Feeding for Milk Components

Adam L. Lock[1] and Michael E. Van Amburgh[2]

[1]Department of Animal Science, Michigan State University, East Lansing, MI 48824, USA
[2]Department of Animal Science, Cornell University, Ithaca, NY 14850, USA
Email: allock@msu.edu

■ Take Home Messages

‣ Recent evidence has increased our understanding of factors affecting milk fat and protein synthesis that should allow for the development of nutritional management systems that allow strategic changes in milk composition.

‣ Fat is typically the most variable component in milk, and is affected by many physiological and environmental factors.

‣ Milk fat depression is due to changes in rumen biohydrogenation of unsaturated fatty acids and the passage of specific intermediates of biohydrogenation out of the rumen that subsequently reduce milk fat synthesis in the mammary gland

‣ Low milk fat tests typically occur as a result of several concurrent diet or management factors rather than as a result of a single factor.

‣ In contrast with milk fat, the impact of nutrition on milk protein content is poorly defined.

‣ From a practical and environmental point of view, to improve the efficiency of use of feed protein, feeding management should focus on reducing excess protein in the diet.

■ Introduction

Producing milk with a composition that is consistent with the demand for milk constituents can not only improve biological efficiency but also increase profitability. For milk producers, nutritional strategies that generate the highest margin would be considered optimal. Margins may be generated by producing milk at least cost for maximum components and/or adding value to the raw material through independent processing and marketing, or enhancing the nutritional quality of milk and dairy products. The primary requirement of processors is for a constant supply of high quality raw material of consistent

composition. In today's climate, milk components and not milk volume are driving producer milk prices. Improvements in animal genetics can be used to align production with demand in the long term, but do not offer a short to medium term solution. The broad role of nutrition on milk composition is well established and indicates the potential to rapidly respond to changes in milk markets. Recent research, however has improved our understanding, such that the emphasis of the current paper is placed on recent developments concerning causes of dietary induced milk fat depression (MFD), and practical solutions to alleviating low milk fat tests.

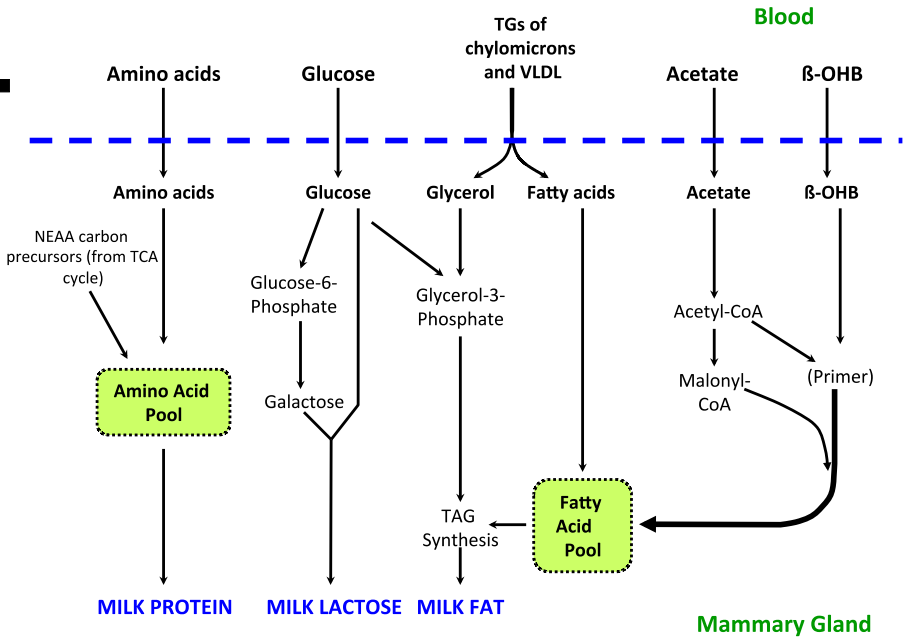# ■ Altering Milk Components

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Figure 1. Metabolic pathways for the synthesis of fat, protein and lactose in the mammary gland. Adapted from Lock and Shingfield (2003).

Milk fat, protein and lactose are synthesised in the mammary gland from precursors absorbed from the peripheral circulation. From the onset of lactation, synthesis of milk constituents occurs at such high rates that without strict regulation metabolic problems would rapidly be encountered. Establishment and co-ordination of these processes through acute and chronic interactions between nutrients, hormones and tissues permit high rates of milk production while still allowing nutrients to be partitioned to tissues other than the mammary gland. Such adaptations have the overall

effect of providing the appropriate quantity and balance of nutrients for milk synthesis (Bauman, 2000). Metabolic pathways for the synthesis of fat, protein and lactose in the mammary gland are presented in Figure 1. Recent evidence has increased our understanding of factors affecting milk fat and protein synthesis in the mammary gland that should allow the development of nutritional management systems that allow strategic changes in milk composition. Nutrition is the primary means of manipulating milk fat content, and represents a short to medium term solution for altering milk protein content. Lock and Shingfield (2004) provides a comprehensive review of the impact of nutrition on milk fat and protein.

Milk Protein

Of all constituents, protein typically has the highest value within milk payment schemes, sometimes receiving a 50% higher premium compared with milk fat. This has led to considerable interest in increasing milk protein yields. In contrast with milk fat, the impact of nutrition on milk protein content is poorly defined. In general, milk protein content tends to increase with increases in energy intake from carbohydrates, but decrease when relatively high levels of fatty acids are included in the diet. Dietary protein supplements typically increase milk protein secretion but have variable effects on milk protein content.

The general consensus in the literature is that increases in milk protein content can be realized by replacing grass silage with corn or whole crop silage, and greater use of high starch concentrates, and to a lesser extent with protein supplements. However the scope to alter milk protein content is rather limited and much lower than that of milk fat. In most cases a significant increase in the protein to fat ratio is only realized through feeding diets stimulating a reduction in milk fat content which in itself is often counter-productive and is discussed in later sections.

The limitation to milk protein synthesis tends to follow a priority of nutrient supply. The primary factor is metabolizable energy supply through effects on insulin, insulin like growth factor–1 and other energy signalling mechanisms (e.g. Mackle et al., 2000) associated with enhanced microbial yield through increased ruminal carbohydrate fermentation. Integrated in the energy signalling are the presence of amino acids and mechanisms like mTOR that potentially modulate protein synthesis depending on not only the availability of energy but the availability of required essential amino acids (e.g. Rius et al. 2010).

From a practical and environmental point of view, to improve the efficiency of use of feed protein, formulation models and feeding management of lactating cattle should focus on reducing the excess protein in the diet. Any protein not required by the cow is excreted in the urine as urinary urea, a consequence of

urea nitrogen recycling and the removal by the kidney of any urea not recognized by the animal as necessary for rumen function. Thus, the objective should be to reduce protein intake to the level necessary to maintain adequate rumen fermentation and microbial yield, and reduce the quantity of urea nitrogen excreted in the urine. This approach assumes that the nutritionist can evaluate the cattle and their diet adequately to determine what is first limiting, metabolizable energy (ME) or protein (MP) and then make the appropriate changes. If ME is first limiting, then reducing the excess crude protein, if done correctly should reduce urinary urea excretion and modestly improve overall efficiency of use of absorbed protein – simply by reducing the excess.

Several studies have been conducted that demonstrate the ability to decrease the CP content of the diet, increasing N efficiency and maintaining milk yield. For example, Cyriac et al. (2008) altered the 2001 Dairy NRC predicted RDP content of the diet from 11.3 to 7.6% of dry mater while simultaneously decreasing the CP content of the four diets fed to lactating dairy cattle. The RUP supply was held constant while the predicted RDP balance ranged from 301 to -574 g/d with corresponding CP levels of 18.4 to 13.6%, respectively. Overall dry matter intake and milk yield were not different when CP was reduced to 15.2% in this experiment, and efficiency increased from 27.7 to 35.5%. At the lowest level of dietary CP, 13.6%, dry matter intake and milk yield were significantly decreased and milk protein yield was also reduced suggesting that both rumen N and MP supply were not met and rumen fermentation was reduced, thus causing a decrease in intake.

Recent data from Cornell University (Recktenwald, 2007; Hofherr, 2010; Higgs et al., 2012) demonstrate that high producing lactating cattle can maintain adequate milk and milk protein yield on relatively low protein diets (14 to 15.5% DM) provided that adequate rumen carbohydrate fermentation is achieved and the balance between rumen ammonia and MP supply is properly formulated and evaluated. In studies by Recktenwald (2007) and Hofherr (2010) high producing cattle were able to achieve 42 to 52 kg of milk yield per day on diets ranging from 14.2 to 15.5% with high quality forages. The key factor was forage quality followed by proper characterization of the cattle characteristics and feed ingredient chemistry. In these studies, milk urea N (MUN) averaged approximately 8 mg/dL with a range of 5.5 to 10 mg/dL and a MUN less than 6.5 resulted in rumen ammonia measurements less than required to maintain adequate fiber digestion. The sum of the available data points indicates that there are efficiencies to be achieved by reducing the excess protein in the diet independent of increases in protein synthesis and milk excretion.

Milk Fat

Diets that allow for an improvement in milk fat output are potentially economically advantageous. The addition of fat to the diet can increase the concentration and yield of milk fat. This response however, is inconsistent and often related to the amount and type of fat being fed. Unsaturated fatty acids have the potential to affect the growth of some groups of rumen bacteria and inhibit fat synthesis in the mammary gland (see following section). On the other hand, saturated fatty acids (e.g. palmitic [C16:0] and stearic [C18:0] acids) are considered to be inert in the rumen and have not been implicated in MFD.

Table 1. The effct of rumen-inert fats containing mostly saturated fatty acids (SFA), mostly monounsaturated fatty acids (MUFA), or mostly polyunsaturated fatty acids (PUFA) on dry matter intake (DMI), milk yield and milk fat synthesis in midlactation dairy cows. Adapted from Relling and Reynolds (2007)

	Diet				P^1
	Control	SFA	MUFA	PUFA	
DMI, kg/d	23.8	23.1	22.1	22.0	0.12
Milk, kg/d	36.9	37.3	35.8	34.8	0.44
Fat, %	3.37	3.86	3.32	2.61	0.03
Fat, g/d	1,249	1,436	1,184	911	0.02

[1]Probability comparing the difference between saturated and unsaturated fat supplements (SFA vs. MUFA and PUFA).

Total milk fat yield as well as fat percentage is often increased when saturated fatty acid supplements are fed. This is highlighted in a recent study comparing the feeding of fat supplements with increasing degree of unsaturation (Table 1). In addition, Christensen et al. (1994) compared the effects of abomasal infusion of saturated long chain fatty acids and unsaturated long chain fatty acids (high oleic canola oil, soybean oil, and sunflower oil) and found that saturated fat infusion increased milk fat yield as compared to the unsaturated fat treatments. There is, however, limited evidence indicating whether specific saturated fatty acids are more or less effective at increasing milk fat production. Steele and co-workers in the 1960's performed a series of studies using relatively pure sources of palmitic, oleic, and stearic acids and their findings suggest that palmitic acid supplementation induces a higher milk fat response (concentration and yield) as compared to oleic and stearic acids supplementation (e.g. Steele and Moore, 1968). More recent work from Enjalbert et al. (1998) suggests that the uptake efficiency of the mammary gland is higher for palmitic acid than for oleic and stearic acids.

In a recent study we found that feeding an 85% palmitic acid fat supplement (2% dietary DM) improved milk fat concentration and yield by 8% as well as efficiency of feed conversion into milk compared to a non-fat supplemented diet (Lock et al., 2011).

■ Milk Fat Depression

Fat is typically the most variable component in milk, and is affected by many physiological and environmental factors. The concentration and yield of milk fat is driven by the nutrition of the dairy cow. Consequently, low (or reduced) milk fat percentage and yield is an important economic issue to dairy farms. Such reductions in fat are common: for example, in the Mideast Federal Order during 2010, the average monthly milk fat percentage was significantly lower for 8 out of 12 months compared to the 10-year average (data from www.lmic.info).
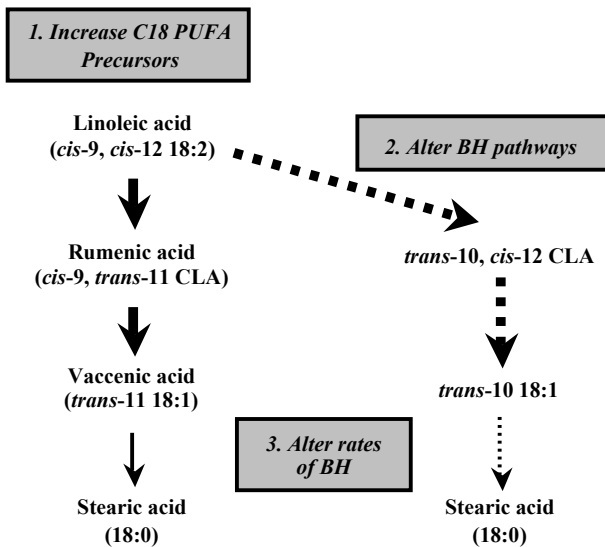
Figure 2. Generalized scheme of ruminal biohydrogenation of linoleic acid under normal conditions (left side) and during diet-induced milk fat depression (dotted lines, right side). The grey boxes highlight three potential means by which dietary components can increase the risk of milk fat depression (Lock, 2010).

The available evidence indicates that MFD is due to changes in rumen biohydrogenation of unsaturated fatty acids and the passage of specific intermediates of biohydrogenation out of the rumen (e.g. trans-10, cis-12

CLA) that subsequently reduce milk fat synthesis in the mammary gland by altering expression of genes involved in fat synthesis. Our recent review on MFD and milk fat synthesis provides further information on this biology (Bauman et al., 2011). Although we have a good understanding of the effect of specific biohydrogenation intermediates in the mammary gland, there is limited information regarding dietary factors that promote their formation in the rumen. A generalized scheme of rumen biohydrogenation of linoleic acid under normal conditions and during diet-induced MFD is shown in Figure 2. Troubleshooting milk fat issues on dairy farms remains one of the more challenging tasks within overall nutritional management of dairy cows. A better understanding of the effect of different diets and specific dietary components on rumen biohydrogenation will allow for the development of nutrition strategies that can diminish the significant financial losses associated with MFD (Lock, 2010).

Dietary Factors Impacting Milk Fat Concentration and Yield

Alteration of the Rumen Environment:

Factors that alter rumen environment are traditionally first considered when troubleshooting MFD on dairy farms. One major change in the rumen environment that may lead to flux of fatty acids through alternate pathways of ruminal biohydrogenation is low rumen pH. Although data are limited, changes in rumen pH are most likely associated with MFD because they cause a change in the bacterial population favouring those that have alternative biohydrogenation pathways. A common misconception, however, is that acidosis is a prerequisite for MFD to occur. This is not the case and in most situations rumen health appears excellent and there are no overt signs of ruminal acidosis.

Diet, and particularly carbohydrate fermentability in the rumen, is an important factor that can result in changes in biohydrogenation pathways and specific intermediates. For example, a cursory review of the literature highlights the impact of different dietary carbohydrates on the risk of MFD as affected by source, processing, and moisture, presumably as a result of differences in the rate of rumen fermentation. Therefore, careful consideration should be given to the fermentation rate of starch sources when troubleshooting MFD issues. For example, a number of studies have reported an effect of corn processing method on risk of MFD. No single factor, however tends to result in low milk fat and an example of the impact of some of these dietary interactions is highlighted in Table 2; this study fed diets containing high moisture and dry ground corn at either a high or low starch concentration. At the low starch level there was no significant effect of grain processing on milk fat parameters, whereas at the high starch level high moisture corn significantly reduced milk fat yield by 15% compared to dry ground corn. Additionally,

cows consuming diets that contain corn silage as the only or major forage source appear to be more susceptible to MFD when unsaturated fats are supplemented. Partial substitution of corn silage with another forage such as alfalfa has been reported to alleviate this negative effect. For example, it has been shown that replacing half the dietary corn-silage with alfalfa silage negated the negative effect of tallow on milk fat yield (Table 3).

Table 2. Effect of corn grain processing method and starch intake on milk fat synthesis. Adapted from Oba and Allen (2003).

	High starch (32% DM)		Low starch (21% DM)	
	High moisture corn	Dry ground corn	High moisture corn	Dry ground corn
Milk yield (kg)	38.8	38.4	33.4	34.3
Milk fat %	3.05[b]	3.59[a]	3.95[a]	3.73[a]
Milk fat yield (kg)	1.17[b]	1.35[a]	1.33[ab]	1.27[ab]

Treatment significance ($P < 0.05$) indicated by differences in superscript letters.

Table 3. Effect of feeding tallow on rumen fermentation and milk fat synthesis in dairy cows fed diets based upon corn silage or alfalfa silage with, or without tallow supplementation. Adapted from Onetti et al. (2004).

	Treatment[1]		
	CS	CST	AST
Milk, kg/d	44.9	44.3	43.6
Fat, %	3.12	2.68	3.32
Fat, kg/d	1.38	1.17	1.45
trans-10 18:1, %	0.75	2.15	0.78

[1]CS = 50% corn silage + 50% conc; CST = 50% corn silage + 50% conc + 2% tallow; AST = 25% corn silage + 25% alfalfa silage + 50% conc + 2% tallow.

It has been reported that monensin can affect biohydrogenation rates through altering rumen fermentation and the bacterial species present, thus potentially increasing rumen outflow of biohydrogenation intermediates. In some cases during established lactation monensin supplementation can result in decreased milk fat percentage and yield (Duffield and Bagg, 2000). These effects are likely the result of interactions with other dietary or management factors that predispose cows to experience MFD. It is important to remember

that an increased rumen outflow of biohydrogenation intermediates will not be a problem if typical biohydrogenation pathways are present. However, even if a small proportion of dietary unsaturated fatty acids are undergoing biohydrogenation through pathways that produce trans-10, cis-12 CLA and related intermediates, monensin can potentially increase the passage of these to the small intestine and increase the risk of MFD.

It is probable that other factors can also cause changes in the rumen bacteria population resulting in an increased flow of fatty acids through alternate pathways of ruminal biohydrogenation. For example, we are currently investigating the possible effects of high dietary wild-yeast counts on rumen biohydrogenation and subsequent risk of MFD. Additional issues that warrant further attention include environmental factors (e.g. heat stress), management issues (e.g. stocking density) and possible dietary components that may aid the maintenance of 'normal' biohydrogenation pathways (e.g. antioxidants, yeast cultures, and live yeast supplements).

Rumen Unsaturated Fatty Acid Load (RUFAL):

Table 4. Fatty acid composition of typical feedstuffs (Data from CPM Feed Library).

Feed Name	Fatty Acid (g/100g fatty acids)					
	C14:0 Myristic	C16:0 Palmitic	C18:0 Stearic	C18:1 Oleic	C18:2 Linoleic	C18:3 Linolenic
Corn Silage	0.46	17.83	2.42	19.24	47.74	8.25
Alfalfa Silage	0.66	18.81	3.35	2.05	15.91	38.71
Grass Hay	0.43	16.44	1.33	2.53	23.38	49.90
Corn Grain	2.33	13.21	1.99	24.09	55.70	1.62
Tallow (Beef)	3.00	24.43	17.92	41.62	1.09	0.53
Soybean Oil	0.11	10.83	3.89	22.82	53.75	8.23
Corn Distillers	0.14	14.05	2.39	24.57	56.11	1.68
Cottonseed	0.69	23.91	2.33	15.24	56.48	0.19

Among the unsaturated fatty acids, linolenic acid is the predominant fatty acid in most grass forage species followed by linoleic acid. In cereal seeds and

corn silage, fatty acids are comprised mainly of linoleic acid followed by oleic acid. Stearic acid is low in plant oils, but present in higher amounts in animal fats, particularly in fats obtained from ruminant species such as beef tallow. Oleic acid is the predominant fatty acid in animal fats and some plant oils, such as canola and palm oil. Linoleic acid is the predominant fatty acid in many plant oils, including cottonseed oil, soybean oil, and corn oil. Table 4 highlights some important feed sources and their respective fatty acid profiles.

Elevating fatty acid concentration in ruminal contents may cause a number of changes in ruminal fermentation characteristics and microbial population distribution. Ruminal changes are the result of the antimicrobial nature of unsaturated fatty acids. Because some bacterial species are more susceptible than others, the result is a microbial shift in the rumen. The fatty acid-induced microbial shift can alter fermentation of carbohydrates and fiber digestion in the rumen. This microbial shift can redirect the pathways of fatty acid biohydrogenation causing accumulation of CLA isomers linked to MFD.

Since various fatty acids can trigger a number of changes in rumen lipid metabolism the feeding of supplemental fat can be challenging. In general, as you increase the degree of unsaturation of supplemental fat and/or the availability of the fatty acids present (e.g. extruded vs. roasted oilseeds), the chances of MFD occurring will increase (e.g. Table 1). This will not happen in all cases but will depend on interactions between the supplemental fat and the basal diet. Furthermore, with the increased availability of corn byproducts (e.g. corn distillers' grains; DDGS) an additional important consideration is their fat content because they can contain a considerable amount of lipid that is predominately linoleic acid (Table 4). The fat content of DDGS is highly variable and this degree of variation can significantly alter the dietary supply of unsaturated fatty acids to the dairy cow, thereby increasing the risk of MFD. For example, we recently analyzed 20 individual samples of DDGS with total fatty acid content ranging from 10% to 18% DM; little to no variation was observed in the fatty acid profile of these samples.

Given that the specific fatty acids that cause MFD are intermediates produced during rumen biohydrogenation of PUFA, it is logical that the amount and/or concentration of unsaturated fatty acids may be related to the amount of the key biohydrogenation intermediates that are produced. Linoleic acid is typically the major dietary fatty acid, particularly when corn silage comprises the majority of the forage base in the ration and oilseeds are the major source of added dietary fat. Estimates of linoleic acid intake indicate that in these situations linoleic acid intake can approach and even exceed 400 to 500 g/d. Therefore, it would appear that typical rations have more than enough substrate as linoleic acid to meet the required presence of PUFA for MFD to occur if rumen fermentation and biohydrogenation pathways are altered. In some circumstances, it would appear that an increase in unsaturated load from increasing oleic acid supply is sufficient to alter biohydrogenation

pathways to favor the production of trans-10, cis-12 CLA and related intermediates from PUFA already in the diet (e.g. Table 3).

Based on this discussion we coined the term "rumen unsaturated fatty acid load" (RUFAL) to reflect the total dietary unsaturated fatty acid supply entering the rumen each day. As defined, RUFAL accounts for intakes of unsaturated fatty acids from all feed ingredients rather than fatty acid intake coming only from fat supplements. RUFAL can be calculated as the sum of the three primary unsaturated fatty acids consumed by dairy cows, namely oleic, linoleic, and linolenic acids. It is proposed that RUFAL is a better indicator of fermentation disruption in the rumen and risk of MFD rather than relying just on the percentage of fat added to the diet or only dietary linoleic acid supply.

Milk Fat Depression Suggestions

- ‣ Don't expect a single dietary factor to be the answer.
- ‣ You can be on the "edge" and be pushed over by one small diet change – don't misinterpret that diet change as evil.
- ‣ Consider rumen unsaturated fatty acid load rather than just the fat supplements
- ‣ Don't ignore amount and type of fiber and/or starch as factors, and management factors.
- ‣ Minimize anything that could lead to "altered ruminal fermentation", especially low pH patterns.

■ References

Bauman, D. E. 2000. Regulation of nutrient partitioning during lactation: homeostasis and homeorhesis revisited. Pages 311-327 in Ruminant Physiology: Digestion, Metabolism and Growth and Reproduction. P. J. Cronje, ed. CAB Publishing, New York, NY.

Bauman, D. E., K. J. Harvatine, and A. L. Lock. 2011. Nutrigenomics, rumen-derived bioactive fatty acids, and the regulation of milk fat synthesis. Annu. Rev. Nutr. 31: 299-319. (Available online at www.nutr.annualreviews.org).

Christensen, R. A., J. K. Drackley, D. W. LaCount and J. H. Clark. 1994. Infusion of four long chain fatty acid mixtures into the abomasum of lactating dairy cows. J. Dairy Sci. 77:1052-1069.

Cyriac, J., A. G. Rius, M. L. McGilliard, R. E. Pearson, B. J. Bequette, and M. D. Hanigan. 2008. Lactation performance of mid-lactation dairy cows fed ruminally degradable protein at concentrations lower than national research council recommendations. J. Dairy Sci. 91:4704-4713.

Duffield, T.F., and R. Bagg. 2000. Use of ionophores in lactating dairy cattle: A review. Can. Vet. J. 41:388-394.

Enjalbert, F., M. C. Nicot, C. Bayourthe, and R. Moncolon. 1998. Duodenal infusions of palmitic, stearic or oleic acids differently affect mammary gland metabolism of fatty acids in lactating dairy cows. J. Nutr. 128: 1525–1532.

Higgs, R. J., L. E. Chase, and M. E. Van Amburgh. 2012. Application and evaluation of the Cornell Net Carbohydrate and Protein System as a tool to improve nitrogen utilization in commercial dairy herds. Prof. Anim. Sci. (in press).

Hofherr, M. W. 2010. The effect of abomasal infusion of histidine and proline on milk composition and mammary amino acid utilization in high producing lactating cows. M.S. Thesis. Cornell University, Ithaca, NY.

Lock, A. L. 2010. Update on dietary and management effects on milk fat. Proc. Tri-State Dairy Nutr. Conf. Pages 15-26. Available at: http://tristatedairy.osu.edu/

Lock, A. L, and K. J. Shingfield. 2004. Optimizing milk composition. Pages 107-88 in UK Dairying: Using science to meet consumer's needs. E. Kebreab, J. Mills, D. Beever eds. Nottingham University Press, Nottingham, UK.

Lock, A. L., C. L. Preseault, K. E. DeLand, and M. S. Allen. 2011. Feeding a C16:0-enriched fat supplement increased the yield of milk fat and improved feed efficiency. J. Dairy Sci. 94 (E-Suppl. 1): 737.

Mackle, T. R., D. A. Dwyer, K. L. Ingvartsen, P. Y. Chouinard, D. A. Ross, and D. E. Bauman. 2000. Effects of insulin and postruminal supply of protein on use of amino acids by the mammary gland for milk protein synthesis. J. Dairy Sci. 83:93-105.

Oba, M., and M. S. Allen. 2003. Effects of corn grain conservation method on feeding behavior and productivity of lactating dairy cows at two dietary starch concentrations. J. Dairy Sci. 86:174-183.

Onetti, S. G., S. M. Reynal, and R. R. Grummer. 2004. Effect of alfalfa forage preservation method and particle length on performance of dairy cows fed corn silage-based diets and tallow. J. Dairy Sci. 87:652-664.

Recktenwald, E. B. 2007. The effect of feeding corn silage based diets predicted to be deficient in either ruminal nitrogen or metabolizable protein on nitrogen utilization and efficiency of use in lactating cows. M.S. Thesis. Cornell University, Ithaca, NY.

Relling, A. E., and C. K. Reynolds. 2007. Feeding rumen-inert fats differing in their degree of saturation decreases intake and increases plasma concentrations of gut peptides in lactating dairy cows. J. Dairy Sci. 90:1506-1515.

Rius, A. G., J. A. Appuhamy, J. Cyriac, D. Kirovski, O. Becvar, J. Escobar, M. L. McGilliard, B. J. Bequette, R. M. Akers, and M. D. Hanigan. 2010. Regulation of protein synthesis in mammary glands of lactating dairy cows by starch and amino acids. J. Dairy Sci. 93:3114-3127.

Steele, W., and J. H. Moore. 1968. The effects of a series of saturated fatty acids in the diet on milk-fat secretion in the cow. J. Dairy Res. 35:361–369.