Troubleshooting milk fat challenges on commercial dairy farms

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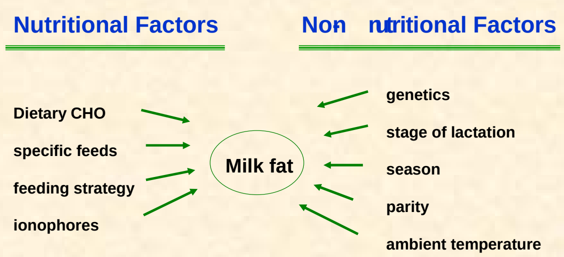
Introduction

- Topic of low milk fat not a new one (first recognized and reported by Boussingault in 1845)
- Recent changes in pricing in U.S.
  - Based upon yields of components, not milk per se
  - 38% of herds from PA, OH, MI, and IN experienced marked (< 3.46%) short-term (one to three-month) decreases in milk fat during any year (Bailey et al., 2005)
- Fat-based quotas in Canada encouraged "healthy" decreases in milk fat
  - Recent changes dictating minimum ratio of fat to SNF changes strategy
- We have learned a lot, but still have lots to learn



Fatty Acids

- Long carbon chains that contain a methyl group (CH3) at one end and a carboxyl group (COOH) at the other
- Fatty acids are what make lipids energy-rich
- Characterized by:
  - Number of carbons (chain length)
  - Number of double bonds (degree of unsaturation)
  - Location and orientation of these bonds (non-conjugated, conjugated; *cis*, *trans*)

Fatty Acid Composition of Different Fats

Fat source	16:0	18:0	18:1	18:2
Corn oil	16	2	30	47
Whole cottonseed	25	3	17	54
Whole soybeans	11	4	24	54
Tallow	24	24	42	5
Hydrogenated tallow	25	25-50	10-40	1
Ca-PFAD	50	4	35	8

Major Fatty Acids in Milk Fat

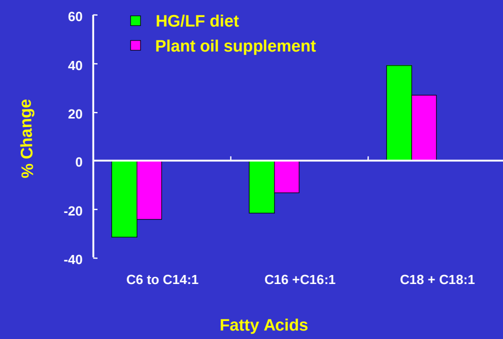
Fatty Acid	% (weight basis)	Fatty Acid Source
4:0	4	*De novo* synthesis
6:0	3	
8:0	2	
10:0	3	
12:0	4	
14:0	11	
16:0	29	*De novo* and preformed
16:1	2	
18:0	12	Uptake of preformed
18:1	25	
18:2	2	
18:3	1	

Diet-Induced Milk Fat Depression Characteristics

- **General dietary factors**
  - **- high concentrate, low fiber**
  - **- low in effective fiber**
  - **- plant and fish oil supplements**
  - **- unsaturated fatty acids**
- **Specific for milk fat, up to 50% decrease**
- **Decreased yield of all fatty acids, but greatest for de novo synthesized fatty acids**
- **Requires two conditions: 1) altered rumen fermentation and 2) dietary presence of polyunsaturated fatty acids**

Bauman et al., 2004

Changes in Milk Fat Composition



Milk Fat Depression Theories

- **Shortage of precursors for milk fat synthesis**
- **Direct inhibition of milk fat synthesis**

Shortage Of Precursors

- **acetate deficiency (↓ rumen production)**
- **β-hydroxybutyrate deficiency (antiketogenic effects of propionate)**
- **glucogenic-insulin theory (tissue competition)**

Acetate Shortage Theory and MFD[a]

	Normal diet	HG/LF Diet
Milk yield	No change	
Milk fat, g/d	683	363
Rumen VFA, %		
Acetate	67	46
Propionate	21	46
Butyrate	11	9
Acetate/Propionate	3.2	1.0

[a]Averaged from Davis et al. 1967 and Bauman et al. 1971.

Acetate Shortage Theory and MFD

	Normal diet	HG/LF Diet
Rumen Production, moles/d		
Acetate	29.4	28.1[a]
Propionate	13.3	31.0[b]
B-hydroxybutyrate	7.0	9.1[c]

[a]Davis et al. 1967
[b]Bauman et al. 1971
[c]Palmquist et al. 1969

Glucogenic-insulin Theory of Milk Fat Depression

High grain:forage diet

↓

Increased propionate

↓

Increased glucose

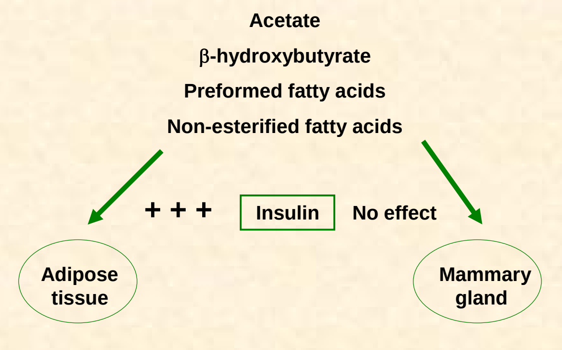
↓

Increased insulin

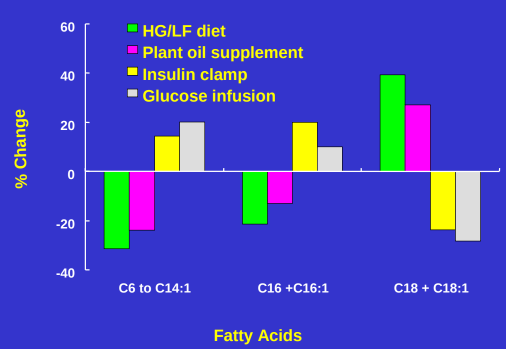
↓

Milk fat depression

Glucogenic insulin Theory of Milk Fat Depression



Changes in Milk Fat Composition



Direct Inhibition of Milk Fat Synthesis

- *Trans* Theory
- Biohydrogenation Theory

Trans theory of milk fat depression

Altered rumen microbes and fermentation

↓

Formation of *trans* fatty acids in the rumen

↓

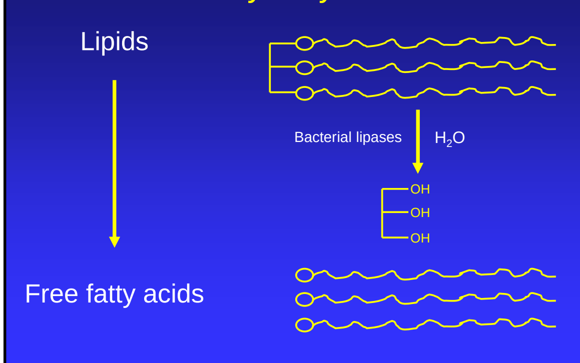
Inhibition of mammary lipogenic enzymes

↓

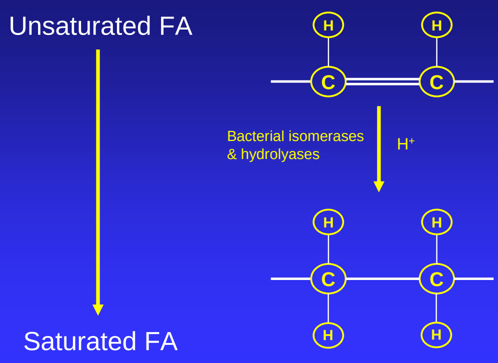
Milk fat depression

Digestion in the Rumen

Hydrolysis

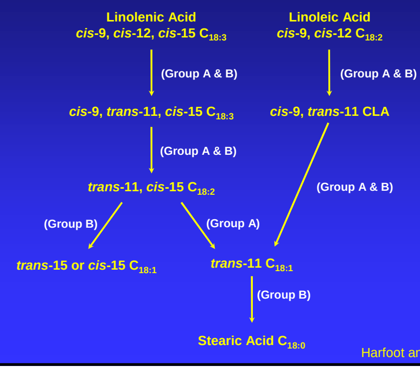


Biohydrogenation



Digestion in the Rumen

Pathways for Rumen Biohydrogenation



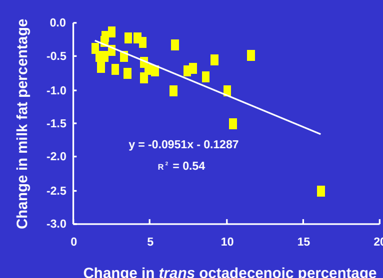
Harfoot and Hazlewood, 1997

Digestion in the Rumen

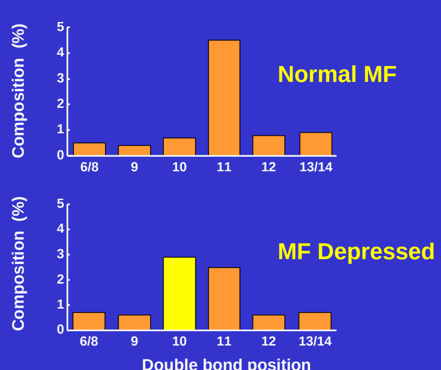
Biohydrogenation intermediates in growing and lactating cattle

Trans 18:1		Conjugated 18:2	
Isomer	Ruminal outflow (g/d)	Isomer	Ruminal outflow (g/d)
trans-4	0.5-0.7	*trans*-7, *cis*-9	<0.01
trans-5	0.4-0.6	*trans*-7, *trans*-9	<0.01-0.05
trans-6-8	0.4-6.7	*trans*-8, *cis*-10	0.01-0.02
trans-9	0.8-6.2	*trans*-8, *trans*-10	<0.01-0.10
trans-10	1.7-29.1	*cis*-9, *cis*-11	<0.01-0.01
trans-11	5.0-121.0	*cis*-9, *trans*-11	0.19-2.86
trans-12	0.5-9.5	*trans*-9, *trans*-11	0.22-0.55
trans-13 + 14	6.5-22.9	*trans*-10, *cis*-12	0.02-0.32
trans-15	3.2-8.5	*trans*-10, *trans*-12	0.05-0.06
trans-16	3.1-8.0	*cis*-11, *trans*-13	0.01-0.10
		trans-11, *cis*-13	0.01-0.46
		trans-11, *trans*-13	0.09-0.40
		cis-12, *trans*-14	<0.01-0.05
		trans-12, *trans*-14	0.08-0.19

Milk Fat Test vs. *trans* 18:1 Fatty Acids

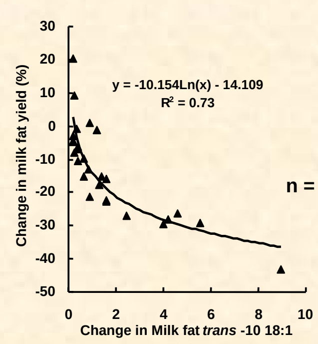


Griinari et al. 1998



Griinari et al., 1998

Relationship between change in milk fat yield and change in fat content of *t*-10 18:1.

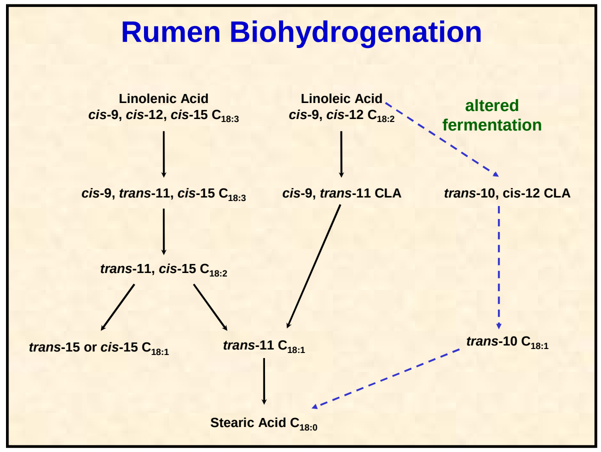


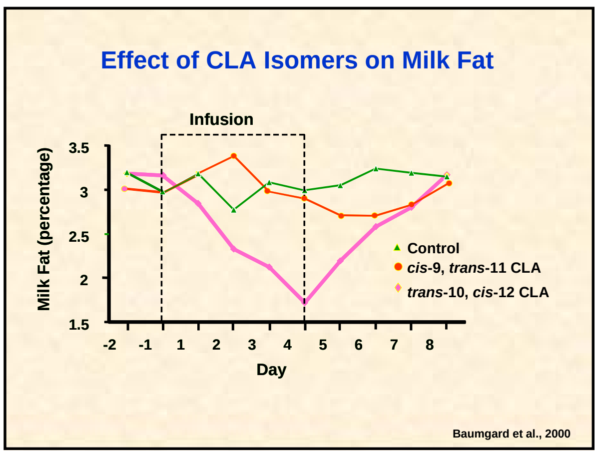
"BIOHYDROGENATION THEORY"

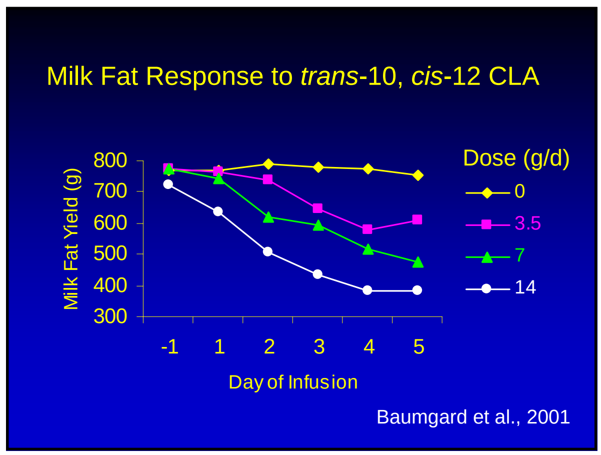
of milk fat depression

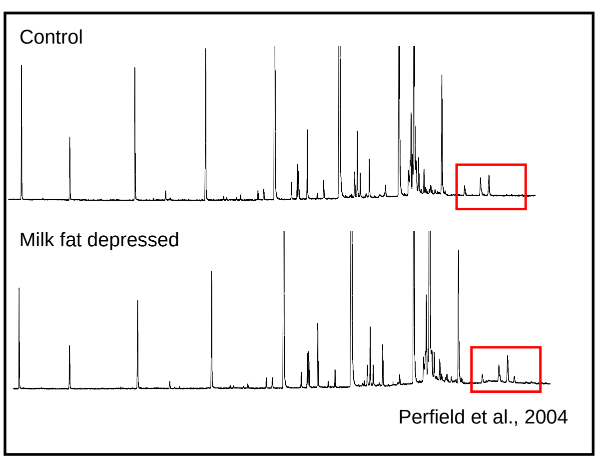
Under certain conditions rumen biohydrogenation results in unique fatty acids that are potent inhibitors of milk fat synthesis – e.g. *trans*-10, *cis*-12 CLA and possibly related intermediates from linolenic acid and other polyunsaturated fatty acids.

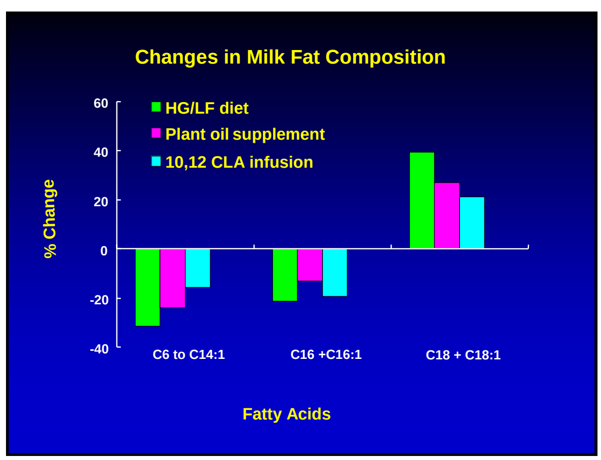
Bauman and Griinari, 2001



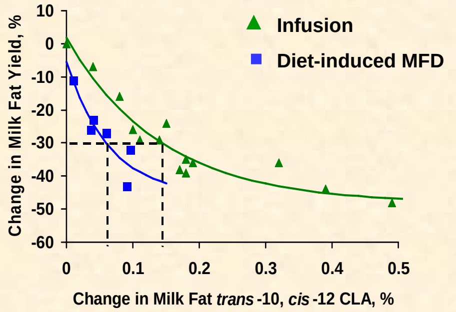








Post-Ruminal Infusion vs. Diet-Induced MFD



Adapted from Peterson et al., 2003 and Griinari and Bauman, 2005

Trans 18:1		Conjugated 18:2	
Isomer	Milk fat response	Isomer	Milk fat response
trans-4		*trans*-7, *cis*-9	
trans-5		*trans*-7, *trans*-9	
trans-6-8		*trans*-8, *cis*-10	No change
trans-9	No change	*trans*-8, *trans*-10	
trans-10		*trans*-9, *cis*-11	MFD
trans-11	No change	*cis*-9, *trans*-11	No change
trans-12	No change	*trans*-9, *trans*-11	No change
trans-13 + 14		*cis*-10, *trans*-12	MFD
trans-15		*trans*-10, *cis*-12	MFD
trans-16		*trans*-10, *trans*-12	No change
		cis-11, *trans*-13	No change
		trans-11, *cis*-13	
		trans-11, *trans*-13	
		cis-12, *trans*-14	
		trans-12, *trans*-14	
		cis-*cis* isomers	

Perfield and Bauman, 2005

How do we find and troubleshoot ruminal outflow of 1 to 2 grams of a specific MFD-causing fatty acid????

Factors that affect substrate supply and availability

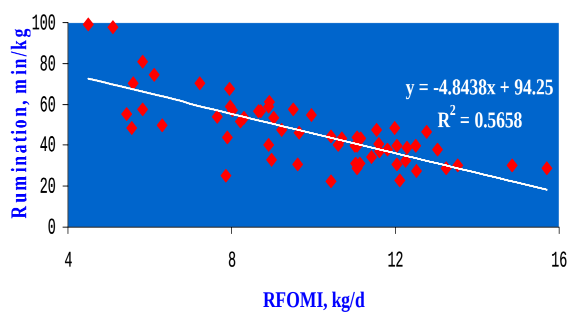
- Linoleic acid (C18:2) supply and availability in the rumen
- CPM-Dairy predictions of linoleic acid intake from high corn silage-based lactating diets in NE U.S. can approach or exceed 400 to 500 g/d
- Ready availability of low-cost byproducts from corn (distillers) or other sources
  - Tremendous variation in fat content within and among production plants
- Any processing method that will increase ruminal availability of unsaturated FA

Factors that result in an altered ruminal environment

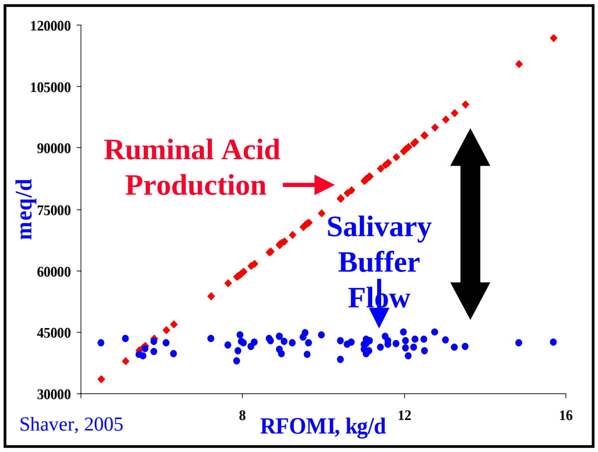
- Dynamics of rumen pH as a balance of
  - Acid production from ruminally fermentable CHO
    - *Dietary CHO profile and Kd of fractions as affected by source, processing, and moisture*
  - Buffer production from salivary and dietary sources
    - *peNDF supply and source*
  - Rate of removal of acids through absorption or passage
  - Feeding management and environmental/facility effects
    - *Mixing, DM changes, feeding frequency, stocking density, heat stress, stall usage, etc.*

Allen, 1997; Shaver, 2005; Von Keyserlingk and DeVries, 2005

Rumination per kg RFOMI vs. RFOMI



Data source: Yang and Beauchemin trials; from Shaver, 2005



Overcrowding & Rumination

- 0 vs 30% overcrowding of stalls and manger (Batchelder, 2000)
  - switchback design
- % cows ruminating in overcrowded group averaged 28% (high of 32%)
- % cows ruminating with no overcrowding was 37% (high of 55%)

Courtesy: Dr. R. Grant

Other factors that may contribute to an "altered" ruminal environment conducive to production of MFD-causing FA

- Off-fermented feeds, particularly high acetic corn silage??
- High mold and yeast counts on ensiled forages??
- High pH water??
- All require controlled study – anecdotal evidence only
- Some evidence (Larondelle et al., 2001; Pottier et al., 2006) that Vitamin E (10,000 to 12,000 IU/d) may help to prevent isomerase shift

Factors that influence biohydrogenation rate

- Anything that slows rates of biohydrogenation at different steps may result in more passage of FA intermediates that cause MFD from the rumen
- These do not cause milk fat problems, but will amplify the effecf of an existing ruminal condition on milk fat
  - Monensin
  - Fish fatty acids (last step of biohydrogenation)

Summary of other experiments in which monensin supplementation started during transition period (adapted from Duffield and Bagg, 1999)

Reference	n	Dose	DIM	Milk (kg)	Fat (%)	CP (%)	Notes
Erasmus (1993)	60	10 ppm	-28	+3.1	NS	NS	
Thomas (1993)	47	150	-28	NS	NS	NS	
		300	-28	NS	NS	NS	
		450	-28	NS	NS	NS	
Abe (1994)	16	CRC	0 to 2	NS	Decr.	NS	Pasture
Granzin (1999)	18	150 mg	-14	+1.9	NS	NS	
		300 mg	-14	+2.6	NS	NS	

Milk production and efficiency of cows fed monensin (Symanowski et al., 1999)

	Monensin (ppm) in ration			
	0	8	16	24
Number of cows	215	210	216	217
DMI, lb/d	43.6	44.1	42.8[a]	42.3[a]
Milk yield, lb/d	64.6	66.8[a]	66.6	67.0[a]
Milk fat, %	3.66	3.61	3.52[a]	3.42[a]
Milk protein, %	3.15	3.16	3.14	3.12[a]
Milk protein/Milk fat	.891	.907	.926[a]	.956[a]
SCM, lb/d	60.4	62.2	60.8	60.4
Efficiency, SCM lb/Mcal	1.90	1.93[a]	1.96[a]	1.97[a]

[a] Significantly different from control, $P < .05$.

Summary of other experiments in which monensin supplementation started after transition period (adapted from Duffield and Bagg, 1999)

Reference	n	Dose (mg/d)	DIM	Milk (kg)	Fat (%)	CP (%)	Notes
Lynch (1990)	90	CRC	46	+1.0	-.40	+.03	Pasture
Phipps (1995)	60	150	42	+2.8	-.33	-.15	
		300	42	+2.5	-.47	-.14	
		450	42	NS	-.47	-.16	
Hayes (1996)	661	CRC	early	+.42	decr.	Decr.	Pasture
Phipps (1997)	98	300	35	+.8	-.11	NS	
Van der Werf (1998)	64	450	35	NS	-.41	NS	
	80	300	35	+1.9	NS	+.06	

Table 3. Mean milk fat percentage for varying doses of monensin.

Monensin[1] mg/kg	Mean milk fat percentage
0	3.62
>0 to 13.6	3.53
>13.6	3.44

[1]Effect of monensin was statistically significant ($P = 0.003$) using an analysis of variance model.

Duffield et al., 2003

TABLE 3. Effect of ionophores on rates of formation of biohydrogenated products from linoleic acid infused continuously into fermenters[1] (n = 2).

Fatty acid	Additive[2] Control	MON	NIG	TET	SE
	(mg/L per h)				
$C_{16:0}$	2.2	2.7	2.3	1.3	0.46
$C_{18:0}$	7.5[a]	1.4[b]	1.5[b]	0.9[b]	0.57
Total $C_{18:1}$	6.0	7.4	7.3	5.3	1.04
trans-$C_{18:1}$	4.2	4.1	4.0	3.7	0.94
cis-$C_{18:1}$	1.7[d]	3.4[c]	3.4[c]	1.6[d]	0.50

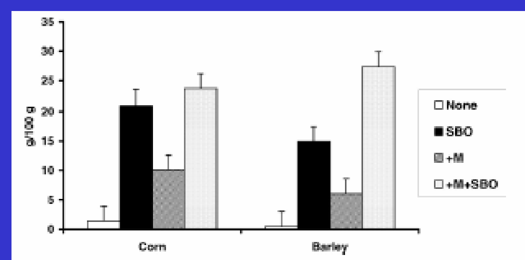
[a,b]Means within a row without a common superscript differ ($P < 0.05$).

[c,d]Means within a row without a common superscript differ ($P < 0.10$).

[1]Based on the hourly addition of 13.8 mg of $C_{18:2n-6}$ to 700 ml of ruminal culture.

[2]MON = Monensin (2 μg/ml of culture), NIG = nigericin (2 μg/ml of culture), and TET = tetronasin (2 μg/ml of culture).

Monensin slows down rates of biohydrogenation (Fellner et al., 1997)



Interactions of grain source, soybean oil, and monensin on concentrations of trans 10 C18:1 in continous culture. Jenkins et al., 2003

Factors that influence rate of passage

- DMI (also relationship with buffer production per kg of RFOM already discussed)
- High consumption of free choice salt or bicarb and relationship with water intake and increased liquid rate of passage?
- Require controlled study

Ongoing field study on milk fat depression and interaction with Rumensin

- Project leaders: Dr. Daryl Nydam and Dr. Tom Overton
- Objectives:
  - Establish risk factors that contribute to MFD when Rumensin introduced into the ration
  - Evaluate bulk tank milk fatty acid profile to determine relationships of MFD with specific fatty acid intermediates
  - To evaluate bulk tank milk FA profiles as a diagnostic test for MFD
  - Gain better sense of ration variables related to CPM Dairy fat submodel and MFD
- Goal: Characterize total of 300 herds (those that did not have MFD after Rumensin inclusion and those that had decreased milk fat < 0.3%)

Upcoming field study on milk fat depression and Rumensin (continued)

- Data collection:
  - Detailed herd, management, and facility characterization
  - Diet composition (ingredient and nutrient) and group DMI estimates
  - Sample of high group TMR
  - Sample of silage components of high group TMR
  - Bulk tank milk sample for FA profile

Summary

- Altered ruminal biohydrogenation of unsaturated fatty acids combined with ruminal dynamics that cause passage of specific intermediate fatty acids to the intestine results in low milk fat test
- Risk factors for reduced milk fat
  - Supply and availability of linoleic acid
  - Altered ruminal environment (pH; perhaps also caused by problems with ensiled feeds)
  - Compounds that affect biohydrogenation rates (Rumensin, fish FA as examples)
  - High rates of passage
- Most often not one factor, but an INTERACTION AMONG MANY FACTORS, responsible for milk fat problems