



# REVIEW: A Meta-Analysis of Lactation Responses to Supplemental Dietary Niacin in Dairy Cows

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## Abstract

A meta-analysis of published data was conducted to examine the response of lactating dairy cows to supplemental dietary nicotinic acid (NA). The data set was developed from 27 studies published between 1980 and 1998 where lactation performance responses to targeted supplementation of 6 and 12 g/d NA were reported. Response variables evaluated were DMI, milk yield and composition, feed efficiency, and plasma beta-hydroxybutyric acid, non-esterified fatty acid, and glucose concentrations. No efficacy of 6 g/d dietary supplemental NA was found. Similarly, dietary supplementation with 12 g/d NA did not affect DMI, milk fat or protein percentages, or measured plasma metabolites. However, responses to dietary supplementation with 12 g/d NA were observed for 3.5% fat-corrected milk (FCM) yield, feed efficiency (when calculated with 3.5% FCM), and milk fat and protein yields. Yields of 3.5% FCM, milk fat, and milk protein were 0.5 kg/d ( $P=0.06$ ), 25.8 g/d ( $P=0.01$ ), and 17.4 g/d ( $P=0.08$ ) higher, respectively, for NA-supplemented cows. Feed efficiency calculated with 3.5% FCM was 0.03 units higher ( $P=0.09$ ). A

*Type I/Type II error economic analysis of the 3.5% FCM yield response showed frequencies of the observed response being greater than the break-even responses by 54 and 57% when NA costs were \$0.01 and \$0.005/g, respectively. Further research on transition cows and incidence of metabolic disorders, higher dosages of NA, and ruminally protected NA appears warranted.*

(Key Words: Niacin, Dairy Cattle, Milk Production, B Vitamins.)

## Introduction

Niacin is the generic descriptor for the vitamers nicotinic acid (NA) and nicotinamide (NAM). Both NA and NAM share similar vitamin activities; the free acid is converted to the amide form within the body. The NAM nucleotide coenzymes nicotinamide adenine dinucleotide and nicotinamide adenine dinucleotide-phosphate are involved in hundreds of metabolic reactions (Bender, 2003).

Ruminant B vitamin research in the mid 1940s showed that even when diets that were relatively free of niacin were fed, the niacin concentrations in ruminal digesta exceeded dietary concentrations. Miller et al. (1986) and Zinn et al. (1987) found that quantities of niacin appearing at the duodenum in steers exceeded that provided by feedstuffs. Because the ruminant microbial population

synthesizes niacin and observed clinical deficiencies have not been observed, it has generally been assumed that additional supplementation of dairy cattle is unnecessary.

Since the early work of Waterman and Schultz (1972) and Waterman et al. (1972), a plethora of research has been conducted investigating the effects of niacin supplementation, making niacin the most comprehensively researched B vitamin in dairy cattle. Approximately 50 research papers on niacin supplementation and lactation performance, metabolism, and in vivo and in vitro digestion can be found. Niacin supplementation of dairy cattle diets also has been extensively reviewed (Brent and Bartley, 1984; Harmeyer and Kollenkirchen, 1989; Drackley, 1992; Erdman, 1992; Flachowsky, 1993; Girard, 1998; NRC, 2001). Although thorough and broad-based, the previous reviews only reported on across-study means and SD or percentage responses vs controls. The objective of this investigation was to apply a meta-analysis approach using mixed model methodology (St. Pierre, 2001) to evaluate the literature regarding the supplementation of diets for lactating dairy cows with niacin. The statistical analysis was constrained to lactation performance and metabolic data, as in vivo ruminal digestion data were limited.

## Materials and Methods

**Data Set Development.** Data from 27 studies (Fronk et al., 1980; Kung

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et al., 1980; Riddell et al., 1981; Bartlett et al., 1983; Dufva et al., 1983; Jaster et al., 1983a, b; Horner et al., 1986, 1988; Muller et al., 1986; Grosse-Holz and Harmeyer, 1988; Skaar et al., 1989; Driver et al., 1990; Erickson et al., 1990, 1992; Jaster and Ward, 1990; Batallas et al., 1991; Martinez et al., 1991; Lanham et al., 1992; Zimmerman et al., 1992; Bernard et al., 1995; Ottou et al., 1995; Christensen et al., 1996; Di Costanzo et al., 1997; Madison-Anderson et al., 1997; Drackley et al., 1998; Minor et al., 1998) designed to evaluate the effects of supplemental NA in lactating dairy cows were utilized. Twenty-five studies were published in peer-reviewed publications, and two were in abstract form. In all studies, diets consisted of a basal control diet and the control diet plus supplemental NA as the treatment. Holstein cows were used in 25 studies; Jersey cows were used in the other two studies. Twenty-four studies were conducted at single sites; multiple farm locations were used in the other three studies. Twenty-five studies were conducted in the United States; two studies were conducted in Europe.

Only studies where NA was supplemented were included in our data set. There were studies that investigated the effects of supplemental dietary NAM available (Jaster and Ward, 1990; Cervantes et al., 1996). However, because differences in efficacy between NA and NAM remain unclear and comparative data are limited, results from NAM supplementation studies were excluded. Distinct control vs treatment comparisons were obtained from within single studies that reported results from multiple experiments and from within experiments when control vs NA comparisons could be distinguished within different diet types, time periods, or parity groups. When a study investigated multiple levels of NA supplementation, each level of NA was evaluated relative to the control. Comparisons included in the data set targeted 6 or 12 g/d NA supplementation vs 0 g/d (control). Although sev-

eral studies supplemented 3, 24, 36, or 48 g/d of NA, numbers of comparisons at these levels were insufficient for statistical analysis across studies. Supplemental NA was top-dressed alone, with a grain pre-mix, or included in the total mixed ration (TMR) in all studies except those of Erickson et al. (1990) and Ottou et al. (1995), where NA was provided by ruminal bolus and duodenal infusion, respectively. The experiments of Riddell et al. (1981) utilized group-fed cows fed diets targeted for 5 g/d supplemental NA. Fronk et al. (1980) supplemented NA at 0.1 g/kg BW<sup>0.75</sup>, which equaled approximately 12 to 14 g/d NA. Comparisons from these two experiments were included with the 6 and 12 g/d NA groups, respectively. The total number of targeted 6 and 12 g/d NA comparisons for each variable investigated are shown in Table 1.

Cows were fed for ad libitum intake in all studies. Of the 23 studies that reported a method of feed delivery, 16 utilized TMR, and the remainder utilized component-feeding systems. In the 22 studies where it was reported or could be calculated, dietary forage-to-concentrate ratio (DM basis) ranged from 22:78 to 87:13 with about three-fourths of the diets ranging between 40:60 and 60:40. Dietary CP, ADF, and NDF (% DM) were reported or could be calculated in 18, 14, and 7 studies and averaged ( $\pm$ SD) 16.7  $\pm$  2.1, 19.4  $\pm$  3.6, and 32.2  $\pm$  6.1% across control and treatment comparisons, respectively.

Time of trial initiation relative to calving reported for 66 comparisons was between 21 and 10 d prepartum, at calving, between 14 and 53 d in milk (DIM), or between 77 and 256 DIM for 17, 9, 22, and 18 comparisons, respectively. Averages and SD for DIM at the time of trial initiation were 61  $\pm$  79 and 18  $\pm$  32 DIM for the 6 and 12 g/d NA groups, respectively. Number of days on treatment was provided for all comparisons and ranged from 14 to 42, 48 to 70, 83 to 147, and 273 to 279 d for 29, 20, 18, and 4 control vs treatment comparisons, respectively.

Prior to statistical analysis, attempts were made to further group the data set beyond 6 and 12 g/d NA supplementation level. Effects such as stage of lactation, dietary forage, and dietary nutrient content were considered. However, it was found that because of often-insufficient description or nonreporting of such parameters, no satisfactory balance of the data could be achieved for a meaningful statistical analysis that included grouping of the data by factors other than level of NA supplementation. For example, data for milk yield was the most frequently reported response. A stage-of-lactation-at-initiation-of-NA-supplementation grouping factor was evaluated with cut points for early and other set at  $\leq$ 40 and  $>$ 40 DIM, respectively. Use of this grouping strategy resulted in 18 and 24 comparisons for 6 and 12 g/d NA for early and 14 and 6 comparisons for 6 and 12 g/d NA for other, respectively. Discrepancies between numbers of comparisons for other responses using this and other criterion were more pronounced. Therefore, because of the variability in experimental protocols, only level of NA supplementation was considered as a reasonable grouping strategy for the data set.

Response variables evaluated were DMI, yields of milk, 3.5% fat-corrected milk (FCM), milk fat and protein percentage and yield, feed efficiency calculated with milk and 3.5% FCM yields, and blood non-esterified fatty acids (NEFA), beta-hydroxybutyric acid (BHBA), and glucose.

**Statistical Analysis.** Residuals normality was evaluated using the *PLOT* and *NORMAL* options of the UNIVARIATE procedure (SAS<sup>®</sup>; SAS Institute, Cary, NC). Numerical tests of residuals normality were considered, but primary consideration was given to the visual results of the stem-leaf, box, and normal probability plots. Potential outliers and influential points were evaluated using the output key words *DFFIT*s and *COOK*D, respectively, following a GLM procedure (SAS, 2004) analysis of the data where NA dose was considered as a fixed ef-

**TABLE 1. Descriptive statistics for amount of supplemental dietary niacin and lactation performance parameters expressed as unit change from control.**

Item	NA (g/d)	Control mean <sup>a</sup>	n	Unit change from control		
				Range	Mean	SD
DMI, kg/d	6	20.1	14	-3.1 to 1.1	-0.3	1.1
	12	19.6	33	-2.0 to 1.4	-0.1	0.7
Milk yield, kg/d	6	27.3	34	-1.7 to 2.9	0.5	1.2
	12	32.0	33	-2.1 to 3.3	0.4	1.3
3.5% FCM <sup>b</sup> , kg/d	6	28.4	29	-2.5 to 3.4	0.2	1.5
	12	31.5	31	-1.8 to 3.0	0.5	1.2
Feed efficiency <sup>c</sup>	6	1.38	14	-0.19 to 0.17	0.01	0.10
	12	1.56	29	-0.18 to 0.19	0.02	0.07
3.5% Feed efficiency <sup>d</sup>	6	1.45	14	-0.18 to 0.12	-0.02	0.10
	12	1.54	29	-0.22 to 0.17	0.03	0.08
Milk fat, %	6	3.76	25	-0.21 to 0.44	-0.04	0.14
	12	3.49	31	-0.30 to 0.34	0.01	0.16
Milk fat, g/d	6	1021.3	25	-112.4 to 133.1	1.01	61.9
	12	1092.5	31	-75.0 to 113.0	23.53	47.2
Milk protein, %	6	3.22	24	-0.26 to 0.20	-0.001	0.11
	12	3.09	30	-0.13 to 0.30	0.01	0.09
Milk protein, g/d	6	860.3	24	-77.1 to 123.7	9.4	45.5
	12	970.7	30	-110.0 to 161.1	13.4	49.7
Plasma NEFA <sup>e</sup> , molar %	6	— <sup>f</sup>	—	—	—	—
	12	269.7	24	-193.3 to 113.7	3.0	60.4
Plasma BHBA <sup>g</sup> , mg/dL	6	9.8	5	-4.0 to 1.4	-1.0	1.9
	12	7.6	24	-5.6 to 2.3	-0.6	1.6
Plasma glucose, mg/dL	6	57.6	10	-1.4 to 3.6	1.1	1.8
	12	62.9	30	-3.6 to 7.4	0.7	2.5

<sup>a</sup>Arithmetic mean.

<sup>b</sup>FCM = fat-corrected milk.

<sup>c</sup>Calculated as kg milk yield/kg DMI.

<sup>d</sup>Calculated using 3.5% FCM yield.

<sup>e</sup>NEFA = non-esterified fatty acids.

<sup>f</sup>NEFA concentrations were not reported in experiments supplementing 6 g/d niacin.

<sup>g</sup>BHBA = beta-hydroxybutyric acid.

fect and study a random effect. Data were analyzed using the MIXED procedure of SAS to evaluate animal response to NA, expressed as the difference from control. The linear model included the fixed effect of NA supplementation level (6 or 12 g/d) and the random effect of study (St. Pierre, 2001). Each response was weighted according to the number of animals used to test for it using the WEIGHT statement. Economics of NA supplementation were evaluated with the production response data using the Type I/Type II error method of Galligan et al. (1991). The spreadsheet version can be found at [\[ductiontools.org\]\(http://www.productiontools.org\) \(accessed March 28, 2005\).](http://www.pro-</a></p>
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## Review and Discussion

Descriptive statistics for evaluated production parameters, expressed as change from control diets, are shown in Table 1. Observations were generally more numerous for the 12 g/d than for the 6 g/d NA treatment groups. Variability in responses was generally higher for 6 g/d than for 12 g/d NA and likely was caused by fewer observations for the 6 g/d-NA group. The variations in response to

supplemental NA were considerable, as also noted by Drackley (1992).

The variability in responses to supplemental NA may be explained partially by dietary effects on ruminal niacin synthesis. Santschi et al. (2004a) fed lactating cows diets containing 58.3% forage (DM basis) and reported that apparent synthesis (calculated as the difference between quantities flowing to the duodenum and dietary intake) of NA and NAM were (LSM  $\pm$  SEM) 912.4  $\pm$  132.4 and 1259  $\pm$  124.8 mg/d, respectively. In an experiment from our laboratory (E. C. Schwab et al., unpublished data), ruminally and duodenally cannulated lactating dairy

cows were fed diets containing 35 or 60% forage (DM basis) and 30 or 40% non-fiber carbohydrates (DM basis). Increasing dietary forage and non-fiber carbohydrates increased NAM ( $P=0.01$ ) and both NA ( $P=0.03$ ) and NAM ( $P<0.01$ ) apparent synthesis, respectively. Considering both reports, estimates of total ruminal niacin (NA + NAM) synthesis ranged from approximately 400 to 2000 mg/d. It appears that dietary factors can greatly affect ruminal niacin synthesis. Therefore, supplemental dietary niacin may be beneficial when ruminal niacin synthesis is limited or microbial growth is not maximized. Flachowsky (1993) concluded that the high variation in response to niacin was due to "...differences in ration formulation, milk performance, stage of lactation, age of cows, level and duration of niacin supplementation, and specific experimental conditions."

Reasons for a negative effect of NA on animal performance are unknown, although Erdman (1992) and Drackley (1992) reported that niacin supplements were unpalatable and should be included in a highly palatable premix to avoid intake depression. Transient toxic effects have been observed in humans given large doses of NA (Bender, 2003); however, Harmeyer and Kollenkirchen (1989) indicated that no toxic effects of NA supplementation have been reported in ruminants.

Least squares means for effects of NA supplementation on production responses and blood parameters are shown in Table 2. There were no lactation performance responses when NA was supplemented at approximately 6 g/d. For cows fed approximately 12 g/d NA, milk and 3.5% FCM yield responses were 0.4 ( $P=0.12$ ) and 0.5 kg/d ( $P=0.06$ ) greater than controls. Because of unchanged DMI and greater milk yields, feed efficiency (kg milk/kg DMI) was 0.03 units higher ( $P=0.09$ ) than that for controls when calculated with 3.5% FCM. Yields of milk fat and protein were 25.8 ( $P=0.01$ ) and 17.4 g/d ( $P=0.08$ ) higher, respectively. Feeding 12

**TABLE 2. Least squares means (LSM) of effect of dietary 6 or 12 g/d nicotinic acid (NA) supplementation expressed as unit change from control.**

Item	NA (g/d)	LSM	SEM	$P=^a$
DMI, kg/d	6	-0.3	0.2	0.21
	12	-0.1	0.2	0.66
Milk yield, kg/d	6	0.3	0.3	0.34
	12	0.4	0.3	0.12
3.5% FCM <sup>b</sup> , kg/d	6	0.2	0.3	0.59
	12	0.5	0.3	0.06
Feed efficiency <sup>c</sup>	6	0.01	0.02	0.65
	12	0.02	0.02	0.26
3.5% Feed efficiency <sup>d,x</sup>	6	-0.02	0.02	0.42
	12	0.03	0.01	0.09
Milk fat, %	6	-0.007	0.03	0.82
	12	0.01	0.03	0.74
Milk fat, g/d	6	12.4	8.6	0.21
	12	25.8	10.2	0.01
Milk protein, %	6	-0.004	0.02	0.95
	12	0.01	0.02	0.58
Milk protein, g/d	6	12.0	9.7	0.25
	12	17.4	9.7	0.08
Plasma NEFA <sup>e</sup> , molar %	6	— <sup>f</sup>	—	—
	12	9.6	14.5	0.51
Plasma BHBA <sup>g</sup> , mg/dL	6	-0.7	0.7	0.35
	12	-0.5	0.4	0.28
Plasma glucose, mg/dL	6	0.9	0.7	0.23
	12	0.7	0.5	0.18

<sup>a</sup>Test for  $H_0$ : change = 0 vs  $H_A$ : change  $\neq$  0.

<sup>b</sup>FCM = fat-corrected milk.

<sup>c</sup>Calculated as kg milk yield/kg DMI.

<sup>d</sup>Calculated using 3.5% FCM yield.

<sup>e</sup>NEFA = non-esterified fatty acids.

<sup>f</sup>NEFA concentrations were not reported in experiments supplementing 6 g/d niacin.

<sup>g</sup>BHBA = beta-hydroxybutyric acid.

<sup>x</sup>Tendency toward significant effect of supplemental niacin level ( $P=0.11$ ).

g/d NA did not affect ( $P>0.10$ ) plasma NEFA or BHBA concentrations. Feed efficiency, when calculated with 3.5% FCM, was greater ( $P=0.11$ ) for the 12 vs 6 g/d NA level. Lack of responses to 6 g/d NA might have occurred because either this dose was insufficient to elicit a response or because cows supplemented this dosage were, on average, supplemented later in lactation. Mechanisms by which NA would elicit the aforementioned production responses are unclear, but effects of NA on rumen fermentation or animal metabolism are possible modes of action.

Rumen fermentation studies (primarily in vitro) have been thoroughly reviewed by others (Harmeyer and Kollenkirchen, 1989; Flachowsky, 1993; Girard, 1998), and beneficial effects of NA on rumen microbial growth, VFA concentrations, pH, and OM digestion have been observed. Reports of effects of NA on ruminal fermentation and nutrient digestibility in vivo are more limited. Results from nine in vivo experiments (Kung et al., 1980; Riddell et al., 1980; Erickson et al., 1990, 1992; Zimmerman et al., 1992; Campbell et al., 1994; Christensen et al., 1996; Doreau and Ot-

tu, 1996; Madison-Anderson et al., 1997) are summarized in Table 3. Overall, effects of supplemental NA on rumen fermentation and nutrient digestibility were minimal. Christensen et al. (1996) reported that NA (12 g/d) decreased ( $P=0.02$ ) total-tract ADF digestibility and tended to decrease ( $P=0.09$ ) NDF digestibility. Further, they reported that NA tended to increase ( $P=0.11$ ) and decrease ( $P=0.08$ ) ruminal propionate and acetate concentrations, respectively. Doreau and Ottou (1996) reported that 6 g/d supplemental NA increased ( $P<0.01$ ) ruminal butyrate concentration. The response most commonly observed from supplemental dietary NA in vivo (Doreau and Ottou, 1996; Erickson et al., 1992) and in vitro (Flachowsky, 1993; Girard, 1998; Harmeyer and Kollenkirchen, 1989) was an increase in ruminal protozoa concentrations, presumably because protozoa require niacin for growth (Hungate, 1966). Although the importance of increased protozoa concentrations is unknown, protozoa engulf starch granules, which may provide a pH-stabilizing effect in the rumen (Russell, 2002).

From the foregoing discussion, it seems unlikely that production responses to 12 g/d NA were due to alterations in ruminal fermentation and beneficial metabolic effects of NA are more likely. Early work in humans (Carlson and Orö, 1962) showed that NA lowered plasma free fatty acids. The molecular mechanisms by which NA elicits its antilipolytic effects on adipose tissue have been reviewed (DiPalma and Thayer, 1991; Karpe and Frayn, 2004). Wisconsin researchers (Waterman and Schultz, 1972; Waterman et al., 1972) showed that pharmacological doses (160 g) of niacin given over 8 h decreased plasma NEFA and ketone body concentrations in dairy cows with clinical or subclinical ketosis. This decrease was followed by a large rebound in plasma NEFA concentrations. Because NA interferes with the ability of the adipocyte to regulate its triglyceride stores normally, this large

rebound presumably occurs when the antilipolytic action of NA ceases (Karpe and Frayn, 2004). Follow-up work (Fronk and Schultz, 1979) in ketotic cows fed 12 g/d NA showed decreased ( $P<0.05$ ) blood free fatty acids and BHBA and an increase ( $P<0.10$ ) in blood glucose 7 d after initiation of NA treatments. In a recent study (French, 2004), multiparous Jersey cows were fed either 0 or 48 g/d NA starting at 30 d prepartum. Plasma NEFA concentrations were less ( $P<0.01$ ) on the day of (491 vs 1244  $\mu\text{mol/L}$ ) and on the day after (328 vs 718  $\mu\text{mol/L}$ ) calving for NA-supplemented vs control cows. Relative to respective 14- to 21-d post-calving averages, percentage of DMI decline during the last week of gestation was less ( $P<0.05$ ) for the NA-supplemented cows (4.7%) than for the control cows (20.5%). Plasma NEFA concentrations are at their highest, and DMI is at its lowest, around calving (Grummer, 1993). Lack of an observed effect of feeding 12 g/d NA on plasma NEFA concentrations in the present analysis might have been because studies in our data set did not target the time period where NEFA concentrations are elevated; control and NA means were primarily calculated from averages across early and mid-lactation, and in a few studies, across an entire lactation. Therefore, potential differences between control and NA-supplemented cows at or around calving might have been masked in the overall averages. Theoretically, NA supplementation may be the most beneficial during the transition period, as niacin status may be poor during this time because DMI and possibly microbial niacin synthesis in the rumen, as a consequence, are reduced.

Triglycerides are primarily exported from the liver as very low density lipoproteins (VLDL; Grummer, 1993). Niacin has inhibited hepatic VLDL synthesis and export in humans (DiPalma and Thayer, 1991; Karpe and Frayn, 2004), but these activities are inherently low in ruminants (Kleppe et al., 1988; Graulet et al., 1998). Stud-

ies evaluating the influence of NA on VLDL synthesis or export in dairy cows are lacking; however, three studies have evaluated the effect of NA on fatty liver. Skaar et al. (1989) fed dairy cows 12 g/d NA from d 17 prior to calving through 15 wk postpartum. Cows fed NA tended ( $P<0.15$ ) to have greater total liver lipid (30% vs 23.7%, DM basis) at freshening than cows that received no NA. Minor et al. (1998) reported that liver triglyceride (DM basis) tended ( $P<0.10$ ) to be less in cows fed 12 g/d NA starting at d 19 prepartum than those fed NA starting on d 14 postpartum. In the experiment of Grum et al. (2002), NA (12 g/d) decreased ( $P<0.01$ ) liver triglyceride (wet weight basis) and total liver lipid (wet weight basis) when cows were fed supplemental fat, but levels were increased by NA when low fat diets were fed. Based on the aforementioned studies, further research is required to address the effects of NA on fatty liver.

For supplemental dietary NA to be physiologically available to the dairy cow, it must be absorbed into the blood. For this to occur, it must either be resistant to ruminal degradation or absorbed across the rumen wall. Zinn et al. (1987), using duodenally cannulated steers (~194 kg BW), showed that 6% of a 2-g ruminal NA dose escaped the rumen, with no significant ( $P>0.05$ ) increase in duodenal niacin flow. In an experiment with lactating dairy cows, Santschi et al. (2004a) reported that 1.5% of a 12-g ruminal NAM dose escaped the rumen. Campbell et al. (1994) reported that 12 g/d of NA or NAM increased ( $P=0.001$ ) duodenal niacin (NA and NAM vs control) concentrations by 58%. Debate also exists as to whether or not ruminal NA absorption occurs. Reports utilizing sheep (Rérat et al., 1958b) and lactating dairy cows (Erickson et al., 1991) reported that niacin is absorbed from evacuated rumens. In contrast, Rérat et al. (1958a) observed no appreciable ruminal absorption in fed sheep. In support of this observation, Santschi et al. (2004b) reported that concentrations

TABLE 3. Effects of dietary supplemental nicotinic acid (NA) on rumen fermentation and digestibility in vivo.

Item	Campbell et al. (1994)		Christensen et al. (1996)		Doreau and Ottou (1996)		Erickson et al. (1992)		Erickson et al. (1990)		Kung et al. (1980)		Madison-Anderson et al. (1997)		Riddell et al. (1980)		Zimmerman et al. (1992)	
	12	12	12	6	6	12	12	12	12	6	6	12	12	~ 4	12	12		
NA, g/d	12	12	12	6	6	12	12	12	12	6	6	12	12	~ 4	12	12		
Effect of supplemental NA <sup>a</sup>																		
Total tract digestibility (%)																		
DM	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
OM	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
ADF	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
NDF	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
CP	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
Starch	— <sup>b</sup>	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
Ruminal digestibility (%)																		
DM	—	—	—	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
OM	—	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
ADF	—	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
NDF	—	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
CP	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Starch	—	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
Ruminal VFA concentration																		
Acetate (A)	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
Propionate (P)	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
Butyrate	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
Total	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
A:P	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
pH	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
NH <sub>3</sub>	—	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
Microbial N flow (g/d)	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
Protozoa concentration	—	—	—	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔

<sup>a</sup>Effects: ↔ = no effect, ++ = significant effect, + = tendency, ↑ = increase, ↓ = decrease; statistical effects as reported by researchers.

<sup>b</sup>Not reported.

<sup>c</sup>Microbial protein reported as mg/100 mL.

of both NA and NAM in ruminal bacteria were approximately 400 times greater than in particle-free rumen fluid. These reports suggest that niacin is primarily sequestered within ruminal bacteria, that little would be available for absorption directly from the rumen, and that the majority of intestinally available niacin is of microbial origin.

Although the aforementioned studies question the availability of supplemental niacin, Driver et al. (1990) and Jaster et al. (1983a) fed 6 and 12 g/d NA and reported increases ( $P < 0.05$ ) in blood NAM and NA concentrations, respectively. In contrast, others supplementing 12 g/d of dietary NA (Martinez et al, 1991; Campbell et al., 1994) or NAM (Campbell et al., 1994) or 6 g/d NA (Lanham et al., 1992) reported no ( $P > 0.05$ ) changes in blood NA or NAM concentrations. Results of these trials suggest that factors other than dosage level and source of supplemental niacin influence the availability of niacin to the dairy cow.

The economics of using or not using 12 g/d NA were evaluated with our production response data using the Type I/Type II error method of Galligan et al. (1991). Required inputs for this analysis are 3.5% FCM response and standard deviation, milk price, DMI change, and ration cost. Outputs include break-even milk yield response, net income from supplement use, and dollar return on investment. Also estimated are cost (\$/d per cow) and frequency of using (Type I error) and failing to use (Type II error) the supplement when the observed response is below or above the break-even response, respectively. Input response values used for 3.5% FCM yield and SD were 0.5 and 1.6 kg/d, respectively. Milk price and NA cost used were \$0.30/kg and \$0.01/g, respectively. Because no ( $P = 0.66$ ) response in DMI was observed, this value was set at zero. The net income from NA was \$0.04/d per cow, for a return on investment of 34%. The 3.5% FCM yield break-even response was 0.39 kg/d per cow. The frequency

of the observed response being greater than the break-even response was 54%. The cost of using NA when the response was below the break-even point (Type I error) was \$0.14/d per cow, and the cost of failing to use NA when the response was above the break-even point (Type II error) was \$0.20/d per cow. If the cost of NA was reduced from \$0.01 to \$0.005/g, then net income from NA, return on investment, and 3.5% FCM yield break-even response were \$0.10/d per cow, 168%, and 0.20 kg/d per cow, respectively. Under this reduced NA cost scenario, the costs of Type I and II errors were \$0.12 and \$0.23/d per cow, respectively, and the frequency of the observed response being greater than the break-even response was 57%. This analysis suggests that supplementing 12 g/d NA may result in a greater than break-even response, but only about 50% of the time. However, it must be noted that responses used in the analysis were from cows across various stages of lactation. Given aforementioned discussions, transition cows may benefit the most from supplemental NA, although more data are needed for an appropriate transition cow economic analysis.

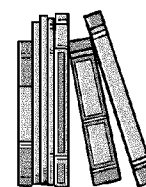
## Implications

Results of our meta-analysis of published trials indicate that dietary supplementation with approximately 12 g/d NA may improve lactation performance. Although the high variability of the response to supplemental NA across trials and tenuous economic benefits may dissuade inclusion on a routine basis in dairy diets, further research on supplemental NA appears warranted for several reasons: beneficial effects of NA observed in transition cow and high inclusion rate studies and the importance of reducing metabolic disorders, evidence of dietary effects on ruminal niacin synthesis, and potential improvements in lactation performance reported herein. Future research should investigate higher dosage levels and focus

on the transition period. Development of ruminally protected niacin supplements could avoid problems associated with ruminal destruction and palatability and reduce required inclusion rate of NA to possibly allow for a more economical delivery.

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