Improving the productivity of lactating dairy cows through supplementation

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Rumen bypass or 'protected' fats are dry fats that are processed to be easily mixed into animal feeds. Because dry fats naturally have high melting points, they are mostly insoluble at rumen temperature.

In essence, dry fats are not as much 'protected' as completely insoluble in the rumen such that they have little impact on rumen fermentation. Today, there are only three methods of producing dry fats for animal feeds. The method that produces the least desirable product for the cow, partial hydrogenation of tallow, is seldom used for dairy rations.

One acceptable method for producing a bypass fat is to hydrolyse the fatty acids from tallow, partially hydrogenate them, and then prill them in a spray-chilling tower. The most widely used and effective method for producing a rumen bypass fat is to react vegetable fatty acids with calcium oxide to form insoluble calcium soaps.

Calcium salts of LCFAs

Within the feed industry, these calcium soaps, or salts, appear on feed labels as 'calcium salts of long chain fatty acids'. Fatty acids distilled from palm oil processing are most commonly used to make calcium salts, because these fatty acids are produced in the greatest quantity worldwide.

By far, calcium salts of palm fatty acids (CSPFA) are the highest quality and best understood bypass fat for dairy cattle.

Adding fat to the diet of high producing dairy cows has become a common practice for most high producing herds. Energy demands exceed energy intake for 80-100 days postpartum.

Severe weight loss can lead to ketosis, fatty liver formation, reduced reproductive performance, and decreased milk yield.

Rumen protected fat supplements can provide a concentrated source of added energy without changing ration fibre and carbohydrate dynamics. Use of various types of fats in a variety of forage based diets was extensively reviewed by Smith and Harris (1992).

This article will concentrate on more recent studies with dry, rumen inert (ie, not significantly changed in the rumen nor having a significant effect on rumen function) supplemental fat sources and resultant responses in DMI, milk production, milk components, and reproduction.

Commercial forms

Many commercially available rumen protected fats sold in the market are shown in Table 1. They contain a fat content of between 80-99%. These specialty fats are specifically processed products that provide fat as their prime nutrient. These fats are commonly referred to as ruminal inert fat, protected fat, escape fat, and bypass fat and are more expensive per unit of energy provided compared to commodity fats.

Commodity fats can affect rumen fermentation by absorbing bacteria and feed particles coating the feed or lower feed digestibility.

Unsaturated fatty acids are more toxic because they bind more to the bacteria and impact the rumen fermentation.

Exposure of the unsaturated fatty acids in the rumen due to oilseed processing (whole seed, rolled, ground, or extruded) or oil will impact field results.

Three main types of rumen inert fats currently used in lactating dairy cow diets are: partially hydrogenated tallows (PHT), Ca salts of fatty acids (CaSFA), and hydrogenated free fatty acids (FFA).

These fat types were developed to be used in dry form to provide dairy producers with a more functional physical product and to facilitate on-farm handling.

Partially hydrogenated tallows were the first generation of rumen inert fats. They are produced by hydrogenating tallow or vegetable fats to increase the melting point of the end product.

Tallow or vegetable fats may contain as much as 85% unsaturated fatty acids prior to biohydrogenation and as little as 15% after the hydrogenation process. The iodine value, an indicator of the degree of unsaturation, can vary from 14 to 31.

Hydrogenation of tallow and vegetable fats reduces negative effects that fatty acids have on rumen fermentation.

However, the same process severely reduces the digestibility of the end product and its potential for value in lactating dairy cow diets.

Elliott et al. (1994, 1999) found that resistance to ruminal and small intestinal lipolysis was a major factor contributing to the poor digestibility of highly saturated triglycerides contained in hydrogenated tallow.

Calcium salts of fatty acids were the second generation of rumen inert fats. Palm oil, soybean oil, and other fat sources are hydrolysed and reacted with Ca to form salts, which increases the end product melting point. Fatty acids of Ca salts are stable in the rumen at pH >6.5.

However, unsaturated fatty acids of CaSFA have been found to be extensively hydrogenated in the rumen. This indicated that dissociation occurred when the pH dropped below 6.5 after a meal or when the pH was manipulated in vitro.

Wu and Palmquist (1991) observed that up to 55% of CaSFA were biohydrogenated. Because Hawke and Silcock (1969) found that a free carboxyl group of fatty acids is required for biohydrogenation to occur, CaSFA have to dissociate prior to biohydrogenation.

This indicated that CaSFA may not be as rumen inert as previously thought and may be deleterious to rumen fermentation and possibly to DMI.

Table 1. Specialty fats and bypass fats that are commercially available.

Products	Ingredient composition	Fat (%)
Megalac	Calcium salts of palm oil fatty acids	84
Energy milk booster	Relatively saturated free long chain fatty acids – prilled fat	99
Booster fat	Tallow plus soybean meal treated with sodium alginate	90
Alifet	Tallow++ mixed with wheat starch and crystallized	92
Dairy 80	Tallow – prilled contains some phospholipid, flavour and colouring agents	80
Carolac	Hydrogenated tallow – prilled	98
Megnapac	Calcium salts of palm oil fatty acids	84
Bergafat 300	Partially hydrogenated palm oil fatty acids	99
New Century	Calcium salts of palm oil fatty acids	84

Third generation fats

Free fatty acids were the third generation of rumen inert fats. Rumen inert FFA are pre-hydrolysed, mostly hydrogenated, and purified during manufacturing.

This form of rumen inert fat requires no further chemical modification by the cow prior to digestion. Free fatty acids usually have a lesser melting point than PHT or CaSFA and have the tendency to be less soluble in the rumen than fat supplements high in unsaturated fatty acids.

Free fatty acids also have little or no negative effects on ruminal fermentation compared with fat sources high in unsaturated fatty acids. They have also been shown to

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have minimal or no negative effects on DMI.

Effects on milk yield

Feeding rumen protected fat to dairy cows has been reported to increase fat corrected milk yield, milk and fat-corrected milk yields, and milk fat percentage without affecting the digestibility of other dietary nutrients.

However, others reported no improvement in milk yield or milk fat content from feeding rumen protected fat. Although rumen inert fats were fed in many studies, only a few have directly compared feeding CaSFA and FFA.

Grummer (1988) and Harvatine and Allen (2002) observed a significant increase in milk yield.

One or more of the following observations can be seen in the field:

- Milk yield increases of 3-8% (1.0-2.5kg) per 0.45kg of added fats have be reported. If all energy consumed from 0.45kg of fat were directly converted to milk production, the predicted milk response could be 2.5-3.0kg. Energetically, the conversion of metabolisable energy to milk energy is highest with dietary fat compared to forage and concentrate sources or mobilised body reserves.

- Fat test can be maintained (during negative energy balance) or increased 0.2-0.3 percentage points. The added fat raises circulating blood lipid levels which contribute 40-50% of total milk fat precursors.

- Reproductive performance can be enhanced because cows return to positive energy balance sooner which can affect follicle size, ovum fertility, and circulating blood progesterone levels. Pennsylvania researchers reported 20% higher first service conception and shorter calving intervals with added fat. A daily shortage of one megacalorie of net energy during the first 20 days of lactation increased the period to first ovulation by 2.7 days.

- Cows can lose over 120kg of body weight in early lactation. If cows maintain high milk yields, it is nearly impossible to regain this lost body condition prior to the next lactation, which can affect future milk production (referred to as sophomore slump in young cows) and reproduction.

- Ketosis continues to be a serious metabolic risk in early lactation. Cows that lose more than 1.0kg of body reserve can experience lowered dry matter intake and increased risk of fatty liver formation.

Overall, energy status can be improved with fat supplementation without risking excessive starch and low fibre intakes.

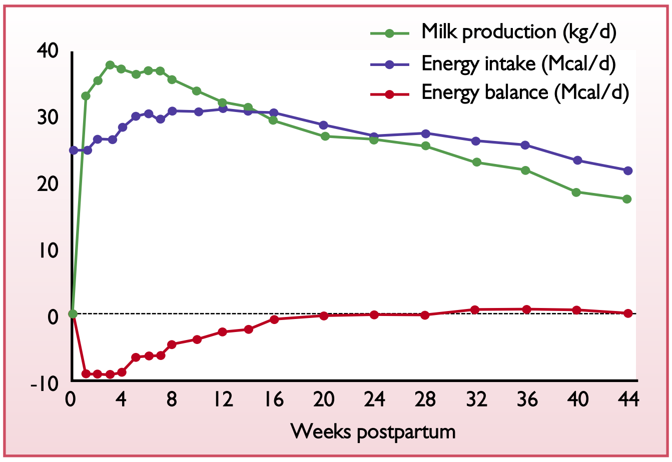

Fig. 1. Early lactation.

Effects on DMI

Many studies directly test differences between FFA and CaSFA on DMI, fatty acid digestibility, and BW changes. Data indicated that there was little difference in digestibility of FA delivered by either CaSFA or FFA. The most pronounced difference between the two rumen inert fats was effect on DMI.

In the two most recent studies, Harvatine and Allen (2002, 2003), found a significant reduction in DMI. Chilliard (1993) reviewed use of rumen inert fats and saturated fats in lactating cow diets. Data from this review are consistent with recent data in that DMI was significantly depressed.

More recently, Allen (2000) extensively reviewed effects of fat supplementation on DMI. Regression equations involving 24 studies, where CaSFA were fed and compared with controls, indicated that for every 1% of added CaSFA over the control, a 2.5% DMI depression was found. This finding is reiterated in the NRC requirements (2001).

Allen (2000) also reported that in 11 of 24 comparisons, CaSFA significantly depressed DMI. Furthermore, 22 of 24 comparisons were numerically less in DMI when CaSFA were added to diets. Allen (2000) also indicated that although energy utilisation is more efficient for digested fat than digested carbohydrate, addition of fat to the diet does not always result in increased net energy intake, especially when reduction in DMI occurs. It is evident that CaSFA in the diets of lactating dairy cows, even at the low level of 0.23kg/d, often fed in field practice with commercial herds, can significantly depress DMI. Allen (2000) also noted that no effect of added fatty acids on DMI was observed for hydrogenated fat in 21 comparisons.

DMI depression caused by the inclusion of CaSFA in the diets of lactating dairy cows is problematic. It is reasonable to assume that if a nutritionist or a dairy producer decided to replace 0.23kg of corn or 0.45 Mcal of NEL with 0.23kg of CaSFA or 1.085 Mcal of NEL, the difference should be 1.085-0.45 or 0.635 Mcal. However, when a 2.5% reduction in DMI is factored in, the net effect is a reduction in total daily NEL intake. Assuming that a cow is consuming 22.7kg/d of DM and that the diet contained 1.72 Mcal of NEL/kg of DM, total daily NEL intake would be 39 Mcal.

If DMI is reduced by 2.5%, or 0.98 Mcal, adding back NEL from CaSFA, or 0.635 Mcal, still leaves a deficit of 0.34 Mcal of NEL.

This is consistent with Chilliard's (1993) review that a negative BW change occurred when CaSFA were included in the ration. Financial consequences can be calculated with current and localised data.

Modes of action

The mode of action affecting DMI depression from feeding CaSFA to lactating cows has been identified in three possible areas: palatability and ruminal and gastro-intestinal motility effects. Grummer et al. (1990) determined palatability effects of four different fat products (sodium alginate encapsulated dry tallow, tallow, FFA, and CaSFA) on two university and two commercial dairy farms involving 209 lactating dairy cows. Different fat products were fed alone, top-dressed on grain, or included in the grain mix. In all cases, after 15 minutes of feeding, FFA were preferred over CaSFA, whether using measurements that were qualitative (scores of 0.33 vs 0.17 for fat fed alone or top-dressed; intake scored on the basis of 0 = no intake, 1 = partial intake, or 2 = total intake) or quantitative (13.2 vs 8.2 for fat fed alone or fat mixed with grain; weighbacks were used to determine intake as a percentage of amount offered that was consumed).

In addition, it was observed that cows improved intake of three fat products, but not of CaSFA, when a seven day period was allowed for adaptation. This observation was important because it indicated a possible inhibitory mechanism beyond palatability or general adaptation that led to continued and prolonged DMI depression.

Disruption of fermentation

A second possible mode of action regarding DMI depression from use of CaSFA is disruption of ruminal fermentation because of unsaturated fatty acid effects. Although CaSFA were observed to be inert in the rumen in vitro, Wu and Palmquist (1991) observed that unsaturated 18 carbon fatty acids in CaSFA were 58% biohydrogenated in vivo.

The researchers stated that biohydrogenation could only occur after dissociation of the Ca salt.

Hawke and Silcock (1969) had similar findings and concluded that a free carboxyl group of the fatty acid was required for biohydrogenation to proceed.

Consequently, CaSFA is not inert in the rumen. Therefore, negative effects of unsaturated fatty acids on rumen fermentation are probable.

Wu and Palmquist (1991) also concluded that the percentage biohydrogenation increased as level of unsaturation increased. Negative effects of unsaturated fatty acids on fibre digestion and milk fat content are well recognised.

However, because studies show only small differences in fibre digestion and milk fat content when CaSFA are fed to lactating cows, this mode of action is probably not the major factor in DMI depression.

Interestingly, significant biohydrogenation of C18:1, C18:2, and C18:3 fatty acids resulted in greater levels of stearic acid reaching the duodenum regardless of whether the dietary source was CaSFA, oil seeds, or forages. Ruminal action largely converts these fatty acids to C18:0.

Applying non-ruminant fat digestion principles to ruminants, particularly when downgrading digestibility of stearic vs palmitic or C18 unsaturated fatty acid, is inappropriate and may confuse this picture.

Minimal variance

Most recently, Bauman et al. (2003) noted that digestibility does not differ significantly between C16 and C18 saturated FA, and is less for longer chain saturated fatty acids as compared with polyunsaturated fatty acids (PUFA).

Those researchers further noted that differences in digestibility among individual fatty acids contribute very little to the extensive variation (~60

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to 90%) in the digestibility of dietary lipids and that the majority of this variation reflects differences among individual experiments, differences in diets, and to specific feed components.

The third possible mode of action regarding DMI depression in cows fed CaSFA is the effect on gastro-intestinal motility. A number of experiments, where 450g/d of oils containing higher levels of saturated FA or unsaturated FA were abomasally infused into lactating dairy cows, were conducted by Drackley et al. (1992), Christensen et al. (1994), and Bremmer et al. (1998).

These data show an average DMI depression of 8% from abomasally infusing PUFA into lactating dairy cows. Reviews of Chilliard (1993) and Allen (2000) estimated a reduction of only 3.5-5.0% at this level of DMI. But all of these researchers, except Chilliard (1993), also concluded that DMI depression and subsequent drop in total energy intake were greater than the energy value of infused PUFA.

Primary mode of action

These three studies illustrated the most likely, primary mode of action affecting DMI depression when feeding CaSFA. As the level of PUFA flow increases into the small intestine, there appears to be a mechanism that triggers the satiety centre to reduce DMI.

Woltman et al. (1995) found that duodenal infusion of oleic acid in rats reduced feed intake and that a portion of the effect was mediated through a gut hormone, cholecystokinin (CCK).

Choi and Palmquist (1996) observed that feeding increasing levels of CaSFA to lactating dairy cows decreased DMI linearly and increased concentrations of CCK.

These researchers concluded that feeding increased amounts of dietary fat (CaSFA) linearly, decreased feed and energy intakes, and linearly increased plasma CCK and pancreatic polypeptide concentrations in lactating cows. They suggested that decreased feed intake in cows fed CaSFA was mediated by increased plasma CCK and pancreatic polypeptide concentrations.

Interestingly, even though DMI and NEL intake decreased, milk production and 4% FCM production increased. A logical reason for the increase in production would have been from mobilisation of body fat stores. This is supported by data from Chilliard's review (1993), indicating an average BW loss of 34g/d per cow for trials with CaSFA (an average from seven trials with 404 early lactation cows that had reduced DMI of 0.7kg daily with 0.9kg more daily milk production compared with non-fat control diets) vs an average BW gain of 55g/d per cow for trials with saturated fats (an average from seven trials with 170 early lactation cows that had no reduction in DMI with 1.8kg more daily milk production compared with non-fat control diets).

Gut motility

The study of Choi and Palmquist (1996) clearly indicated a physiological mechanism associated with DMI reduction because of CaSFA addition to lactating dairy cow diets and is in agreement with Allen's (2000) review. Drackley et al. (1992) also suggested that the degree of unsaturation of fatty acids reaching the small intestine of dairy cows could affect gastrointestinal motility and reduce DMI.

Given that DMI depression experienced when CaSFA are fed is well documented, the dilemma becomes how to meet early lactation, high producing dairy cows' energy requirements for milk production, reproduction, and BW gain.

A recent review summarised time required after calving for lactating cows to reach positive energy balance and concluded that total energy intake was the key factor.

Energy intake was even more highly correlated than FCM production with days postcalving before cows reached positive energy balance. Energy intake is the product of energy density in the diet and DMI.

If an increase in energy density is accompanied by a reduction in DMI, the level of energy intake is limited, which in turn limits the return to positive energy balance and/or reduces production response.

Fertility and performance

It is well accepted that supplemental rumen protected fat benefits herd reproductive performance by minimising body weight loss and accelerating body weight gain after calving.

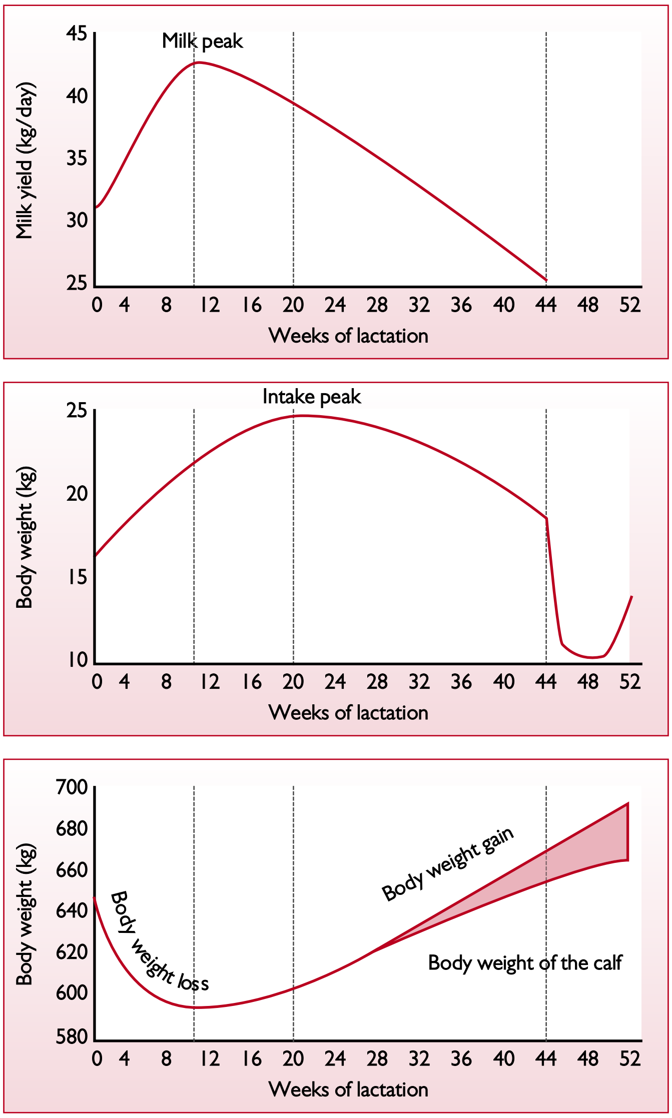
In addition, research strongly suggests that unsaturated vegetable fatty acids could have additive effects on reproductive parameters in the cow, including follicular size and hormone patterns. Linoleic acid has been identified as one of the essential fatty acids that may have direct effects on reproductive function.

In fact, higher linoleic acid levels is the basis for at least one rumen protected fat product that is promoted within the feed industry for its supposed ability to improve reproductive performance.

Although this approach to improving reproductive performance makes biological sense, there is currently very little supporting data to prove these products are truly worth the money.

That is, there is a large body of data that shows that calcium salts of palm fatty acids are very effective in statistically improving reproductive performance over and above the benefits of tallow and other unprotected fats. What future research must determine is whether 'reproduction formulas' are in fact statistically superior to 'regular' protected vegetable fats in enhancing reproduction.

Fig. 2. Early lactation.



Effect on conception

Research when feeding FFA and CaSFA showed significant positive effects on services per conception, pregnancy rates, and days open.

However, others have observed a combination of negative results, positive results, and some contradictory results.

A review of nine studies with 701 cows found very few significant differences caused by high variability in data. Thus, reproductive parameters require more observations to make meaningful statistical comparisons.

There are fewer published studies regarding the effects of added FFA to control diets on reproductive measurements. Ferguson et al. (1990) compared FFA added at 500g/d to control diets fed in three Pennsylvania herds and one Israeli herd. Researchers generally concluded that FFA addition to diets benefited reproduction by minimising BW loss and hastening BW gain postpartum. Both of these effects have been shown to benefit conception rate.

Most recently, Frajblat and Butler (2003) reported reproductive responses when 81 dry cows were fed daily either 200g FFA or no FFA during the last 21 days of the dry period (close-up cows). Cows were bred beginning at day 55 postpartum and were bred by signs of behavioural oestrus until day 220 postpartum.

Frajblat and Butler (2003) observed close-up cows receiving 200g/d of FFA had greater 50 day postpartum. Frajblat and Butler (2003) also observed that cows fed 200g/d FFA in the close-up period, and that had an ovulation prior to 50 days postpartum, were even more likely to be pregnant at 220 days postpartum.

Furthermore, cows losing less body condition score in early lactation were observed to have more ovulations prior to 50 days in milk.

These results are the first to show a benefit when fat was fed to dry cows. A possible mechanism for this response may be derived from work of Moallem et al. (1999), who observed that oleic and linoleic unsaturated fatty acids were found in lesser concentrations in non-oesterified fatty acid fraction of follicular fluid in oestradiol active vs oestradiol inactive or oestradiol less active follicles. Oestradiol active or inactive follicles were determined by follicular size.

A significant negative correlation coefficient between these two unsaturated fatty acids and the oestradiol concentration in follicular fluid suggested that preovulatory growth was accompanied by a decrease in these two unsaturated fatty acids and an increase in the proportion of the saturated palmitic FA. The saturated stearic fatty acid was numerically elevated by nearly 14% at the same time in non-oesterified fatty acid fraction of follicular fluid of oestradiol active follicles vs the inactive or less active follicles.

Practical measures

Although the primary reason for feeding fat is for its energy density, it is becoming increasingly evident that essential fatty acids supplied by fat may have an important role in the nutrition of the high producing cow.

Unfortunately, fatty acid metabolism in the dairy cow is quite complex. It may be some years before it is accurately known which and how much fatty acid to feed, in order to manipulate milk composition, reproduction, or other health or metabolic parameters in the cow.

However, a few generalisations can be made regarding fatty acids:

- Vegetable fats have more value than animal fats.
- Animal fats have more saturated fatty acids, such as stearic acid, that are associated with reduced fat digestibility.
- Compared to animal fats, vegetable fats have very low levels of stearic acid and much higher levels of the key essential fatty acids, linoleic and linolenic acid. Linoleic acid particularly, has been shown to have possible favourable effects on reproductive performance.

Palatability

Different classes of bypass fats may differ slightly in their palatability. Calcium salts of palm oil have a very pungent odour and a slightly bitter taste, and there is evidence that cows can detect these fats when they are initially added to the ration.

Therefore, animals that have not had previous exposure to these fats may require an adaptation period.

In addition, when calcium salts of palm oil are fed, greater care should be taken to ensure these products are thoroughly incorporated into the ration, so that feed intake is not affected.

In general, palatability should not be considered a criterion for determining which protected fat source to purchase, unless that fat source will be used at low levels in a transition ration or perhaps top-dressed on to the ration.

Physical form

Most classes of bypass fats are handled and mixed into dairy feeds with relative ease. Calcium salts of palm oil tend to be favoured during very hot weather, because flowability of soy based calcium salts and prilled fats can be greatly reduced during warm weather.

Particle size could be a criteria for purchasing a specific class or brand of protected fat depending on the application.

Finer particle sizes may improve mixability of the salts within mineral mixes, but may lead to reduced flowability or excessive dustiness in feedmills or mixer wagons. For example, calcium salts of palm fatty acids tend to be slightly dustier, but more flowable than prilled fatty acid products.

Basal diets typically contain 2.5-3.0% fat from forage and grain sources. Cows can support 25-30kg of 4%FCM from high quality forages and concentrates. Cows over 25kg can be fed 0.45-0.7kg of added fat from commodity fat sources or a total of 4.5-5.0% total fat in the ration dry matter.

The next increment of added fat would be provided by specialty fat products increasing the diet fat levels from 5-7%.

These fats sources will be inert in the rumen and not affect rumen microbial characteristics and fibre digestion.

The maximum amount of fat appears to be 7-8% in the ration dry matter or 16-20% of metabolisable energy from fat sources.

Ohio researchers recommend that one third of dietary fat would be provided from typical feed sources, one third from commodity fat sources, and one third from specialty fat sources.

Conclusion

Dry fat products are thought to be rumen inert and have beneficial physical properties for on-farm use. Partially hydrogenated tallow is limited primarily by its greater melting point, which reduces its digestibility and subsequent energy value.

Free fatty acids and CaSFA now have a considerable body of literature for comparison of effects when fed to lactating dairy cows. Direct comparison studies of these two dry fat sources found primary differences caused by greater DMI and palatability when rations contained FFA. This has corresponding positive effects on energy balance, milk production, BW change, and reproductive performance with similar digestibility.

Mode of action for reduced DMI when using CaSFA appears primarily caused by negative effects of gastrointestinal motility, rumen function, and palatability. Reduced DMI impacts amount and duration of negative energy balance in early lactation, subsequent milk production and reproduction, and economic value.

Selecting the best value in bypass fat is not an easy task because of the growing number of available fat sources. In addition, we now understand that complicated factors, such as fatty acid composition, can also create potentially greater value for some bypass fats. Non-nutritional factors that will sometimes influence which bypass fat to purchase include level of supplier trust, storage facilities and mixing requirements, and ration feeding method.

To assure obtaining the greatest economic value from a bypass fat, nutritional factors should be considered in this order:

- Digestibility. Vegetable sources are higher than animal sources.
- Fatty acids. Vegetable fats have more favourable fatty acid profiles than animal fats.
- Palatability. Although there are 'preference' differences among prilled fats and calcium salts when these are either top-dressed or fed in their pure form, when properly mixed into feeds, palatability differences between these fat types are not typically observed.

Many specialty bypass fats are appearing in the market. These include reproduction and functional feed formulas that promote high levels of conjugated linoleic acid in the milk. Although these 'improved' bypass fats suggest an exciting future for fatty acid nutrition in the dairy cow, it may be a few more years before we understand how much of these fats to feed and the economic threshold for feeding these fats. ■

References are available from the author on request.