk production requires large amounts of protein and energy and these two nutrients make up about 80% of total feed costs. About 70% of the energy consumed by a cow is derived from carbohydrates, therefore, energy nutrition is largely a function of carbohydrate utilization. Because protein and energy have a substantial impact on milk production and production costs, diets must be formulated properly for these two nutrients.

Carbohydrates

Carbohydrates are divided into two main classes by dairy nutritionists: neutral detergent fiber (NDF) and nonfiber carbohydrate (NFC). Feeds are analyzed directly for NDF but NFC is usually calculated as 100 - NDF - crude protein - fat - ash. The NDF fraction is comprised mostly of cellulose, hemicellulose, and lignin, and the NFC fraction is mostly starch, simple sugars, soluble fiber, and organic acids (acids are not carbohydrate but because NFC is calculated by difference, acids are included). The major nutritional differences between NDF and NFC are their site, rate, and extent of digestion. Usually about 90% of the digestion of NDF occurs in the rumen. Depending on the feed, between 60 and 80% of digestible NFC is digested in the rumen and 20 to 40% is digested in the small intestine. The rate of digestion in the rumen is usually rapid for NFC and slow to moderate for NDF. Total tract digestibility of NFC is usually greater than 90% and 30 to 60% for NDF. These differences between NDF and NFC must be considered when formulating diets.

Nonfiber carbohydrates

Cows do not have a requirement for NFC, but because NFC is highly digestible it is a primary energy source for cows. Because NFC is digested rapidly, increasing NFC usually increases dry matter (DM) intake. The same properties (rate and extent of digestion) that make NFC desirable can be detrimental to the health and long term productivity of cows. Excess dietary NFC causes ruminal acidosis which is related to

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depressed milk fat, metabolic disorders, reduced DM intake, and laminitis. The relationship between NFC concentration and energy intake is not linear. Increasing dietary NFC increases energy intake to a point and then further increases in NFC generally decreases energy intake (Figure 1). A good diet should provide enough NFC to promote high energy intake without adversely affecting the health of the cow.

Neutral detergent fiber

Because NDF is usually digested slowly and not very extensively, it often limits energy intake. Conversely, adequate NDF is needed to maintain proper rumen pH and prevent acidosis related problems. The slow rate of digestion of NDF in the rumen reduces acid production preventing a large drop in rumen pH. In addition, forage is usually a primary source of NDF and the physical characteristics of most forages stimulate chewing which increases saliva flow helping to buffer the rumen. The NDF in feed that promotes chewing is called effective NDF. Although effective NDF is used in some ration software, no uniform method of measuring effective NDF has been adopted, therefore concentrations of effective NDF cannot be measured. To overcome this problem the NRC (2001) adopted a simple approach of dividing NDF into NDF provided by forages and NDF provided by other feedstuffs. This is the approach that will be discussed.

Carbohydrate Recommendations

Dietary recommendations for NDF and NFC are closely related; the concentration of one influences the needed concentration of the other. One reason for this relationship is simply mathematical. The concentration of NFC is calculated by difference therefore diets with higher concentrations of NDF usually have lower NFC and vice versa. Because protein, fat, and ash concentrations vary between diets, the relationship between NDF and NFC is not perfect. The second reason for the relationship is biological; NDF and NFC have essentially opposite effects on rumen pH and energy intake. Other factors influencing the recommended concentrations of NDF and NFC include the source of NDF (forage, vs. nonforage), effectiveness of the feed in promoting chewing, the source of NFC, use of supplemental buffers, and feeding management. The NRC (2001) guidelines (Table 1) are a good starting point in ration formulation. The dietary concentration of forage NDF (% of DM) determines the recommended concentrations of total NDF and NFC. As the amount of forage NDF in a diet decreases, the amount of total NDF needed increases and the maximum concentration of NFC decreases. In general NDF from forage is about twice as effective at maintaining rumen pH than NDF from nonforage sources. Therefore, a 1-unit decrease in forage NDF results in a 2-unit increase in recommended NDF concentration and a 2-unit decrease in maximum NFC. The recommendations in Table 1 are based on the following assumptions: 1) forages have adequate particle size, 2) dry ground corn is the primary starch source, and 3) the diet is fed as a TMR. If these assumptions are not true for a particular situation, modifications to Table 1 are needed.

Particle size of forage. Finely-chopped forages promote less chewing than more coarse forages, therefore when forages are finely chopped, concentrations of forage NDF and total NDF should be higher and NFC concentrations should be lower than the values in Table 1. Unfortunately we do not yet have an adequate method of evaluating adequate particle size. Particle size distribution using the Penn State Particle Separator has not been related to chewing or rumen pH. Diets with very little material on the top screen of the Penn State Separator have maintained rumen pH as well as diets with substantial amounts of material on the top screen. Differences in the amount of material in the pan also are not related to rumen pH. Rather than giving recommendations for particle size that are not supported by any scientific data, I suggest that nutritionists closely monitor the herd. If the diet appears adequate on paper, but milk fat is lower than expected or if day-to-day variation in DM intake is excessive, particle size of the forage may not be adequate and modifications should be made to the diet.

Source of starch. The starch in dry ground corn is less digestible in the rumen than many other starch sources, therefore, ruminal acid production is lower with dry corn than some other feeds. The starch in high moisture corn, steam-flaked corn, and small grains (wheat, barley, oats) is more digestible in the rumen and produces more acids than dry ground corn. Because acid production is higher with those ingredients, concentrations of total NDF should be higher and NFC concentrations should be lower than values in Table 1. A good general rule is to increase NDF by 2-units and decrease NFC by 2-units when those grains are fed. Very wet high moisture corn and very thinly flaked steam-flaked corn may require an increase of 3 or 4 units in NDF (and a similar decrease in NFC) to maintain rumen pH.

Other factors. When diets are fed as a TMR, intake of NFC and NDF are more or less concurrent. When forage and concentrate are fed separately, cows can consume large quantities of NFC from the concentrate in a relatively short period of time. This can result in a large increase in ruminal acids and low pH. Quantitative data are not available, however, when forage and concentrate are fed separately and when the concentrate is made primarily of starchy ingredients diets should have higher NDF and lower NFC concentrations than shown in Table 1. Feeding supplemental buffers can reduce the minimum concentration of total NDF by about 1-unit and increase the maximum concentration of NFC by about 1-unit. Whole-linted cottonseed stimulates chewing about as well as forage. When cottonseeds are fed the NDF provided by the cottonseed can be considered as forage NDF.

Protein

Protein nutrition of dairy cows is complex, and simply balancing diets for crude protein is not adequate for high production or for efficient use of protein. Diets should be balanced for rumen degradable protein (RDP) and rumen undegradable protein (RUP). Overfeeding RDP does not affect RUP requirement and results in increased excretion of nitrogen via the urine and may reduce reproductive efficiency. When RDP is deficient, overfeeding RUP can make up for that deficiency but when adequate RDP is fed overfeeding RUP has the same effects as overfeeding RDP.

Rumen degradable protein

Cows do not require RDP but rumen microorganism do. The amount of RDP needed depends on the metabolic activity of rumen microbes which ultimately depends on the amount of energy available to the microbes. As energy intake increases, microbial protein production increases and the requirement for RDP increases. When diets are deficient in RDP microbial growth and microbial protein production are reduced. This can reduce fiber digestion, DM intake, and ultimately milk production. The RDP requirement is based solely on energy intake; increased milk production does not effect RDP requirement unless energy intake is increased (Table 2).

Rumen undegradable protein

Assuming adequate RDP is fed, microbial protein production ranges from about 3.5 to 5 lbs/day. Although this is a large amount, microbial protein alone can usually only maintain the cow and provide adequate protein for 25 to 30 lbs of milk. High milk production requires a substantial amount of RUP. This does not necessarily mean that feeds with high concentrations of RUP are always needed. A simple diet of high quality alfalfa, corn silage, corn grain, and soybean meal can support about 85 lbs of milk production by midlactation cows. In very early lactation (<30 days in milk), when DM intake is depressed, that same diet can only support about 60 lbs of milk. Diets for early lactation cows and high producing cows usually require special attention to protein supplementation. In those cases, ingredients with high concentrations of RUP usually will be needed in the diet.

Concentrations of RDP and RUP in feeds

The degradability of protein depends mostly on the feedstuff and DM intake. Hay crop forages have high protein degradability, conventional oilseeds have high to moderate protein degradability, most corn products have moderate to low protein degradability, and heat-treated products and animal protein meals have low protein degradability. The effect intake has on degradability depends on the feed (Table 3). The protein in haycrop forages has a very rapid rate of digestion and intake has little effect on RDP concentrations. The protein in animal protein meals (e.g., blood meal) is digested very slow and again intake has little effect on concentrations of RDP. Oilseed meals and some byproducts have an intermediate rate of protein degradation and increased intake reduces protein degradability (i.e., increases the RUP concentration).

Protein Recommendations

Although variation exists, the RDP requirement for most cows will be met if diets contain about 10% RDP (DM basis). Because the cost of under feeding RDP (reduced intake causing reduced milk production) is greater than the cost of slightly overfeeding RDP (slightly increased feed costs, small increase in excretion of nitrogen via urine, and slightly increased risk of reduced reproductive performance) a small excess of RUP (5 to 10%) should be fed (approximately 10.5 to 11% of DM). If additional RDP is needed, hay crop forages, urea, or oilseed meals are good sources. Once the RDP requirement is met, RUP supply must be evaluated. The supply of RUP can be increased by increasing the total CP content of a diet or by selecting feeds with high RUP concentrations. In many cases, providing slightly more CP than required to meet RUP requirements is the most economical alternative. However, this option increases excretion of nitrogen via manure, and environmental regulations may make this option less economically feasible.

When microbial protein and standard protein supplements are not adequate, judicious supplementation with specific feeds can be used to meet the RUP requirement of high producing and early lactation cows without excessive loss of nitrogen to the environment. When choosing an RUP source, the digestibility of the RUP must be considered (Table 4). For example, about 73% of the DM in batch-dried blood meal is RUP, but the average digestibility of the RUP is only 65%, therefore digestible RUP is 73 x 0.65 = 47.5% of the DM. Heat-treated soybean meal averages 39% RUP (DM basis) that is 93% digestible equaling 36% digestible RUP. The difference in digestible RUP between those two sources is much less than the difference in RUP. Price comparisons must be made on a digestible RUP basis, not on an RUP basis. If the batch-dried blood meal cost more than about 1.25 times the price of the heat-treated soybean meal, it would not be a wise purchasing decision. The second factor to consider when choosing a source of RUP is amino acids. Cows (as do all animals) require amino acids, not protein. The best method of ensuring an adequate balance of amino acids is to evaluate the diet using a nutrition model such as the NRC (2001) or the Cornell program. These programs estimate amino acid supply; the Cornell model also estimates requirements. Because of limited data we are less certain about amino acid requirements than amino acid supply. Lysine or methionine is generally the first limiting amino acid for milk protein production. If the model you are using suggests the diet is limited in methionine then RUP sources that are good sources of methionine should be used (Table 4). Conversely if lysine is limiting, use lysine sources. Diets with large amounts of corn products (corn silage, corn grain, distillers grains) will be lysine-limited, and diets with high amounts of alfalfa protein usually are limited in methionine.

Summary

Carbohydrate balance affects production and health of cows. Most diets should contain 27 to 32% NDF and 35 to 40% NFC, but specific situations may require concentrations outside this range. Diets that contain excessive amounts of NDF (usually means NFC is low) often reduces energy intake and diets with excessive amounts of NFC (i.e., NDF is low) can reduce energy intake and are related to rumen health problems. Diets should be formulated for RDP and RUP rather than CP. This will increase utilization efficiency of nitrogen (reduced excretion of N) and allow for high milk production. Most diets should contain about 10% RDP (% of DM) and varying amounts of RUP depending on intake and milk production. Early lactation and high producing cows usually require substantial amounts of RUP. The RUP supplement used should be highly digestible and provide the proper balance of amino acids.

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Table 1. Recommended (NRC, 2001) concentrations of NDF and NFC in lactation diets (% of diet DM). Diets should not exceed 44% NFC or contain less than 25% total NDF or less than 15% forage NDF. See text for important details.

Minimum forage NDF	Minimum diet NDF	Maximum diet NFC
19	25	44
18	27	42
17	29	40
16	31	38
15	33	36

Table 2. Effect of milk production and intake on rumen degradable protein (RDP) requirements of an average Holstein cow (calculated using NRC, 2001). Note the comparison between 75 and 100 lbs of milk when intake is the same (RDP requirement does not change but RUP increases with increasing milk production).

Milk, lbs/day	DM intake, lbs/day	RDP		RUP	
		% of DM	lbs/day	% of DM	lbs/day
50	44	10.0	4.4	3.6	1.6
75	52	10.0	5.2	5.2	2.7
100	52	10.0	5.2	7.7	4.0
100	61	9.7	5.9	6.2	3.8

Table 3. Average RUP digestibility of some common feeds that are high in RUP plus soybean meal and cottonseed meal. Amino acid class designates whether a given feed contains above average concentrations of lysine or methionine. When diets are limited by lysine, feeds classified as lysine should be used, and when diets are limited by methionine, feeds classified as methionine should be used. To estimate RUP (% of DM), dry matter intake was set at 50 lbs/day.

Feedstuff	RUP, % of DM	RUP Digestibility, %	Digestible RUP, % of DM	Amino Acid Class
Blood meal, batch dried	73	65	47.5	Lysine
Blood meal, ring-dried	73	80	58.4	Lysine
Brewers grains, dried	16	80	12.8	Neither
Corn gluten meal	47	92	43.2	Methionine
Distillers grains	15	80	12.0	Neither
Fish meal	44	88	38.7	Lys/met
Soybean meal, heat treated	31	93	28.8	Lysine
Soybean meal, 48% CP	22	93	20.5	Lysine
Cottonseed meal, 50% CP	21	92	19.3	Neither

Table 4. Effect of DM intake on RUP concentrations (% of total CP) in some common feeds.

Feedstuff	DM intake, lbs/day	
	40	55
Alfalfa hay, immature	15.3	16.4
Alfalfa silage, midbloom	17.2	18.2
Blood meal, ring-dried	74.5	77.1
Brewers grains, wet	32.5	35.3
Corn silage	34.2	35.1
Corn grain, ground	42.9	46.8
Cottonseed meal, 50% CP	44.4	47.4
Cottonseed, whole	20.4	22.6
Distillers grains	47.1	50.3
Fish meal	63.1	65.5
Soybean meal, 48% CP	37.4	41.9
Soybean meal, heat-treated	64.3	68.2

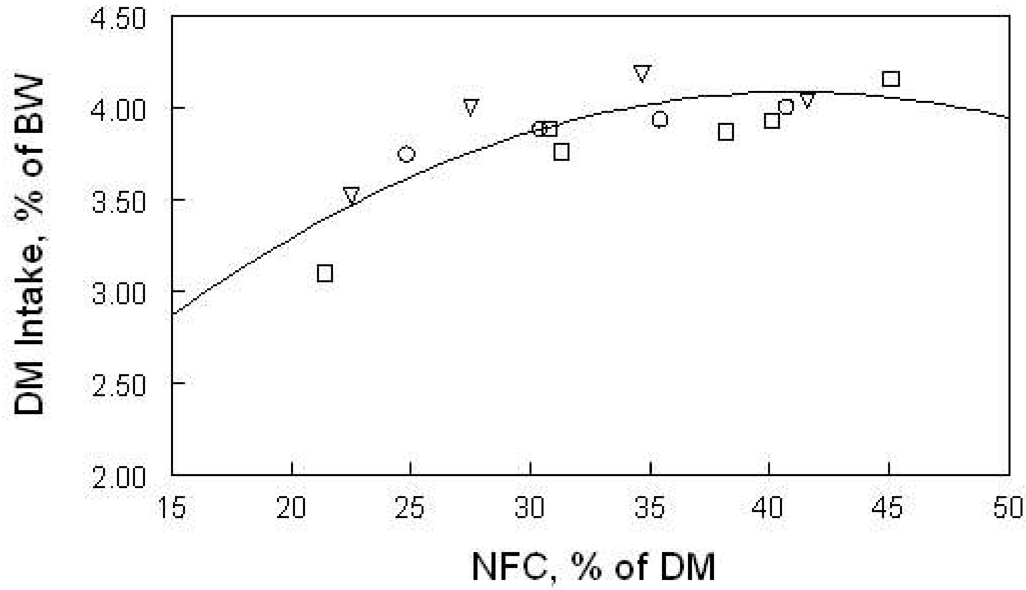

Figure 1. Relationship between DM intake and dietary NFC concentrations (calculated as 100 - NDF - CP - ash - fat). The equation is DM intake (% of BW) = 1.07 + 0.147 X - $0.00179X^2$. Maximum intake occurred at 41% NFC. Source of data: Triangles = Valadares Filho et al., 2000; Cirlces = Batajoo and Shaver, 1994; Squares = Weiss and Shockey, 1991.