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Update on Fats and Oils for Ruminant Diets

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Introduction.

Supplementing cows with fat can have several beneficial effects. It usually increases the energy density of the diet, as starch or fiber is replaced with fatty acids. If milk production is increased, then feed efficiency may be improved. Less heat may be produced in the rumen during digestion of fat-supplemented diets as fatty acids are not digested in the rumen. Less heat produced during digestion would help cows during heat stress conditions. Palatability might be improved and feed particle separation may be reduced when fat is included in a supplement if dustiness is reduced. In fact, build up of feed particles on equipment used for feed mixing at the mill can be minimized by inclusion of some fat in the supplement. As a result, fat inclusion can be a good feed ingredient for ruminants, diet formulators, and supplement manufacturers.

Much is currently happening in the lipid supplementation area. I've selected some of the recent advances in our understanding of feeding lipid sources to briefly discuss for this paper. These include 1) quality factors influencing the feeding of whole cottonseeds, 2) combining fats and molasses for lactating cows, 3) the interaction of lipid source and fiber source, and 4) the potential importance of feeding specific fatty acids on ruminant reproduction.

Fatty Acid Profiles of Fat Sources.

Just as we have described feed protein according to their amino acid profiles, so we must describe fats according to their fatty acid profiles. The body requires specific amino acids and likewise requires specific fatty acids. However we are in the earliest stages of learning about the specific effects that dietary fatty acids can have on ruminants. Each fat and oil contains various proportions and types of fatty acids. The fatty acids are described in shorthand according to the length (number) of carbons and the number and location of double bonds between the carbon storage conditions keep cotton wet. Free fatty acids are those not bound to glycerol. Free fatty acids per se are not likely to have a negative impact on ruminant growth or milk production if fed in moderate amounts but they do make the fat more susceptible to rancidity. The southeastern cotton crop of 2002 was of lower quality (high FFA concentrations) due to poor harvesting conditions. It is thought that WCS containing higher concentrations of FFA might negatively affect ruminal digestion that, in turn, would decrease DM intake and milk production. However Georgia studies reported that the performance and digestion by dairy cows fed WCS (12.5% of dietary DM) that contained up to 14.7% FFA were not negatively affected (Bernard, 2003). Synthesis of microbial nitrogen in the rumen was reduced when WCS having a FFA concentration of 18% were fed at 12.5% of dietary DM.

Cottonseeds also contain the polyphenolic compound, gossypol, which can exert some toxic effects on ruminants if consumed in large enough quantities. The ruminal microbes do a reasonable job of converting "unbound" gossypol to bound gossypol thus rendering it unabsorbable. Concentrations of "unbound" gossypol averaged 1.06 and 0.72% of DM for whole linted Upland and cracked Pima types, respectively. Feeding up to 950 mg of unbound gossypol per kg of feed DM (~20% of diet as WCS) did not affect yield of milk or milk components (Santos et al., 2003). This would be 21.4 g/day of unbound gossypol intake for a cow eating 50 lb of DM daily. However, a lower percentage of cows (n = 792 total) were pregnant at 170 days in milk when they consumed unbound gossypol at ~24 g/d compared to those consuming ~17 g/d (70.6 vs. 79.1%) (Santos et al., 2003). This negative effect was not evident at the first AI. Concentrations of plasma gossypol increased with days in milk and likely reflected increasing DM intake postpartum. As plasma gossypol increased, the risk of infertility increased. The incidence rate of abortion doubled from 3.3 to 7.9% for the two groups of cows. This negative influence of gossypol on pregnancy may have been due to decreased fertilization and(or) reduced embryo quality and viability but the mechanism is yet undetermined. The gossypol in Pima cottonseed appears to increase plasma gossypol to a greater degree than the gossypol in Upland cottonseed. This is possibly due to less free gossypol in Pima being detoxified by ruminal bacteria because it stays in the rumen a shorter period of time due to having less lint than Upland seed. In order to eliminate or minimize the potential negative effects of feeding WCS on conception and embryo survival, plasma concentrations of total gossypol should be less than 5 ug/ml. This may equate to a maximum dietary concentration of Pima seed of 5% of dietary DM whereas that of Upland WCS could be as high as 15% if the seeds have similar gossypol content as those used by Santos et al. (2003).

Impact of Fats on Dairy Cow Performance.

Mixing fats/oils with liquid molasses. By adding fat at 5% or less to molasses aids the handling characteristics of molasses by reducing the accumulation of sugars on mixer paddles for TMR mixes. Fats have made up to ~20% of a molasses-fat mixture in some studies (as-is basis). Some molasses-fat mixtures have been evaluated for lactating dairy cows in a few university studies.

A mixture of soybean oil soapstock (a byproduct from the refining of soybeans for oil) and molasses improved milk production by 9.9% when the oil was fed at 0.9% of dietary DM (Shain et al., 1993) and by 10.2% when fed at 1.5% of dietary DM (Oldick et al., 1997). However the oil did not affect milk production when fed at 1.5% (Oldick et al., 1997), 1.8% (Shain et al., 1993), 2% (Boken et al., 2004), or 2.25% (Abel-Caines et al., 1998) of dietary DM.

production was not improved but milk fat% was depressed from 3.50 to 2.83% by feeding a diet of 5% yellow grease (2.3 lb/d of grease) at Clemson University (Jenkins and Jenny, 1989). Digestibility of dietary fiber (ADF) was reduced in cows consuming yellow grease (21.6 vs. 31.6%). As a result, dry matter intake was reduced from 50.5 to 45.2 lb/d. Feeding 2.2 lb of yellow grease per day did not change milk production or milk fat% of cows fed high grain diets with wheat silage (74% concentrate 26% wheat silage) at the University of Georgia (Nianogo et al., 1991). Feeding higher amounts of fat in these two studies (> 2 lb of fat daily) may have prevented a positive response or the forage source may have played a key role.

Tallow. Tallow is primarily derived from ruminant fat. It can contain some fat from nonruminants such as swine but too much pork fat will reduce the titre ("hardness" of the fat) and move the fat from the tallow (minimum of 40.5 or 41 titre) to the grease (minimum of 36 titre) classification. Tallow can be classified into many grades with the allowable concentration of FFA increasing with decreasing fat quality.

When alfalfa was 90 to 100% of the dietary forage, supplementing tallow at 2.5% of dietary DM increased milk production without changing fat% (Wu et al., 1993) or increased milk fat% without changing milk production (Schauff et al., 1992). The DM intake was unchanged in these studies. However, another picture develops when corn silage is the forage source. Five studies fed diets of 0 or 2 - 2.5% tallow in corn silage-based diets (40 to 50% of dietary DM) (Table 2). Feeding tallow significantly decreased DMI in 3 of the 5 studies, ranging from 1.7 to 3.3 lb/day. This decreased feed intake was accompanied by reduced milk production of 4.5 lb in one study (Onetti et al., 2001). However in two other studies, milk production was increased by 4.2 lb/d (Smith et al., 1993) and 5.1 lb/d (Onetti et al., 2002). In the most recent study (Ruppert et al., 2003), the 2 lb/d increase in milk by cows fed tallow was not statistically different from the control cows. In all five studies, milk fat % was significantly depressed from as little as 0.15% to as much as 0.47% units, with the average depression being 0.3% units. Based upon this limited number of studies, what might be expected from our cows when tallow is added to corn silage-based diets at 2 to 2.5% of the dietary DM? Assuming a similar response to that shown in Table 2, the DM intake will likely be reduced (3 to 5%), milk production be increased (3%), and milk fat % be decreased by 0.3 percentage units (e.g. from 3.3 to 3.0%).

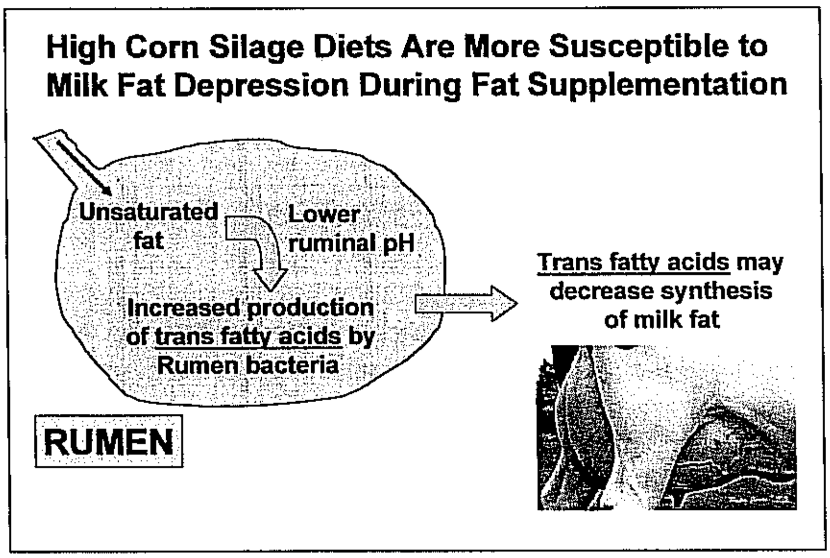
Table 2. Effect of feeding tallow on performance of lactating dairy cows fed diets containing 40 to 50% corn silage (DM basis).

Reference	% tallow in diet	DM intake, lb/d	Milk, lb/day	Milk fat, %
Smith et al., 1993	0	56.0	50.9	3.30
	2.5	57.8	55.1*	3.15*
Adams et al., 1995	0	48.1	58.8	3.65
	2.5	47.2	58.4	3.35*
Onetti et al., 2001	0	58.0	93.2	3.30
	2	54.7*	89.7*	2.83*
Onetti et al., 2002	0	50.9	77.6	3.11
	2	49.2*	82.7*	2.82*
Ruppert et al., 2003	0	49.8	71.2	3.18
	2	47.2*	73.2	2.89*

* $P \leq 0.05$ (estimated if reference did not report exact comparison).

compared to a lower grain diet (Griinari et at., 1998). These trans fatty acids can be formed by a diverse range of bacteria in the rumen during biohydrogenation of unsaturated fatty acids (Bauman et al., 2000). Trans-C18:1 acids were formed as the major end product of biohydrogenation rather than C18:0 when increased levels of C18:2 were present (Polan et al., 1964). Tallow is generally quite low in C18:2 whereas cis-C18:1 is dominant (Table 3). Possibly the isomerization of cis-C18:1 in tallow to trans-C18:1 is carried out under more acidic conditions in the rumen when fewer fiber-digesters are present. Trans fatty acids leave the rumen with the digesta, are absorbed into the blood from the small intestine, and are taken to the mammary gland where they are incorporated into the milk fat. These trans fatty acids may inhibit the synthesis of the short chain fatty acids by the mammary gland, thus accounting for the depressed milk fat % due to the feeding of tallow. It is these trans fatty acids that may be the cause of the lowered milk fat by tallow supplementation to corn silage-based diets (Figure 1). When 200 or 400 g of a commercially available calcium salt of trans C18:1 (EnerG-I, Bioproducts, Inc.) was fed daily to lactating dairy cows, milk fat% was decreased from 3.30 to 3.04 to 2.98% (Moallem et al., 2002). It is thought that the trans-10 isomer of C18:1 may be responsible for reducing the synthesis of short chain fatty acids by the mammary gland.

Figure 1.



Whole cottonseeds. About 70% of the fatty acids in cottonseeds are unsaturated. This unsaturated fat can reduce milk fat % just as tallow has done. The milk fat % was numerically depressed by feeding WCS (10 to 15% of dietary DM) in all nine studies in which corn silage was the main forage fed but was only significantly lower in two studies (Figure 2). The average depression was 0.29% units. In a longer term study from calving through 17 weeks postpartum, Jersey cows were fed diets of 0 or 12.9% WCS in which all of the forage came from corn silage. Over the course of the study, cows fed WCS produced milk of significantly lower milk fat % (4.60 vs. 4.88%) (Bertrand et al., 1998). As was the case with tallow, milk fat % responded differently to WCS when alfalfa hay partially replaced corn silage. Milk fat % was increased by addition of WCS to diets when alfalfa hay replaced 25% (3.55 vs. 3.30%) or 50% (3.46 vs. 3.25%) of the corn silage whereas WCS had little effect on milk fat % when corn silage was the only forage (3.27 vs. 3.33%) (Smith et al., 1993). In another study, milk fat % was increased by addition of WCS to diets when bermudagrass hay replaced 25% of corn silage (3.60 vs. 3.37%)

dietary concentration of tallow of 2.4% (6 x 19) ÷ (47.1%) ÷ (100%) x (100%) without resulting in a milk fat depression. Using the NDF values from the corn silage-based diets from references cited in Table 2, no milk fat depression would be expected if tallow was fed at less than 2.6% (Onetti et al., 2001), 2.9% (Onetti et al., 2002), 2.8% (Ruppert et al., 2003), 2.9% (Adams et al., 1995), and 3.1% (Smith et al., 1993). However, milk fat depression was observed when tallow was fed at 2 to 2.5% of diet DM indicating that the equations may need to be adjusted if corn silage is the sole forage source in the diet. Equations that would have maximized tallow to <2 to 2.5% of dietary DM in the previous references have the initial coefficients reduced as follows:

(4.5 x % dietary ADF) ÷ etc. and

(2.5 x % dietary NDF) ÷ etc.

As more studies are conducted with fat supplements in corn silage-based diets, proper equations can be developed.

Using the equation guidelines of Jenkins (1993), maximum feeding of whole cottonseeds is 8.9% when diets are of minimum fiber concentration. Whole cottonseeds are 18% fat with 71% of the fatty acids as unsaturated fatty acids. Therefore the maximum feeding of whole cottonseeds = (6 x 19) ÷ (71) ÷ 18 x 100 = 8.9%. The studies in Figure 2 fed diets of 10 to 15% whole cottonseeds. The pattern of milk fat depression across these studies may have been eliminated if level of dietary cottonseed had been reduced.

Lipid supplementation and reproduction.

Exciting strategies have developed to integrate nutritional and reproductive management. The supplementing with some sources of fat to lactating dairy cows has improved reproductive performance. In several studies, lactating cows fed a basal diet containing WCS (~9% C18:2) and further supplemented with Ca salts of palm oil (CaPO; (~8% C18:2) experienced a better rate of conception or pregnancy than cows fed the diet containing only WCS (Staples et al., 1998). Lactating cows fed tallow (4.3% C18:2) at 3% of dietary DM tended to have a better conception rate by 98 days in milk than cows not fed tallow (Son et al., 1996). Grazing dairy cows supplemented with soybean oil soapstock (53% C18:2) at ~2% of dietary DM experienced a greater pregnancy rate than controls (62.5 vs. 22.2%) whereas those fed fat and housed in a freestall barn had lower pregnancy rates than controls (0 vs. 22.2%) (Boken, 2004). In separate studies, dairy cows had better pregnancy rates when fed a calcium salt-fat complex high in C18:2 (Megalac-R; Arm and Hammer Nutrition, Princeton, NJ; Cullens et al., 2004) (Bioproducts, Inc., Fairlawn OH; Cerri et al., 2004). Primiparous beef heifers also have experienced greater pregnancy rates (94, 90, 91, and 79%) from being fed rolled and cracked safflower seeds, soybeans, or sunflower seeds, all high in C18:2 concentration, during the last 65 days of pregnancy (Bellows, 1999).

How Might the Feeding of Additional Fat Improve Fertility? Some have suggested that the feeding of additional energy in the form of fat reduces the cow's negative energy status so that she returns to estrus earlier after calving and therefore conceives sooner. However, the energy status of cows supplemented with fat is unchanged most of the time because of a nonsignificant depression in feed intake and/or an increase in milk production. In fact, dairy cows fed tallow at 3% of dietary DM had a greater pregnancy rate despite having a more lactating dairy cows with fish meal has improved conception rates (Staples et al., 1998). First service conception rate tended to be greater (P = 0.14) for lactating primiparous beef cows (n = 82) fed fish meal compared to corn gluten meal (75.6 vs. 61.5%) (Bonnette et al., 2001). Serum progesterone concentrations after insemination were similar between the two groups of cows.

A fourth reason offered is that supplemental fats are alleviating an essential fatty acid (**EFA**) deficiency (linoleic acid [**C18:2**] and C18:3) of the modern high-producing dairy cow. Deficiencies of EFA have reduced reproductive performance of nonruminants. Using the recent fat sub-model developed for use in the CPM-Dairy model, Sanchez and Block (2002) suggested that the amount of C18:2 excreted in 100 lb of milk daily exceeds the post ruminal uptake from typical diets. Therefore fat sources that supply additional EFA may minimize the need to mobilize EFA from tissues, thus protecting their functional integrity. According to the scientific literature dealing with human and lab animal nutrition, a ratio of C20:3 to C20:4 in tissues/serum that exceeds 0.4 is indicative of a C18:2 deficiency or an imbalance of C18:2 to C18:3. If the ratio of C20:3 to C20:5 exceeds 0.4, a deficiency of C18:3 is suspected. The rational behind this ratio is that the synthesis of C20:3 n-9 from oleic acid increases when C18:2 or C18:3 are deficient. It might be productive if these same ratios could be relevant to identify situations, if any, in which supplemental EFA would benefit the bovine.

Lastly, an improved fertilization rate and embryo quality may also result when lactating cows are supplemented with select fat sources. Dairy cows supplemented with a calcium salt blend of linoleic acid and monoenoic trans fatty acids (C18:1) or a calcium salt of palm oil (Bioproducts, Inc. Fairlawn, OH) from 25 d before calving through ~55 d postpartum were timed AI and flushed 5 d after AI with recovered structures evaluated (Santos et al., 2004). Cows fed the linoleic acid and monoenoic trans fatty acids tended to have (P = 0.11) a greater fertilization rate (87 vs. 73%), had more accessory sperm per structure collected (34 vs. 21), and tended to have (P = 0.06) a greater proportion of embryos classified as high quality (73 vs. 51%). In an accompanying study, conception rate at first AI was greater for cows fed the linoleic and trans acid salt (38.9 vs. 25.9%).

Sources of Fat Supplements. Only calcium salts of long chain fatty acids and fish meal have been evaluated in repeated studies for their reproductive effects, both having improved pregnancy or conception rates in a limited number of studies. The unique fatty acids in fish meal may be responsible for enhanced fertility. Animal tallow, flaxseed, safflower seeds, soybeans, sunflower seeds, and oil originating from soybeans have proven beneficial for ruminants in even more limited work. Obviously more studies are needed with these fat sources. If linoleic acid is a limiting fatty acid postruminally, then fat sources containing high concentrations of this fatty acid would be a good choice. Soybeans appear to deliver more linoleic acid to the small intestine than cottonseeds. Roasting of soybeans may be an effective way to reducing biohydrogenation in the rumen, thus increasing the delivery of EFA to the small intestine for absorption.

In summary, evidence is accumulating that the design and delivery of supplemental unsaturated fatty acids to the lower gut for absorption (specifically linoleic acid, linolenic acid, EPA, and DHA) may target reproductive tissues to improve reproductive function and fertility. Improvement in pregnancy may be associated with improved embryo survival due to increased production and/or decreased clearance of progesterone as well as the suppression of uterine prostaglandin secretion by omega-3 fatty acids. Further work is needed to determine if the modern high-producing dairy cow is deficient in essential fatty acids.

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