

## Balancing Rations for Milk Components

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**ABSTRACT:** Yields of protein and fat are positively correlated with yield of milk but increased milk yield can dilute the percentages of protein and fat in milk. Milk components can be altered through ration formulation. Fat is easier to change than protein which is easier to change than lactose. Substrates for mammary synthesis of milk components are provided by fermentation in the rumen and by digestion in the small intestine. Substrates like *trans* octadecenoic acids can inhibit mammary synthesis of fat. Imbalances of amino acids can lower mammary synthesis of protein. Carbohydrates affect milk yield through the supply of glucose to the mammary gland and milk protein through growth of ruminal bacteria. Fibre is needed to maintain normal rumen function. Through altered carbohydrate fermentation and decreased bacterial growth, subclinical rumen acidosis can decrease yields of milk, protein and fat. Buffers affect milk fat by increasing acetate:propionate and by decreasing ruminal synthesis and mammary uptake of *trans* octadecenoic acids. Rumen bacteria need degradable protein. Escape protein should contain amino acids that promote synthesis of milk protein. Balancing rations for amino acids increases mammary synthesis of protein and milk yield is increased in early lactation cows. Rations with added fat need to contain more rumen escape protein. Ionophores provide a means of increasing the ratio of protein:fat in milk.

**Key Words:** Milk, Fat, Protein, Carbohydrate, Acidosis, Balanced Rations

### INTRODUCTION

Non-nutritional factors known to affect milk composition include genetics, season of year, stage of lactation and mastitis (Chalupa and Galligan, 1989; Kennelly *et al.*, 1999; Barbano, 1999). This report is directed towards nutritional factors that affect milk components.

Milk may be priced on the concentration of components or on the yield of milk components. While yields of milk protein and fat are positively correlated with yield of milk, increased yield of milk is usually associated with decreased percentages of protein and fat in milk (Table 1). This "dilution effect" occurs because mammary synthesis of protein, fat and lactose involve pathways that are not necessarily linked. Table 2 lists possible outcomes of concentration of protein and fat that can occur with differential changes in yields of milk, protein and fat.

### CONCENTRATION VERSUS YIELD OF MILK COMPONENTS

Component	Parity <sup>2</sup>	DIM	n	D <sup>3</sup>	SE	r
Protein	P	7-56	246	-.0207	.0029	-.42
Protein	P	57-283	684	-.0229	.0022	-.36
Fat	P	7-56	246	-.0247	.0078	-.20
Fat	P	57-283	684	-.0311	.0046	-.25
Protein	M	7-56	436	-.0124	.0022	-.26
Protein	M	57-283	1268	-.0205	.0011	-.46
Fat	M	7-56	436	-.0122	.0052	-.11
Fat	M	57-283	1268	-.0194	.0023	-.23

1. Pitcher *et al.*, (1994). Based on Pa DHIA data.  
 2. P = primiparous; M = multiparous.  
 3. Dilution effect: marginal change in milk component concentration (%) per change in milk yield (kg). D values are different from zero at p<.05.

### CAN MILK COMPONENTS BE ALTERED BY DIET?

The potential to change milk components through ration formulation depends upon the component (Bequette *et al.*, 1998; Kenelley *et al.*, 1999; Sutton, 1989). Milk fat is easily changed. Production of milk with low concentrations of fat occurs when high concentrate rations are fed, when rations are deficient in effective fibre or when rations

contain unsaturated fatty acids (Sutton, 1989, Van Soest, 1994). Fatty acids in milk fat can be altered by feeding fats that are inert in the rumen (protected fats) and by fermentative modification of rumen active dietary fatty acids (Kennelly *et al.*, 1999). The ability to modify fatty acid composition of milk fat has important human health and disease implications like lowering blood cholesterol, inhibiting carcinogenesis, modulating the immune system and prevention of diabetes (Kennelly, 1999).

**Table 2.** Impacts of differential changes of yields of milk, protein and fat on changes of concentration of protein and fat in milk.

Change in yield			Change in concentration (%)	
Milk	Protein	Fat	Protein	Fat
Decrease	Decrease (=MY)	Decrease (=MY)	No change	No change
Decrease	Decrease (<MY)	Decrease (<MY)	Increase	Increase
Decrease	Decrease (>MY)	Decrease (>MY)	Decrease <sup>1</sup>	Decrease
Decrease	No change	No change	Increase	Increase
Decrease	Increase	Increase	Increase <sup>1</sup>	Increase
No change	Decrease	Decrease	Decrease	Decrease
No change	No change	No change	No change	No change
No change	Increase	Increase	Increase	Increase
Increase	Decrease	Decrease	Decrease	Decrease
Increase	No change	No change	Decrease	Decrease
Increase	Increase (=MY)	Increase (=MY)	No change	No change
Increase	Increase (<MY)	Increase (<MY)	Decrease	Decrease
Increase	Increase (>MY)	Increase (>MY)	Increase	Increase

1. Bold indicates a lesser or greater change in the percentage of milk protein and fat.

Ration components affect synthesis but usually not concentration of milk lactose. At least 85% of the carbon in milk lactose is derived from glucose. The linear relationship between glucose uptake by the mammary gland and milk volume (Kronfeld, 1976) reflects increased lactose synthesis along with dilution to maintain osmolarity of milk.

### SUBSTRATES FOR MAMMARY SYNTHESIS OF MILK COMPONENTS

Substrates for mammary synthesis of milk components are provided by fermentative digestion in the rumen and hydrolytic digestion in the small intestine.

Infusion of "pure nutrients" to cows fed basal rations that essentially provided required energy and protein gives insight on how diet might impact milk yield and its composition (Table 3). Milk yield was increased by acetate, glucose, amino acids and long-chain fatty acids. Milk fat content was increased by acetate, butyrate and long-chain fatty acids but decreased by propionate and glucose. Milk protein content was increased by propionate and amino acids

Kronfeld (1976) proposed that maximal efficiency of milk production depended upon the balance of nutrients. In terms of ME, he suggested 16% aminogenic nutrients, 5% exogenous glucose, 24% propionic acid, 39% acetic acid and derivatives of butyric acid, and 16% exogenous long chain fatty acids.

Some of concepts illustrated by the infusion experiments need modification. For example, the feeding of high concentrate diets is known to decrease mammary synthesis of fat (Sutton, 1989, Van Soest, 1994). Decreased synthesis of milk fat could be due to a shortage of lipid precursors to the mammary gland or to production of metabolites in the rumen that directly inhibit mammary synthesis of fat. High concentrate diets narrow ruminal ratios of acetate:propionate but this is due to increased production of propionate and not decreased production of acetate (Table 4).

**Table 3.** Effects of infusion of nutrients on milk yield and composition<sup>1</sup>

Product of Digestion	Site of Absorption	Response (% of control)			
		Milk (kg/d)	Fat (%)	Protein (%)	Lactose (%)
Acetate	Rumen	+8	+9	-1	+2
Propionate	Rumen	-2	-8	+7	+1
Butyrate	Rumen	-5	+14	+2	+2
Glucose	Sm. Intestine	+6	-10	-1	+1
Amino Acids	Sm. Intestine	+7	-3	+6	+1
LCFA	Sm. intestine	+2	+13	----	----

1. Thomas and Martin (1988). Basal rations provided required energy and protein.

<b>Table 4.</b> Rumen Volatile Fatty Acids, Milk Yield and Milk Fat <sup>1</sup>		
Parameter	Normal	High Grain
Grain (%DM)	50	80
Forage (%DM)	50	20
Molar Percentage		
Acetate	67	53
Propionate	21	47
C <sub>2</sub> /C <sub>3</sub>	3.3	1.0
Pool (Moles/Rumen)		
Acetate	2.40	2.06
Propionate	0.83	2.42
Production (Moles/d)		
Acetate	29	28
Propionate	13	31
Milk		
Yield (kg/d)	19	21
Fat (%)	3.60	1.75
Fat (g/d)	684	368
1. Adapted from Van Soest (1994).		

Narrowed ratios of acetate:propionate were also suggested to increase insulin release to preferentially direct nutrients to adipose tissue rather than to the mammary gland (Van Soest, 1994). Griinari *et al.*, (1997) using the hyperinsulinemic-euglycemic clamp technique to elevate insulin while maintaining glucose could find no support for a role in insulin in milk fat depression. Dietary unsaturated fatty acids (linoleic and linoleic acids) are usually hydrogenated in the rumen to stearic acid (Jenkins, 1993). When high concentrate diets are fed, ruminal biohydrogenation of unsaturated fatty acids is incomplete leading to the accumulation of *trans* octadecenoic acids (Kalscheur *et al.*, 1997). There is a high correlation between changes in milk fat concentration of *trans* octadecenoic acids and changes in milk fat percentage (Griinari *et al.*, 1998). This supports the notion that substrate supply to the mammary gland for synthesis of milk components must not only consider substrates that are used directly for synthesis of milk components but also must include compounds that might inhibit mammary synthesis of milk components. A similar situation was

shown for amino acid balance where the proportions and ratios of methionine and lysine in absorbed protein had dramatic impacts on mammary synthesis of protein (Rulquin *et al.*, 1993).

### IMPACT OF RATION INGREDIENTS ON MILK COMPONENTS

As a starting point for balancing rations for milk components, we propose that the amount of fat, protein and lactose synthesised by the mammary gland is dependent on substrate supply. That would be acetate, products of butyrate, and long chain fatty acids for milk fat; amino acids for milk protein; and glucose for milk lactose. Substrates that can inhibit mammary synthesis of fat (*trans* octadecenoic acids) and protein (imbalances of amino acids) would lower the amount of the component produced.

Concentration of fat and protein in milk would depend on milk volume. Milk volume is primarily determined by uptake of glucose by the mammary gland. Glucose is derived mainly from propionate but amino acids are also important substrates. Gluconeogenicity of rations (those high in grain and protein) can be used to control the concentration of protein and fat in milk by regulating milk volume

### Carbohydrates

These are the primary energy-yielding nutrients in the rumen and at the tissue level of metabolism. Carbohydrates differ in their rate and extent of fermentation in the rumen. Sugars are fermented faster than starch. Starch and pectins are fermented faster than fibre. Starches in grains are fermented at different rates (wheat > barley > corn > sorghum). Fermentation of fibre and starch is increased when particle size is reduced by chopping or grinding. Reducing particle size increases surface area per unit weight making feed particles more accessible to microbial enzymes. Gelatinisation of starch, brought by steam-processing grains, increases fermentability of starch in the rumen and digestion of rumen escape starch in the intestines (Theurer *et al.*, 1999). Thus, the kind of carbohydrate and how it is processed affects the energy value of a ration. Because only carbohydrates provide energy at rates sufficient for growth of most ruminal microbes (Nocek and Russell, 1988), the kind of carbohydrate also affects the metabolisable protein value of a ration.

How carbohydrate fermentability can affect milk yield and components, was shown in a series of experiments on steam-flaking corn or sorghum grain (Theurer *et al.*, 1999). Compared to dry-rolling, steam-flaking corn or sorghum increased starch digestion in the rumen and intestines (Table 5). Because carbohydrate fermentability determines growth of ruminal bacteria (Chalupa and Sniffen, 1996), steam-flaking corn increased the flow of microbial protein to the small intestine.

**Table 5.** Effect of steam-flaking versus dry-rolling corn on starch digestion and microbial protein flow to the small intestine<sup>1,2</sup>

Measurement	Processing		P<
	Dry-rolled	Steam-flaked	
Starch digestibility			
Ruminal (% intake)	35	52	0.03
Intestinal (% entry)	61	93	0.05
Microbial protein (kg/d)	1.04	1.23	0.08
1. Theurer <i>et al.</i> , (1999)			
2. Similar results were reported for steam-flaked sorghum			

**Table 6.** Effect of steam-flaking (SF) corn or sorghum versus steam-rolling (SR) corn or dry-rolling (DR) sorghum on mammary uptake of substrates<sup>1</sup>

Net mammary uptake	Processing		P<
	SR CORN AND DR sorghum	SF corn and SF sorghum	
<i>a</i> - Amino acid N (g/d)	61	84	0.01
Glucose (g/d)	1609	1726	0.16
L-Lactate (g/d)	68	94	0.19
Acetate (mol/d)	11	12	0.58
Propionate (mol/d)	0.21	0.27	0.09
n-Butyrate (mol/d)	0.05	0.05	0.91
<i>B</i> -Hydroxybutyrate (mol/d)	2.20	2.70	0.03
1. Theurer <i>et al.</i> , (1999)			

An increased mammary uptake of amino acids (Table 6) in cows fed steam-flaked grains was associated with an increased yield of milk protein (Table 7). Milk fat yield (Table 7) was not increased by feeding steam-flaked grains but neither were mammary uptakes of the milk fat precursors acetate and butyrate (Table 6). Steam-flaking increased mammary uptake of glucose (Table 6) that was accompanied by an increased milk yield (Table 7). Kronfeld (1976) estimated that 1 kg of milk is produced for every 72 g of glucose uptake. Data in Table 6 shows that mammary uptake of glucose was increased 117 g/d when cows were fed steam-flaked corn or sorghum versus steam-rolled corn or dry rolled sorghum. This equates to 1.6 kg/d milk. Milk yield of cows fed steam-flaked corn was 2.2 kg/d greater than cows fed steam-rolled corn (Table 7). When cows were fed steam-flaked grains, protein yield increased more than milk yield so concentration of protein in milk increased (Table 7). On the other hand, feeding steam-flaked grains did not increase fat yield so concentration of fat in milk decreased (Table 7).

Processing methods developed for corn and sorghum cannot be applied directly to barley (Beauchemin and Rode, 1998). In the corn endosperm, starch is tightly packed within a protein matrix. The objective of corn processing is release of starch from the matrix so that digestion is increased.

Because barley is encased in a hull, the objective of processing barley is breaking the hull so that starch can be digested. Barley starch is more fermentable than corn starch. Because steam processing grains increases ruminal fermentation of starch, application of steam processing methods to barley may excessively increase ruminal fermentation of starch to cause low ruminal pH, acidosis and metabolic problems. On the other hand, under-processing can lead to reduced ruminal and intestinal digestibility. Beauchemin and Rode (1998) suggested that fine grinding is the most appropriate way to process barley. However, lower milk production in cows fed barley versus corn-based rations (Overton *et al.*, 1995; Yang *et al.*, 1997) illustrates the need for detailed studies on optimal processing methods for barley.

Fibre is fermented at slower rates than non-fibre carbohydrates but fibre is needed for the formation of an adequate ruminal mat (limits loss of fine particles from the rumen), adequate rumination and salivation, and rumen buffering (Van Soest, 1994; Mertens 1997). NRC (1989) suggests that rations for high producing cows contain minimums of 19% ADF and 25% NDF with 75% of total ration NDF from forage. However, effectiveness of fibre in maintaining rumen function depends on particle size of fibre (Mertens, 1997).

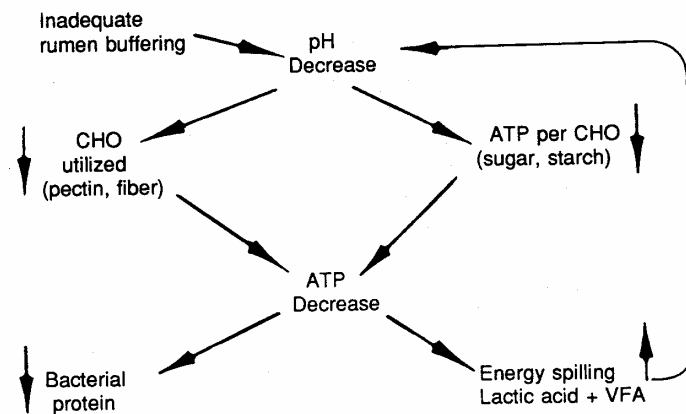
Measurement	Processing		Response	P
	SR corn	SF corn		
Milk (kg/d)	35.80	38.0	+2.20	0.02
Protein				
(kg/d)	1.07	1.16	+0.09	0.01
(%)	2.99	3.06	+0.07	0.11
Fat				
(kg/d)	1.12	1.13	+0.01	0.44
(%)	3.11	2.98	-0.13	0.02
1. Theurer <i>et al.</i> , (1999)				
2. Similar results were reported for steam-flaked versus dry rolled sorghum				

Obtaining proper proportions of fibre and non-fibre carbohydrates in rations is a “balancing act” (Stone, 1999). Effective fibre is needed for normal rumen function but excessive fibre can limit intake and ration energy density. Non-fibre carbohydrates increase ration energy but the production of volatile fatty acids can exceed the buffering capacity of the rumen to lead to low ruminal pH. The minimum effective fibre in rations should be based on maintenance of “adequate ruminal pH.” It is variable and depends on fermentability of carbohydrates to volatile fatty acids (Allen, 1997). As noted before, starch in barley is fermented faster than starch in corn. Thus, it is not surprising that more forage NDF was needed to avoid milk fat depression in barley versus corn based rations (Beauchemin and Rode, 1997).

“Adequate ruminal pH” does not seem to be defined well but based on fibre digestion and

maintenance of concentration of milk fat, a mean pH of 6.0 seems to be a good target (Mertens, 1997). Stone (1999) considers a herd to sub clinically acidotic if 2/3 of animals tested have pH values less than 5.8.

Inadequate buffering in the rumen leading to decreased ruminal pH affects both fermentation of carbohydrates and bacterial growth (Figure 1). As pH decreases below about 6.0, there is less energy (ATP) for microbial growth. This occurs because fermentation of fibre and pectin decreases and the amount of ATP derived from fermentation of sugar and starch is lower. Decreased fermentation of fibre and pectin also leads to lower production of acetate. Propionate (and lactate) is produced from fermentation of starch and sugar. Low pH alone, by inhibiting methanogenesis, also promotes production of propionate (Russell, 1998).



**Figure 1.** Effect of rumen pH on bacterial growth and acid production (adapted from Strobel and Russell (1986) and Van Soest (1995)).

Subclinical rumen acidosis can affect milk yield and components (Stone, 1999). In a NY dairy, milk yield was about 3 kg less than expected, milk fat was 3.4%, milk true protein was 2.8% and rumen pH was less than 5.8 in 6 out of 11 cows tested. High moisture ear corn was replaced with corn meal and soybean hulls. After the ration adjustment, rumen pH was below 5.8 in only 1 cow out of 7. Dry matter intake increased 1.5 kg/d, milk increased 3 kg/d, milk fat was 3.7% and milk true protein was 2.9%. As noted above,

rumen pH is affected by physically effective NDF (Mertens, 1997) and by fermentable carbohydrate (Allen, 1997). In the Stone (1999) case study, only fermentable carbohydrate was adjusted.

Buffers increase mammary synthesis of fat, especially when rations are low in fibre or when corn silage is the main forage (Erdman, 1988). Buffer alleviation of milk fat depression is usually associated with an increased ratio of ruminal acetate:propionate. Another mechanism for alleviation of milk fat

depression with dietary buffers involves decreased ruminal synthesis and mammary uptake of trans octadecenoic acids (Kalscheur *et al.*, 1997; Kennelly *et al.*, 1999). As noted before, mammary uptake of *trans* octadecenoic acids appears to inhibit synthesis of milk fat. The effect of buffers is usually attributed to an increase in ruminal pH (Erdman, 1998) but buffers also increase ruminal fluid dilution rate (Russell and Chow, 1993; Rogers *et al.*, 1982). Both ruminal pH and rumen fluid dilution rate can adjust the balance of bacterial species and fermentation products.

### Protein

Like other mammalian species, the dairy cow's requirement for protein is a requirement for specific amounts and balances of amino acids. Amino acid supply to the mammary gland can affect milk protein synthesis and milk volume. In addition, amino acids can impact productivity by affecting metabolism and immune function (Chalupa and Sniffen, 1997).

Metabolisable (absorbed) protein and amino acids that the cow uses for synthesis of milk protein are the sum of microbial protein and intestinally digested rumen escape feed protein. In well-balanced rations, about 50 to 55% of metabolisable protein and amino acids are provided by energy-yielding ingredients through growth of ruminal bacteria and about 45 to 50% of metabolisable protein and amino acids are provided by protein-yielding ingredients through rumen escape of dietary protein (Chalupa and Sniffen, 1996).

When rations contain low levels of crude protein (10 to 14%) increasing crude protein to 18 to 20% increases milk yield (Thomas and Martin, 1988; Roffler *et al.*, 1986). Digestibility and feed consumption often are increased when concentration of dietary protein is increased so that effects of protein are the combination of impacts upon energy- and protein-yielding nutrients (Oldham, 1984).

Some of the protein in all feed ingredients except NPN escapes ruminal fermentation but there are large differences between ingredients. The extent of protein degradation in the rumen depends on the degradation rates of protein fractions and their passage rates (Russell *et al.*, 1992). Even though research has not demonstrated consistent production responses (Santos *et al.*, 1998), rations for lactating cows usually contain ingredients with protein fractions that are slowly degraded in the rumen. Examples are plant proteins like distillers grains, brewers grains, corn gluten meal and treated or specially processed soy bean meals; non-ruminant animal proteins such as blood meal, meat and bone meal and feather meal; marine proteins; and proprietary blends of non-ruminant animal and marine proteins.

Disappointing research results (Santos *et al.*, 1998) with feed ingredients that have high ruminal escape of protein fractions might discourage balancing rations on the basis of amino acids. However, in many of these studies, synthesis of microbial protein was compromised because of shortages of rumen available nitrogen so that duodenal flows of nitrogen, total essential amino acids, lysine and methionine were not increased. Few of these studies considered the amino acid composition of the ruminal escape protein and rations were not balanced based on amino acids. An encouraging finding (Santos *et al.*, 1998) was that fish meal, which has good balances of methionine and lysine (Chalupa and Sniffen, 1996), improved milk yield when cows were producing in excess of 70 lb/d milk

Rations can be balanced for amino acids using classical factorial methods and by ideal protein methods (Rulquin *et al.*, 1993; Schwab, 1996). Factorial methods require efficiency coefficients that describe the transfer of metabolisable (absorbed) amino acids into milk protein. Factorial methods use linear transfer coefficients. Thus, the factorial method may describe production responses adequately when amino acids are limiting, but will over-estimate production responses when there are excess of amino acids. The ideal protein methods are based on responses of milk protein to methionine and lysine expressed as concentrations of metabolisable protein (Rulquin *et al.*, 1993) or as concentrations of duodenal essential amino acids (Schwab, 1996). Because responses are curvilinear, milk protein production is not over-estimated when there are excess amino acids. Sloan *et al.*, (1999) used CPM-Dairy (1998) to examine responses to methionine and lysine in the data set compiled by Garthwaite *et al.*, (1998). Increases in yield of milk (3.7 lb/d), yield of milk protein (0.20 lb/d) and concentration of protein in milk (0.10%) only occurred when Met/MP was greater than 2.2%, Lys/MP was greater than 6.8% and Lys/Met exceeded 3. Chalupa *et al.*, (1999) used CPM-Dairy (1998) to formulate amino acid (Ajinomoto Corp. Inc., Tokyo) enriched fresh-cow rations. Met/MP was increased from 1.89 to 2.35%. Lys/MP was increased from 6.38 to 7.45%. Lys/Met in the amino acid enriched ration was 3.2 (Table 8). Feeding the amino acid enriched ration increased mammary synthesis of protein in both multiparous and primiparous cows. Because milk yield increased in multiparous cows, the increased mammary synthesis of protein was "diluted" and concentration of protein in milk was not changed. In primiparous cows, milk yield was only marginally increased so the increased mammary synthesis of protein was seen as an increase in the concentration of protein in milk. Feeding the amino acid enriched ration did not affect mammary synthesis of fat in either multiparous or primiparous cows.

Table 8. Responses of lactating cows to rumen protected methionine and lysine <sup>1</sup>							
		Rulquin Ratio <sup>2</sup> (% AA in MP)					
		Met	Lys	Met	Lys		
Measurement <sup>3</sup>	Parity <sup>4</sup>	1.89	6.38	2.35	7.45	Response	P
Milk (kg/d)	M	32.96		35.28		+2.32	<.05
	P	26.28		27.96		+1.68	>.10
C Protein (%)	M	3.12		3.20		+0.08	>.10
	P	3.09		3.26		+0.17	<.01
C Protein (g/d)	M	1015		1097		+82	<.01
	P	805		894		+89	<.01
Fat (%)	M	4.24		4.05		-0.19	>.10
	P	4.21		3.96		-0.25	>.10
Fat (g/d)	M	1371		1401		+30	>.10
	P	1098		1094		-4	>.10
1. Chalupa <i>et al.</i> , (1999); 2. Rulquin <i>et al.</i> , (1993)							
3. For the first 4 weeks of lactation when the amino acid enriched ration was fed							
4. M = multiparous; P = primiparous							

Based upon evaluation of published research, we propose that balancing rations on the basis of amino acids will increase mammary synthesis of protein but the type of production response will vary depending upon parity and stage of lactation. Because growth is a higher metabolic priority than milk secretion, response in primiparous animals may depend upon body size at calving. Amino acids seem to increase milk volume if started at or prior to calving. If delayed until after peak production, milk volume increases are small so the main response to amino acids is increased concentration of protein in milk.

Microbial protein has an amino acid profile that more closely matches the profile of milk than do the profiles of most ingredients used in feeding dairy cattle. Thus, it is easier to balance rations based on amino acids if the ration promotes good bacterial growth (i.e. 50 to 55% of metabolisable protein from bacteria).

### Fat

Replacing grain with fat is a method of increasing energy density without compromising fibre content. However, the rumen system is not designed to use fat. Long chain fatty acids can affect fermentation by adsorption of the fat onto feed particles and bacteria. Adsorption onto bacteria impairs nutrient uptake. Coating feed particles decreases digestibility (Palmquist and Jenkins, 1980).

Fats can be classified on how they affect ruminal fermentation and fibre digestion (Jenkins, 1997). Fats like tallows, greases, oils, and the fat in oil seeds (cotton and soybeans) are available in the rumen and can cause problems in fermentation and digestion. Calcium salts of fatty acids and hydrogenated fats are inert in the rumen. Jenkins (1997) proposed that the amount of rumen available fat that is tolerated depends upon the unsaturated fatty acids content of the fat and the fibre content of the ration. In general, rations can contain about 5% rumen available fat. If higher levels of fat are needed, it must ruminally inert.

By supplying substrates, dietary fat can increase mammary synthesis of fat. Dietary fat, however, also increases milk yield (Jenkins, 1997). Increased milk volume may reflect fat sparing glucose from metabolism by the mammary gland. Some glucose is metabolised via the pentose pathway to provide NADPH needed for synthesis of short chain and medium chain fatty acids. Increased extraction of LCFA from blood by the mammary gland decreases synthesis of short chain and medium chain fatty acids (Palmquist and Jenkins, 1980).

Concentration of protein in milk is often decreased when rations contain fat (Chalupa and Galligan, 1989; Sanchez, *et al.*, 1998). This is partly due to dilution of mammary synthesised protein by increased milk yield. However, there is decreased mammary synthesis casein when fat is fed (Chalupa and Galligan, 1996). This probably reflects a lower supply of amino acids to the mammary gland. Fat is usually substituted for carbohydrates. As noted before, ruminal bacteria grow on carbohydrates but not on fat (Nocek and Russell, 1988). Thus, rations containing supplemental fat can be expected to yield less ruminally synthesised protein and should contain more undegraded intake protein (Sanchez *et al.*, 1998).

### Ionophores

These adjust the balance of bacterial species in the rumen to produce changes in the products of ruminal fermentation. Effects of ionophores are due to differences in cell membrane structure. Gram-positive bacteria are sensitive to ionophores while Gram-negative bacteria are ionophore resistant. Certain methanogenic bacteria, lactic acid producing- bacteria and bacteria that use amino acids as their sole source of energy are sensitive to ionophores. Bacteria that utilise lactic acid are resistant to ionophores. By increasing production of propionic acid while decreasing production of lactic acid, ionophores improve the efficiency of energy metabolism and may decrease the risk of metabolic

disorders like ketosis and acidosis (Kenelly *et al.*, 1998).

In a collaborative study (Symanowski *et al.*, 1999) with 305 primiparous and 553 multiparous Holstein cows, monensin at 8 to 24 ppm of the ration increased milk yield 2.2 lb/d and decreased milk fat percentage 0.14 units. Concentration of protein in milk was not affected. In pasture-fed cattle (1109 cows in 12 Australian dairy herds), monensin delivered by a slow-release intraruminal bolus increased milk 1.7 lb/d without affecting concentrations of protein and fat in milk (Beckett *et al.*, 1998). In studies summarised by Kenelly *et al.*, (1998), ionophores usually decreased concentration of fat in milk but there was considerable variation in responses of milk yield. Responses to ionophores may depend upon ration components but they seem to provide a means of increasing the ratio of protein:fat in milk.

## REFERENCES

- Allen, M. S. 1997. Relationships between fermentation acid production in the rumen and the requirement for physically effective fibre. *J. Dairy Sci.* 80:1447.
- Beauchemin, K. A. and L. M. Rode. 1998. Effective fibre in barley-based diets. *Adv. Dairy Technology* 10:151.
- Beauchemin, K. A. and L. M. Rode. 1997. Minimum versus optimum concentrations of fibre in dairy cow diets based on barley silage and concentrates of barley or corn. *J. Dairy Sci.* 80:1629.
- Barbano, D. M. 1999. Trends in milk composition and analysis in New York. *Proc. Cornell Nutr. Conf. Cornell Univ., Ithaca NY.* p. 32.
- Beckett, S., I. Lean, R. Dyson, W. Tranter and L. Wade. 1998. Effects of monensin on the reproduction, health and milk production of dairy cows. *J. Dairy Sci.* 81:1563.
- Bequette, B.J., F. R. C. Backwell and L. A. Crompton. 1998. Current concepts of amino acid and protein metabolism in the mammary gland of the lactating ruminant. *J. Dairy Sci.* 81:2540.
- CPM-Dairy. 1998. Cornell Univ., Ithaca NY; Univ. Pennsylvania, Kennett Square PA; W.H. Miner Agricultural Research Institute, Chazy NY.
- Chalupa, W. and D. T. Galligan. 1989. Manipulating protein levels in milk. *In: Biotechnology and the Feed Industry.* Ed. T.P. Lyons. Altech Technical Publications, Nicholasville KY, p. 63.
- Chalupa, W. and C. J. Sniffen. 1996. Matching protein delivery to milk production. *Adv. Dairy Technology* 8:69.
- Chalupa, W. and C. J. Sniffen. 1997. Formulating diets for dairy cattle on the basis of amino acids. *Proc. Maryland Nutr. Conf.*
- Chalupa, W., C.J. Sniffen, W.E. Julien, H. Sato, T. Fujieda, T. Ueda and H. Suzuki. 1999. Lactation responses of cows in a commercial dairy to rumen protected methionine and lysine. *J. Dairy Sci.* 82(Suppl.1):121.
- Erdman, R. A. 1988. Dietary buffering requirements of the lactating dairy cow. *J. Dairy Sci.* 71:3246
- Garthwaite, B.D., C.G. Schwab and B.K. Sloan. 1998. Amino acid nutrition of the early lactation cow. *Proc. Cornell Nutr. Conf.* p. 38
- Griinari, J. M., M. A. Mcguire, D.A. Dwyer, D.E. Bauman and D.L. Palmquist. 1997. Role of insulin in regulation of milk fat synthesis in dairy cows. *J. Dairy Sci.* 80:1076.
- Griinari, J. M., D. A. Dwyer, M. A. Mcguire, D. E. Bauman, D.L. Palmquist and K.V.V. Nurmela. 1998. *Trans*-octadecenoic acids and milk fat depression in lactating dairy cows. *J. Dairy Sci.* 81:1251.
- Jenkins, T. C. 1993. Lipid metabolism in the rumen. *J. Dairy Sci.* 76:3851.
- Jenkins, T. 1997. Success of fat in dairy rations depends on choosing the right amount. *Feedstuffs* 69(2):14.
- Kenelly, J. J., L. Doepel and K. Lien. 1998. Ionophores-Mode of action and effects on milk yield and composition. *Adv. Dairy Technology* 10:67.
- Kenelly, J. J., D.R. Glimm and L. Ozimek. 1999. Milk composition in the cow. *Proc. Cornell Nutr. Conf. Cornell Univ., Ithaca NY.* p. 1.
- Kenelly, J. J., B. Robinson and G.R. Khorasani. 1999. Influence of carbohydrate source and buffer on rumen fermentation characteristics, milk yield, and composition in early-lactation Holstein cows. *J. Dairy Sci.* 82:2486.
- Kalscheur, K. F., B. B. Teter, L. S. Piperova and R.A. Erdman. 1997. Effect of dietary forage concentration and buffer addition on duodenal flow of *trans*-C<sub>18:1</sub> fatty acids and milk fat production in dairy cows. *J. Dairy Sci.* 80:2104.
- Kronfeld D. S. 1976. Bovine ketosis in high yielding dairy cows. The potential importance of the proportions of glucogenic, lipogenic and aminogenic nutrients in regard to the health and productivity of dairy cows. *Fortschr. Tierphysiol. Tierernahr.* 7:3.
- Mertens, D. R. 1997. Creating a system for meeting fibre requirements of dairy cows. *J. Dairy Sci.* 80:1463.
- NRC. 1989. Nutrient Requirements of Dairy Cattle. *Natl. Acad. Sci., Washington, DC.*
- Nocek, J. E and J. B. Russell. 1988. Protein and energy as an integrated system: Relationship of ruminal protein and carbohydrate availability to microbial synthesis and milk production. *J. Dairy Sci.* 71:2070.
- Oldham, J. D. 1984. Protein and energy inter-relationships in dairy cows. *J. Dairy Sci.* 67:1090.
- Overton, T. R., M. R. Cameron, J. P. Elliot, J. H. Clark and D. R. Nelson. 1995. Ruminal fermentation and passage of nutrients to the duodenum of lactating cows fed mixtures of corn and barley. *J. Dairy Sci.* 78:1981.
- Palmquist, D. L. and T. C. Jenkins. 1980. Fat in lactation rations: review. *J. Dairy Sci.* 63:1.
- Pitcher, P.M., J. D. Ferguson, D. T. Galligan and W. Chalupa. 1994. Importance of differentiating true and dilution effects on milk composition. Unpublished data. Univ. Pennsylvania, Kennett Square.
- Roffler, R. E., J. E. Wray and L. D. Satter. 1986. Production responses to additions of soybean meal to diets containing predominantly corn silage. *J. Dairy Sci.* 69:1055.
- Rogers, J. A., C. L. Davis and J. H. Clark. 1982. Alteration of rumen fermentation, milk fat synthesis and nutrient utilisation with mineral salts in dairy cows. *J. Dairy Sci.* 65:577
- Rulquin, H. P. M. Pisulewski, R. Verite and J. Guinard. 1993. Milk production and composition as a function of postruminal lysine and methionine supply: a nutrient-response approach. *Livestock Prod. Sci.* 37:69.
- Russell, J. B. 1998. The importance of pH in the regulation of ruminal acetate to propionate ratio and methane production *in vitro*. *J. Dairy Sci.* 81:3222.
- Russell, J. B and J. M. Chow. 1993. Another theory for the action of ruminal buffer salts: decreased starch fermentation and propionate production. *J. Dairy Sci.* 76:826.
- Russell, J. B., J. D. O'Connor, D. G. Fox, P. J. Van Soest and C.J. Sniffen. 1992. A net carbohydrate and protein system



- for evaluating cattle diets. I. Ruminal fermentation. *J. Anim. Sci.* 70:3551.
- Sanchez, W.K., I.P. Moloi and M.A. McGuire. 1998. Relationship between UIP and inert fat examined. *Feedstuffs* 70(27):12.
- Santos, F.A.P, Santos, J.E.P., C.B. Theurer and J.T. Huber. 1998. Effects of rumen-undegradable protein on dairy cow performance: a 12-year literature review. *J. Dairy Sci.* 81:3182.
- Schwab, C.G. 1996. Amino acid nutrition of dairy cows. *Proc Cornell Nutr. Conf. Cornell Univ., Ithaca NY.* p. 184.
- Sloan, B.K., B.D. Garthwaite and C.G. Schwab. 1999. Fine-tuning sub-model may optimise production. *Feedstuffs* 71(33): 11.
- Stone, W.C. 1999. The effect of subclinical rumen acidosis on milk components. *Proc. Cornell Nutrit Conf. Cornell Univ., Ithaca NY.* p. 40.
- Strobel, H.J. and J.B. Russell. 1986. Effect of pH and energy spilling on bacterial protein synthesis by carbohydrate-limited cultures of mixed rumen bacteria. *J. Dairy Sci.* 69:2941.
- Sutton, J.D. 1989. Altering milk composition by feeding. *J. Dairy Sci.* 72:2801.
- Symanowski, J.T., H.B. Green, J.R. Wagner, J.I.D. Wilkinson, J.S. Davis, M.R. Himstedt, M.S. Allen, E. Block, J.J. Brennan, H.H. Head, J.J. Kennelly, J.N. Nelson, J.E. Nocek, J.J. Van Der List and L.W. Whitlow. 1999. Milk production and efficiency of cows fed monensin. *J. Dairy Sci.* 82(Suppl. 1):75.
- Theurer, C.B., J.T. Huber, A. Delgado-Elorduy and R. Wanderley. 1999. Invited review: Summary of steam-flaking corn or sorghum grain for lactating cows. *J. Dairy Sci.* 82:1950.
- Thomas, P.C. and P.A. Martin. 1988. The influence of nutrient balance on milk yield and composition. *In: Nutrition and Lactation in the Dairy Cow.* Ed. P.C. Garnsworthy. Butterworths, London, p. 97.
- Van Soest, P.J. 1994. *Nutritional Ecology of the Ruminant.* Cornell Univ. Press. Ithaca NY.
- Yang, W.Z., K.A. Beauchemin, B.I. Farr and L.M. Rode. 1997. Comparison of barley, hull-less barley, and corn in the concentrate of dairy cows. *J. Dairy Sci.* 80:2885.

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