Effects of nicotinamide on milk composition and production in dairy cows fed supplemental fat

Antonio Cervantes-Nunez
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Effects of nicotinamide on milk composition and production in dairy cows fed supplemental fat

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Iowa State University, 1992
Effects of nicotinamide on milk composition and production in dairy cows fed supplemental fat
by
Antonio Cervantes-Nunez

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1992
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INTRODUCTION

In recent years much progress has been made in increasing the genetic merit for productivity of dairy cows. In the United States, the average milk production per cow increased almost twofold between 1960 and 1983 (Majeskie, 1988). Energy requirements concomitant with increasing milk production require special attention, especially during early lactation when peak feed intake lags behind peak milk production (NRC, 1989). Feeding different sources of supplemental fat can increase energy density of rations as well as energy intake, and milk production is usually increased (Anderson et al., 1979; Andrews and Lewis, 1970; Casper and Schingoethe, 1989; Palmquist and Jenkins, 1980). Unsaturated fat supplements are used in limited amounts because of their inhibitory effects on rumen microbial activity (Palmquist and Jenkins, 1980).

At present, ruminally inert types of commercial fats, which minimize adverse effects on ruminal fermentation and fiber digestion, have been developed (Schauff and Clark, 1989; Shaver, 1990). Incorporation of ruminally inert or "bypass" fat into dairy diets has shown benefits by increasing milk production (Schauff and Clark, 1989; Erickson et al., 1990; Shaver et al., 1990; Klusmeyer et al., 1991), optimizing energy utilization (Kronfeld et al., 1980; Storry, 1988), and improving reproductive performance (Ferguson et al., 1990). There are negative side effects on milk protein content, however, regardless of the type of fat being fed (Emery, 1978; De Peters et al., 1985; De Peters et al., 1987).

Recent trends in consumer demands for low fat products and the increasing proportion of commercial milk utilized for manufacturing cheese
have led to an emphasis on changing to multicomponent milk pricing systems (Ferris and Vasavada, 1989; Chase, 1990; Legates, 1990). Consequently, there is an increasing concern of the dairy industry for finding methods to alleviate the depression of milk protein percentage in cows fed high fat diets (Casper and Schingoethe, 1989).

The impact on the income of dairy farmers caused by changes in milk protein content can be substantial. For example, Zurborg (1978) calculated that the income of U.S. dairy farmers could be increased as much as $211,000,000 annually for each .1% incremental increase of the average protein content of milk priced by the Minnesota-Wisconsin formula, which influences almost 80% of the milk sold in the United States.

Although research results have not been consistent, supplemental nicotinic acid (NA) or its amide, nicotinamide (NM), seems to be beneficial for counteracting some negative effects of adding fat to diets of lactating cows. These benefits might result from local effects at the rumen level (Bartley et al., 1979; Riddell et al., 1980; Abdouli and Shae, 1986) or at the systemic level (Waterman et al., 1972; Thornton and Shultz, 1980).

It has been postulated that microbial synthesis of niacin (unspecified form) is metabolically regulated in the rumen (Riddell et al., 1985, Abdouli and Schaefer, 1986a). Additional amounts of dietary niacin, therefore, might be converted to other niacin derivatives to keep ruminal concentrations optimal.

There are clear differences in physical properties and physiological effects between the two forms of niacin (Collins and Chaykin, 1972; Hotz, 1983; Weiner and Van Eys, 1983). Limited data that compare both forms of
niacin (i.e., NA and NM) supplemented to dairy cows in early and mid-lactation have shown different results for milk yield and composition (Jaster and Ward, 1990). Most recently, Erickson et al. (1991) suggested that NM might elicit its benefits on the performance of cows by acting at the systemic level, whereas NA might act at the ruminal level by increasing the population of protozoa. Consequently, the site and extent of niacin absorption might have effects on the benefits of niacin supplementation.

The overall objective of the two experiments reported in this dissertation was to investigate whether incorporation of 3% nicotinamide into a commercial source of calcium salts of fatty acids (CSFA) could prevent the depression in milk protein content often caused by supplementing fat to lactating cows and to determine concentrations of NM in blood of cows given single doses of either NM or NA every 24 h. Specific objectives were to:

1) determine whether the process of blending NM and CSFA could prevent NM from dissolving in ruminal fluid during in vitro incubations,

2) explore effects of supplementing CSFA, NM, and CSFA plus NM either blended at manufacture of CSFA or later added separately on milk yield and composition,

3) determine effects of supplementing CSFA, NM, and CSFA plus NM on plasma metabolite concentrations, blood NM, body weight, and body condition scores, and

4) determine differences in blood NM concentration patterns as a reflection of niacin absorption from the gastrointestinal
tract after single bolus doses of NM or NA were administered to lactating cows.

Explanation of Dissertation Format

Two separate papers have been prepared from research conducted to partially fulfill requirements for the Ph.D. degree. Each paper is complete in itself and includes an abstract, introduction, material and methods, results and discussion, and references. A review of literature precedes these papers. The papers report research from two different experiments, but the close relationship of subject matter permits presentation of a single general summary. References cited in the general introduction, and review of literature follow the general summary.
REVIEW OF LITERATURE

This review is intended to present a general overview of problems related to high producing cows fed different sources of fat and their implications for milk production and composition. Emphasis is placed on some of the approaches that address particular effects of supplemental niacin on milk protein content and production, as well as on the general status of dairy cows.

Production Potential and Early Lactation

During the three last decades, milk production in the United States has increased greatly. In 1960 average milk production per cow was 3915 kg, whereas by 1991 average milk production had increased to 6760 kg (Majeskie, 1992). The introduction of an evaluation model to estimate the transmitting ability of dairy cows and sires was a major advance in 1960, but there are still major expectations for further genetic improvement.

Sexing semen, reducing generation intervals, selection for disease resistance, use of cloning procedures to produce multiple-generation bovine clones, and use of molecular genetics to regulate gene expression are tools that have valuable potential to further increase production of lactating cows in the future (Freeman and Lindberg, 1992). Some implications of such remarkable progress are clearly evident; there still will be more challenges to overcome in the areas of nutrition, reproduction, health, and general management to match production and productivity.

During early lactation, high producing dairy cows are normally in negative energy balance because feed intake is limited by physical capacity
of the rumen and/or appetite of cows (Andrews and Lewis, 1970; Palmquist and Conrad, 1978; Anderson et al, 1984. Energy intake is affected by amount and energy density of the feed consumed; therefore, a practical method to increase energy consumption is by adding feedstuffs with a high energy density into the diet (Ruegsegger and Shultz, 1985).

Increasing the proportion of grain in the diet is one common practice used by dairymen to increase energy intake. When the concentrate exceeds 70% of ration dry matter (DM), however, forage intake becomes insufficient, which results in changes in rumen fermentation that usually lead to acidosis, a decrease in milk fat content, and sometimes off-feed with a concomitant decrease in milk production (Shaver, 1990).

Energy Value of Fat

Fat contains more gross energy per unit of weight than other feed ingredients. It is assumed under the total digestible nutrient system that fat contains 2.25 times more net energy of lactation (NE\textsubscript{L}) than carbohydrates. The energy value of most common feed-grade fats goes from 5.8 to 8.0 Mcal NE\textsubscript{L}/kg of DM (Shaver, 1990). According to actual values in the net energy system, however, fat contains nearly 2.6 times more NE\textsubscript{L} because less energy is utilized during fat metabolism (Palmquist, 1980). Recently, Andrew et al. (1990) determined NE\textsubscript{L} to be 6.52 Mcal/kg DM for a commercial source of calcium salts of long chain fatty acids (LCFA). This value represented about 72% efficiency for use of metabolizable energy for milk production. Assuming that NE\textsubscript{L} of corn is 1.96 Mcal/kg DM, LCFA
contained nearly 3.3 times more NE\textsubscript{i} than corn. The NE\textsubscript{i} value of fats is determined mainly by their degree of digestibility (Palmquist, 1991).

**Fat in Early Lactation**

Research between the late 1920s to the mid 1940s showed some beneficial effects of feeding fat in early lactation on milk production (Maynard and Loosli, cited by Palmquist and Jenkins, 1980). However, dairy producers showed little interest for adding fat to diets of dairy cows. In an excellent review, Palmquist (1987) attributed this phenomenon to the following factors: a) energy requirements of dairy cows could be met with grains, b) grains were abundant and cheap, c) fats were difficult to handle, and d) research showed detrimental effects of fats on rumen fermentation.

Recently, the higher genetic potential of cows for milk production, the negative effects of feeding high concentrate diets, the abundant availability of different sources of feed-grade fat, and the continuous generation of data showing methods to optimize and maximize fat utilization have combined interest in the use of fat in formulating dairy rations. Several effects of dietary fat on rumen fermentation, ration digestibility, milk production and composition, cow fertility, and overall performance of dairy cows remain unclear, however.

**Types of Fat**

Shaver (1990) grouped fat sources for dairy cows into two major categories: a) natural fats known as "commodity" fats and b) commercial or
"specialty" fats. A detailed fatty acid profile of various fat sources was presented by Shaver (1990).

**Plant fats**

*Oils.* There is a wide range of vegetable oils that have been fed to lactating dairy cows. Each of these vegetable oils have different physical/chemical characteristics that are associated with their fatty acid composition (CAST, 1991). Eight of these vegetable oils are listed in increasing order according to their FA composition (i.e. ratio of saturated to polyunsaturated FA) (Agricultural Handbook, 1979):

1) rapeseed oil, also known as canola oil (0.07).
2) linseed oil, (0.09)
3) safflower oil, (0.10)
4) sunflower oil, (0.14)
5) soybean oil, (0.18)
6) cottonseed oil, (0.37)
7) palm oil, (1.04), and
8) coconut oil, (46.0)

It is important to mention that linseed oil, obtained from flaxseed, contains approximately 57% linolenic acid, which is much higher than that in soybean oil (7.0%), coconut oil (2.6%), safflower oil (4.4%), or cottonseed oil (2.1%) (Edwards, 1964).

Although FA profiles of oils are clearly different, recent advances in genetic modification of oil through plant breeding have shown that it is feasible to create oilseed genotypes with significantly altered oil composition; consequently, it is possible, at an experimental level, to
manipulate the relative percentages of the main FA constituents to a preferred concentration (CAST, 1991).

**Whole oilseeds.** Whole oilseeds also are good sources of protein and fiber. One characteristic, in addition to those mentioned before, that plays a role in the general considerations for adding oilseeds into diets for lactating cows is the high acid detergent fiber (ADF) content of cottonseeds (34%). Sunflowers seeds are also high in ADF (26%), but they are encapsulated with a hard seed coat (Linn, 1983). Although soybeans can be fed raw, extruding or roasting soybeans increases the amount of protein escaping ruminal degradation (Stern et al., 1985). Finally, feeding whole flaxseeds to dairy cows has demonstrated the feasibility of increasing omega-3 fatty acids in animal products (Stitt, 1988).

**Animal fats**

These sources of fat have a high content of oleic acid (Jenkins and Jenny, 1989) and more saturated FA than do oilseeds (i.e., 52 and 41% for tallow and lard, respectively) (Bisplinghoff, 1990), but are more difficult to handle because they are solid or semisolid at room temperature (Linn, 1983).

There are different types of tallow, and they are graded according to purity, which determines their quality. Some of these types are: edible tallow, fancy tallow, extra fancy tallow, bleachable fancy tallow, and prime tallow (Shaver, 1990). Yellow grease, which is mostly lard, is a waste from food service operations. It contains different proportions of vegetable and animal fats, and it is less saturated and has a lower melting point than does tallow (Bisplinghoff, 1990).
Tallow has been the most popular animal fat used in the dairy industry of the United States. Animal fats are generally cheaper than commercial fats. The cost of tallow may range between $.20 to .30 per pound, whereas commercial fat may sell for $.35 to .45 per pound. Tallow has been used in either protected (Bines et al., 1978; Smith et al., 1978; Wrenn et al., 1978; Kronfeld et al., 1980) or unprotected forms (Storry et al., 1973; Palmquist and Conrad, 1980; Heinrichs et al., 1982; Mattias et al., 1982; Drackley et al., 1992; Wu et al., 1992; Eastridge and Firkins., 1992; Gallegos et al., 1992).

**Commercial fats**

Specialty fats are preparations containing animal or plant fats that were developed to minimize detrimental effects on ruminal fermentation and fiber digestion (Palmquist and Jenkins, 1982; Shauff and Clark, 1989). The most popular commercial fats marketed as ruminally "inert" include: Megalac (Church and Dwight Co. Inc., Princeton, NJ), Alifet (Alifet USA Inc., Cincinnati, OH), Boster Fat 95 (Balanced Energy Co., Clinton, IA), Carolac (Specialty Animal Products Division, Greensboro, NC), and Energy Booster 100 (Milk Specialties Co., Dundee, IL). Characteristics of the fatty acid profiles are described by Shaver (1990); but, as a general feature, they contain mostly saturated fats.

**Effects of Source of Fat on Rumen Fermentation, Nutrient Intake, and Digestibility**

**Plant Fats**

**Oils.** One general characteristic of most plant oils is their high content of unsaturated fatty acids (FA), which varies from 73% for
cottonseed oil to 94% for canola oil. Coconut oil is an exception because it contains a high percentage of short-chain saturated FA (Agric. Handbook, 1979). For the purpose of this review, unsaturated oils will be used in referring to the selected reports presented for this type of fat.

Some studies indicate that unsaturated oils have toxic effects on certain cellulolytic and methanogenic ruminal bacteria. Marwaha et al. (1973) found a decreased number of ruminal bacteria in cows fed diets supplemented with linseed oil, whereas with saturated coconut oil the protozoal and bacterial populations increased slightly. The toxic effects decreased fiber digestibility and protein degradability in the rumen (Davison and Woods, 1963; Johnson and McClure, 1973; Varma and Ranjhan, 1973; Kowalczyk et al., 1977; Marksimov and Datsun, 1981; Ikwuegbu and Sutton, 1982; Ikwuegbu, 1984; Drackley et al., 1985). Depressed cellulose digestibility because of unsaturated FA has been observed in sheep (Davison and Woods, 1963; Varma and Ranjhan, 1973; Devendra and Lewis, 1974) and steers (Drackley et al., 1986).

Total production of volatile fatty acids (VFA) can be decreased by feeding unsaturated oils (Sutton, 1980). Storry (1970, 1973) found a decrease in the acetate:propionate ratio in the rumen. Other studies have shown little or no change in rumen VFA because of feeding unsaturated oils (Steele et al., 1971; Goering et al., 1976). Saturated FA, however, are less digestible than are unsaturated FA in the small intestine (Bayley and Lewis, 1965; Steele and Moore, 1968; Jenkins and Jenny, 1989).

Whole oilseeds. Several types of oilseeds have been used as a source of fat in dairy diets. They include whole cottonseed (Moody, 1978;
Anderson et al., 1979, 1984; DePeters et al., 1985), whole soybeans (Perry and MacLeod, 1968; Larson and Shultz, 1970; Mohamed et al., 1988; Mielke and Schingoethe, 1981; Bernard, 1990; Kim et al., 1991), heat-treated soybeans (Driver et al., 1990; Faldelt and Satter, 1991), extruded soybeans (Kim et al., 1991), whole sunflowers (McGuffey and Schingoethe, 1982; Drackley et al., 1985; Finn et al., 1985; Drackley and Schingoethe, 1986), whole rolled sunflowers (Finn et al., 1985), whole flaxseeds (Stitt, 1988; Okine and Kenelly, 1992), whole safflower seed (Stegman et al., 1992), and whole canola seeds (Murphy et al., 1987; Ashes, et al., 1992; Khorasani, et al., 1992). Oilseeds are suitable sources of fat, fiber, and protein and have advantages over pure fats in processing, mixing, and handling (Drackley et al., 1985). Such convenience makes them one of the cheapest sources of dietary fat (Shauff et al., 1992).

There is some controversy about dry matter intake (DMI) and apparent digestibility of nutrients when whole oilseeds are included in the diet of lactating cows. Bernard (1990) found benefits on apparent digestibility when whole soybeans were fed to dairy cows as 9.4% of dietary dry matter (DM). This effect was attributed to a higher intake of acid detergent fiber (ADF). Some workers reported no differences in apparent digestibility of DM, organic matter (OM), or cellulose (Larson and Shultz, 1970; Palmquist and Conrad, 1978; Stern et al., 1985). Accordingly, whole cottonseeds do not seem to affect DMI of cows (Anderson et al., 1979; Smith et al., 1981: DePeters et al., 1985) or digestibility of DM or cellulose (Smith et al., 1981). In addition, Anderson et al. (1979) found a tendency for higher acetate:propionate ratios in cows fed cottonseed. In contrast,
Kutjens and Shultz (1972) showed a reduction of the acetate:propionate ratio, and Mohamed et al. (1988) found lower DM digestibilities for cows fed either whole soybeans or whole cottonseeds compared with controls.

Sunflower seeds have a composition similar to that of cottonseeds, but they are encapsulated within a hard seed coat. Anderson et al. (1984) compared sunflower seeds with whole cottonseeds or extruded soybeans with each fed at levels of 5, 10, or 12% of ration DM. Lower DM intake was found for cows fed sunflower seeds due to lower acceptability; in addition, whole sunflower seeds were observed in the feces. The authors concluded that processing or grinding might alter acceptability by cows. Nevertheless, Rafalowski and Park (1982) and McGuffey and Schingoethe (1982) reported no effects on DMI or changes in the acetate:propionate ratio (Rafalowski and Park, 1982) of cows fed diets with up to 10% of sunflower seeds in dietary DM.

Although digestibility of OM is decreased in the rumen, total digestibility may be affected little or not at all because of compensatory digestion in the hindgut (Palmquist and Jenkins, 1980; Murphy et al., 1987). The negative effect of fats on fiber digestibility is more commonly observed with low fiber rations (Palmquist and Conrad, 1978). On the other hand, increased apparent digestibility of ether extract (EE) has been reported consistently (Bernard, 1990), which might be caused by greater EE intake and reduced endogenous losses. The fat in ordinary diets contains significant amounts of sterol, waxes, and terpenoids, which represent a large fraction of endogenous losses (Palmquist and Conrad, 1978) compared with diets with added fat containing FA that are highly digestible. The
extent of fat digestibility is directly related to degree of saturation, which influences postruminal FA digestibility in sheep (MacLeod and Buchanan-Smith, 1972) and lactating cows (Jenkins and Jenny, 1989). Furthermore, digestibility of saturated fat is indirectly related to FA chain length (Steele and Moore, 1968).

Feeding whole oilseeds has three advantages: a) on nutrient digestion, the benefit might be due to the partial protection of the oil by the seed coat and slow release of the oil into the rumen followed by slower microbial hydrogenation (Steele et al., 1971; Moody, 1978; Chilliard, 1991), b) on rumen fermentation, the high fiber content from the coat structure of the seed which contributes to maintain proper rumen function (Horner et al., 1986), and c) on fat digestibility. The benefit might be due to the partial protection of the oil from microbial biohydrogenation (Scott et al., 1971; Drackley et al., 1986).

Animal fats

Effects of tallow on DMI of lactating cows have been minimal when fed at 2 to 5% of ration DM (Wrenn et al., 1978; Mattias et al., 1982; Drackley et al., 1992a). Eastridge and Firkins (1992) found lower DMI with fancy bleachable tallow, however, compared with either flaked or prilled tallow fed at 5% of DM. When higher amounts are added to dairy rations, feed consumption is decreased (Kowalcyzk et al., 1977). Clapperton and Steele (1983) found reductions in DMI when tallow was fed at 7 to 10% of the ration DM, and Palmquist and Conrad (1980) reported a tendency for DMI and molar percentages of propionic acid to decrease in cows fed 5% tallow. On
the other hand, protected tallow has a detrimental effect on DMI of cows 
(MacLeod et al., 1976; Bines et al., 1978; Smith et al., 1978).

Commercial fats

Inert fats contain FA that are largely unavailable in the rumen because of their low solubility or high saturation and melting point (Chalupa et al., 1986; Palmquist, 1991), and they are less likely to adsorb onto bacteria (Chalupa et al., 1984). Consequently, any detrimental effects on ruminal fermentation (Hill and West, 1990), digestibility of DM, OM, NDF, ADF, and crude protein (CP), and DMI (Grummer, 1988; Schneider et al., 1988; Klusmeyer et al., 1989; Shauff and Clark, 1989; Canale et al., 1990; West and Hill, 1990) are minimized.

Palmquist et al. (1991) compared five commercial fat supplements at two levels of intake (100 and 500 g/d) in Jersey cows. Despite differences in FA composition and technology for production, the results showed that mean DMI, concentrations of molar proportions of VFA, and digestibility of nutrient components (DM, N, ADF, NDF, Ca, and Mg) were unaffected by fat source. Digestibility of P and DMI, however, were decreased by higher fat intake.

Another important feature of inert fats is the protection of FA from biohydrogenation in the rumen, which influences the extent of digestibility in the lower tract (Wu et al., 1991). There are well documented data that show positive effects of feeding inert fat on FA digestibility.

Work published by Jenkins and Palmquist (1984) showed that apparent digestibility of a commercial CSFA product was 85%, compared with 60% for the control ration. Later, Schneider et al. (1988) and Andrew et al.
(1990) reported similar results for true digestibility. Recently, Wu et al. (1991) compared biohydrogenation changes in FA of CSFA with animal vegetable blended fat. The authors found that FA in CSFA were subjected to less biohydrogenation in the rumen and were more digestible than animal vegetable blended fat, which suggested partial protection of CSFA. This protection is particularly important because unsaturated FA are more digestible than saturated FA of the same chain length (Sklan et al., 1985). Because of the higher solubility of unsaturated FA; the increased digestibility facilitates micellar formation with bile salts (Andrews and Lewis, 1970) and faster transit through the unstirred water layer, which may be the primary rate-limiting barrier for uptake of FA from the small intestine (Friedman and Nylund, 1980).

In contrast, Palmquist (1991) found no differences in FA digestibility among five different types of fat with iodine numbers ranging from 14 to 92. Jenkins and Jenny (1989) found that digestibility of hydrogenated yellow grease (iodine number = 19) was lower than that of yellow grease (iodine number = 58). Palmquist (1991) concluded that the fine particle size of fat with the smaller iodine number apparently facilitated its association with feed particles and becoming emulsified in the intestine. He compared the effects of feeding two types of tallow with the same iodine value (14.5) but different size (flaked or prilled) on performance of lactating cows. Dry matter intake, production of milk, and 4% FCM were higher for cows fed the prilled form; in addition, milk fat percentage and nutrient digestibilities were also higher.
It has been suggested that results among different studies on fat digestibility often are inconsistent, because no rigid rules have been formulated to rank the relative importance of factors that regulate FA absorption (Palmquist, 1991).

Role of Calcium and Magnesium in High Fat Diets

Addition of calcium (Ca) to the diets of dairy cows usually increases fecal excretion of insoluble calcium salts of LCFA (Johnson and McClure, 1973). Some workers have reported decreased digestibility of Ca and magnesium (Mg) in cows fed high fat diets (Kronfeld et al., 1980; Jenkins and Palmquist, 1981). Other reports showed improvements of fiber digestibility when additional Ca was provided to either growing cattle (Devendra and Lewis, 1974; Drackley et al., 1985) or lactating cows (DePeters et al., 1987) fed unsaturated oils or tallow (Palmquist and Conrad, 1980). Palmquist and Jenkins (1980) suggested that the benefit of additional Ca was because formation of insoluble fatty acid salts decreased microbial inhibition; furthermore, they reported that palmitic and stearic acids were more likely to form insoluble fatty acid salts than were unsaturated FA. Finn et al. (1985) found no changes in concentrations of insoluble fatty acid salts in dairy cows fed diets containing 10% sunflower seeds and 3.5% additional limestone based on ration DM. Intake of DM was higher for cows receiving the additional limestone, however, compared with those fed sunflower seeds without limestone. In another trial with the same diets, Drackley et al. (1985) reported similar results on rumen concentration of insoluble fatty acid salts in growing steers. Detrimental
effects of sunflower seeds on digestion of NDF, ADF, and cellulose were prevented by additional calcium, which was in accordance with earlier reports on lambs supplemented with corn oil plus additional CaCO₃ or CaCl₂ (Davison and Woods, 1963).

Later, Palmquist et al. (1986) demonstrated that dicalcium phosphate and CaCO₃ were not soluble enough at ruminal pH to combine with FA. Consequently, by linking palm oil fatty acids with Ca, preformed Ca soaps are now manufactured. The main characteristic of these commercial fats is their inertness in the rumen when rumen pH is 5.5 or above (Pritam and Palmquist, 1990), which prevents dissociation of Ca salts and further biohydrogenation by the ruminal bacteria. Reasons for adding extra Ca and Mg to dairy rations are unclear (Coppock and Wilks, 1991). From a practical standpoint, Palmquist (1984) suggests that there should be 1.0% Ca and .30% Mg in dairy rations, compared with recommended levels of .80% and .25%, respectively (NRC, 1989).

Effects of Source of Fat on Milk Production and Composition

Plant Fats

Oils. Some studies indicate that fats, mainly unsaturated oils, depress milk fat percentage (Pan, 1972; Storry et al., 1973, 1974; Pennington and Davis, 1975; Goering et al., 1976). Storry (1970) suggested that depression of milk fat is associated with a negative shift in the acetate:propionate ratio in the rumen. Some studies have shown little or no change in rumen VFA because of oil feeding (Plowman et al., 1971; Steele et al., 1971; Goering et al; 1976); however, when protected oil that is
resistant to breakdown in the rumen is fed or when oil is administered directly into the abomasum, fat depression is reversed (Plowman et al., 1971; Pan, 1972; Storry et al., 1973, 1974; Goering et al., 1976; Yang, 1978; Kundu and Mudgal, 1985). For example, supplementation of protected safflower oil to dairy cows increased fat and protein content in milk, whereas unprotected oil decreased these milk components (Plowman et al., 1971; Pan, 1972). Similar results were reported by Goering et al. (1976) from supplementation with protected soybean oil. No effects on milk production, however, were observed.

Whole oilseeds. Whole cottonseeds (WCS) have become a popular source of fat among dairy producers. Cottonseeds are fed at average levels of 11.5% of DM (Smith et al., 1981; Van Horn et al., 1984; DePeters et al., 1985; Baker et al., 1986; Horner et al., 1986; Mohamed et al., 1988). Milk fat is not depressed when whole WCS are fed (Moody, 1978), and it may be increased (Stanley et al., 1969; Smith et al., 1981; DePeters et al., 1985; Anderson et al., 1984). This increase may be caused by partial rumen bypass of the oil in the whole seed, by slow release of oil in the rumen (Moody, 1978), or by the seed hulls having a high fiber content, which is considered to be an indispensable feed ingredient to maintain milk fat percentage (Devendra and Lewis, 1974).

Nevertheless, it seems that effects of supplemental WCS on milk production and composition are greatly influenced by the type of dietary forage. When corn silage constitutes a substantial proportion of the forage, there is a response in milk production with a concomitant reduction of the milk fat content (Van Horn et al., 1984; Baker et al., 1989). On
the other side, when the main source of forage is alfalfa, the effect of WCS on milk production is minimal, and an increase of milk fat percentage is evident (Smith et al., 1981; DePeters et al., 1985; Palmquist, 1987; Hein et al., 1990). Other reports showed no definitive effects on milk production or composition (Horner et al., 1986; Mohamed et al., 1988).

Rafalowski and Park (1982) found no depression of milk fat or protein percentages when 10, 20, or 30% whole sunflower seed concentrate was fed to milking cows. Moreover, cows fed the 10% sunflower diet produced more milk and were more efficient energetically.

Modest results also have been found when feeding whole sunflower seeds (McGuffey and Schingoethe, 1982). Finn et al. (1985) showed in a 120-day continuous trial that cows fed whole sunflower seeds produced less 4% FCM, probably because of the faster release of oil from rolled seeds. On the other hand, McGuffey and Schingoethe (1982) did not observe milk fat depression when feeding whole rolled sunflower seeds. Their trial, however, used short (28 d) periods, which may not have been long enough to detect the effects of fat depression. Milk fat depression did not become apparent until week 5 to 6 of the trial, which was conducted in early lactation (Finn et al., 1985; Drackley and Schingoethe, 1986).

Anderson et al. (1984) reported higher yields of milk, 4% FCM, and protein from cows fed whole sunflower seeds. The better performance was partly attributable to greater intakes of DM. A new variety of high oleic acid sunflower seeds (>80% oleic acid) seems to maintain milk fat percentages when fed at 20% of concentrate DM (Saer et al., 1987; Casper et al., 1988).
Feeding coarsely ground or whole soybeans resulted in milk fat containing 24% more C18:2 (Hutjens and Shultz, 1970; Steele et al., 1971). These outputs may indicate that some C18:2 avoided complete hydrogenation in the rumen and was transferred from the blood into the milk fat (Finn et al., 1985; Drackley and Schingoethe, 1986). This marked increase of polyunsaturated FA, particularly C18:2, also has been found in milk of cows fed whole sunflower seeds (McGuffey and Schingoethe, 1982; Baer et al., 1987; Casper et al., 1988), protected canola seeds (Ashes et al., 1992), or whole flaxseed (Okini and Kennelly, 1992). Nevertheless, Rafalowski and Park (1982), DePeters et al. (1987) and Murphy et al. (1990) observed no increments in milk C18:2 when whole sunflower seeds, WCS or ground rapeseeds were incorporated into diets of dairy cows.

Finally, linseed oil, obtained from flaxseed, contains up to 92% unsaturated FA. About 62% of this quantity is polyunsaturated (C18:3), and, as a result, flaxseed is one of nature's more abundant sources of linolenic acid. Flaxseed may be an important feedstuff, therefore, to increase omega-3 FA content in milk and other dairy products (Stitt, 1988).

Commercial fats

Commercial fats may be used with high efficiency by the lactating cow as an energy source and as a precursor for milk fat synthesis. In an extensive review on the effects of commercial fats on milk production and composition, Shaver (1990) reported average production increments of 3.1 (lb/d) for milk, 4.0 lb/d for 4% FCM, .19 lb/d for fat, and .05 lb/d for protein from cows fed 2 to 3% of ration DM as CSFA (Megalac). Milk fat
content was increased by .11%, but milk protein percentage was reduced by .08%. Megalac often, but not always, increases milk yield and fat content. DePeters et al. (1990) found no effects on milk production or milk fat percentage in cows supplemented with 2.9% Megalac. Higher concentrations of CSFA in the diet, however, seem to have negative effects on DMI and milk production. Dry matter intake, energy intake, and milk production were substantially decreased in cows supplemented with 9% Megalac (Schauff and Clark, 1990). This effect also was observed in lactating goats fed 3, 6, and 9% of diet DM as CSFA. Milk production and body weight of goats were higher when fed at 3% compared to 6 and 9% of CSFA in DM (Ogden et al., 1992). The response from fat feeding varies according to lactation number. Fat-corrected milk production was increased 2.7 lb/d in primiparous cows compared with 7.1 lb/d for multiparous cows (Robb and Chalupa, 1988; Chalupa and Ferguson, 1990).

Recently, Canale et al. (1990) fed .5 kg of CSFA (Megalac) with 25 or 31% of NDF to cows in early and midlactation. No interactions were found between CSFA and concentration of NDF, and primiparous and multiparous cows responded similarly to the treatments. Production of milk, 4% FCM, and fat was increased, but milk protein percentage was decreased. Average responses of milk production from cows fed encapsulated tallow coated with sodium alginate (Energy Booster) at 2.5 to 5% of ration DM were: 1.7 lb/d of milk, 1.3 lb/d of 4% FCM, and .08 lb/day of protein. Fat production was not affected, but protein percentage was increased by .04%. Salfer et al. (1992) found no differences in milk or FCM production or in milk composition when prilled hydrogenated tallow (Alifat) was fed at 2% of
ration DM to primiparous or multiparous cows. Jerred et al. (1990) reported an increase of FCM production when prilled fat was fed at 5% of ration DM to cows in early lactation, but this effect was evident from week 6 to week 14 of lactation. Cows receiving supplemental fat, furthermore, were producing less milk than control cows during the first 3 weeks of the trial.

Effects of Fat on Reproduction

During early lactation, as mentioned already, high producing cows are under tremendous metabolic stress. At this stage, milk production has a higher metabolic priority than does reproduction (Harrison, 1989). As milk production of dairy cows continues to increase, the relationship between milk production and reproductive efficiency is becoming a higher priority to dairy scientists and producers.

Spalding et al. (1975) found that the highest quartile of producers averaged 20.5 percentage units lower conception rate at first service than did the lowest producing quartile. Olds et al. (1979) reported that the partial regression coefficient for Holstein was \(0.014 \pm 0.001\) more services for each additional 100 kg of milk up to 120 days postpartum. For Jersey and Guernsey, \(0.028 \pm 0.008\) more services were required during the same milking period. Laben et al. (1982), by using over 130,000 records from 201 California dairy herds, confirmed that higher producing cows exhibit a detectable antagonism between production and reproductive performance. Longer intervals before first service (Laben et al., 1982; Hillers et al.,
1984) and more mild or silent estruses have been consistently reported for
high producers compared with low producers (Morrow et al., 1966).

Reproductive performance of lactating cows is highly correlated with
changes in body condition. Smith et al. (1985) clearly showed that as body
weight (BW) losses of lactating cows progressed from minor to severe;
intervals from calving to first ovulation, first heat, and conception
increased directly. Concomitantly, conception rates at first service were
reduced. Harrison et al. (1990) reported higher percentage loss of BW
during wk 2, 3, 4, and 5 postpartum for high producing cows compared with
average producers.

In general, it is believed that cows in lower or negative energy
balance have poorer reproductive performance (Butler and Smith, 1989);
therefore, dietary ingredients used to alleviate negative energy balance
may provide substantial benefits to the reproductive performance of cows.
Moreover, high milk production per se is not the cause of poor reproductive
performance. Detrimental effects of milk production on reproduction are
mainly the result of a tremendous mobilization of body tissues caused by
inadequate energy nutrition (Chalupa and Galligan, 1990).

Long intervals from calving to first ovulation may be alleviated
partly by feeding high energy dense supplements, such as fat, through
effects on the overall energy status of cows (Lucy et al., 1991) and on
other sites of action. Cholesterol is a precursor for progesterone
synthesis by luteal cells. It can originate from de novo synthesis or from
uptake of circulating lipoprotein cholesterol (Grummer and Carrol, 1990).
West and Hill (1990) found an increase in plasma cholesterol of Holstein
and Jersey cows fed .45 and .35 kg of CSFA daily, which is in agreement with Combs et al. (1989) who added prilled fat at 5% of dietary DM for Holstein cows. Palmquist and Conrad (1978) demonstrated that the amount of cholesterol in blood plasma of cows was related positively to the amount of fat in their diets from whole raw soybeans at 2.9 to 10.8% EE in the diet.

Furthermore, fat supplementation had positive effects on ovarian structures and on plasma progesterone concentrations (Rodes et al., 1978; Williams, 1989; Highshoe et al., 1990; Sklan et al., 1991), but it failed to increase plasma prostaglandin F₂α concentrations (Lucy et al., 1991). Nevertheless, conception rates and proportions of cows pregnant at 150 d after parturition were higher for cows supplemented with CSFA from calving to 120 d postpartum compared with cows without CSFA supplementation (Sklan et al., 1991; Garcia-Bojalil et al., 1992).

No differences were shown in reproductive performance or body weight change in cows fed diets containing soybean meal or 2.9 kg/d whole heat-treated soybeans from d 10 to wk 15 postpartum. Cows consuming diets containing whole soybeans, however, produced 2 to 3 kg/d more milk during wk 5 through wk 15, (Ruesegger and Shultz, 1985). Similar results were reported by Schingoethe and Casper (1989) when feeding additional fat from either extruded soybeans or sunflower seeds. Earlier, Johnson et al. (1988) found that increments in blood plasma cholesterol of cows supplemented with raw peanut hearts were related positively to amounts of fat in diets.
Effects of Fat on Metabolic Disorders

Fatty liver and ketosis are interrelated metabolic disorders that are manifested during periods of negative energy balance of dairy cows, especially during early lactation. Ketosis is characterized by elevated blood nonesterified fatty acids (NEFA) and ketones and by low blood glucose and insulin (Littledike et al., 1981; Veenhuizen et al., 1991; Drackley et al., 1989, 1992b). Veenhuizen et al. (1991) found that liver triglycerides (TG) increased four to five fold and reached a peak 2 weeks before cows showed an experimental ketosis. Grummer (1992) stated that susceptibility of the liver to accumulate TG is dependent on rates of hepatic FA uptake and esterification versus the rate of exporting esterified FA.

Several excellent reviews related to nutritional status and etiology of fatty liver have been written (Kronfeld, 1982; Anderson, 1988; Grummer and Carroll, 1991). As stated by Young et al. (1990), fatty liver potentially can have many negative effects on the overall metabolism of high producing cows because the liver is the "crossroad" of metabolism, and any abnormality of the liver can affect metabolism of carbohydrate, lipid, and protein.

It is generally accepted that development of ketosis in early lactating cows is related to high energy requirements that often cannot be met with normal diets because of the limited physical capacity of cows during early lactation (Baird, 1982). Initially glycogen, protein, and primarily FA can be utilized by the mammary gland for milk synthesis; however, nutrients necessary for sustained increases in milk production are derived from increased feed intake and simultaneous changes in nutrient
metabolism in many tissues (Bauman et al., 1988). Some modifications in such changes have been listed as potential mechanisms by which supplemental fat may help to decrease the predisposition of cows to develop fatty liver and ketosis (Grummer and Carroll, 1991; Chilliard and Lavau, 1992). The modifications are interrelated and include: 1) decreasing fatty acid mobilization from adipose tissue, 2) alleviating a shortage of fatty acid precursors for mammary triglyceride synthesis, and 3) sparing oxidation of glucose in mammary tissue by lowering the requirement of reduced nicotinamide adenine dinucleotide phosphate (NADPH) for mammary fatty acid synthesis.

Cummings and Sartin (1987) speculated that feeding a high-fat diet may create hormonal changes in metabolism that are similar to those occurring during a shift from negative to positive energy balance. Nevertheless, there are no consistent data on changes in blood plasma glucose, insulin, or somatotropin concentrations when fat is incorporated into dairy diets (Palmquist and Moser, 1981; Cummins and Sartin, 1987; Lough et al., 1988). Horner et al. (1986) observed negative effects on glucose and insulin concentrations in blood plasma of cows fed WCS. In 1988, however, Horner et al. (1988a) found no effects when they used the same diets as well as cows in the same stage of lactation.

Concentrations of plasma somatotropin in cows supplemented with fat have remained unchanged (Palmquist, 1981b; Cummins and Sartin, 1987) or have decreased (Schneider et al., 1988). In some studies, however, tendencies for increasing insulin: somatotropin ratios have been observed (Schneider et al., 1988; Palmquist et al., 1991). It is generally accepted
that an increase of the insulin:somatotropin ratio would have an effect on antilipolytic signals. Consequently, plasma NEFA concentrations would decrease and so would the predisposition for fatty liver and ketosis (Grummer and Carroll, 1991).

Plasma NEFA concentrations of lactating cows supplemented with dietary fat are increased consistently (Hutjens and Shultz, 1970; Goering et al., 1976; Bines et al., 1978; Smith et al., 1978; DePeters et al., 1989; Canale et al., 1990), but concentrations of plasma β-hydroxybutyrate usually do not increase (Bines et al., 1978; Selner and Shultz, 1980; Skaar et al., 1989). These observations may indicate that the ability to oxidize FA to CO₂ was not exceeded and that mammary uptake of FA for triglyceride synthesis occurred. Feeding supplemental dietary fats has consistently decreased short- and medium-chain fatty acids and increased long-chain fatty acids in milk fat (DePeters et al., 1985, 1987; Finn et al., 1985; Baer et al., 1987; Okine and Kennelly, 1992; Stegman et al., 1992) because of lower de novo FA synthesis in mammary gland (Grummer, 1991).

Fatty acid synthesis in the mammary gland depends upon availability of reducing equivalents (i.e., NADPH), and almost 50% of these are believed to be provided by glucose oxidation via the pentose shunt (Bauman and Davis, 1974). When dietary fat is supplemented to lactating cows, therefore, there is potential to decrease the utilization of glucose for fat synthesis by the mammary gland (Cummins and Russell, 1985) and to divert it for other purposes (Palmquist, 1984).
Implications of Feeding Fat to Dairy Cows

There are both several advantages and several disadvantages of feeding supplemental fat to dairy cows. Subsequent paragraphs briefly list and discuss major advantages and disadvantages.

Advantages of feeding fat

High energy density per unit of feed weight. There is considerable lack of information about the actual energy content of fats, but fats contain more energy per unit of weight than other feeds. Andrew et al. (1990) determined the NE\textsubscript{L} value of Megalac for lactating cows to be 6.52 Mcal/kg DM. The actual energy value of any fat will be determined primarily by its digestibility.

Greater energy consumption and milk production. Dry matter intake of cows supplemented with fat is generally maintained or slightly decreased, so that the net result is an increase in the NE\textsubscript{L} consumed with a concomitant increase in milk production.

Adequate fiber consumption. It is well documented that when grain concentrates exceed 55-60\% of the ration dry matter it often results in problems such as rumen acidosis, off-feed, reduced fiber digestibility, and milk fat depression. These problems are alleviated by feeding fat because energy density of the diet is increased without reducing the forage portion, and consequently fiber intake.

High efficiency of energy utilization. Long chain fatty acids (C\textsubscript{16} to C\textsubscript{18}) can be incorporated directly into milk fat by the mammary gland, thus increasing efficiency of energy utilization.
Improved reproductive performance. Specific effects of fat supplementation on reproduction are not clear. There is a possibility of improving reproductive performance through the overall energy status of cows, which relates to concentrations of various metabolic hormones known to modify reproductive functions.

Decreased fatty liver and ketosis. There are clear indications linking inadequate energy intake and increased metabolic disorders such as fatty liver and ketosis. Although supplemental fats do not seem to decrease accumulation of liver triglyceride, the potential indirect antiketogenic effects of fat supplementation are related to a glucose sparing effect.

Persistence of lactation and residual effects. Lactation trials that include almost complete lactations indicate that persistency of lactation and residual responses of cows supplemented with dietary fat are substantial.

Positive effects for heat-stressed cows. Due to the low heat increment characteristic of fats, fat supplementation permits higher NE\textsubscript{i} intake with concomitant increments in milk and FCM production.

Modifying composition of milk fat. It is becoming evident that alterations of FA composition of milk fat can be achieved by adding protected unsaturated FA or whole oilseeds to the diet of milking cows. Therefore, a more desirable product (e.g., increased polyunsaturated to saturated FA ratio) can increase acceptability and consumption of dairy products.
Disadvantages of feeding fat

Antimicrobial effect and fiber digestion. It is well-documented that unprotected unsaturated FA inhibit microbial metabolism. This inhibition depresses fiber digestion, changes FA ratios in ruminal fluid, and decreases milk fat percentage. Although negative effects on fiber digestibility are usually found with low-fiber rations, no effect is usually observed on high fiber rations.

Handling. At room temperature tallow, yellow grease, and blended fats are solid. These types of fats have to be melted for transport and handling and special equipment is needed for heating and pumping.

Decreased milk protein content. Another effect on milk composition has become apparent. Concentration of milk protein often has been decreased, particularly with feeding of protected fats (DePeters and Cant, 1992). Changes, however, are not limited to these types of fats, and may reflect only the higher amounts of fat usually fed with these products. Some proposed mechanisms for the milk protein depression caused by dietary fat include: a) dilution effect, b) reduction of microbial protein synthesis, c) restricted availability of glucose, d) insulin resistance by the mammary gland, which impairs amino acid transport and milk protein synthesis, e) decreased release of somatotropin by the anterior pituitary, which decreases mammary gland uptake of amino acids, and f) an increasing effect on the synthesis of nonnitrogenous compounds of milk (i.e., lactose and fat) but a decreasing effect on milk protein synthesis.
Niacin

Niacin is a generic name that can apply to both nicotinamide (NM) and nicotinic acid (NA). In monogastrics, when dietary niacin is fed within the physiological range, both NM and NA are equally effective as nutrients or cofactors (Shibata and Matsuo, 1990; DiPalma and Thayer, 1991). In ruminants, however, the situation is not that simple. The unique and complex relationships between niacin synthesized by rumen microorganisms and the different chemical and physical properties of dietary niacin (i.e., NM or NA) seem to have an impact on both the site and extent of action of niacin (Erickson et al., 1991).

Some important chemical and physiological characteristics that may influence the effects of dietary niacin on the metabolism of ruminants will be described in paragraphs that follow.

Nicotinamide

This is the predominant form of the circulating free vitamin, and it has a longer half-life than NA (DiPalma and Thayer, 1991). Nicotinamide is very soluble in water (1 g/ml) (Merck Index, 1989), is weakly acidic, and has a pKa of 14 (Morrison and Boyd, 1987). This form of niacin can be used more efficiently than NA for synthesis of nicotinamide adenine dinucleotide (NAD) (McLaren et al., 1973; Duvfa et al., 1983), which takes place in all organs (Shibata, 1987). In addition, at pharmacological doses nicotinamide improved glucose tolerance and decreased glucose excretion substantially in partly depancreatized rats (Yonemura et al., 1984).
Nicotinic acid

Nicotinic acid is about 60-fold less soluble in water than NM (1 g/60 ml) and its pKa is about 4.85 (Merck Index, 1989). The biotransformation of NA to NAD occurs only in liver, kidney, and heart, and, as stated before, the transformation is less efficient than for NM (Shibata, 1983). The shorter half life of NA compared with that of NM may be due to the lesser effectiveness in conversion to NAD (Weiner and Van Eys, 1983). The anti-hyperlipidemic effects of pharmacological doses of NA are consequences of at least four interrelated effects: a) inhibition of lipolysis in adipose tissue, b) inhibition of synthesis and secretion of very low density lipoproteins by the liver, c) a lowering of serum concentration of low density lipoproteins, and d) an increase of serum concentration of high density lipoproteins. Nicotinamide shares none of these actions (DiPalma and Thayer, 1991).

Synthesis of niacin

Ruminants are able to synthesize all of the B vitamins, including niacin (Hungate, 1966). According to Wegner et al. (1940), an increase in the nitrogen content of a diet fed to steers had negative effects on the microbial synthesis of niacin. Lardinois et al. (1944) showed, however, that in the presence of readily available carbohydrates, addition of urea caused increased synthesis of niacin by ruminal microorganisms. Agrawala et al. (1953) reported that calves fed purified diets synthesized up to 154 mg of niacin within 6 h after feeding.

It has been postulated that synthesis of niacin by ruminal microbes is depressed by dietary niacin (Hannah and Stern, 1985; Riddell et al.,
In contrast, niacin synthesis by ruminal microorganisms compensates for consumption of low dietary niacin (Hannah and Stern, 1985; Abdouli and Shaefer, 1986). It has been suggested that the concentration of niacin in the rumen reaches an optimal below which microbial synthesis is stimulated and above which there is no net synthesis. Furthermore, excess dietary niacin may be degraded for other purposes (Kon and Porter, 1954; Hannah and Stern, 1985). Brent and Bartley (1984), however, reported that niacin flow and absorption from the small intestine increased by 62% and 71%, respectively, in cows receiving 6 g of supplemental niacin daily.

Absorption of niacin

Few experiments have been conducted to determine whether or not NA and NM can be absorbed directly from the rumen. Rerat et al. (1954, 1958) showed that the rumen wall is permeable to most B vitamins, including niacin. In these experiments, the workers found that an average of 14% of the niacin introduced into the isolated rumen of two sheep disappeared after 2 h with a concomitant 30% increase in blood niacin concentrations in the ruminal veins. At this time, it was considered that the extent of absorption of niacin from the rumen was of minor importance because most of the niacin was located within the microorganisms and small amounts were in free form (Hungate, 1966).

Rerat et al. (1959) determined the total concentration of niacin in the ruminal digesta of steers fed normal diets. They found that only 3 to 7% of total niacin was in free form and the other portion was present as microbial niacin. These values are similar to those found by Abdouli and Schaefer (1986) in ruminal contents of mid-lactation cows fed diets.
containing barley (high in niacin content) or oats (low in niacin content). Total niacin concentrations in ruminal digesta of Holstein cows, however, increased when 2 g of niacin were fed three times daily. The increments were higher at 2 and 4 h (30 and 25%, respectively) after feeding and had returned to normal by 6 h (Riddell et al., 1985). This increment would be expected to increase the portion of free niacin (Erickson et al., 1991) because the concentration of microbial NAD is independent from concentration of the extracellular or free niacin (Abdouli and Schaefer, 1986b).

Recently, Erickson et al. (1991) found differences in the rates of absorption of NM and NA from the rumen. Whereas NM was absorbed at .98 g/h, NA did not seem to be absorbed over the 1-h period of the experiment. This effect was associated with differences of ionization in the rumen due to differences in pKa. Thus, when niacin is supplemented above its usual nutritional requirements, the amount and rate of absorption from the rumen could become important because of effects on rumen fermentation (Bartley et al., 1979) and changes in rate of passage of ingesta as suggested by Schussler et al. (1978) and Schaetzel and Johnson (1981).

Effects of niacin on rumen functions

Volatile fatty acid production. There are some contradictory results among experiments conducted both in vitro and in vivo to determine effects of niacin on rumen fermentation. In a series of in vitro and in vivo studies Riddell et al. (1980) found no effects of niacin (undefined form) on fermentability, measured as gas production, of different types of substrates. In vivo feeding of supplemental niacin to rumen fistulated
cows had no effects on molar proportions of acetic, butyric, or valeric
acids. Niacin, however, increased rumen propionic acid at 3 and 6 h after
feeding. Although this increment of propionate was significant only at 6 h, the ratio of acetic to propionic acid was significantly decreased at
both 3 and 6 h after feeding.

In another in vitro trial, Schaetzel and Johnson (1981) compared the
impact of adding NA to fermenters inoculated from NA-adapted and non-
adapted donors. When inocula from non-adapted donors was used, NA had no
effects on production of total VFA or individual acids. Fermentations
started with inoculum from an adapted animal, however, resulted in greater
production of total VFA and propionic acid by 9 and 25%, respectively.
These findings suggested that rumen adaptation to NA increases microbial
fermentation efficiency; however, the authors speculated that their
findings might have been due to biological variations across time because
instability of microbial populations influence changes in fermentation.

Horner et al. (1988), however, corroborated these findings. They
reported higher molar percentages of propionic acid, with a peak at 6 h
postfeeding, in Holstein heifers fed a control diet supplemented with 6 g
of niacin compared with cows fed 15% whole cottonseeds without niacin
supplementation. Hannah and Stern (1985) reported lower butyrate
concentrations in a dual-flow continuous culture due to the addition of 100
mg of niacin per kg of substrate, and Danesi et al. (1987) found no effects
of niacin on gas or total VFA production.

Fiber digestibility. Nicotinamide and NA seem to have different
effects on the extent of fiber digestibility in continuous culture. Hannah
and Stern (1985) found that digestibilities of ADF and cellulose were higher with NM supplementation compared with NA. Other studies have shown that niacin has positive effects on in vitro cellulose digestion (Schussler et al., 1978; Riddell et al., 1980) as well as an in vivo cellulose digestion (Horner et al., 1988).

There are few reports on the effects of NM and NA on nutrient digestibility in lactating cows. Erickson et al. (1991) showed no effects on apparent digestibilities of DM, nitrogen, NDF, and ADF in lactating Holstein cows supplemented with 12 g/d of either NM or NA. The authors, however, found, higher digestibilities of fat in cows supplemented with NA compared with cows fed NM.

**Microbial protein synthesis.** Effects of supplemental niacin on in vitro microbial protein synthesis (MPS) have been inconsistent. Several studies (Schussler et al., 1978; Bartley et al., 1979; Riddell et al., 1980, 1981; Dennis et al., 1982; Shields et al., 1983) have shown increased MPS. On the other hand, Schaetzel and Johnson (1981), Danesi et al. (1982), Hannah and Stern (1985), and Abdouli and Schaefer (1986a) failed to show increases in MPS in response to niacin supplementation.

It seems that sources of substrate and inocula play key roles on influencing the effects of feeding niacin on MPS. Riddell et al. (1981) found that MPS was greater with niacin and soybean meal as substrates than with niacin and urea plus corn. When inoculum was taken from sheep fed a high-concentrate, low-roughage diet, niacin failed to increase MPS; the opposite was shown when donors of inoculum had been fed a low-concentrate, high-roughage diet (Schussler et al., 1978). Furthermore, Horner et al.
(1988b) showed that addition of whole cottonseed at levels of 5, 10, or 15% decreased MPS on in vitro ruminal fermentation; when either NM (100 ppm) or NA (200 ppm) were added to the culture system, the negative effects of 15% WCS on MPS were nullified.

Adding niacin to diets of Holstein steers alleviated the negative effects of heated soybean meal on rumen protozoal numbers (Dennis et al., 1982). Horner et al. (1988a), reported higher MPS and numbers of protozoa in Holstein heifers supplemented with 6 g/d of niacin compared to those fed the control ration. In a recent experiment both NM and NA supplementation increased total protozoal numbers in rumen fluid of midlactation cows (Erickson et al., 1991). This result was due primarily to increased numbers of entodinia. The authors suggested that the benefit of such an effect in cows fed high concentrate diets may be due to the capacity of entodinia to engulf starch, which would help to stabilize rumen fermentation and provide additional microbial protein to cows.

Effects on energy metabolism

Nicotinic acid is known to depress basal lipolytic rates in adipose tissue and to inhibit the action of a number of agents that stimulate adipose tissue lipolysis (Hotz, 1983). It seems possible that NA may exert its antilipolytic action by depressing the production of 3′,5′-cAMP (Peterson et al., 1968). Nicotinic acid administered to a variety of experimental animals under different conditions decreases blood plasma NEFA (Nye and Buchanan, 1969; Waterman and Schultz, 1972a,b; Waterman et al., 1972; Fronk and Schultz, 1979).
Intravenous administration of 500 mg of NA decreased NEFA and ketones in blood plasma of normal sheep (Nye and Buchanan, 1969). These effects also were observed in normal and 24-h fasted lactating goats supplemented with NA at 3 g/d (Waterman and Schultz, 1973). Furthermore, administering NA orally to goats at levels of .4, .6, and .8 g/kg increased plasma insulin values by 2- to 4-fold and kept them elevated after glucose loading, which indicates that NA may result in resistance to insulin action (Thornton et al., 1975; Williams et al., 1977). These results were confirmed later by Thornton and Schultz (1980) in a series of experiments with goats. Oral administration of single doses of NA (6.5 and 17.0 g) elevated blood plasma glucose and insulin and impaired glucose tolerance. The maximal effect occurred after 2 to 3 days, and the magnitude was related positively to NA dosage. The workers suggested that NA, in addition to its effects on lipid metabolism, had an impact on carbohydrate metabolism.

Acute administration of NA at 160 g/d (Waterman and Schultz, 1972b) to normal cows, subclinically ketotic cows, and clinically ketotic cows showed an initial inhibition of lipolysis during the first 2 d. This inhibition was followed by a rebound in plasma NEFA concentration, increased blood ketones, decreased blood glucose, and decreased milk production. After 2 d, however, DMI, glucose concentrations in blood plasma, and milk production were improved rapidly (Waterman and Schultz, 1972a; Waterman et al., 1972).

Fronk and Schultz (1979) found that relatively low doses of NA (12 g/d) supplemented to lactating cows with subclinical and clinical
ketosis were effective in decreasing blood plasma NEFA and BHBA concentrations (47 and 35%, respectively) and increasing blood plasma glucose and milk production (17 and 13%, respectively). These positive effects were apparent after 7 days of NA supplementation. Faster effects, within 24 h, on the decrease of plasma NEFA and BHBA were reported when a single oral dose of either 12 or 120 g of niacin were given to cows (Jaster et al., 1983a).

Bartlett et al. (1983) reported that 6 g/d of niacin supplemented to cows in early lactation decreased the concentration of urine ketones with a concomitant reduction of the incidence of clinical ketosis from 4.8 to 1.5%. Similar results were found by Duvfa et al. (1983) when 6 or 12 g/d of niacin was given to multiparous cows. Cows treated with niacin had higher plasma glucose and lower NEFA and BHBA concentrations than control cows. Recently, Zimmerman et al. (1992) showed antilipolytic effects of dietary niacin in multiparous cows, but this effect was not apparent in primiparous cows.

Effects of niacin and niacin plus fat on milk production and composition

Niacin. Supplementation of dairy cows with niacin (unspecified form) had beneficial effects on milk production and lactation persistency (Kung et al., 1980; Riddell et al., 1981). The benefit was greater in cows in early lactation than in midlactation. The effects of supplemental niacin on milk composition were reported by Riddell et al. (1981). They found that milk from cows supplemented with niacin at 6 g/d had higher protein content (.067%) compared with milk from cows on the control diet.
Jaster et al. (1983b) reported several findings from a field trial that used 300 lactating cows from six dairy farms. High producing primiparous heifers supplemented with niacin at 6 g/d produced more milk (32 kg/d) than heifers fed the control diet (30 kg/d). Milk production of older cows producing greater than 39 kg/d of milk was not affected by niacin, but fat content was increased by .2%. In addition, thin cows (body condition score averaging 2 on a scale of 1 = thin to 5 = fat) supplemented with niacin produced less milk than control cows with the same body condition score, probably because of the antilipolytic actions of niacin. In another field trial conducted during the summer, Muller et al. (1986) found positive effects from niacin supplementation in all cows regardless of parity. Cows receiving 6 g/d of niacin produced more milk, 4% FCM, and milk protein than cows without niacin supplementation. Furthermore, the greatest benefit of niacin was observed in cows producing greater than 34 kg milk/d (36.4 vs 34.0 kg/d, for niacin and control cows, respectively). No effects on milk protein percentages were reported, however.

Experiments to compare effects of source of niacin (NM vs NA) in multiparous Holstein cows were conducted by Erickson et al. (1990) and Jaster and Ward (1990). Whereas Erickson et al. (1990) found no effects on milk production and composition in midlactation cows supplemented with 12 g/d of either NM or NA; Jaster et al. (1990) found that cows in early lactation supplemented with 6 g/d NM, beginning 2 wk prepartum and continuing to 12 wk postpartum, produced more milk and 4% FCM during wk 9, 11, and 12. Furthermore, during wk 11 and 12, actual milk production was 13% greater for NM-supplemented cows compared with that of controls.
Although milk production of cows receiving 6 g of NA daily was intermediate, it was not significantly different from that of control cows.

Niacin plus fat. In a recent review by DePeters and Cant (1992), it was concluded that addition of supplemental fat to dairy rations decreased the content of milk protein. The authors stated that true understanding of the milk protein response to fat supplementation of dairy rations will require quantitative integration of effects of several organ systems, namely, the rumen, gastrointestinal tract, liver, mammary tissue, and muscle.

In an attempt to counteract some of the negative effects of feeding fat to dairy cows on the percentage of milk protein, several trials have been conducted with supplemental niacin. Results have been contradictory. In an experiment with 6 primiparous and 22 multiparous cows averaging 45 d postpartum both niacin (6 g/d) and WCS fed alone or together increased milk fat percentage. Milk protein percentage and production, on the other hand, were higher with niacin, but they tended to be lower with WCS. The milk protein depression exerted by WCS was alleviated by niacin due to stimulation of mammary casein synthesis. Nevertheless, lactose and minerals of milk were lowest in cows supplemented with niacin (Horner et al., 1986). DePeters and Cant (1992) hypothesized that dietary fat per se has a greater effect on the synthesis of non-nitrogenous components of milk (i.e., lactose and fat) than on protein synthesis, thus a depression in protein percentage occurs.

Subsequent work (Horner et al., 1988b) with the same type of cows (55 d postpartum) and diets being used to compare different doses of niacin
supplementation (0, 3, 6, and 12 g/d) failed to show benefits of niacin on milk production and composition. Moreover, milk from cows supplemented with 3 and 6 g/d niacin had lower milk protein percentage, but milk from cows receiving 12 g/d niacin was not different from the control. The workers postulated that these differences in results were because all cows were receiving 6 g/d of niacin during the 7-d standardization period. In addition, an unintentionally high dietary protein in the diet (20 vs 16.6% in the first experiment) for cows with similar milk production may have overridden the contribution of niacin to MPS in the rumen that had been shown in other studies.

Nicotinic acid supplementation (12 g/d) of diets containing 3% of diet DM as CSFA increased milk protein percentage and milk production of early lactation Holstein cows (Erickson et al., 1989a). However, in an experiment of similar design, except that early lactation Jersey cows were used, NA supplementation had no effects on milk protein percentage or production (Erickson et al., 1989b).

Later studies in Holstein cows fed different sources of fat have shown different outputs also. Benefits of NA supplementation on milk protein content were reported for cows in early lactation fed heat-treated whole soybeans (Driver et al., 1990). No effects on milk production and composition due to NA supplementation were observed when either 2% yellow grease (Martinez et al., 1991) or 15% WCS (Lanham et al., 1992) were fed to cows averaging 84 d in milk or in late lactation, respectively.
Summary of the Literature

It is clearly evident that milk production potential of dairy cows in the United States has improved substantially. Concomitantly, the requirements of cows for some nutrients (i.e., energy, protein, and some vitamins) have become difficult to fulfill with traditional feedstuffs without altering the delicate equilibrium of the metabolism of cows, as well as the quantity and quality of some desired characteristics of the milk produced.

Recent research has shown the effectiveness of dietary fat to increase milk production and fat percentage and also to have potential beneficial effects on health and overall performance of lactating cows. There are many different opinions in the current literature on the degree of impact of feeding novel dietary nutrients to dairy cows on their metabolism and on their milk production and composition. The different opinions and interpretations may be attributed to variations possibly caused by stage of lactation, body condition score, parity, milk production, as well as source and amount of forage being fed.

Many problems related to nutritional requirements of high producing dairy cows have been solved already. There are undesirable effects caused by alternative feedstuffs such as fats, however, which require further research. These problems need to be addressed to determine how nutrients can be manipulated to support optimal outputs of milk and milk ingredients. Niacin has been shown, in some instances, to have beneficial effects on milk production and composition. Knowledge about the site and extent of absorption of both types of niacin and the consequences at ruminal and
target organs is limited. The purpose of the research reported in this
dissertation was to expand the knowledge relating to the use of niacin in
diets of dairy cows.
PAPER I. SUPPLEMENTATION WITH NICOTINAMIDE AND LONG CHAIN FATTY ACIDS ON MILK PRODUCTION AND COMPOSITION OF LACTATING COWS.
ABSTRACT

Fifty Holstein cows, 20 primiparous and 30 multiparous, averaging 121 d postpartum were assigned to one of five treatments according to parity and milk production and composition. There were five treatments: a control, calcium salts of fatty acids or nicotinamide fed alone, and calcium salts of fatty acids supplemented with nicotinamide during manufacture or added separately to the feed. Periods lasted 5 wk during which cows were fed complete mixed rations. During wk 1 all cows received the control diet to provide covariate data, during wk 2 they were adapted to treatments, and during wk 3, 4, and 5 they received individual treatments. Feeding calcium salts of fatty acids did not alter DMI and tended to increase BW, BCS, and milk fat and milk protein production, but it increased production of milk, and 4% FCM. Intakes of DM, OM, NDF, ADF, and CP, and production of milk, 4% FCM, milk protein, and milk protein percentage were increased by feeding nicotinamide. Concentration of plasma NEFA was higher, BHBA was not affected, and blood nicotinamide was lower in cows receiving CSFA. Nicotinamide supplementation increased plasma glucose and blood nicotinamide but had no effects on NEFA and BHBA. Milk production and blood nicotinamide were higher, and milk protein production tended to be higher in cows supplemented with CSFA plus NM compared with the CSFA group. Blending with CSFA did not seem to be a strong possibility for bypassing NM past the rumen. Nicotinamide is active after being blended with CSFA, however, and 400 g/d of the blended compound exerted the same benefits as when CSFA plus 12 g/d nicotinamide were supplemented to dairy cows.
INTRODUCTION

Adding supplemental dietary fat has proven to be a good alternative to increase energy consumption of high producing cows in early lactation (Shaver, 1990; Palmquist, 1991). There are documented data showing benefits of adding fat to diets of dairy cows on milk, 4% FCM production, and milk fat percentage (Anderson et al., 1979, 1984; Baker et al., 1989; Ballenger and Palmquist, 1990; Canale et al., 1990; Chalupa and Ferguson, 1990). On the other side, milk protein concentration usually has decreased by .1 to .3 percentage units in cows in early lactation regardless of the source of fat being fed, diet composition, or parity status (DePeters and Cant, 1992).

Casein is the constituent of milk protein found to be particularly affected by the addition of fat to diets of dairy cows (Horner et al., 1986; Dunkley et al., 1977; DePeters et al., 1987; DePeters and Cant, 1992). This decrease in casein is a concern for the dairy industry, not only because casein constitutes 76 to 86% of the protein in milk (DePeters and Cant, 1992), but also because casein is the single most important component in milk for manufacturing purposes (Hettinga, 1989).

The amount of milk utilized for manufacturing cheese has almost doubled since 1970. The total production of cheese in the United States was approximately 640 million kg in 1970; in 1987, it was 1.22 billion kg (National Food Review, 1990). This changing market may bring important changes in milk pricing systems (Ferris and Vasavada, 1989; Sutton, 1989; Legates, 1990). Therefore, a decrease in milk protein can have a
substantial economic impact on the dairy industry (Zurborg, 1978; Gibson, 1989; Martinez et al., 1991).

Mechanisms causing the changes in milk protein observed with fat feeding have not been established clearly. Sporndly (1989) found a negative relationship between dietary fat and milk protein concentration. This negative effect was independent of energy intake; consequently, it was attributed specifically to the fat content of the diet. Others have proposed that supplemental fat may exert its detrimental effects at the ruminal level (Dunkley et al., 1977; Amos, 1984; Horner, et al., 1988a), at the systemic level (Schmidt, 1966; Smith et al., 1978; Palmquist and Moser, 1981; Palmquist, 1984; Horner et al., 1988b; Casper and Schingoethe, 1989; Erickson et al., 1992), or at both levels (Horner et al., 1988a; DePeters and Cant, 1992). Recently, DePeters and Cant (1992) proposed that the mechanism of the milk protein depression induced by dietary fat is likely to occur because dietary fat increases synthesis of milk fat and lactose to a greater extent than protein synthesis.

Niacin may counteract some of the negative effects observed in the percentage of milk protein of cows supplemented with fat. Although data are not consistent, supplementing lactating cows with niacin has increased microbial protein synthesis in both vitro (Riddell et al., 1980; Shields et al., 1983; Brent and Barley, 1984) and vivo (Schussler et al., 1978; Riddell et al., 1980, 1985; Brent and Barley, 1984), increased protozoal numbers (Dennis et al., 1982; Erickson et al., 1990), increased propionic acid production (Riddell et al., 1980), and increased in vitro and in vivo cellulose digestion (Schussler et al., 1978; Horner et al., 1988a).
Cellulose digestion seems to increase more with nicotinamide (NM) than with nicotinic acid (NA) supplementation (Hannah and Stern, 1985). At the systemic level, supplemental niacin increased blood plasma glucose concentrations of both ketotic and normal lactating cows (Fronk and Schultz, 1979; Duvfa et al., 1983; Jaster and Ward, 1990; Zimmerman et al., 1992), and it decreased blood plasma NEFA and β-hydroxybutyrate (BHBA) concentrations.

Niacin supplementation to lactating dairy cows has increased milk production (Kung et al., 1980; Riddell et al., 1981; Harmeyer et al., 1982; Muller et al., 1986) and alleviated the milk protein depression induced by added dietary fat (Horner et al., 1986; Driver et al., 1990). This benefit seems to be greater with NM than with NA supplementation (Jaster and Ward, 1990). The response from adding niacin to dairy diets generally has been greatest for cows in early lactation (Jaster et al., 1983; Lanham et al., 1992), which may be related to its effects at the rumen level, systemic level, or both (Fronk and Schultz, 1979; Dennis et al., 1982; Horner et al., 1986; Horner et al., 1988a, 1988b; Erickson et al., 1992).

It is generally accepted that the amount of niacin synthesized by rumen microbes may be inadequate for high-producing dairy cows (Riddell et al., 1980). Spector (1956, cited by Kronfeld and Raggi, 1964) calculated that the outflow of nicotinamide in milk is about 850 mg/L. The contrast, rumen niacin concentrations may be regulated metabolically (Riddell et al., 1985; Abdouli and Schaefer, 1986). Therefore, dietary niacin may decrease ruminal niacin production (Brent and Bartley, 1984), which consequently may have an effect on the formation of two essential co-enzymes, nicotinamide
adenine dinucleotide (NAD) and NAD phosphate (Horner et al., 1986). In addition, the half life for niacin infused into the rumen was calculated to be only 14 min. (Nye and Buchanan, 1969).

Objectives of our study were to determine for lactating Holstein cows averaging 120 d in lactation, the effects of supplementing CSFA, NM, or CSFA plus NM either blended during the process of manufacturing or added separately on: a) feed intake, and changes in body weight and body condition score, b) milk production and composition, c) blood plasma metabolite concentrations of glucose, NEFA and BHBA, and d) blood NM concentrations.
MATERIALS AND METHODS

Extraction of Niacin

A main focus of this research revolved around calcium salts of fatty acids supplemented in diets of dairy cows. The source of CSFA was MEGALAC®, which is marketed by the Church and Dwight Co., Princeton, NJ. Throughout this report, CSFA will be the term used most frequently and MEGALAC will be used only rarely. The two terms are intended to be completely interchangeable.

Before the feeding trial was done, preliminary explorations were done to determine whether NM was stable when blended during the manufacture of MEGALAC and to determine whether there was a possibility that NM in MEGALAC particles would serve as a rumen escape for NM. Niacin was extracted from MEGALAC by using a 75% McDougall buffer solution (pH 6.5) plus 25% of a 2:1 chloroform:methanol mixture. Three representative samples (.5 g) were placed in 125-ml Erlenmeyer flasks and 100 ml of the mixed solution were added to each flask. After vigorous manual homogenization, one 1-ml sample was taken from each flask with 2-ml syringes loaded with a .45-μm filter (Millipore, Bedford, MA. U.S.A.). Samples were then refrigerated until analyzed.

Incubation and Analytical Procedures

A series of in vitro experiments were conducted to determine the degree of escape protection from blending CSFA and niacin. The amount of niacin leaching from either ruminal fluid or McDougall buffer solution
(Marten and Barnes, 1980) at different pH's was measured. The effects of different particle sizes of CSFA were explored as well.

**Experiment 1**

CSFA were sifted through metal sieves so that four particle sizes were obtained (size 1, .279 mm; size 2, .200 mm; size 3, .059 mm; and size 4, < .059 mm). The different proportions by weight for sizes 1 to 4 were as follows: 12%, 15%, 16%, and 57%.

Duplicate samples (.5 g) of each of the four particle sizes, plus samples of "unsifted" MEGALAC (size 5), were placed in 125-ml Erlenmeyer flasks and incubated at 38°C in 100 ml of a pH 6.5 McDougall buffer solution. Samples from each flask (1 ml) were taken with 2-ml plastic syringes loaded with .45-μm filter at 0, 1, 4, 8, 24, and 48 h. The samples were then refrigerated at 5°C for 2 d until analyzed.

**Experiment 2**

Duplicate samples of size 1, 2, and a combination of sizes 3 and 4 were incubated, as in experiment 1, in 100 ml of McDougall buffer solutions at four different pH's (5.5, 6.0, 6.5, and 7.0), which were adjusted by adding either .1 N NaOH or HCL. Samples were obtained at the same time intervals, filtered, and stored as in experiment 1.

**Experiment 3**

Duplicate samples of "unsifted" CSFA were incubated as in experiment 1 in either McDougall solution (pH 6.5) or in ruminal fluid. Samples were obtained at 0, 1, 4, 8, 18, and 48 h, and filtered, and stored as in experiment 1. Ruminal fluid had been collected from a fistulated cow, strained through four layers of cheesecloth, and mixed with two or three
drops of saturated mercuric chloride; 500 ml were then centrifuged at 1000 x g for 10 min. to remove feed particles and protozoa.

A method for the simultaneous determination of both forms of niacin (NM and NA) was set up by using high performance liquid chromatography (HPLC) separation. HPLC was performed on a Waters HPLC system using a liquid chromatographic detector, ISCO-UA5 (Water Assoc., Milford, MA), a Rheodyne syringe-loading sample injector, Model 7120 (Rheodyne, Berkeley, CA.), and a C-18 column, 150 X 4.6 mm I.D., particle size 4.5 µm (Alltech Assoc. Inc., USA). The detection wavelength was 260 nm. The HPLC system was interfaced with an integrator (Waters Model 730 Data Module) for data processing. The samples containing niacin were injected as an aqueous solution and chromatographed with a degassed solution of 50 mM potassium dihydrogen phosphate and acetonitrile buffer solution (90:10, V/V, pH 4.5). About 6 min were required to separate both compounds.

Cows, Diets, and Management

For the feeding trial, 50 Holstein cows, 20 primiparous and 30 multiparous, between 60 to 200 days in lactation were grouped into 10 blocks of 5 cows each. Each block was matched as closely as possible for parity, stage of lactation, production level, milk composition, body weight, and body condition score (Table 1). Cows selected for each block were allocated randomly to one of five dietary treatments. Thus, there were five dietary groups of 10 cows each. Cows were housed in a tie-stall barn and fed a complete mixed ration individually at 0800 and 1500 h for ad libitum intake and to allow for approximately 10% weighback each day. The
TABLE 1. Characteristics of cows for individual replications.

<table>
<thead>
<tr>
<th>Block</th>
<th>Parity</th>
<th>Days in milk (Avg.)</th>
<th>Milk produced (kg/d)</th>
<th>Milk fat (%)</th>
<th>Milk protein (%)</th>
<th>Body weight (kg)</th>
<th>Body condition score&lt;sup&gt;2&lt;/sup&gt;</th>
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<tr>
<td>1</td>
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<td>167</td>
<td>32.3</td>
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<tr>
<td>2</td>
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<td>561</td>
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<td>3.71</td>
<td>3.49</td>
<td>619</td>
<td>2.55</td>
</tr>
</tbody>
</table>

Average 121 36.1 3.55 3.28 586 2.57

SD 34 5.8 .37 .24 63 .34

<sup>1</sup> M = multiparous, P = primiparous.

<sup>2</sup> Body condition scores range from 1 = very thin to 5 = obese. Scoring was done by the same two people each time, and results were averaged.
trial was conducted from May 25 to December 6, 1991. Average ambient temperatures are in Table 2.

The five diets were based upon a control diet (C) that was fed as a total mixed ration, which was made up of alfalfa hay or alfalfa haylage, corn silage, and commercial concentrate (Table 3). Dietary composition changed between replications because of different levels of production and different dietary needs (NRC, 1989); however, all cows in an individual replication were fed the same diet with no dietary changes during that replication (Table 4). Alfalfa hay was provided to the cows during the first four replications, but it was replaced with alfalfa haylage during the last six replications (Table 4).

A mixture of CSFA and 3% NM were blended by the Church and Dwight Co. during the synthesis of one lot of CSFA (CSFA+NMB). By adding supplemental ingredients to the control diet, five diets were prepared for the five treatments. Those five were: 1) control; 2) CSFA+NMB at 412 g/d, 3) CSFA at 400 g/d, 4) NM (Sigma Chemical Co., St. Louis, MO.) at 12 g/d, and 5) CSFA at 400 g/d plus 12 g/d of separate NM added to the diet (CSFA+NMS). Diets 2, 4, and 5 were designed to provide equal amounts of nicotinamide. Supplements were individually mixed into the ration daily.

Each replication involved 5 wk. During the wk 1, which always began on Saturday, all five cows were fed the control diet. Week two was for adjustment as CSFA and/or NM were gradually incorporated into the diets. During wk 3, 4, and 5 the cows received the diet prescribed for each treatment.
TABLE 2. Average daily temperatures for each month of the experiment.

<table>
<thead>
<tr>
<th>Month</th>
<th>Range</th>
<th>Average</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>8.3 to 32.8</td>
<td>21.0</td>
<td>6.4</td>
</tr>
<tr>
<td>June</td>
<td>12.2 to 35.6</td>
<td>23.3</td>
<td>6.7</td>
</tr>
<tr>
<td>July</td>
<td>10.0 to 34.4</td>
<td>23.2</td>
<td>7.2</td>
</tr>
<tr>
<td>August</td>
<td>9.4 to 31.1</td>
<td>21.9</td>
<td>6.1</td>
</tr>
<tr>
<td>September</td>
<td>-1.1 to 30.6</td>
<td>17.4</td>
<td>9.0</td>
</tr>
<tr>
<td>October</td>
<td>-6.1 to 27.8</td>
<td>10.6</td>
<td>9.6</td>
</tr>
<tr>
<td>November</td>
<td>-21.1 to 12.2</td>
<td>-2.0</td>
<td>8.1</td>
</tr>
<tr>
<td>December</td>
<td>-20.0 to 8.3</td>
<td>-2.4</td>
<td>6.4</td>
</tr>
</tbody>
</table>
### TABLE 3. Chemical composition of feedstuffs used during the experiment.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Alfalfa hay</th>
<th>Alfalfa haylage</th>
<th>Corn silage</th>
<th>Concentrate grain mixture'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter</td>
<td>% in ingredients</td>
<td>% of dry matter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude protein</td>
<td>12.4</td>
<td>15.3</td>
<td>8.0</td>
<td>22.3</td>
</tr>
<tr>
<td>Acid detergent fiber</td>
<td>45.7</td>
<td>34.7</td>
<td>22.4</td>
<td>7.4</td>
</tr>
<tr>
<td>Neutral detergent fiber</td>
<td>54.2</td>
<td>43.7</td>
<td>47.1</td>
<td>9.0</td>
</tr>
<tr>
<td>Calcium</td>
<td>1.35</td>
<td>1.36</td>
<td>.33</td>
<td>.74</td>
</tr>
<tr>
<td>Phosphorous</td>
<td>.25</td>
<td>.28</td>
<td>.26</td>
<td>.69</td>
</tr>
<tr>
<td>Net energy of lactation</td>
<td>1.10</td>
<td>1.39</td>
<td>1.69</td>
<td>1.78</td>
</tr>
</tbody>
</table>

'The concentrate mixture contained: 60% corn, 36% SBM (44% crude protein), 1% sodium bicarbonate, .5% magnesium oxide, 1.0% dicalcium phosphate, .5% calcium carbonate, .75% trace mineralized salt, 4400 IU vitamin A per kg, and 1100 IU vitamin E per kg.
TABLE 4. Summary of feeds fed during individual replications'.

<table>
<thead>
<tr>
<th>Replication</th>
<th>% of dry matter</th>
<th>Alfalfa hay</th>
<th>Alfalfa haylage</th>
<th>Corn silage</th>
<th>Concentrate grain mixture'</th>
<th>Forage to concentrate ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14.6</td>
<td>-</td>
<td>45.8</td>
<td>39.6</td>
<td>60:40</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>16.6</td>
<td>-</td>
<td>41.8</td>
<td>41.6</td>
<td>58:42</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>4.6</td>
<td>-</td>
<td>46.2</td>
<td>49.2</td>
<td>51:49</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2.4</td>
<td>-</td>
<td>44.1</td>
<td>53.5</td>
<td>46:54</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>21.1</td>
<td>44.8</td>
<td>34.1</td>
<td>66:34</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>-</td>
<td>11.1</td>
<td>30.1</td>
<td>58.8</td>
<td>41:59</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>-</td>
<td>10.9</td>
<td>24.4</td>
<td>65.7</td>
<td>35:65</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>-</td>
<td>9.3</td>
<td>25.3</td>
<td>65.4</td>
<td>35:65</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>-</td>
<td>6.9</td>
<td>34.9</td>
<td>58.2</td>
<td>42:58</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td>8.0</td>
<td>27.5</td>
<td>64.5</td>
<td>35:65</td>
<td></td>
</tr>
</tbody>
</table>

'Feeds were different for each replication because amounts of milk produced were different and because available feed ingredients changed somewhat.
Amounts of feed offered and refused were recorded daily. Samples of the control diet were collected five times each week and composited by week. Refusals were collected daily and composited by week. Cows were milked twice daily, and milk weights recorded. Milk samples were collected in two 100-ml plastic tubes containing approximately 50 mg of potassium dichromate. There were four collections at the end of wk 1 and 5 (Wednesday p.m., Thursday a.m. and p.m., and Friday a.m.) and two collections at the end of wk 3 and 4 (Thursday p.m. and Friday a.m.).

Blood samples were taken from the jugular vein twice during wk 1 and 5 (Thursday and Friday) and once during wk 3 and 4 (Friday), approximately 4 h after the a.m. feeding. Blood samples were collected into three 5 ml tubes. Two tubes containing 50 USP units of heparin and 75 μl of 4% NaF were maintained in ice until being centrifuged for 10 min, after which plasma was collected and stored at -20°C. Another 5 ml heparinized tube containing whole blood, without NaF, was maintained on ice and processed within 3 h (Shibata, 1987). The supernatant then was frozen at -20°C and later analyzed for NM content (Shibata, 1987).

Body weights were recorded before blood sampling (Friday) during wk 1 and 5. Body condition scores, on the other hand, were determined once at the end of wk 1 and 5. A score of one indicated a very thin cow and five represented a very obese cow (Wildman et al., 1982).

Chemical Analyses

Milk samples for each cow for a given week were assayed for protein and fat (courtesy of Swiss Valley Farms Laboratory, Farley, IA) by using an
infrared analyzer (Milk-O-Scan 203, Foss Food Technology, Eden Prairie, MN). Solids-not-fat and fat-corrected-milk were calculated also (Tyrrell and Reid, 1965; NRC, 1989).

Feed and refusal samples were dried at 55°C, allowed to equilibrate with air, and ground through a 1-mm screen in a Wiley Mill. Samples were analyzed for DM, CP, ether extract, and ash according to procedures of the Association of Official Analytical Chemists (AOAC, 1984). Neutral detergent fiber and ADF were determined by the procedures of Goering and Van Soest (1970).

Blood plasma samples were analyzed enzymatically for concentrations of glucose by using glucose oxidase (Sigma glucose kit #315-500, Sigma Chemical Co., St. Louis, MO.). Intra- and inter-assay coefficients of variation (CV) for glucose were determined from a plasma pool from a control cow (58.4 ± 0.31 mg/dl) and was 1.87 and 1.98%, respectively. Nonesterified fatty acid (NEFA) concentrations were determined by using a modification of a commercial kit (NEFA-C kit, WAKO Chemical Co. USA, Dallas, TX) as described by Drackley (1989). Intra- and inter-assay coefficients were determined from another control cow, which had a concentration of 142 ± 14 μmol/L and were 5.3 and 5.8%, respectively. One milliliter of plasma was deproteinized by using 2 ml of .3 N Ba(OH), and 2 ml of 5% ZnSO4 (Somogyi, 1945). The protein-free filtrates then were assayed enzymatically for β-hydroxybutyrate (Williamson and Mellanby, 1974). β-hydroxybutyrate had a plasma pool concentration of 3.98 ± .06 mg/dl and an intra- and inter-assay of 4.02 and 4.58%, respectively.
Blood nicotinamide content was determined by using HPLC as described by Shibata (1987).

Statistical Analyses

All data were subjected to analysis of variance by using the general linear models procedure of SAS (SAS Institute, 1982) for a split-plot design. An analysis of variance was conducted on a fixed linear model with treatment, parity, and cow-within-parity as main effects. The subplot effects were week and treatment by week. Data from week 1 of each replication were used as covariates. Comparisons among treatments were by orthogonal, single degree of freedom contrasts.
RESULTS AND DISCUSSION

Stability and In Vitro Solubility of Protected Niacin

It has been reported that niacin seems to be very resistant separately to heat, air, and alkali; however, it will undergo decarboxylation when high temperature and an alkaline medium are combined (Merck Index, 1989). Therefore, our first objective was to extract the NM from CSFA to determine its stability after having undergone the normal process of blending during synthesis of CSFA. Our results showed that the method used for extracting niacin was both fast and effective. The values for niacin concentration obtained after 30 S of manual homogenization were practically the same as those obtained after up to 48 h of incubation at 38°C, which clearly showed that almost all the niacin had been rapidly separated from the CSFA (approximately 3.0 % of the total weight). From this amount found by HPLC separation, 90% was identified as NM and 10% as NA, showing that although some deamidation may have occurred during the process used by Church and Dwight, most of the niacin was still active.

The total amount of niacin leached from CSFA at incubation times up to 72 h with various buffers or ruminal fluid was very similar to the 3% values obtained by using the extraction method. (Approximately 3% was the calculated amount added by Church and Dwight.) Most of the niacin had, in fact, leached out by 6 to 10 h, which indicated that NM blended into CSFA is not a strong possibility for escaping niacin past the rumen and into the small intestine. The data obtained using McDougall buffer at different pHs
(5.5, 6.0, 6.5, and 7.0) indicated that under these conditions pH does not have a major effect on the leaching of niacin from CSFA.

Using four particle sizes indicated that the smaller the particle size, the faster niacin gets into solution. For instance, size one had 45, 30, 22, and 10% less niacin leaching than size five at 1, 4, 8, and 24 h of incubation, respectively. These findings were corroborated in another experiment by comparing ground and unground "complete" CSFA. Less niacin leached out of the unground compared with the ground CSFA at 1 h (35%), 4 h (22%), and 8 h (18%); therefore, about 20% of the niacin was protected at 8 h of incubation. By 12 h, all the niacin contained in both ground and unground CSFA was into the buffer solution.

General Characteristics of Cows

Characteristics of cows, averaged for each replication, are shown in Table 1. As stated before, there were six replications of multiparous and four replications of primiparous cows. Average days in milk at the start of each replication ranged from 71 to 167 with a general average of 121 d. Values for milk production and composition are averages of the last three days of the week before the beginning of each replication. Body condition score was not measured during the first replication. Two replications of cows, one multiparous and one primiparous, were used twice during the trial. Cows in replications two and six were used again for replications five and nine, respectively; with either 4 or 5 wk on the control diet before cows were reassigned to treatments.
Chemical Composition of Feedstuffs

Chemical composition of forages and the concentrate grain mixture is given in Table 3. These ingredients are typical components in diets for dairy cows in the midwestern region of the United States. Alfalfa hay was fed to the cows in replications one to four (Table 4), but it was replaced by alfalfa haylage during replications five to ten. Forage to concentrate ratios of the complete diets ranged from 66:34 to 35:65 (Table 4) in order to adjust for variable energy requirements, which were different (Table 1) because of parity, days in milk production, milk fat percentage, and body weight (NRC, 1989).

Intake, Body Weight, and Body Score Changes

Pretreatment feed intake

Average pretreatment daily intakes of dry matter (DM), organic matter (OM), NDF, ADF, ether extract (EE), and crude protein (CP) are in Table 5. Dry matter consumption averaged about 3.8% of body weight. Daily intake of DM, OM, NDF, EE, and CP were not different among groups; intake of ADF, however was about 6% lower for control cows compared with all other treatments. We observed that some cows were selective for choosing either the concentrate or the forage portion of the ration; in addition, the cows were fed amounts to allow approximately 10% weighback, this may explain some of the differences in intakes of NDF, ADF, EE and CP observed in wk 3, 4, and 5. Parity significantly affected intake measures; multiparous cows, as anticipated, had higher (P<.01) intakes than primiparous cows for all individual constituents (data not shown).
TABLE 5. Average pretreatment feed intake from cows fed one of five different diets.

<table>
<thead>
<tr>
<th>Item</th>
<th>Dietary groups</th>
<th>Contrasts</th>
<th>C vs. all CSFA groups</th>
<th>C vs. all NM groups</th>
<th>NM vs. both CSFA+NM groups</th>
<th>CSFA vs. both CSFA+NM groups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>CSFA+</td>
<td>CSFA</td>
<td>NM</td>
<td>CSFA+</td>
<td>SE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NMB</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intake (kg/d)</td>
<td>22.4</td>
<td>22.2</td>
<td>22.9</td>
<td>22.4</td>
<td>23.4</td>
<td>.69</td>
</tr>
<tr>
<td>Dry matter</td>
<td>21.1</td>
<td>20.9</td>
<td>21.6</td>
<td>21.1</td>
<td>22.1</td>
<td>.65</td>
</tr>
<tr>
<td>Organic matter</td>
<td>7.3</td>
<td>7.5</td>
<td>7.7</td>
<td>7.7</td>
<td>7.8</td>
<td>.22</td>
</tr>
<tr>
<td>Neutral detergent fiber</td>
<td>3.9</td>
<td>4.1</td>
<td>4.1</td>
<td>4.1</td>
<td>4.2</td>
<td>.12</td>
</tr>
<tr>
<td>Acid detergent fiber</td>
<td>.71</td>
<td>.70</td>
<td>.72</td>
<td>.72</td>
<td>.73</td>
<td>.02</td>
</tr>
<tr>
<td>Ether extract</td>
<td>3.5</td>
<td>3.4</td>
<td>3.6</td>
<td>3.4</td>
<td>3.7</td>
<td>.10</td>
</tr>
</tbody>
</table>
Diets were: C - control, CSFA+NMB = calcium salts of fatty acids plus 3% nicotinamide blended during synthesis, CSFA = calcium salts of fatty acids, NM = nicotinamide, CSFA+NMS = calcium salts of fatty acids plus nicotinamide added separately.

These contrasts were calculated for pretreatment data collected before cows were assigned to the diets indicated.

C vs. CSFA+NMB, CSFA, and CSFA+NMS.

C vs. CSFA+NMB, NM, and CSFA+NMS.

NM vs. CSFA+NMB and CSFA+NMS.

CSFA vs. CSFA+NMB and CSFA+NMS.
Treatment feed intake

Average daily intakes of cows during wk 3, 4, and 5 for all individual feed constituents, except EE, were not different among dietary groups (Tables 6, 7, and 8) and also were not affected by parity (data not shown). Dry matter intake is not affected by CSFA supplementation at levels of 3% of ration DM (Schneider et al., 1988; Schauff and Clark, 1989; West and Hill, 1990; Hansen et al., 1991; Erickson et al., 1992; Wu et al., 1992). Klusmeyer et al. (1991) reported that cows supplemented with CSFA at 4% DM of the diet consumed about 1.2 kg/d less DM and OM than cows fed diets without CSFA, but these differences were not significant. When CSFA is added into the diet at higher levels (6 or 9% DM), however, DM intake decreases linearly (Schauff and Clark, 1990). Our levels of CSFA supplementation represented about 2.1% of ration DM. Because DM intake was not altered by treatment, the difference in EE intake was attributed to CSFA supplementation. When data for wk 3, 4, and 5 were averaged (Table 9), however, the group of cows receiving the NM diet had higher intakes (P ≤ .06) of all individual feed constituents measured compared with the group of cows supplemented with both CSFA+NM.

Similar results were reported by Kung et al. (1980) and Riddell et al. (1981) in early and midlactation Holstein cows supplemented with 6 g of NA or supplemented with 6 g of niacin plus heat-treated soybeans (Driver et al., 1990). Other reports, however, have shown no effects of supplemental niacin on DM intake of cows in early or midlactation (Horner et al., 1986, 1988b; Martinez et al., 1991; Erickson et al., 1992). Detrimental effects
TABLE 6. Feed intake during week 3 for cows fed one of five different diets.

<table>
<thead>
<tr>
<th>Item</th>
<th>Dietary groups</th>
<th>Contrasts</th>
<th>Contrasts</th>
<th>Contrasts</th>
<th>Contrasts</th>
<th>Contrasts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>CSFA+</td>
<td>NMB</td>
<td>CSFA</td>
<td>NM</td>
<td>CSFA+</td>
</tr>
<tr>
<td>Dry matter (kg/d)</td>
<td>19.7</td>
<td>19.8</td>
<td>19.3</td>
<td>21.1</td>
<td>21.0</td>
<td>.84</td>
</tr>
<tr>
<td>Organic matter</td>
<td>18.6</td>
<td>18.6</td>
<td>18.1</td>
<td>19.8</td>
<td>19.8</td>
<td>.80</td>
</tr>
<tr>
<td>Neutral detergent fiber</td>
<td>6.4</td>
<td>6.3</td>
<td>6.3</td>
<td>6.7</td>
<td>6.7</td>
<td>.28</td>
</tr>
<tr>
<td>Acid detergent fiber</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.7</td>
<td>3.7</td>
<td>.15</td>
</tr>
<tr>
<td>Ether extract</td>
<td>.95</td>
<td>1.5</td>
<td>1.5</td>
<td>1.1</td>
<td>1.6</td>
<td>.03</td>
</tr>
<tr>
<td>Crude protein</td>
<td>3.2</td>
<td>3.2</td>
<td>3.1</td>
<td>3.6</td>
<td>3.4</td>
<td>.13</td>
</tr>
</tbody>
</table>
Diets were: $C =$ control, $CSFA+NMB =$ calcium salts of fatty acids plus 3% nicotinamide blended during synthesis, $CSFA =$ calcium salts of fatty acids, $NM =$ nicotinamide, $CSFA+NMS =$ calcium salts of fatty acids plus nicotinamide added separately.

$^3$Covariate adjusted for pretreatment (wk 1) feed intake.

$^3$C vs. $CSFA+NMB$, $CSFA$, and $CSFA+NMS$.

$^4$C vs. $CSFA+NMB$, $NM$, and $CSFA+NMS$.

$^5$NM vs. $CSFA+NMB$ and $CSFA+NMS$.

$^6$CSFA vs. $CSFA+NMB$ and $CSFA+NMS$. 
TABLE 7. Feed intake during week 4 for cows fed one of five different diets.

<table>
<thead>
<tr>
<th>Item</th>
<th>Dietary groups¹</th>
<th>Contrasts²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>CSFA+</td>
</tr>
<tr>
<td></td>
<td>NMB</td>
<td>NMS</td>
</tr>
<tr>
<td>Item</td>
<td>Intake (kg/d)</td>
<td>P &gt; F</td>
</tr>
<tr>
<td>Dry matter</td>
<td>19.5</td>
<td>18.8</td>
</tr>
<tr>
<td>Organic matter</td>
<td>18.4</td>
<td>17.6</td>
</tr>
<tr>
<td>Neutral detergent fiber</td>
<td>5.9</td>
<td>5.7</td>
</tr>
<tr>
<td>Acid detergent fiber</td>
<td>3.7</td>
<td>3.2</td>
</tr>
<tr>
<td>Ether extract</td>
<td>1.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Crude protein</td>
<td>3.1</td>
<td>3.0</td>
</tr>
</tbody>
</table>
Diet were: C = control, CSFA+NMB = calcium salts of fatty acids plus 3% nicotinamide blended during synthesis, CSFA = calcium salts of fatty acids, NM = nicotinamide, CSFA+NMS = calcium salts of fatty acids plus nicotinamide added separately.

Covariate adjusted for pretreatment (wk 1) feed intake.

C vs. CSFA+NMB, CSFA, and CSFA+NMS.

C vs. CSFA+NMB, NM, and CSFA+NMS.

NM vs. CSFA+NMB and CSFA+NMS.

CSFA vs. CSFA+NMB and CSFA+NMS.
<table>
<thead>
<tr>
<th>Item</th>
<th>Dietary groups</th>
<th>Contrasts</th>
<th>Contrasts</th>
<th>Contrasts</th>
<th>Contrasts</th>
<th>Contrasts</th>
<th>Contrasts</th>
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<th>Contrasts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>C vs. all</td>
<td>C vs. all</td>
<td>NM vs. both</td>
<td>CSFA vs. both</td>
<td>CSFA+NM groups</td>
<td>CSFA+NM groups</td>
<td></td>
</tr>
<tr>
<td>Item</td>
<td>C</td>
<td>CSFA</td>
<td>NM</td>
<td>CSFA+NMS</td>
<td>SE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Intake (kg/d)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry matter</td>
<td>18.1</td>
<td>19.5</td>
<td>19.7</td>
<td>21.4</td>
<td>18.3</td>
<td>1.0</td>
<td>.63</td>
<td>.41</td>
<td>.16</td>
</tr>
<tr>
<td>Organic matter</td>
<td>17.0</td>
<td>18.4</td>
<td>18.5</td>
<td>20.2</td>
<td>17.2</td>
<td>.96</td>
<td>.63</td>
<td>.41</td>
<td>.16</td>
</tr>
<tr>
<td>Neutral detergent fiber</td>
<td>5.8</td>
<td>6.1</td>
<td>6.1</td>
<td>6.7</td>
<td>5.5</td>
<td>.31</td>
<td>.81</td>
<td>.57</td>
<td>.16</td>
</tr>
<tr>
<td>Acid detergent fiber</td>
<td>3.3</td>
<td>3.4</td>
<td>3.5</td>
<td>3.7</td>
<td>3.2</td>
<td>.09</td>
<td>.81</td>
<td>.62</td>
<td>.21</td>
</tr>
<tr>
<td>Ether extract</td>
<td>1.1</td>
<td>1.5</td>
<td>1.5</td>
<td>1.2</td>
<td>1.5</td>
<td>.04</td>
<td>.0001</td>
<td>.0001</td>
<td>.0001</td>
</tr>
<tr>
<td>Crude protein</td>
<td>2.9</td>
<td>3.2</td>
<td>3.2</td>
<td>3.5</td>
<td>3.0</td>
<td>.16</td>
<td>.62</td>
<td>.40</td>
<td>.20</td>
</tr>
</tbody>
</table>
Diets were: C = control, CSFA+NMB = calcium salts of fatty acids plus 3% nicotinamide blended during synthesis, CSFA = calcium salts of fatty acids, NM = nicotinamide, CSFA+NMS = calcium salts of fatty acids plus nicotinamide added separately.

Covariate adjusted for pretreatment (wk 1) feed intake.

C vs. CSFA+NMB, CSFA, and CSFA+NMS.

C vs. CSFA+NMB, NM, and CSFA+NMS.

NM vs. CSFA+NMB and CSFA+NMS.

CSFA vs. CSFA+NMB and CSFA+NMS.
TABLE 9. Average feed intake for weeks 3, 4, and 5 for cows fed one of five different diets

<table>
<thead>
<tr>
<th>Item</th>
<th>Dietary groups¹</th>
<th>Contrasts²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>CSFA+</td>
</tr>
<tr>
<td>Dry matter</td>
<td>19.3</td>
<td>19.3</td>
</tr>
<tr>
<td>Organic matter</td>
<td>18.0</td>
<td>18.2</td>
</tr>
<tr>
<td>Neutral detergent fiber</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Acid detergent fiber</td>
<td>3.4</td>
<td>3.4</td>
</tr>
<tr>
<td>Ether extract</td>
<td>1.1</td>
<td>1.5</td>
</tr>
<tr>
<td>Crude protein</td>
<td>3.1</td>
<td>3.1</td>
</tr>
</tbody>
</table>
Diets were: C = control, CSFA+NMB = calcium salts of fatty acids plus 3% nicotinamide blended during synthesis, CSFA = calcium salts of fatty acids, NM = nicotinamide, CSFA+NMS = calcium salts of fatty acids plus nicotinamide added separately.

'Covariate adjusted for pretreatment (wk 1) feed intake.

'C vs. CSFA+NMB, CSFA, and CSFA+NMS.

'C vs. CSFA+NMB, NM, and CSFA+NMS.

'NM vs. CSFA+NMB and CSFA+NMS.

'CSFA vs. CSFA+NMB and CSFA+NMS.
were found on DM intake of cows in similar stages of lactation under heat stress conditions (Skaar et al., 1989; Lanham et al., 1992). Multiparous cows had higher (P = .05) NDF intake than primiparous cows (data not shown). To our knowledge, data are not available for effects of NM on intake of individual constituents; Dufva et al. (1983), however, observed a lower intake of hay and a higher intake of grain in cows supplemented with niacin compared to controls. Why this effect in our trial was more evident in primiparous than in multiparous cows is unknown.

**Initial body characteristics of cows and changes during the trial**

Initial body weight (BW) and body condition scores (BCS) are shown in Table 10. Multiparous cows were heavier (P < .01), as expected, than primiparous cows (623 vs 538 kg, data not shown). Average BW gain (kg/d) measured during the last 4 wk of the experiment tended to be higher (P < .13) for cows in all NM groups compared to control (C) cows (Table 10), whereas cows in all CSFA groups had higher (P ≤ .10) weight gain than C cows. The average cumulative gain for the group of control cows was only 2.5 kg, whereas the average cumulative gain for cows in all CSFA and all NM groups was approximately 11 kg and 10 kg, respectively. Average daily gain was not affected by parity.

Initial BCS and changes in BCS also were affected by parity. Multiparous cows had lower (P < .01) initial BCS (2.50 vs 2.71, data not shown) and showed lower (P = .08) increases in BCS (.04 vs .13) than primiparous cows. Change of BCS, on the other hand, was similar for all cows in all the CSFA groups and was significantly higher for cows in the NM groups compared to cows in group C (P = .04). Wildman et al. (1982) found
TABLE 10. Initial body characteristics and changes during the entire trial for cows fed one of five different diets.

<table>
<thead>
<tr>
<th>Item</th>
<th>Dietary groups</th>
<th>Contrasts</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CSFA+</td>
<td>CSFA</td>
<td>NM</td>
<td>CSFA+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>NMB</td>
<td></td>
<td></td>
<td></td>
<td>CSFA</td>
<td>NM</td>
<td>CSFA+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item</td>
<td>C vs. all CSFA groups</td>
<td>C vs. all NM groups</td>
<td>NM vs. CSFA+NM groups</td>
<td>CSFA vs. both CSFA+NM groups</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body weight:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial (kg)</td>
<td>590</td>
<td>591</td>
<td>597</td>
<td>562</td>
<td>605</td>
<td>21.4</td>
<td>.53</td>
<td>.93</td>
<td>.12</td>
<td>.88</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change (kg/d)</td>
<td>.09</td>
<td>.34</td>
<td>.46</td>
<td>.41</td>
<td>.37</td>
<td>.20</td>
<td>.10</td>
<td>.13</td>
<td>.63</td>
<td>.47</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body condition score:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial'</td>
<td>2.53</td>
<td>2.46</td>
<td>2.68</td>
<td>2.75</td>
<td>2.59</td>
<td>.15</td>
<td>.67</td>
<td>.74</td>
<td>.55</td>
<td>.36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change*</td>
<td>.03</td>
<td>.11</td>
<td>.06</td>
<td>.11</td>
<td>.13</td>
<td>.05</td>
<td>.10</td>
<td>.04</td>
<td>.77</td>
<td>.30</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Diets were: C = control, CSFA+NMB = calcium salts of fatty acids plus 3% nicotinamide blended during synthesis, CSFA = calcium salts of fatty acids, NM = nicotinamide, CSFA+NMS = calcium salts of fatty acids plus nicotinamide added separately.

Contrasts for initial values were calculated for pretreatment data collected before cows were assigned to the diets indicated.

C vs. CSFA+NMB, CSFA, and CSFA+NMS.

C vs. CSFA+NMB, NM, and CSFA+NMS.

NM vs. CSFA+NMB and CSFA+NMS.

CSFA vs. CSFA+NMB and CSFA+NMS.

BS = body condition score. Five point scale, where 1 = thin and 5 = obese.

From wk 1 to wk 5.
a significant correlation coefficient indicating that as BCS increased, body weight increased. No differences were detected among groups of cows supplemented with CSFA, CSFA plus both forms of NM, or NM.

There are relatively few reports of the effects of fat and/or niacin on BW or BCS changes in cows. Schneider et al. (1988) found no effects of CSFA on BW of Jersey and Holstein cows in early lactation supplemented with .45 or .50 kg/d, respectively. Accordingly, West and Hill (1990) reported no BW changes with cows of the same breed averaging 95 d in milk. Although fat supplementation did not decrease BW loss in early lactation, cows supplemented with prilled fat increased the rate of BW gain after 8 wk postpartum, and NA supplementation seemed to decrease BW loss during wk 2 to 4. Interestingly, fat and NA treatments together seemed to have additive effects and aided cows in returning to their 2 wk postpartum BW faster than cows without supplementation (Skaar et al., 1989). Additive effects of supplemental NA X level of protein on BW of early lactation cows were found by Zimmerman et al. (1992). Cows receiving 12 g/d NA in a high protein diet gained weight (.27 kg/d) during wk 2 to 5 of lactation, whereas cows receiving either a high protein diet without NA or low protein diets with and without NA were losing an average of .64 kg/d.

The only experiment that compared the effects of adding 12 g/d of either NA or NM to diets of lactating cows from 2 wk prepartum to 12 wk postpartum was done by Jaster and Ward (1990). Beginning with wk 6 and continuing through wk 12 postpartum, average daily gain of cows receiving NM was .41 kg compared with .25 and .33 kg for cows receiving NA or control diet. In contrast, other reports showed no effects of dietary
Body condition score (BCS) is becoming an important indicator of the potential ability of cows to produce milk, reproduce at ideal intervals, and attain longevity in the herd (Sniffen and Ferguson, 1991). Nevertheless, most researchers do not measure this parameter to determine effects of a given diet on the general condition of cows.

Some reports indicated that BCS tended to increase by .03 and .08 units in cows during early lactation that were supplemented with .45 kg of MEGALAC beginning at wk 2 or 6 of lactation, respectively (Eastridge and Palmquist, 1988). Similar trends but stronger responses were shown by Son et al. (1992) when fat was supplemented to lactating cows either from parturition to wk 14 of lactation (early supplementation) or from wk 5 to wk 14 of lactation (delayed supplementation). The increased increments reported for BCS were .23 and .26 for early and delayed supplementation cows, respectively, compared with control cows. The cows used in our experiment had an initial average BCS of 2.60 and a final BCS of 2.69, which is within the optimal range for cows in early and midlactation (2.60 to 3.25) as suggested by Sniffen and Ferguson (1991).

Some data on effects of niacin on BCS of lactating dairy cows show contradictory results. Jaster et al. (1983) reported the same BCS for primiparous or multiparous cows supplemented with 6 g/d NA during the first 10 wk postpartum as for cows without NA supplementation, whereas Eastridge et al. (1990) found higher BCS in cows receiving 6 g/d NA supplementation during wk 2 to 15 of lactation versus cows receiving the control diet.
Milk Production and Composition

**Pretreatment data**

Figures for milk production and composition, discussed later in this section are presented in two forms: A) actual means for milk production and composition and B) adjusted means for milk production and composition as a covariate of wk 1.

Average milk production and composition of groups of cows during the pretreatment period were similar for all the parameters measured (Table 11) except for milk protein production of cows in the C group compared with groups of cows receiving NM supplementation (P ≤ .06). This difference may be attributed to lower average milk production and protein percentage of cows in the NM group. During the pretreatment period, all the production parameters (milk, FCM, fat, and protein) were higher (P < .01) for multiparous than for primiparous cows (data not shown). Fat percentage was similar, but protein content was higher (P < .05) in primiparous than in multiparous cows. As parity increases, casein content of milk decreases (Waite et al., 1956); previously, higher concentrations of milk protein were observed for primiparous than for multiparous cows (DePeters et al., 1985, 1989; Chow et al., 1990).

**Treatment data**

Average production of milk during wk 3 and 4 of the trial was not affected by treatment (Tables 12 and 13, respectively) or by parity (data not shown). During these weeks, however, milk production of cows in the C and CSFA groups tended to decrease faster than cows in the CSFA+NMB, CSFA+NMS, and NM groups (Figure 1); nevertheless, the group of cows
TABLE II. Average of pretreatment milk production and composition for cows fed one of five different diets.

<table>
<thead>
<tr>
<th>Item</th>
<th>Dietary groups'</th>
<th>Contrasts'</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>CSFA+ NMB</td>
</tr>
<tr>
<td>Milk, kg/d</td>
<td></td>
<td>35.5</td>
</tr>
<tr>
<td>4% FCM, kg/d</td>
<td></td>
<td>30.4</td>
</tr>
<tr>
<td>Fat, %</td>
<td></td>
<td>3.07</td>
</tr>
<tr>
<td>Fat, kg/d</td>
<td></td>
<td>1.08</td>
</tr>
<tr>
<td>Protein, %</td>
<td></td>
<td>3.10</td>
</tr>
<tr>
<td>Protein, kg/d</td>
<td></td>
<td>1.10</td>
</tr>
<tr>
<td>Total solids, %</td>
<td></td>
<td>11.94</td>
</tr>
</tbody>
</table>
Diets were: C - control, CSFA+NMB = calcium salts of fatty acids plus 3% nicotinamide blended during synthesis, CSFA = calcium salts of fatty acids, NM = nicotinamide, CSFA+NMS = calcium salts of fatty acids plus nicotinamide added separately.

These contrasts were calculated for pretreatment data collected before cows were assigned to the diets indicated.

'C vs CSFA+NMB, CSFA, and CSFA+NMS.

'C vs. CSFA+NMB, NM, and CSFA+NMS.

'NM vs. CSFA+NMB and CSFA+NMS.

'CSFA vs. CSFA+NMB and CSFA+NMS.

'FCM = fat-corrected milk.
TABLE 12. Milk production and composition during week 3 for cows fed one of five different diets.

<table>
<thead>
<tr>
<th>Item</th>
<th>Dietary groups'</th>
<th>Contrasts²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>CSFA+</td>
</tr>
<tr>
<td>Milk, kg/d</td>
<td>33.4</td>
<td>33.3</td>
</tr>
<tr>
<td>4% FCM¹, kg/d</td>
<td>30.8</td>
<td>31.0</td>
</tr>
<tr>
<td>Fat, %</td>
<td>3.47</td>
<td>3.56</td>
</tr>
<tr>
<td>Fat, kg/d</td>
<td>1.16</td>
<td>1.17</td>
</tr>
<tr>
<td>Protein, %</td>
<td>3.13</td>
<td>3.03</td>
</tr>
<tr>
<td>Protein, kg/d</td>
<td>1.04</td>
<td>1.0</td>
</tr>
<tr>
<td>Total solids, %</td>
<td>12.07</td>
<td>12.32</td>
</tr>
</tbody>
</table>
Diets were: C - control, CSFA+NMB = calcium salts of fatty acids plus 3% nicotinamide blended during synthesis, CSFA = calcium salts of fatty acids, NM = nicotinamide, CSFA+NMS = calcium salts of fatty acids plus nicotinamide added separately.

Covariate adjusted for pretreatment (wk 1) milk production and composition.

C vs. CSFA+NMB, CSFA, and CSFA+NMS.

C vs. CSFA+NMB, NM, and CSFA+NMS.

NM vs. CSFA+NMB, and CSFA+NMS.

CSFA vs. CSFA+NMB, and CSFA+NMS.

FCM = fat-corrected milk.
TABLE 13. Milk production and composition during week 4 for cows fed one of five different diets.

<table>
<thead>
<tr>
<th>Item</th>
<th>Dietary groups1</th>
<th>Contrasts2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>CSFA+</td>
</tr>
<tr>
<td>Milk, kg/d</td>
<td>32.2</td>
<td>33.0</td>
</tr>
<tr>
<td>4% FCM', kg/d</td>
<td>29.9</td>
<td>30.1</td>
</tr>
<tr>
<td>Fat, %</td>
<td>3.50</td>
<td>3.43</td>
</tr>
<tr>
<td>Fat, kg/d</td>
<td>1.13</td>
<td>1.12</td>
</tr>
<tr>
<td>Protein, %</td>
<td>3.16</td>
<td>3.07</td>
</tr>
<tr>
<td>Protein, kg/d</td>
<td>1.00</td>
<td>1.01</td>
</tr>
<tr>
<td>Total solids, %</td>
<td>12.07</td>
<td>12.15</td>
</tr>
</tbody>
</table>
Diets were: C = control, CSFA+NMB = calcium salts of fatty acids plus 3\% nicotinamide blended during synthesis, CSFA = calcium salts of fatty acids, NM = nicotinamide, CSFA+NMS = calcium salts of fatty acids plus nicotinamide added separately.

Covariate adjusted for pretreatment (wk 1) milk production and composition.

^C vs. CSFA+NMB, CSFA, and CSFA+NMS.

^NM vs. CSFA+NMB, and CSFA+NMS.

^CSFA vs. CSFA+NMB, and CSFA+NMS.

^FCM = fat-corrected milk.
Figure 1. Milk production for cows given one of five different dietary treatments. The graph represents either (A) actual data or (B) data that were covariate adjusted based upon values for wk 1.
Experimental diets fed for 5 weeks on trial.
receiving CSFA increased milk production at wk 5; consequently, cows in all the groups receiving CSFA and all the groups receiving NM were producing an average of 2.8 kg/d (P = .004) and 3.1 kg/d (P = .001) more milk, respectively, than the C group (Table 14). Increased milk production because of CSFA supplementation is a common finding. Robb and Chalupa (1987) found average responses for milk production of up to 2.8 kg/d in multiparous and primiparous cows. Shaver (1990) showed that effects on milk production due to CSFA in 10 different experiments averaged 1.4 kg/d. During wk 5, no differences in milk production were detected because of parity (data not shown) or among cows receiving any form of supplementation (Table 14) even though the groups of cows supplemented with CSFA plus NM averaged 1.3 kg/d more milk production (P = .18) compared with cows fed the CSFA diet. When data of wk 3, 4, and 5 were averaged (Table 15), however, milk production for the two groups of cows receiving CSFA plus NM was higher (P = .03) than for the group of cows supplemented with CSFA.

Milk production responses to dietary niacin have been variable. Muller et al. (1986) used 240 cows from five herds that averaged 143 d postpartum, and they showed increased milk production for both primiparous and multiparous cows during the summer season. The response to NA supplementation, however, was three fold higher (2.4 milk kg/d) for cows producing greater than 34 kg milk/d. Dufva et al. (1983) observed no response to niacin in cows supplemented from 2 wk prepartum to 4 wk postpartum, and Jaster and Ward (1990) also did not find responses during the first 8 wk of NM supplementation in a longer experiment (2 wk prepartum to 12 wk postpartum). From wk 9 to 12, however, cows receiving 12 g/d of
TABLE 14. Milk production and composition during week 5 for cows fed one of five different diets.

<table>
<thead>
<tr>
<th>Item</th>
<th>Dietary groups¹</th>
<th>Contrasts²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>C vs. all</td>
</tr>
<tr>
<td></td>
<td>CSFA+NMB</td>
<td>C vs. all</td>
</tr>
<tr>
<td></td>
<td>CSFA</td>
<td>NM vs. both</td>
</tr>
<tr>
<td></td>
<td>NM</td>
<td>CSFA vs. both</td>
</tr>
<tr>
<td></td>
<td>CSFA+NMS</td>
<td>SE</td>
</tr>
<tr>
<td>Milk, kg/d</td>
<td>30.4</td>
<td>.004</td>
</tr>
<tr>
<td>4% FCM, kg/d</td>
<td>28.3</td>
<td>.010</td>
</tr>
<tr>
<td>Fat, %</td>
<td>3.50</td>
<td>.001</td>
</tr>
<tr>
<td>Fat, kg/d</td>
<td>1.07</td>
<td>.780</td>
</tr>
<tr>
<td>Protein, %</td>
<td>3.15</td>
<td>.183</td>
</tr>
<tr>
<td>Protein, kg/d</td>
<td>.94</td>
<td>.799</td>
</tr>
<tr>
<td>Total solids, %</td>
<td>12.02</td>
<td>.005</td>
</tr>
</tbody>
</table>

\[ P > F \]
Diets were: C = control, CSFA+NMB = calcium salts of fatty acids plus 3% nicotinamide blended during synthesis, CSFA = calcium salts of fatty acids, NM = nicotinamide, CSFA+NMS = calcium salts of fatty acids plus nicotinamide added separately.

Covariate adjusted for pretreatment (wk 1) milk production and composition.

C vs. CSFA+NMB, NM, and CSFA+NMS.

C vs. CSFA+NMB, and CSFA+NMS.

NM vs. CSFA+NMB, and CSFA+NMS.

CSFA vs. CSFA+NMB, and CSFA+NMS.

FCM = fat-corrected milk.
TABLE 15. Average milk production and composition of data for weeks 3, 4, and 5 for cows fed one of five different diets.

<table>
<thead>
<tr>
<th>Item</th>
<th>C</th>
<th>CSFA+</th>
<th>CSFA</th>
<th>NM</th>
<th>CSFA+NM</th>
<th>SE</th>
<th>C vs. all CSFA groups¹</th>
<th>C vs. all NM groups¹</th>
<th>NM vs. both CSFA+NM groups¹</th>
<th>CSFA vs. both CSFA+NM groups¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk, kg/d</td>
<td>31.9</td>
<td>33.2</td>
<td>32.3</td>
<td>33.8</td>
<td>33.8</td>
<td>.66</td>
<td>.03</td>
<td>.002</td>
<td>.40</td>
<td>.03</td>
</tr>
<tr>
<td>4% FCM¹, kg/d</td>
<td>29.7</td>
<td>30.6</td>
<td>30.5</td>
<td>30.2</td>
<td>31.5</td>
<td>.74</td>
<td>.04</td>
<td>.05</td>
<td>.23</td>
<td>.30</td>
</tr>
<tr>
<td>Fat, %</td>
<td>3.49</td>
<td>3.49</td>
<td>3.65</td>
<td>3.33</td>
<td>3.59</td>
<td>.11</td>
<td>.28</td>
<td>.90</td>
<td>.02</td>
<td>.36</td>
</tr>
<tr>
<td>Fat, kg/d</td>
<td>1.12</td>
<td>1.15</td>
<td>1.16</td>
<td>1.11</td>
<td>1.20</td>
<td>.04</td>
<td>.10</td>
<td>.30</td>
<td>.07</td>
<td>.73</td>
</tr>
<tr>
<td>Protein, %</td>
<td>3.15</td>
<td>3.10</td>
<td>3.14</td>
<td>3.28</td>
<td>3.11</td>
<td>.04</td>
<td>.43</td>
<td>.52</td>
<td>.0001</td>
<td>.26</td>
</tr>
<tr>
<td>Protein, kg/d</td>
<td>1.00</td>
<td>1.02</td>
<td>1.01</td>
<td>1.11</td>
<td>1.04</td>
<td>.02</td>
<td>.11</td>
<td>.0009</td>
<td>.0004</td>
<td>.18</td>
</tr>
<tr>
<td>Total solids, %</td>
<td>12.04</td>
<td>12.22</td>
<td>12.14</td>
<td>12.25</td>
<td>12.29</td>
<td>.15</td>
<td>.27</td>
<td>.18</td>
<td>.92</td>
<td>.43</td>
</tr>
</tbody>
</table>
Diets were: C = control, CSFA+NMB = calcium salts of fatty acids plus 3% nicotinamide blended during synthesis, CSFA = calcium salts of fatty acids, NM = nicotinamide, CSFA+NMS = calcium salts of fatty acids plus nicotinamide added separately.

Covariate adjusted for pretreatment (wk 1) milk production and composition.

C vs CSFA+NMB, CSFA, and CSFA+NMS.

C vs. CSFA+NMB, NM, and CSFA+NMS.

NM vs. CSFA+NMB, and CSFA+NMS.

CSFA vs. CSFA+NMB, and CSFA+NMS.

FCM = fat-corrected milk.
NM produced an average of 4 kg/d more milk than control cows. Accordingly, Kung et al. (1980) showed positive effects from NA supplementation only during the last 2 wk of a 10 wk trial with cows in early and midlactation. The response was greater in early lactation cows. There are reports, however, in which niacin did not increase milk production of either multiparous or primiparous cows in early, mid, or late lactation (Horner et al., 1986; Skaar et al., 1989; Erickson et al., 1990; Driver et al., 1990; Martinez et al., 1991; Lanham et al., 1992).

Fat-corrected milk (FCM) production was not affected significantly by treatment during wk 3, and 4 (Tables 12 and 13), but the average was higher for cows in CSFA+NMS and CSFA groups (Figure 2) during wk 3. The temporary effect may be due to a higher fat content in milk of the CSFA group, whereas cows in the CSFA+NMS group showed a nonsignificantly higher milk production with a slightly higher fat content (Figure 3). During wk 4 cows fed the CSFA diet had an abrupt decrease in 4% FCM (Figure 2) due to a sudden decrease in milk fat content (Figure 3). The decrease in fat content was observed also in milk of the groups of cows supplemented with NM (Figure 4) and resulted in significantly different averages (P = .02) compared with cows in both of the CSFA+NM groups (Table 13). Fat-corrected milk production for cows in the CSFA+NMS group was slightly higher than CSFA+NMB due to more sustained increase in fat content of milk (Figure 4).

During wk 5 (Table 14) the effects of supplementation were clearly shown (P < .01) as cows in all treatment groups were producing more 4% FCM than C cows (2.4 and 1.9 FCM kg/d for all CSFA and all NM groups,
Figure 2. Fat-corrected milk production for cows given one of five dietary treatments. The graph represents either (A) actual data or (B) data that were covariate adjusted based upon values of wk 1.
Figure 3. Milk fat content for cows given one of five different dietary treatments. The graph represents either (A) actual data or (B) data that were covariate adjusted based upon values of wk 1.
Experimental diets fed

WEEKS ON TRIAL
respectively). When data for wk 3, 4, and 5 were averaged (Table 15) effects of supplementation were diluted, but still were significant ($P < .05$).

Milk fat production (kg/d) followed patterns (Figure 5) that were similar to those for FCM production and milk fat percentage. Treatment effects were shown only for wk 5 of the trial (Table 14) by increments of .09 and .08 kg/d of fat for cows in all the CSFA groups versus control ($P = .05$) and for cows on all the NM groups versus control ($P = .09$), respectively. Cows in the NM group tended to produce less fat compared with cows in all the CSFA groups ($P = .19$); this effect became significant ($P = .07$) when data were averaged for wk 3, 4, and 5 (Table 15).

Our results showing the effects of MEGALAC on production of 4% FCM and milk fat, as well as on fat percentage, were similar to average responses found in 10 trials. Shaver (1990) reported average increments of 1.8, and .09 kg/d for 4% FCM and fat production, as well as an increase of .11% in milk fat in cows supplemented with CSFA. Responses to NM supplementation on 4% FCM, and milk fat production and percentage, however, are not consistent. Muller et al. (1986) reported an increase in FCM and milk fat production of 2.2 and .08 kg/d in Holstein cows receiving 6 g/d NA, but fat content was not affected by treatment. Jaster et al. (1983b) found no effects on 4% FCM production of cows supplemented with NA, but fat content was increased by .20%. In both experiments, effects of dietary NA were more evident in cows producing greater than 34 kg/d of milk. Other workers reported positive responses in 4% FCM production (Horner et al.,
Figure 4. Milk fat production for cows given one of five different dietary treatments. The graph represents either (A) actual data or (B) data that were covariate adjusted based upon values of wk 1.
Experimental diets fed

WEEKS ON TRIAL

MILK FAT PRODUCTION (kg/d)
Figure 5. Milk protein content for cows given one of five different dietary treatments. The graph represents either (A) actual data or (B) data that were covariate adjusted based upon values of wk 1.
Experimental diets fed

MILK PROTEIN (%)

WEEKS ON TRIAL
1986; Jaster and Ward, 1990; Zimmerman et al., 1992) and in milk fat content (Horner et al., 1986) for cows supplemented with niacin. In contrast to our findings, other experiments showed no response of cows to niacin supplementation on FCM, milk fat production, or milk fat content (Riddell et al., 1981; Skaar et al., 1989; Driver et al., 1990; Erickson et al., 1990; Martinez et al., 1991).

The protein content of milk from the C group was increasing, as expected, as lactation progressed (Figure 5). Milk percentage of groups of cows supplemented with CSFA or CSFA+NMS followed the same trend during wk 3 of the trial, whereas protein content of groups of cows supplemented with CSFA+NMB decreased slightly. Cows receiving the CSFA diet did not show the milk protein depression attributed to supplemental fat. There have been reports in which fat did not depress the protein content of milk (Palmquist and Conrad, 1978; Kronfeld et al., 1980; Grummer, 1988; Mohamed et al., 1988; Schauff and Clark, 1989; Batallas et al., 1991).

There was a rapid response of cows supplemented with NM on milk protein percentage, which kept increasing steadily during wk 4 and 5 (Figure 5); as a consequence, there were significant differences in milk protein content of groups of cows supplemented with NM compared with both groups receiving CSFA+NM diets during wk 3, 4, and 5 (Tables 12, 13, and 14). During wk 5, milk of groups of cows supplemented with the CSFA+NM diets increased an average of .07 units in protein percentage (Figure 5), but milk protein content still was similar to that of C cows (Table 14). When data were averaged for weeks 3, 4, and 5 (Table 15) the
difference in milk protein percentage between groups supplemented with NM and both groups receiving CSFA+NM was stronger ($P = .0001$).

Milk protein content and production from cows supplemented with niacin have shown inconsistent results. Erickson et al. (1990), Martinez et al. (1991), and Lanham et al. (1992) found no effects on milk protein percentage or production of midlactation cows receiving dietary niacin. Moreover, feeding either 3 or 6 g/d of niacin decreased protein percentage of milk from cows averaging 55 d postpartum. Riddell et al. (1981), Horner et al. (1986) and Erickson et al. (1989), however, showed improvement of milk protein content and production from cows in early lactation. Furthermore, Driver et al. (1990) found a significant fat by niacin interaction, indicating that niacin may reverse the depression of milk protein caused by fat in early lactation cows.

Milk protein production tended to decrease in control cows, as expected, as lactation progressed (Stanton et al., 1992) (Figure 6). Cows in the CSFA+NMB and CSFA groups produced ($P = .008$) less milk protein than the NM group during wk 3 (Table 12) because of lower protein content and lower milk production, respectively. Cows in the CSFA+NMS group steadily maintained production of milk protein throughout the entire trial, whereas milk protein production in the group of cows fed NM increased rapidly in wk 3 and was maintained high during wk 4 and 5 (Figure 6). Milk protein production in the groups of cows supplemented with NM was significantly
Figure 6. Milk protein production for cows given one of five different dietary treatments. The graph represents either (A) actual data or (B) data that were covariate adjusted based upon values of wk 1.
Experimental diets fed

WEEKS ON TRIAL

A

B
higher than groups of cows in both the CSFA+NM groups during wk 3 (P = .008) and wk 4 (P = .03) (Tables 12 and 13). The difference in production between the NM and both CSFA+NM groups was approximately 10 and 5% for wk 3 and 4, respectively, and was due mainly to the increase in milk protein content. At wk 4 primiparous cows had higher (P = .07) milk protein production than multiparous cows (data not shown).

During wk 5, cows in all the CSFA and all the NM groups were producing about 10 and 13% more milk protein than control cows, respectively (P < .01) (Table 15). As a consequence, milk protein production for cows fed the NM diet was similar to both CSFA+NM supplemented cows.

Finally, when data from wk 3, 4, and 5 were averaged, the groups receiving the CSFA supplement tended to produce (P = .11) more milk protein than C cows. Control cows produced less milk protein than all NM groups (P = .0009). Cows in the NM group produced an average of approximately 7% more milk protein (Table 15) than cows in both of the CSFA+NM groups, which tended to produce more milk protein than the group receiving the CSFA supplement (P = .18). Primiparous cows tended to produce more milk protein (P = .14) than multiparous cows (data not shown) because of higher but non-significant increases in milk protein content in primiparous (.15%) versus multiparous cows (.08%). The increments of milk protein percentage and production are similar to those found by Erickson et al. (1989) in early lactation cows supplemented with 12 g/d of NA.

Percentage of total solids in milk was not affected by treatment during wk 3, 4, and 5 (Tables 12, 13, and 14) or by parity (data not
shown). Cows in all supplemented groups tended to produce milk with slightly higher content of solids during wk 3 (Figure 7), but the increases (2.2%) over the control group were not significant. Total solids in milk has not been changed by adding fat (Schauff and Clark, 1989; West and Hill, 1990; Martinez et al., 1991) or niacin (Kung et al., 1980; Horner et al., 1986; Martinez et al., 1991; Lanham et al., 1992) to diets of dairy cows.

Metabolites and Nicotinamide in Blood

Pretreatment data

Concentration of metabolites in blood during the pretreatment period were similar among dietary groups (Table 16), but plasma BHBA concentration (data not shown) was higher \( (P = .06) \) for multiparous than for primiparous cows (5.01 versus 3.96 mg/dl). There was some variation in blood nicotinamide content between the C group and all NM groups \( (P = .09) \), perhaps due to variability between cows, but no differences were detected because of parity (data not shown).

Reports of normal levels of niacin in blood of lactating cows have been variable because of different analytical methods used with either plasma or whole blood. Jaster et al. (1983a) monitored plasma NA concentration in cows from 2-wk prepartum to 10-wk postpartum. They found average values of approximately 8 \( \mu \)g/ml, whereas in another experiment with cows at 6 wk postpartum they found levels of plasma NA between 1.5 and 2 \( \mu \)g/ml, which are similar to values for male goats (2 to 4 \( \mu \)g/ml) reported by Williams et al. (1977). In contrast, Lanham et al. (1992) reported much
Figure 7. Milk total solids for cows given one of five different dietary treatments. The graph represents either (A) actual data or (B) data that were covariate adjusted based upon values of wk 1.
Experimental diets fed

WEEKS ON TRIAL

MILK TOTAL SOLIDS (%)
TABLE 16. Average of pretreatment plasma glucose, nonesterified fatty acids (NEFA) and \( \beta \)-hydroxybutyrate (BHBA), and blood nicotinamide (NM) from cows fed one of five different diets.

<table>
<thead>
<tr>
<th>Item</th>
<th>Dietary groups(^1)</th>
<th>Contrasts(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>CSFA+</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glucose, mg/dl</td>
<td>61.1</td>
<td>61.4</td>
</tr>
<tr>
<td>NEFA, ( \mu )mol/L</td>
<td>146</td>
<td>131</td>
</tr>
<tr>
<td>BHBA, mg/dl</td>
<td>4.0</td>
<td>4.9</td>
</tr>
<tr>
<td>NM, mg/ml</td>
<td>2.01</td>
<td>1.70</td>
</tr>
</tbody>
</table>

\(^1\)Diets were: C = control, CSFA+NM = calcium salts of fatty acids plus 3% nicotinamide blended during synthesis, CSFA = calcium salts of fatty acids, NM = nicotinamide, CSFA+NM = calcium salts of fatty acids plus nicotinamide added separately.

\(^2\)These contrasts were calculated for pretreatment data collected before cows were assigned to the diets indicated.
C vs. CSFA+NMB, CSFA, and CSFA+NMS.
C vs. CSFA+NMB, NM, and CSFA+NMS.
NM vs. CSFA+NMB and CSFA+NMS.
CSFA vs. CSFA+NMB and CSFA+NMS.
higher values of plasma niacin concentration (10 mg/dl) for cows in early lactation. Our average pretreatment values for whole blood NM concentration ranged from 1.68 to 2.01 μg/ml, which were higher than concentrations of plasma NM reported by Driver et al. (1990).

Treatment data

Concentrations of glucose in plasma were not significantly different between dietary groups at wk 3, 4, or 5 (Tables 17, 18, and 19 and Figure 8) or because of parity (data not shown). When data for wk 3, 4, and 5 were averaged (Table 20) cows in all the CSFA groups tended to have higher plasma glucose concentrations than C cows (P = .10), which agrees with other studies on fat supplementation (Kronfeld et al., 1980; Jenkins and Jenny, 1989). Other reports on cows fed fat showed either no effects (Palmquist and Conrad, 1978) or decreased plasma glucose concentrations (Palmquist and Moser, 1981; Erickson et al., 1992). Differences in response to dietary fat may be due to differences in energy balance of cows at the time of supplementation or due to type of dietary fat being fed (Driver et al., 1990).

Cows in all the NM groups had higher (P = .07) glucose in plasma than cows in the C group (59.7 vs 58.4 mg/dl, respectively) and tended to be higher (P = .15) than both CSFA+NM groups (Table 20). Contents of glucose in plasma were increased by niacin supplementation in cows showing subclinical or clinical ketosis (Fronk and Schultz, 1979) and in normal cows during early lactation (Dufva et al., 1983; Horner et al., 1986), but other researchers failed to show increased glucose concentrations in plasma of normal cows in early lactation (Jaster et al., 1983a; Skaar et al.,
Figure 8. Blood plasma glucose concentration of cows given one of five dietary treatments. The graph represents data that were covariate adjusted based upon values of wk. 1.
Experimental diets fed 2-3 weeks on trial.
TABLE 17. Concentrations of plasma glucose, nonesterified fatty acids (NEFA), and \( \beta \)-hydroxybutyrate (BHBA), and blood nicotinamide (NM) during week 3 from cows fed one of five different diets.

<table>
<thead>
<tr>
<th>Item</th>
<th>C</th>
<th>CSFA-NMB</th>
<th>CSFA</th>
<th>NM</th>
<th>CSFA+NMB</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose, mg/dl</td>
<td>58.4</td>
<td>58.9</td>
<td>60.8</td>
<td>61.6</td>
<td>60.2</td>
<td>2.9</td>
</tr>
<tr>
<td>NEFA, ( \mu \text{mol/L} )</td>
<td>109</td>
<td>141</td>
<td>161</td>
<td>111</td>
<td>161</td>
<td>8.2</td>
</tr>
<tr>
<td>BHBA, mg/dl</td>
<td>5.2</td>
<td>5.0</td>
<td>5.4</td>
<td>4.8</td>
<td>5.0</td>
<td>.64</td>
</tr>
<tr>
<td>NM, mg/ml</td>
<td>1.71</td>
<td>1.71</td>
<td>1.70</td>
<td>2.05</td>
<td>1.70</td>
<td>.04</td>
</tr>
</tbody>
</table>

\(^a\)Diets were: C = control, CSFA+NMB = calcium salts of fatty acids plus 3% nicotinamide blended during synthesis, CSFA = calcium salts of fatty acids, NM = nicotinamide, CSFA+NMS = calcium salts of fatty acids plus nicotinamide added separately.

\(^b\)Covariate adjusted for pretreatment (wk 1) plasma and blood composition.

\(^c\)C vs. CSFA+NMB, CSFA, and CSFA+NMS.
C vs. CSFA+NMB, NM, and CSFA+NMS.

NM vs. CSFA+NMB and CSFA+NMS.

CSFA vs. CSFA+NMB and CSFA+NMS.
TABLE 18. Concentrations of plasma glucose, nonesterified fatty acids (NEFA), and β-hydroxybutyrate (BHBA), and blood nicotinamide (NM) during week 4 from cows fed one of five different diets.

<table>
<thead>
<tr>
<th>Item</th>
<th>C</th>
<th>NMB</th>
<th>CSFA</th>
<th>NM</th>
<th>NMS</th>
<th>SE</th>
<th>C vs. all CSFA groups</th>
<th>C vs. all NM groups</th>
<th>NM vs. both CSFA+NM groups</th>
<th>CSFA vs. both CSFA+NMS groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose, mg/dl</td>
<td>58.7</td>
<td>58.5</td>
<td>60.8</td>
<td>59.6</td>
<td>60.8</td>
<td>.97</td>
<td>.42</td>
<td>.56</td>
<td>.94</td>
<td>.50</td>
</tr>
<tr>
<td>NEFA, µmol/L</td>
<td>100</td>
<td>142</td>
<td>148</td>
<td>114</td>
<td>140</td>
<td>8.2</td>
<td>.01</td>
<td>.08</td>
<td>.11</td>
<td>.51</td>
</tr>
<tr>
<td>BHBA, mg/dl</td>
<td>4.8</td>
<td>4.0</td>
<td>4.6</td>
<td>4.4</td>
<td>4.6</td>
<td>.31</td>
<td>.70</td>
<td>.64</td>
<td>.94</td>
<td>.74</td>
</tr>
<tr>
<td>NM, mg/ml</td>
<td>1.64</td>
<td>1.88</td>
<td>1.62</td>
<td>1.91</td>
<td>1.85</td>
<td>.01</td>
<td>.49</td>
<td>.15</td>
<td>.85</td>
<td>.04</td>
</tr>
</tbody>
</table>

Diets were: C = control, CSFA+NMB = calcium salts of fatty acids plus 3% nicotinamide blended during synthesis, CSFA = calcium salts of fatty acids, NM = nicotinamide, CSFA+NMS = calcium salts of fatty acids plus nicotinamide added separately.

Covariate adjusted for pretreatment (wk 1) plasma and blood composition.
C vs. CSFA+NMB, CSFA, and CSFA+NMS.

C vs. CSFA+NMB, NM, and CSFA+NMS.

NM vs. CSFA+NMB and CSFA+NMS.

CSFA vs. CSFA+NMB and CSFA+NMS.
TABLE 19. Concentrations of plasma glucose, nonesterified fatty acids (NEFA), and β-hydroxybutyrate (BHBA), and blood nicotinamide (NM) during week 5 from cows fed one of five different diets.

<table>
<thead>
<tr>
<th>Item</th>
<th>Dietary groups</th>
<th>Contrasts&lt;sup&gt;2&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>C vs. all</td>
</tr>
<tr>
<td></td>
<td>CSFA+</td>
<td>VS. all</td>
</tr>
<tr>
<td></td>
<td>NMB</td>
<td>NM vs. both</td>
</tr>
<tr>
<td></td>
<td>CSFA</td>
<td>CSFA vs. both</td>
</tr>
<tr>
<td></td>
<td>NM</td>
<td>CSFA+NM</td>
</tr>
<tr>
<td></td>
<td>CSFA+NMS</td>
<td>CSFA+NM</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Item</th>
<th>C</th>
<th>CSFA+</th>
<th>NMB</th>
<th>CSFA</th>
<th>NM</th>
<th>CSFA+NMS</th>
<th>SE</th>
<th>C vs. all</th>
<th>C vs. all</th>
<th>NM vs. both</th>
<th>CSFA vs. both</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose, mg/dl</td>
<td>58.0</td>
<td>59.0</td>
<td>59.3</td>
<td>59.6</td>
<td>59.7</td>
<td>.75</td>
<td>.35</td>
<td>.24</td>
<td>.36</td>
<td>.82</td>
<td></td>
</tr>
<tr>
<td>NEFA, µmol/L</td>
<td>144</td>
<td>142</td>
<td>147</td>
<td>114</td>
<td>132</td>
<td>8.1</td>
<td>.56</td>
<td>.38</td>
<td>.46</td>
<td>.32</td>
<td></td>
</tr>
<tr>
<td>BHBA, mg/dl</td>
<td>4.8</td>
<td>4.2</td>
<td>4.5</td>
<td>4.4</td>
<td>4.5</td>
<td>.30</td>
<td>.78</td>
<td>.79</td>
<td>.95</td>
<td>.95</td>
<td></td>
</tr>
<tr>
<td>NM, mg/ml</td>
<td>1.64</td>
<td>1.88</td>
<td>1.67</td>
<td>1.91</td>
<td>1.94</td>
<td>.01</td>
<td>.07</td>
<td>.007</td>
<td>.27</td>
<td>.08</td>
<td></td>
</tr>
</tbody>
</table>

<sup>1</sup> Diets were: C = control, CSFA+NMB = calcium salts of fatty acids plus 3% nicotinamide blended during synthesis, CSFA = calcium salts of fatty acids, NM = nicotinamide, CSFA+NMS = calcium salts of fatty acids plus nicotinamide added separately.
Covariate adjusted for pretreatment (wk 1) plasma and blood composition.

*C vs. CSFA+NMB, CSFA, and CSFA+NMS.
*C vs. CSFA+NMB, NM, and CSFA+NMS.
*NM vs. CSFA+NMB and CSFA+NMS.
*CSFA vs. CSFA+NMB and CSFA+NMS.
TABLE 20. Average concentrations of plasma energy metabolites and blood nicotinamide (NM) of data for weeks 3, 4, and 5 from cows fed one of five different diets.

<table>
<thead>
<tr>
<th>Dietary groups¹</th>
<th>Contrasts²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
<td>C vs. all</td>
</tr>
<tr>
<td></td>
<td>CSFA</td>
</tr>
<tr>
<td>Glucose, mg/dl</td>
<td>58.4</td>
</tr>
<tr>
<td>NEFA, μmol/L</td>
<td>117</td>
</tr>
<tr>
<td>BHBA, mg/dl</td>
<td>4.9</td>
</tr>
<tr>
<td>NM, mg/ml</td>
<td>1.68</td>
</tr>
</tbody>
</table>

⁰Diets were: C = control, CSFA+NMB = calcium salts of fatty acids plus 3% nicotinamide blended during synthesis, CSFA = calcium salts of fatty acids, NM = nicotinamide, CSFA+NMS = calcium salts of fatty acids plus nicotinamide added separately.

⁴Covariate adjusted for pretreatment (wk 1) plasma and blood composition.
C vs. CSFA+NMB, CSFA, and CSFA+NMS.

C vs. CSFA+NMB, NM, and CSFA+NMS.

NM vs. CSFA+NMB and CSFA+NMS.

CSFA vs. CSFA+NMB and CSFA+NMS.
1989), or in midlactation cows with fat (Horner et al., 1988b; Driver et al., 1990; Martínez et al., 1991) or without fat supplementation (Erickson et al., 1990). Our findings are in partial agreement with the study of Jaster and Ward (1990) in which plasma glucose was increased in cows supplemented with 12 g/d NM compared with their control group.

Concentration of NEFA in blood plasma was increased in all groups of fed CSFA diets and tended to remain elevated, whereas in the C group and in the NM groups plasma NEFA concentrations decreased during wk 3 and 4 but increased in wk 5 (Figure 9). Concentrations of plasma NEFA were highest (Table 17 and 18) for groups of cows supplemented with CSFA and they averaged 42% greater than the C group at wk 3 (P = .006) and at wk 4 (P = .01). During wk 3 and 4 NEFA were lower in the control group compared with the NM group (p ≤ .10), which had lower plasma NEFA concentrations than both of the CSFA+NM groups during wk 3 (P = .02) and tended to be lower at wk 4 (P = .11). Table 19 shows that there were no effects by treatment on blood plasma concentrations of NEFA during wk 5 due to an increase of NEFA concentrations of plasma NEFA in both the C and NM groups. Nevertheless, when data were averaged (Table 20) all CSFA groups and both CSFA+NM groups had higher (P < .01) plasma NEFA concentrations than the control group and the NM group. The C and NM groups had similar values.

Changes in plasma concentrations of NEFA are observed commonly in cows supplemented with fat, which is probably due to hydrolysis of increased blood triglycerides (Scow et al., 1973; Palmquist and Conrad, 1978; Palmquist and Moser, 1981; DePeters et al., 1989; Schauff et al., 1992). On the other hand, effects of niacin supplementation on plasma NEFA
Figure 9. Blood plasma NEFA concentration of cows given one of five dietary treatments. The graph represents data that were covariate adjusted based upon values of wk 1.
Experimental diets fed

- C
- CSFA+NMB
- CSFA
- NM
- CSFA+NMS

WEEKS ON TRIAL

PLASMA NEFA (μmol/L)
concentrations were shown mainly with subclinically ketotic cows (Waterman and Schultz, 1972b; Waterman et al., 1972; Fronk and Schultz, 1979). Others have reported lower plasma NEFA concentrations only during wk 1 postpartum in Holstein cows fed 6 g/d of niacin from 2 wk prepartum to 4 wk postpartum (Dufva et al., 1983). Jaster and Ward (1990), however, in a similar experiment, but comparing NM and NA, found lower plasma NEFA concentrations only in the NM group at wk 4 postpartum. In contrast, no effects of niacin supplementation on NEFA concentrations were reported in early and midlactation cows with fat supplementation (Martinez et al., 1991; Erickson et al., 1992) or without fat supplementation (Skaar et al., 1989; Driver et al., 1990; Erickson et al., 1990). Zimmerman et al. (1992), however, found lower NEFA concentrations in cows because of an interaction of a high protein diet with niacin supplementation. Parity had no effects on plasma NEFA concentrations in our study (data not shown).

Average concentrations of BHBA in plasma were not different among groups because of treatments at wk 3, 4, and 5 or when data were averaged (Tables 17, 18, 19, and 20). There also were no differences because of parity (data not shown). At wk 4 plasma BHBA of cows in the two CSFA+NMB groups decreased approximately 20% compared to concentrations at wk 3 (Figure 10), but the reason for the decrease is unknown. Dietary niacin decreased plasma BHBA of cows exhibiting clinical or subclinical ketosis (Fronk and Shultz, 1979) or cows in early lactation (Dufva et al., 1983; Jaster and Ward, 1990; Erickson et al., 1992; Zimmerman et al., 1992). In contrast Jaster et al. (1983a), Skaar et al. (1989), and Driver et al.
Figure 10. Blood plasma BHBA concentration of cows given one of five dietary treatments. The graph represents data that were covariate adjusted based upon values of wk 1.
Experimental diets fed

○○ C
●● CSFA+NMB
□□ CSFA
△△ NM
■■ CSFA+NMS

PLASMA BHBA (mg/dl)

0 1 2 3 4 5
WEEKS ON TRIAL

Experimental diets fed
failed to show changes in plasma BHBA of early lactation cows supplemented with niacin. Niacin supplementation would elicit its effect on clinically or subclinically ketotic cows by decreasing lipid mobilization and, consequently, plasma BHBA concentrations (Waterman et al., 1972; Waterman and Schultz, 1972ab; Fronk and Schultz, 1979). Our cows were past peak milk production and in positive energy balance; therefore, they were maintaining normal concentrations of plasma BHBA.

Blood NM concentrations were not affected by parity during the entire trial (data not shown). Nicotinamide in blood of C and CSFA groups decreased as lactation progressed (Figure 11), but it decreased during wk 3 and increased at wk 4 in both of the CSFA+NM groups. On the other hand, blood NM of cows in the NM group was increased rapidly at wk 3 and tended to keep above the initial concentration during wk 4 and 5. As a consequence, blood NM of cows in all NM groups tended to be greater than for the C group at wk 3 (P = .18) and at wk 4 (P = .15), and it was significantly greater (P = .002) at wk 5 (Tables 17, 18, and 19). Blood NM in all NM groups was also greater (P = .0002) than for both CSFA+NM groups at wk 3 but not at wk 4 or 5 (Tables 17, 18, and 19). At wk 4 and 5, blood NM of both CSFA+NM groups was about 15% higher than for the CSFA group. Average data for wk 3, 4, and 5 (Table 20) shows greater blood NM in all NM groups than in group C (P = .002) and in the NM group versus both CSFA+NM groups (P = .009), whereas both CSFA+NM groups had higher blood NM than the CSFA group (P = .01).

Lanham et al. (1992) found no differences in plasma niacin concentration of cows fed diets containing 0 or 15% whole cottonseeds supplemented with 6 g/d of NA. In contrast, NA concentration was increased about 19% in whole
Figure 11. Blood nicotinamide concentration of cows given one of five dietary treatments. The graph represents data that were covariate adjusted based upon values of wk 1.
Experimental diets fed 2-3 weeks on trial.
blood of midlactation cows receiving 12 g/d of NA (Martinez et al., 1991). Accordingly, Driver et al. (1990) reported a greater plasma NM concentration in cows fed whole soybeans plus 6 g/d NA compared with a group without NA supplementation (.99 and .57 μg/ml, respectively). These concentrations are lower than those found in our trial, probably because the former authors were measuring NM concentrations in plasma, whereas we determined NM in whole blood and most of the NM is located within the red blood cells (DiPalma and Thayer, 1991).
ACKNOWLEDGMENTS

The authors thank R. Lenius and Swiss Valley Farms Co., Davenport, IA, for cooperation in analysing milk samples. Appreciation is extended to Dennis Crawley for providing cows, and facilities, to T. Faidley for coordinating care and feeding of cows, to M. Richard, M. Hofmeister, and S. Dawson for assistance with laboratory analyses, to T. Smith for assistance in statistical analyses, and to P. Biskner for assistance in the preparation of the manuscript. Special appreciation is extended to J. Kent for assistance on scoring cows. This research was supported in part by a grant from Church and Dwight Co., Inc., Princeton, NJ 08540.
REFERENCES


Chalupa, W., and J. D. Ferguson. 1990. Immediate and residual responses of lactating cows in commercial dairies to calcium salts of long chain fatty acids. J. Dairy Sci. 73(Suppl. 1):244.(Abstr.)


PAPER II. BLOOD NICOTINAMIDE CONCENTRATIONS OF DAIRY COWS
ADMINISTERED EITHER NICOTINAMIDE OR NICOTINIC ACID
ABSTRACT

Six late-lactation Holstein cows were used in a switchback design of 9 d periods to measure changes in blood nicotinamide concentration as a reflection of niacin absorption from the gastrointestinal tract. Cows were administered orally 12 g/d of either nicotinamide or nicotinic acid during the first 5 d of each period. Blood nicotinamide concentration of the group treated with nicotinamide peaked earlier and higher than for the nicotinic acid group (1 vs 12 h, and 2.48 vs 2.01 µg/ml, respectively), and it tended to be higher on d 2 compared to d 1 during the first 2 h after administration for both groups. Blood nicotinamide concentration averaged 18% above baseline at 12 h during the 5 d of niacin administration and was not different between treatments. The area under the blood nicotinamide curve in the nicotinamide group was higher than that for the nicotinic acid group at 1, 2, 3, 4, and 6 h after administration, and, at 6 h, it represented 38% vs 15% of the total area of the respective groups during the 24 h sampling time. No differences were found due to treatment in blood concentration or area under the curve of nicotinamide at 8, 12, and 24 h after administration of niacin. Nicotinamide was about 20-fold more soluble in ruminal fluid than was nicotinic acid. These data suggest that nicotinamide is absorbed faster than nicotinic acid at the rumen level, probably because of its higher solubility and pKa. Total niacin absorption, however, was similar for both nicotinamide and nicotinic acid due to a higher absorption of nicotinic acid from the lower digestive tract.
INTRODUCTION

Early experimental work showed that ruminant microorganisms are able to synthesize B vitamins in the rumen (Rerat et al., 1954; Hungate, 1966). Agrawala et al. (1953) reported that calves fed purified diets synthesized up to 154 mg of niacin in the rumen within 6 h after feeding. It has been postulated that rumen microbial synthesis of niacin is depressed by supplementary niacin (Riddell et al., 1985). In contrast, synthesis of niacin by ruminal microorganisms compensates for low dietary niacin consumption (Abdouli and Schaefer, 1986). Byers (1981) suggested that niacin concentration reaches an optimum in the rumen below which microbial synthesis is stimulated and above which there is no net synthesis; furthermore, excess dietary niacin may be degraded for other purposes. However, Brent and Bartley (1984) reported that niacin flow to the small intestine and absorption from the small intestine increased by 62 and 71%, respectively, in cows receiving 6 g of supplemental niacin.

Rerat et al., (1954, 1958) showed that although, the rumen wall is permeable to most B vitamins in the free form, including niacin, absorption of B vitamins at this site is of minor importance because they are contained within the bodies of microorganisms. Later, Rerat et al., (1959) measured the proportions of niacin either in the free form or bound to microorganisms in the digestive tract of sheep fed normal diets. They found proportions of 4, 9, 66, 86, 80, and 8% of free versus bound niacin at the rumen, omasum, abomasum, duodenum, ileum, and cecum, respectively; they concluded that absorption of niacin in sheep fed regular diets started at the abomasum and was completed at the small intestine. More recently,
Abdouli and Schaefer (1986) reported free niacin proportions of 10% in the rumen. Nevertheless, total niacin concentration in ruminal digesta of Holstein cows was increased by feeding 2 g of niacin three times daily. The concentration changes were higher at 2 and 4 h (30 and 25%, respectively) and returned to normal at 6 h (Riddell et al., 1985). This 30% increment would be expected to increase the portion of free niacin (Erickson et al., 1991) because the concentration of microbial NAD is independent from free extracellular niacin concentration (Abdouli and Schaefer, 1986). Under these conditions, the amount and rate of niacin absorption from the rumen could become important due to its effects on microbial niacin production, and on rumen fermentation and dilution rates (Bartley et al., 1979; Schaetzel and Johnson, 1981).

Relatively few trials have been conducted to test whether niacin and its amide, nicotinamide (NM), can be absorbed directly from the rumen. One trial was conducted by Rerat et al. (1954) in isolated rumen of sheep with either normal circulation or with a perfusion technique. When a solution containing a mixture of free B vitamins at concentrations 3 to 4 times higher than those found in the rumen of two normal fed sheep was placed in the emptied and washed isolated rumen with normal circulation, the authors reported that 7% of niacin (form not identified) disappeared from the rumen after 1 h with a concomitant increase in niacin concentrations in ruminal veins of 19 and 35% at .5 and 1 h, respectively. The increases in blood niacin were much higher in sheep with perfused rumens than in sheep with normal circulation, which were about four-fold at 1 h suggesting that higher amounts of niacin were absorbed from the rumen.
Recently, Erickson et al. (1991) found differences in the rates of absorption of NM and NA from the rumen. Whereas NM was absorbed at .98 g/h, NA appeared not to be absorbed within the 1-h period of sampling. The results were attributed to differences in pKa between the two forms of niacin, which may have affected the likelihood of their absorption from the rumen. The workers also suggested that NA may be converted to NM before absorption from the rumen occurs.

Nicotinamide has proven to be more effective than NA for increasing digestibility of fiber in continuous in vitro fermentors (Hannah and Stern, 1985) and for increasing milk and 4% FCM production of cows in early lactation (Jaster and Ward, 1990), and NM may be more effective in decreasing lipolysis (Erickson et al., 1991). In contrast, NA may be more effective than NM for increasing protozoa numbers, which may result in an increased flow of microbial protein to the small intestine. There are two levels at which supplemental niacin may exert effects; ruminal and systemic. It is important to determine differences of rate and extent of absorption between both NM and NA, which may influence their site and extent of action.

The objective of this experiment was to compare the relative absorption of NM and NA from the gastrointestinal tract as reflected by concentration patterns of NM in blood for 24 h after a bolus dose of NM or NA was given to dairy cows.
MATERIALS AND METHODS

Management of Cows and Design of Experiment

Six Holstein cows averaging 277 d in lactation (SD = 28 d) were used in a switchback design with 9 d periods and 1 d between periods. Cows were housed in a tie-stall barn and were fed a complete mixed ration (Table 1) at 0600 and 1500 h for ad libitum intake to allow approximately 10% weighback. Cows had access to water for ad libitum intake and were milked at 0200 and 1400 h. They were fitted with indwelling jugular vein catheters 24 h before the beginning of the trial. Each cow was given a gelatin capsule orally by bolus gun at 0800 (0 h) on d 1 to 5 of each period. Capsules contained 12 g of NM or NA (Sigma Chemical Co., St. Louis, MO), they had been tested and verified to dissolve in warm water within 2 min. No supplemental NM or NA was provided to the cows during d 6 to 9.

Blood Collection and Analyses

Baseline blood samples of 10 ml were collected in heparinized tubes at -2, -1, and 0 h of d 1. On d 1, 2, and 5 blood samples were taken at 1, 2, 3, 4, 6, 8, 12, and 24 h after the bolus dose was administered. Additional blood samples, were obtained at 11, 12, and 13 h of d 3, and at 0, 8, and 12 h of d 8 and 9. After each sampling, catheters were flushed with approximately 3 ml of heparinized saline (40 units/ml). Blood samples were maintained in ice and processed within 6 h, as described by Shibata et al. (1987). The supernant was frozen at -20°C, and blood NM content was determined later by high performance liquid chromatography (HPLC) analysis (Shibata et al., 1987).
TABLE 1. Composition and analysis of forage and grain mixture fed to cows.¹

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Forage and grain mixture¹</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Composition</strong></td>
<td></td>
</tr>
<tr>
<td>Alfalfa haylage</td>
<td>23.7</td>
</tr>
<tr>
<td>Corn silage</td>
<td>44.8</td>
</tr>
<tr>
<td>Concentrate grain mixture²</td>
<td>31.5</td>
</tr>
<tr>
<td><strong>Analysis</strong></td>
<td></td>
</tr>
<tr>
<td>Forage and grain mixture</td>
<td>19.4</td>
</tr>
<tr>
<td>Neutral detergent fiber</td>
<td>13.9</td>
</tr>
<tr>
<td>Crude protein</td>
<td></td>
</tr>
<tr>
<td>Alfalfa hay³</td>
<td></td>
</tr>
<tr>
<td>Neutral detergent fiber</td>
<td>54.2</td>
</tr>
<tr>
<td>Crude protein</td>
<td>12.4</td>
</tr>
</tbody>
</table>

¹The forage and grain mixture was a combination of the ISU herd silage mix (73%, as fed) and concentrate mix (27%, as fed), and was 57.8% DM.

²The concentrate grain mixture contained: 22.3% crude protein, 1.78 Mcal/kg NE₃, 1% bicarbonate of soda, 0.5% magnesium oxide, 1.0% dicalcium phosphate, 0.5% calcium carbonate, 0.75% trace mineralized salt, 4400 IU vitamin A per kg, and 1100 IU vitamin E per kg.

³Cows also had access to an estimated 3 kg (DM) of alfalfa hay daily.
Solubility of Niacin in Ruminal Fluid

Ruminal fluid was obtained from a midlactation ruminally-cannulated cow. Contents were strained through four layers of cheesecloth and centrifuged for 10 min at 10,000 x g to sediment feed particles and protozoa in order to obtain particle-free liquid. Quadruplicate samples (2 g) of either NM or NA were placed in 125-ml Erlenmeyer flasks. Ruminal fluid at about 38°C was added slowly to each flask and mixed until all NM or NA was dissolved into the ruminal fluid. Then, the amount of added fluid was recorded. Another sample of ruminal fluid was analyzed for pH by a combination electrode on an Orion Research digital IONALISER® pH meter (Model 701A).

Statistical Analyses

Statistical analysis was done by using the general linear models procedure of SAS (SAS, 1984). Data were analyzed as a split plot in time design where periods, treatments, and their interactions were main effects. Data obtained from blood collected at -2, -1, and 0 h were used as the base for a covariate analysis. Significance was declared at P < .05 unless otherwise noted.
RESULTS AND DISCUSSION

Data corrected for baseline NM concentration and averaged for d 1 and 2 of cows for both NM and NA supplemented groups showed two peaks (Figure 1). Blood NM concentration of the group given 12 g of NM peaked earlier (1 h) than the group given 12 g of NA (12 h). The baseline concentration for blood NM was similar for both treatments (Table 2). The maximal concentration (2.48 µg/ml) of NM in blood of cows supplemented with NM was observed at 1 h and represented a 45% increase above baseline concentration, whereas the maximal concentration of blood NM for the group receiving NA was observed 12 h after vitamin administration and represented a 22% increase above baseline values.

After ingestion of most drugs, there is a lag time before the drug appears in the systemic circulation (Koch-Weser, 1965). This delay reflects the time required for the drug to dissolve into water, and for most drugs, the time necessary to reach the small intestine. Further, passage across the intestinal mucosa is limited to the undissociated form; therefore, chemical properties of the drug influence the site of absorption. Nicotinamide is about 60 fold more soluble than NA in water (Merck index, 1989) and about 20-fold more soluble in ruminal fluid (Table 3). In addition, its pKa is about 14 (Hotz, 1983), so at rumen pH most NM would have been in the undissociated form (Erickson et al., 1991) which would enhance its rate of absorption from the rumen. Nicotinic acid has a pKa of 4.85 (Meiner and Eys, 1982), and the degree of ionization would have been greater at rumen pH (Erickson, et al., 1991); consequently, its absorption was decreased.
Figure 1. Blood nicotinamide concentration of cows orally administered either nicotinamide or nicotinic acid. The graph represents data averaged for d 1 and 2 that were covariate adjusted based upon values for -2, -1, and 0 h before niacin administration. The arrow shows hour of niacin administration.
BLOOD NICOTINAMIDE (µg/ml)

HOURS AFTER ADMINISTRATION

- - - NA

○ ○ NM

1.4

1.7

2.0

2.3

2.6

0 4 8 12 16 20 24

10 4 8

0 4 8 12 16 20 24

HOURS AFTER ADMINISTRATION
TABLE 2. Effects of nicotinamide or nicotinic acid administration on blood concentration of nicotinamide in cows.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Nicotinamide (12 g/d)</th>
<th>Nicotinic acid (12 g/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X'</td>
<td>SD</td>
</tr>
<tr>
<td>Baseline, μg/ml</td>
<td>1.69</td>
<td>.25</td>
</tr>
<tr>
<td>Maximal concentration, μg/ml</td>
<td>2.48</td>
<td>.37</td>
</tr>
<tr>
<td>Maximal time, h</td>
<td>1.00</td>
<td>---</td>
</tr>
<tr>
<td>Maximal concentration/ Baseline, μg/ml</td>
<td>1.45</td>
<td>.22</td>
</tr>
</tbody>
</table>

'n = 6 cows.'
Erickson et al. (1991) reported no absorption of NA from the rumen during their experiment, which lasted for 1 h of sampling. The authors suggested that NA may have to be converted to NM before substantial absorption can take place from the rumen. Collings and Chaykin (1972) found that after administration of NM to mice the only form detectable in portal blood was NM. When ["C"]-NA was administered, however, 33% of the increment in blood corresponded to NM and 66% to NA. This implies that some NA was converted to NM as it crossed the intestine, even though drug absorption from the small intestine is favored by a low degree of ionization at the pH of the intestinal absorbing surface, which was calculated to be 5.3.

Figure 2 shows blood nicotinamide concentrations for both d 1 and 2. The peak concentration of blood NM in the NM group was higher (P < .05) for d 2 than for d 1 at 1 h (2.70 vs 2.22 μg/ml). The effect was not cumulative, however, because the concentration at d 5 (data not shown) was similar to d 2. Blood NM concentration at 12 h was not affected by day, but it increased (P = .001) above baseline values an average of 17 and 20% for NM and NA groups, respectively, during the 5 d of niacin administration (Figure 3). When niacin administration to cows stopped, blood NM returned to baseline values. No differences between treatments were detected (P = .40).

The area under the response curve was calculated as μg x ml x h to determine both, the rate and extent of niacin absorption. Average blood NM data for d 1 and 2 are shown in Figure 4. The NM group had higher NM blood concentration area than the NA group immediately after NM administration at 1, 2, 3, 4, and 6 h and represented about 10, 5, 4, 3, and 2.6-fold
TABLE 3. Solubility of nicotinamide or nicotinic acid in ruminal fluid.

<table>
<thead>
<tr>
<th>Solubility:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nicotinamide</td>
<td>52.8 ± 3.6 g/100 ml</td>
</tr>
<tr>
<td>Nicotinic acid</td>
<td>2.5 ± .12 g/100 ml</td>
</tr>
</tbody>
</table>

'Ruminal fluid pH was 5.96 at 38°C (n=4).
increase, respectively (Table 4). The NM area under the curve at 6 h represented about 38% of the total area found at 24 h for the NM group, whereas less than half of this amount (15%) was represented for the NA group. No differences due to treatment were found at 8, 12 or 24 h ($P > .10$). Interestingly, Brent and Bartley (1984) reported increased ruminal niacin concentrations in cows fed niacin at 6 g/d compared to unsupplemented cows at 2, 4, and 6 h (55, 41, and 11%, respectively) postfeeding. Therefore, the higher NM concentration and area under the response curve found in our experiment during the first 4 h after administration may be due to higher absorption in the rumen because of higher availability of NM in free form, greater solubility and a more basic pKa. The second peak, which occurred at 6 h may be because of increased NM concentration in the small intestine with a concomitantly more sustained absorption from this section of the lower tract. Nicotinic acid, on the other hand, was absorbed poorly from the rumen because of its lower pKa and solubility in ruminal fluid. Nevertheless, total niacin absorption (ruminal plus postruminal) was similar for NM and NA.

Blood NM areas for both the NM and NA groups were higher ($P = .08$) on d 2 than on d 1 at 1, 2, 3, 4, and 6 h (Figure 5). Blood NM area for the NM group on d 2 was about 80% higher than for d 1 during the first 6 h after NM administration, whereas the difference in the NA group, during the same period of time, was about 4-fold higher (Table 5). Reasons for these differences are not apparent, but Rerat et al. (1958) reported that only a small portion (4%) of the B vitamins, including niacin, administered into
Figure 2. Blood nicotinamide concentration of cows orally administered either nicotinamide or nicotinic acid. The graph represents data for d 1 and 2 that were covariate adjusted based upon values for -2, -1, and 0 h before niacin administration. The arrows show h of niacin administration.
BLOOD NICOTINAMIDE (µg/ml)

HOURS AFTER ADMINISTRATION
Figure 3. Blood nicotinamide concentration of cows orally administered either nicotinamide or nicotinic acid. The graph represents actual data for d 1 to 9 of the trial at 12 h. The arrows show d of niacin administration.
Figure 4. Blood nicotinamide area of cows orally administered either nicotinamide or nicotinic acid. The graph represents data averaged for d 1 and 2 that were covariate adjusted based upon values for -2, -1, and 0 h before niacin administration. The arrow shows h of niacin administration.
TABLE 4. Changes in the area of the blood nicotinamide curves averaged for d 1 and 2 for cows administered nicotinamide or nicotinic acid.

<table>
<thead>
<tr>
<th>Time after administration (h)</th>
<th>Treatment'</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NM²</td>
<td>NA²</td>
<td>SE</td>
</tr>
<tr>
<td>1</td>
<td>.38⁺</td>
<td>.04⁺</td>
<td>.06</td>
</tr>
<tr>
<td>2</td>
<td>.97⁺</td>
<td>.19⁺</td>
<td>.14</td>
</tr>
<tr>
<td>3</td>
<td>1.30⁺</td>
<td>.37⁺</td>
<td>.23</td>
</tr>
<tr>
<td>4</td>
<td>1.55⁺</td>
<td>.52⁺</td>
<td>.30</td>
</tr>
<tr>
<td>6</td>
<td>2.33⁺</td>
<td>.90⁺</td>
<td>.53</td>
</tr>
<tr>
<td>8</td>
<td>2.86</td>
<td>1.48</td>
<td>.84</td>
</tr>
<tr>
<td>12</td>
<td>3.96</td>
<td>2.89</td>
<td>1.18</td>
</tr>
<tr>
<td>24</td>
<td>6.15</td>
<td>5.93</td>
<td>2.73</td>
</tr>
</tbody>
</table>

'NM = nicotinamide, NA = nicotinic acid.

²Area measured as μg x ml x h.

⁺⁺Means between columns with different superscripts differ (P < .001).

⁺⁺⁺Means between columns with different superscripts differ (P < .01).

⁺⁺⁺⁺Means between columns with different superscripts differ (P < .05).
Figure 5. Blood nicotinamide area of cows orally administered either nicotinamide or nicotinic acid. The graph represents data for d 1 and 2 that were covariate adjusted based upon values for -2, -1, and 0 h before niacin administration. The arrows show h of niacin administration.
TABLE 5. Changes in blood nicotinamide area during d 1 and 2 in cows administered nicotinamide or nicotinic acid.

<table>
<thead>
<tr>
<th>Time after administration (h)</th>
<th>Day 1 Treatment</th>
<th>Day 2 Treatment</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NM²</td>
<td>NA²</td>
<td>SE</td>
</tr>
<tr>
<td></td>
<td>Treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NM²</td>
<td>NA²</td>
<td>SE</td>
</tr>
<tr>
<td>1</td>
<td>.26e</td>
<td>.01e</td>
<td>.06</td>
</tr>
<tr>
<td>2</td>
<td>.67*</td>
<td>.07*</td>
<td>.13</td>
</tr>
<tr>
<td>3</td>
<td>.90*</td>
<td>.15*</td>
<td>.16</td>
</tr>
<tr>
<td>4</td>
<td>1.11*</td>
<td>.22*</td>
<td>.20</td>
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<tr>
<td>6</td>
<td>1.90*</td>
<td>.52*</td>
<td>.26</td>
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<tr>
<td>8</td>
<td>2.32</td>
<td>1.16</td>
<td>.54</td>
</tr>
<tr>
<td>12</td>
<td>3.60</td>
<td>2.82</td>
<td>.96</td>
</tr>
<tr>
<td>24</td>
<td>5.68</td>
<td>5.81</td>
<td>1.85</td>
</tr>
</tbody>
</table>

*NM = nicotinamide, NA = nicotinic acid.

²Area measured as µg x ml x h.

*"Means between columns with different superscripts differ (P < .01).

*"Means between columns with different superscripts differ (P < .05).
the isolated rumen of two sheep was found in the perfused blood. The workers replaced the solution of B vitamins in the rumen by water and found an increase in B vitamins in the perfused blood as well as in the water in the rumen. They attributed their findings, therefore, to a temporary storage of B vitamins in the rumen wall.

Additional work with both NM and NA is needed to substantiate the present results, to establish amounts and supplementation strategies, and to determine the impact that the different extent and rate of ruminal absorption of niacin sources may have on rumen fermentation and overall animal performance.
ACKNOWLEDGMENTS

Appreciation is extended to Dennis Crawley for provision of cows and facilities, to Terry Faidley for coordinating care of cows, to Terry Smith for assistance in catheterizing cows and on statistical analysis, to Chris Nizzi for assistance in HPLC analyses, Travis Knight, Michelle Hofmeister and Marlene Richard for technical assistance, and to Peggy Biskner for assistance in preparation of the manuscript. This research was supported in part by a grant from Church and Dwight Co., Inc., Princeton, NJ 08540.


The objectives of the first experiment reported in this dissertation were to determine: 1) the stability and the extent of protection of nicotinamide from leaching during in vitro incubations after being blended into CSFA during the regular manufacturing of MEGALAC by Church and Dwight and 2) the effects, in multiparous and primiparous lactating cows, of calcium salts of fatty acids or nicotinamide fed alone, and calcium salts of fatty acids plus nicotinamide either blended or added separately to the feed on: a) feed intake, body weight and body condition score changes, b) milk production and composition, and c) blood plasma metabolites and blood plasma nicotinamide concentrations.

Results of the first experiment (Section I) indicate that most of the nicotinamide blended into CSFA is active after the regular manufacturing process for CSFA is completed. It seems, however, that some nicotinamide (about 10%) is deamidated to nicotinic acid during the process. Although some of the nicotinamide did not leach out of CSFA during the first 4 h of in vitro incubations, blending it with CSFA during the regular process of manufacturing MEGALAC does not seem to be a good method for protecting nicotinamide from leaching out in ruminal conditions.

Dry matter intake was not affected in cows fed 400 g/d of CSFA or 400 g/d of CSFA supplemented with nicotinamide either blended or added separately to the diet, but it was increased in cows receiving 12 g/d of nicotinamide. This increase was not significant separately during wk 3 and 4 of the trial, but it tended to be significant during wk 5, and it became
significant when data were averaged and showed that the response was not immediate.

Dietary CSFA tended to increase body weight gain and body condition score of cows compared to the control group, whereas nicotinamide supplementation tended to increase body weight and increase body condition score of cows compared to the control group. It seems that either CSFA or nicotinamide supplementation can cause increases in body weight and body condition score in lactating cows, but these effects did not seem to be synergistic. Longer experiments with an expanded experimental design may help to clarify these responses.

Differences in milk and fat corrected milk production were not apparent due to treatment during wk 3 and 4 of the experiment. By wk 5, however, cows receiving CSFA and/or nicotinamide were producing more milk and 4% FCM than cows in the control group, and cows in the two CSFA+NM groups tended to produce more milk than cows in the CSFA group. The difference became significant when data for wk 3, 4, and 5 were averaged. Milk fat percentage was higher for all CSFA groups than for the NM group during wk 4 due to a sudden decrease of milk fat content.

Milk fat and milk protein content seem to keep an inverse relationship. Nevertheless, due to their higher milk production, milk fat production of cows in the NM group was higher than for the control group, but tended to be lower than for cows in both of the CSFA+NM groups due to their lower fat percentage in milk during wk 5. Milk protein percentage, on the other hand, increased rapidly in the NM group and was higher than both CSFA+NM groups during wk 3, 4, and 5 of the trial; consequently milk
protein production of cows in the NM group was greater than for cows in both of the CSFA+NM groups during wk 3 and 4, but it only tended to be higher during wk 5 because of a nonsignificant increase of milk protein content for cows in both of the CSFA+NM groups, which then caused their greater milk protein production compared with control cows. Averaged data for wk 3, 4, and 5 showed that the highest milk protein production was for the NM group, followed by both of the CSFA+NM groups, and their milk protein production tended to be higher than for the CSFA group.

Milk protein percentage was not affected in cows receiving CSFA. This lack of an effect was not anticipated because of the common depression of milk protein when fat is fed. Milk protein percentage is often, but not always, affected by fat supplementation, and it is a consequence of the relationship between protein yield and milk yield. Many studies have demonstrated that total protein production remain unchanged or even increased with fat supplementation to dairy cows. In some cases, however, milk production is increased to such an extent that protein concentration is decreased. In our experiment, averaged data for wk 3, 4, and 5 shows that milk production of cows in the CSFA group was only 1.3% higher than for cows in the control group, whereas milk production for cows in the NM and both of the CSFA+NM groups was increased by 6 and 5%, respectively, compared to control cows.

Total solids percentage in milk was not affected by treatment during wk 3, 4, and 5, but it tended to be higher in milk of cows in all of the NM groups compared to the control group when data were averaged.
Cows in all of the NM groups tended to have higher blood plasma glucose concentrations than cows in the control group during wk 3, but the difference was not significantly higher during wk 4 and 5. The difference between all of the NM groups and the control group became significant when data for wk 3, 4, and 5 were averaged. No major differences in glucose concentration in blood plasma between all of the CSFA groups and the control group were observed during wk 3, 4, and 5. Averaged data for wk 3, 4, and 5 indicated only tendencies for higher plasma glucose in all of the CSFA groups compared to the control group.

Cows in all of the CSFA groups experienced increased blood plasma NEFA concentrations during wk 3 and 4 compared to the control group, which had lower concentrations of plasma NEFA than all of the NM groups during wk 3, but the CSFA groups only tended to be higher during wk 4. Nevertheless, during wk 5, differences in plasma NEFA concentration among groups were not found due to a sudden increase of plasma NEFA in cows of both control and NM groups. Averaged data for wk 3, 4, and 5, however, clearly shows the highest plasma NEFA concentration for the CSFA group followed by both of the CSFA+NM groups. These differences are likely to be of a dietary origin rather than from lipolysis in adipose tissue because blood plasma BHBA concentration was not affected by treatment as cows were past peak lactation and in positive energy balance.

Concentration of NM in blood of cows in the NM group was increased rapidly at wk 3 and remained above baseline during wk 4 and 5. Although blood NM concentration decreased during wk 3 in cows on both of the CSFA+NM groups, during wk 4 the concentrations increased and remained above
baseline values during wk 5. The control and CSFA groups, however, showed
decreased blood NM concentrations as lactation progressed. Interestingly,
when data for wk 3, 4, and 5 were averaged, blood NM concentrations for
cows in both of the CSFA+NM groups were similar to those of cows in the NM
group and higher than the blood NM concentration for the CSFA group.

Effects of both CSFA and NM supplementation have been more apparent on
high producing dairy cows in early stages of lactation. Nevertheless,
under the conditions of our experiment with cows averaging 121 d in
lactation and producing an average of 36 kg/d of milk during the beginning
of each replication, the beneficial effects of CSFA and/or NM
supplementation on milk production and composition were observed mainly
during the last wk of the trial, which suggests that a period of adaption
is necessary before an effect is shown. Body weight and body condition
score tended to increase because of CSFA supplementation, but body
condition scores were higher for cows in the NM group compared to the
control group. The beneficial or detrimental effects may be more apparent
in longer trials and in cows at an earlier stage of lactation that are
being subjected to a higher demand for nutrients and increased metabolic
stress. From a practical standpoint, CSFA plus blended NM may be a
convenient way to supplement high producing dairy cows in early or
midlactation.

The second experiment reported in this dissertation was designed to
answer questions raised at the conclusion of the series of experiments,
which failed to show the possibility of protecting NM by blending it into
CSFA to prevent leaching out during passage through the rumen. Some of the
questions were: 1) Is it essential to bypass niacin past the rumen to obtain beneficial effects? 2) Is either nicotinamide or nicotinic acid absorbed at the rumen level? 3) Is the rate and extent of absorption at the rumen level similar for both compounds? 4) Would the rate and extent of absorption of nicotinamide or nicotinic acid at the rumen level influence their total absorption from the gastrointestinal tract?, and 5) Is the solubility of both compounds similar in ruminal fluid under in vitro conditions?.

Results of this experiment (Section II) showed that blood nicotinamide concentration in cows given 12 g/d of nicotinamide orally peaked earlier and higher than blood concentration of cows receiving nicotinic acid similarly, which suggested faster absorption of nicotinamide from the rumen. Although blood nicotinamide concentration was higher after 1 h during d 2 compared with d 1 of nicotinamide administration, the effect was not cumulative because blood nicotinamide concentration during d 5 was similar to blood nicotinamide concentration during d 2. Concentrations of nicotinamide in blood of cows found at 12 h during 5 d of nicotinamide or nicotinic acid administration were above baseline, but values were similar between treatments. The area under the response curve, measured as μg x ml x h, showed that the value found by 6 h represented about 40% of the total area eventually detected at 24 h after nicotinamide administration, whereas only 15% was represented for the nicotinic acid group. Nevertheless, the area under the response curve at 12 h after nicotinamide or nicotinic acid administration was not significantly different and by 24 h values for both groups of cows were almost the same, reflecting a similar extent of total
niacin absorption. It may be not critical, therefore, to bypass niacin past the rumen to obtain benefits in lactating cows. Nicotinamide was shown to be about 20-fold more soluble than nicotinic acid in rumen fluid. This characteristic, along with its more basic pKa, may have influenced the increased rate of absorption of nicotinamide from the rumen.

It has been suggested that nicotinamide and nicotinic acid may exert their effects at either the ruminal or at the systemic level, or both. Additional studies are needed to determine the effects that their different rates of absorption from the rumen may have on ruminal microbial synthesis and fermentation, on overall metabolism, and consequently, on animal performance. Combinations and strategies of supplementation may be demonstrated that take advantage of differences in physical and metabolic characteristics of nicotinamide or nicotinic acid.
REFERENCES


Chalupa, W., and J. D. Ferguson. 1990. Immediate and residual responses of lactating cows in commercial dairies to calcium salts of long chain fatty acids. J. Dairy Sci. 73(Suppl. 1):244.(Abstr.)


Danesi, L. M., T. W. Perry, and D. R. Shields. Effects of niacin supplementation on in vitro fermentations at three levels of nitrogen. J. Dairy Sci. 65(Suppl. 1):409.(Abstr.)


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