Milk Fat Depression:
What do we know and what can we do about it?

Adam L. Lock
Tom R. Overton & Dale E. Bauman

2007 Penn State Dairy Nutrition Workshop
Elanco Animal Health Preconference Symposium, November 13th 2007

DBM 0048

Objectives

- Provide an overview of the biology of rumen lipid metabolism and FA digestion
- Update on the theories and biology related to milk fat depression
- Introduction to troubleshooting milk fat depression

DBM 0048

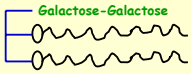
Introduction

- All FA are not the same
- FA ≠ Simply Energy
- FA interact with
  - Metabolism
    - Energy
    - Cell components
    - Signaling molecules
  - Physiology
    - Intake
    - Reproductive efficiency
    - Milk fat synthesis
    - Nutrient partitioning
    - Ruminal fermentation

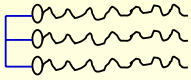
DBM 0048

Fat Sources

- Forages
  - Glycolipids
    - Rich in 18:3



- Grains & Concentrates
  - Triglycerides
    - Rich in 18:2



- Fat Supplements
  - Triglycerides
  - Free fatty acids

DBM 0048

Fatty Acid Composition of Typical Feedstuffs
(Data from CPM Feed Library)

Feed Name	C14:0	C16:0	C18:0	C18:1C	C18:2	C18:3
Corn Silage	0.46	17.83	2.42	19.24	47.74	8.25
Alfalfa Silage	0.66	18.81	3.35	2.05	15.91	38.71
Alfalfa Hay	0.85	25.01	4.01	2.43	18.49	36.79
Grass Hay	0.43	16.44	1.33	2.53	23.38	49.90
Corn Grain (GrndFine)	2.33	13.21	1.99	24.09	55.70	1.62
Corn HM22%Med	0.26	13.57	1.83	25.99	55.08	1.64
Tallow (Beef)	3.00	24.43	17.92	41.62	1.09	0.53
Soybean Oil	0.11	10.83	3.89	22.82	53.75	8.23
Megalac	1.60	50.80	4.10	35.70	7.00	0.20
Energy Booster	2.90	40.00	40.70	10.40	1.80	0.00
Corn Dist Ethanol	0.14	14.05	2.39	24.57	56.11	1.68
Cottonseed (WholewLint)	0.69	23.91	2.33	15.24	56.48	0.19

DBM 0048

Fatty Acid Intake
(CPM Dairy 100 lb cow)

	Fatty Acid (g/d)					
	C16:0	C18:0	C18:1c	C18:2	C18:3	Total
Alfalfa Silage	15	3	2	13	31	80
Corn Silage	30	4	32	79	14	166
Soybean Hulls	3	1	3	8	3	20
Corn Grain Ground	28	4	51	117	3	211
Soybean Meal	14	3	10	42	7	78
Blood Meal	2	2	2	1	0	7
Cottonseed Whole	92	9	58	217	1	384
Megalac	107	9	75	15	0	210
Ration	290	35	234	496	59	1161

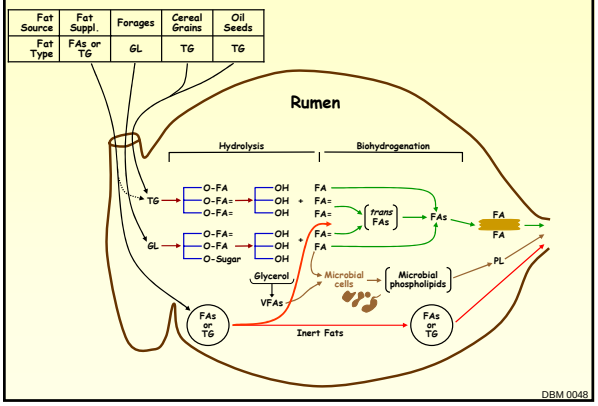
DBM 0048

Digestion of Dietary Fats in the Rumen

- Rumen transforms UFA
  - Dietary UFA toxic to rumen bacteria
  - Converts UFA to SFA via hydrolysis & biohydrogenation by rumen bacteria
- Rumen is transformed by FA
- Lipid material leaving the rumen consists primarily of free FA that are highly saturated

DBM 0048

Digestion of Dietary Fats in the Rumen



DBM 0048

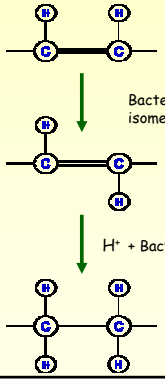
Digestion of Dietary Fats in the Rumen

Biohydrogenation:

Unsaturated FA

Trans intermediates

Saturated FA

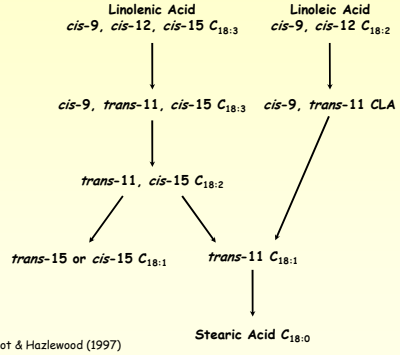


Bacterial isomerases

H^+ + Bacterial hydrolyases

DBM 0048

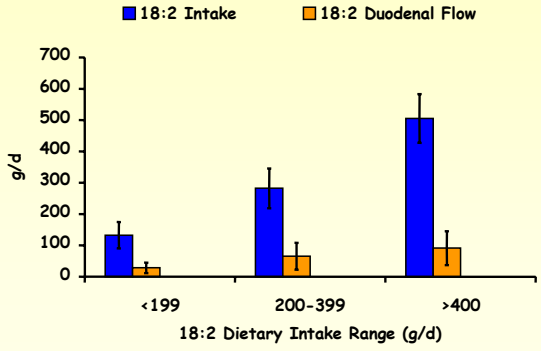
Pathways for Rumen Biohydrogenation



Harfoot & Hazlewood (1997)

DBM 0048

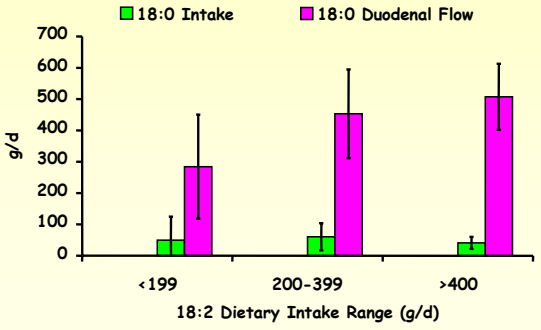
Relationship Between Linoleic Acid (18:2) Intake and Duodenal Flow



Lock et al., 2006

DBM 0048

Relationship Between Stearic Acid (18:0) Intake and Duodenal Flow



Lock et al., 2006

DBM 0048

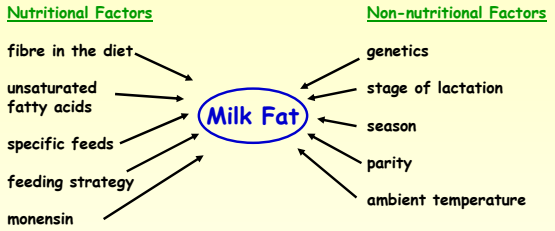
Range of Positional and Geometric Isomers of *trans* 18:1 & CLA & Their Ruminal Outflow (g/day) in Lactating Dairy Cows

Trans 18:1	Ruminal Outflow		Conjugated Linoleic Acids	Ruminal Outflow	
Isomer	Min	Max	Isomer	Min	Max
trans-4	0.4	2.0	*trans*-7, *cis*-9	<0.01	0.01
trans-5	0.4	3.4	*trans*-7, *trans*-9	<0.01	0.02
trans-6-8	0.4	16.2	*trans*-8, *cis*-10	<0.01	0.3
trans-9	1.4	13.1	*trans*-8, *trans*-10	<0.01	0.10
trans-10	1.5	114.0	*cis*-9, *trans*-11	0.31	2.86
trans-11	17.0	148.0	*trans*-9, *trans*-11	0.14	0.29
trans-12	1.9	20.8	*trans*-10, *cis*-12	0.02	1.84
trans-13 + 14	4.2	60.3	*trans*-10, *trans*-12	0.05	0.23
trans-15	2.0	29.0	*cis*-10, *trans*-12	0.08	0.29
trans-16	2.3	18.2	*cis*-11, *trans*-13	0.01	0.33
			trans-11, *cis*-13	<0.01	0.46
			trans-11, *trans*-13	0.09	2.02
			cis-12, *trans*-14	0.12	0.85
			trans-12, *trans*-14	0.07	0.19

Bauman & Lock (2006)

DBM 0048

Factors Affecting Milk Fat

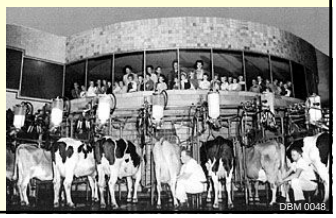


- Nutrition has a major impact on milk fat content and composition
- Key is to understand the interrelationship between dietary supply of lipid, rumen fermentation and mammary synthesis of milk fat

DBM 0048

Borden's
"Dairy World of Tomorrow"

1939 World's Fair
New York City



DBM 0048

Milk Fat Depression

- Naturally occurs with certain diets
  - high concentrate, low fibre
  - plant and fish oil supplements
  - unsaturated fatty acids
- Milk fat reduced but milk yield and other milk components unaffected
- Decreased yield of all fatty acids, but greatest for de novo synthesized fatty acids
- Many theories proposed but most shown to be inadequate

DBM 0048

MFD Theories

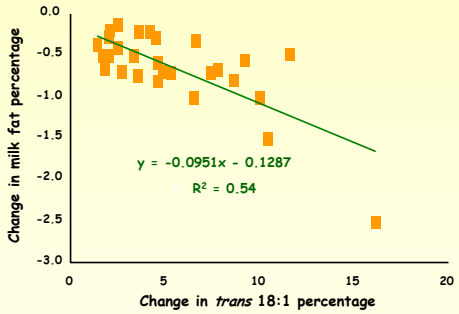
Substrate Shortage
- Acetate shortage
- β-OH Butyrate shortage
- Glucogenic-insulin

Direct Inhibitors
- *Trans* fatty acids
- Biohydrogenation theory

➢ **Overall, studies provide no support for theories involving a shortage of precursors for milk fat synthesis**

DBM 0048

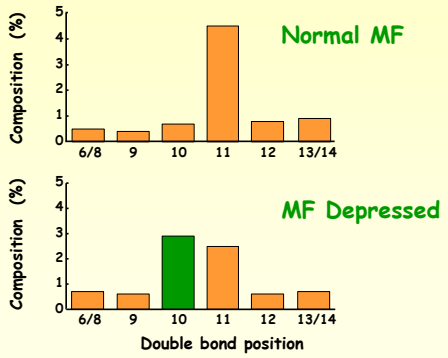
trans Fatty Acids & Milk Fat Depression



Griinari et al., 1998

DBM 0048

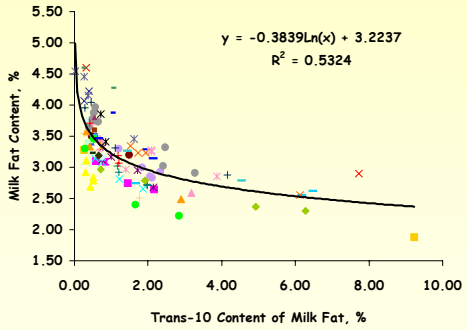
trans Fatty Acids & Milk Fat Depression



Griinari et al., 1998

DBM 0048

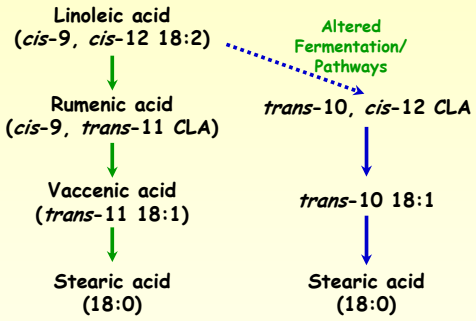
Relationship Between Milk t10 18:1 Content & Milk Fat %



Hinrichsen, Lock & Bauman, 2006

DBM 0048

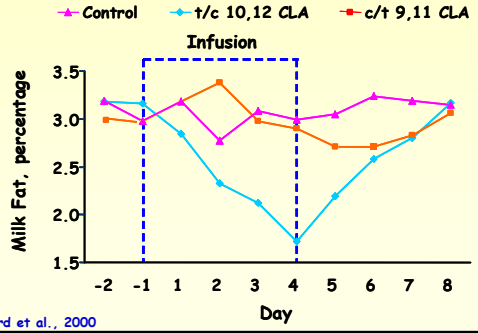
Pathways for Rumen Biohydrogenation



Griinari & Bauman (1999)

DBM 0048

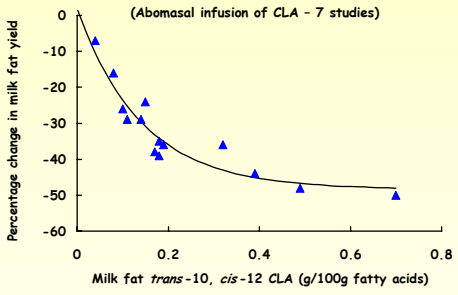
Effect of CLA Isomers on Milk Fat %



Baumgard et al., 2000

DBM 0048

Relationship Between *t*10, *c*12 CLA in Milk Fat and Change in Milk Fat Yield



de Veth et al. (2004)

DBM 0048

"Biohydrogenation Theory" of Milk Fat Depression

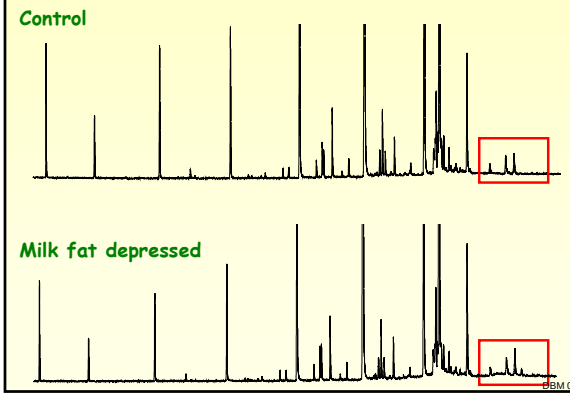
Under certain conditions rumen biohydrogenation results in unique fatty acids that are potent inhibitors of milk fat synthesis – e.g. *trans*-10, *cis*-12 CLA and possibly related intermediates from linolenic acid and other polyunsaturated fatty acids.

Bauman and Griinari, 2001

➢ 2 additional CLA isomers recently identified as inhibitors of milk fat synthesis (t9, c11 and c10, t12)

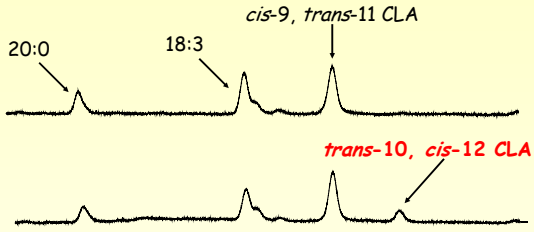
DBM 0048

Gas Chromatogram of Milk Fat Samples



DBM 0048

Gas Chromatogram of Milk Fat Samples

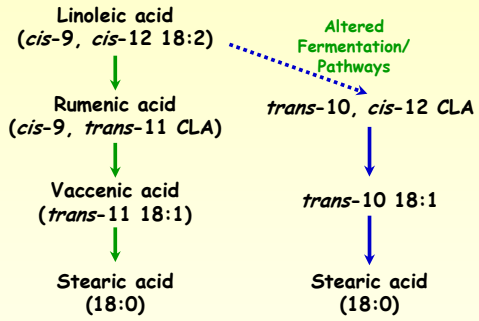


trans-10, *cis*-12 CLA:

- 0.18% of total fatty acids
- 1.2 g/d in milk fat ⇒ ~5 g/d exiting rumen
- 27% decrease in milk fat yield

DBM 0048

Pathways for Rumen Biohydrogenation



Griinari & Bauman (1999)

DBM 0048

The *trans*-10 shift is indicative of complex changes in ruminal BH pathways characteristic of MFD

- Although *trans*-10 18:1 does not directly inhibit mammary synthesis of milk fat, it is relatively easy to analyze
- In general, it can serve as a surrogate marker for the type of alterations in rumen BH that characterize diet-induced MFD

DBM 0048

How Can We Use Our Understanding of the Biology of MFD to Troubleshoot Fat Test on Farms?

DBM 0048

Biology of Milk Fat Depression

Altered rumen microbes and fermentation

↓

Formation of specific bioactive FA in the rumen

↓

Inhibition of mammary lipogenic enzymes

↓

Milk fat depression

DBM 0048

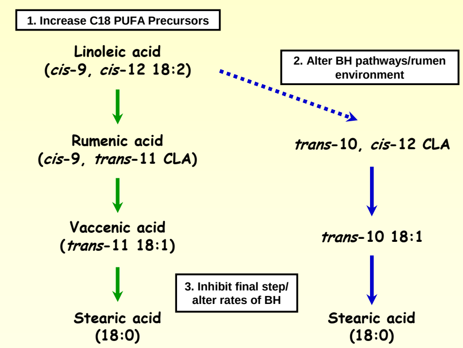
Milk Fat Depression

Requires two conditions:

1) Dietary presence of PUFA

2) Altered rumen fermentation

Dietary components can impact the risk of MFD in 3 ways

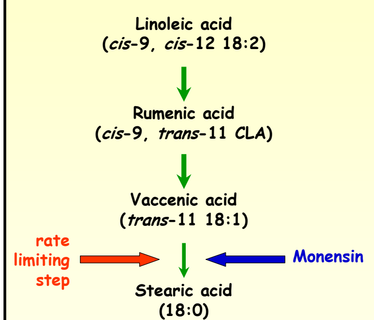


Monensin and MFD

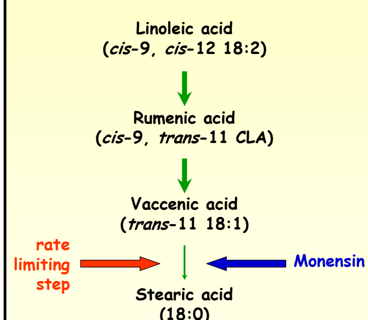
- Under some circumstances specific feed components can alter rumen fermentation in a manner that results in changes in BH rates of FA
- Anything that slows rates of BH at different steps may result in more passage of FA intermediates that cause MFD from the rumen
- Monensin can affect BH rates through altering rumen fermentation and the bacterial species present

➢ Will not directly cause MFD, but will amplify the effect of an existing ruminal condition on milk fat

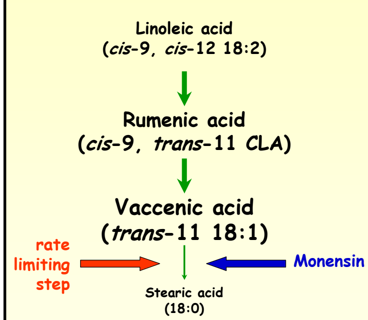
Pathways for Rumen Biohydrogenation



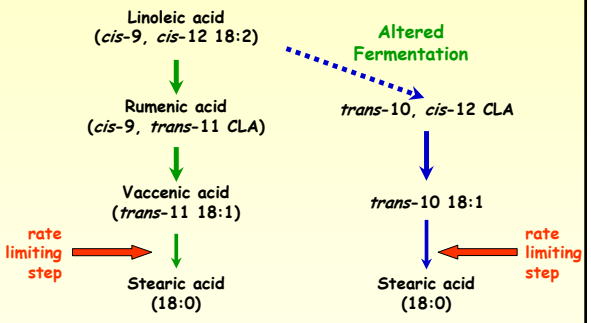
Pathways for Rumen Biohydrogenation



Pathways for Rumen Biohydrogenation

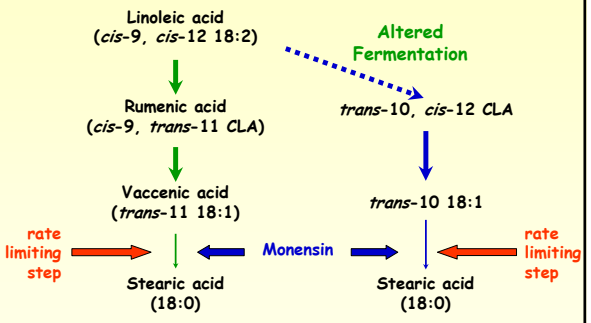


Pathways for Rumen Biohydrogenation



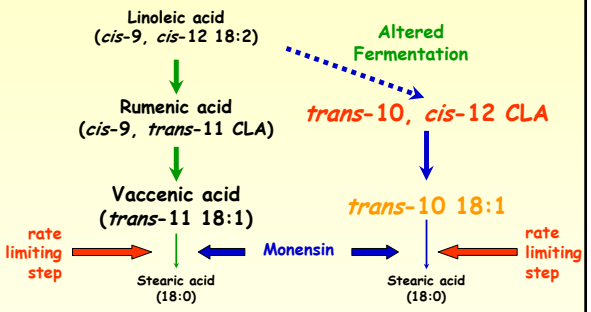
DBM 0048

Pathways for Rumen Biohydrogenation



DBM 0048

Pathways for Rumen Biohydrogenation



DBM 0048

Summary

DBM 0048

- Changes in ruminal microbial processes are an essential component for the development of MFD
- Centered on both an altered rumen environment and an alteration in the rumen pathways of PUFA BH
- Key is to understand the interrelationship between dietary supply of lipid, rumen fermentation and mammary synthesis of milk fat

DBM 0048

Take Home Message

Current evidence indicates that all situations of MFD are due to changes in rumen BH of unsaturated FA and the passage of specific intermediates out of the rumen that reduce milk fat synthesis in the mammary gland

DBM 0048

DISCOVER Conferences

ADSA Science, education and service for the dairy industry

14th ADSA Discover Conference

Lipids for Dairy Cattle:
Today's Issues, Tomorrow's Challenges

Co-chairs: Dr Tom Jenkins, Clemson University tjnkns@CLEMSON.EDU
Dr Adam Lock, University of Vermont adam.lock@uvm.edu

May 18 to 21, 2008
Nashville IN

Questions?

Adam.Lock@uvm.edu

The UNIVERSITY of VERMONT

Milk Fat Background

- Synthesis of milk fat represents the major energy cost in the production of milk components
- Responsible for many of the sensory, physical and manufacturing characteristics of milk
- Economic value
- Predominately triglycerides (>95%)
- Many fatty acids (>400)
  - Saturated and unsaturated
  - Vary in chain length
  - Vary in double bond position and configuration
- Milk fat content and fatty acid composition can be significantly altered through nutrition: +ve and –ve effects

DBM 0048

Source of Milk Fatty Acids

- De novo synthesis
  - C4 to C14 plus part of C16
  - Acetate
  - B-hydroxybutyrate
- Uptake of preformed fatty acids
  - Part of C16 and all long chain
  - Absorbed from digestive tract
  - Mobilized from body fat

DBM 0048

Milk Fatty Acid Analysis

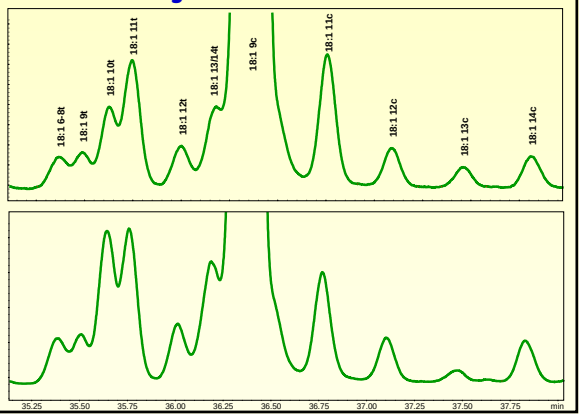
53% forage diet vs 16% forage diet; MFY ↓ 27%

Fatty acid, %	Control	HC/LF
18:0	12.08	7.88
18:1 *trans*-6 to 8	0.39	0.84
18:1 *trans*-9	0.31	0.56
18:1 *trans*-10	0.70	3.17
18:1 *trans*-11	1.07	1.81
18:1 *trans*-12	0.61	0.94
Total *trans* 18:1	3.08	7.32
18:1 *cis*-9	26.60	24.05
18:2 *cis*-9, *cis*-12	3.16	4.82
18:2 *cis*-9, *trans*-11 CLA	0.43	1.07
18:2 *trans*-10, *cis*-12 CLA	<0.01	0.06
18:3	0.43	0.41

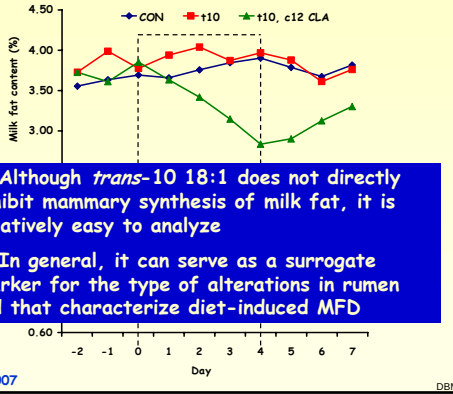
Peterson et al., 2003

DBM 0048

Changes in *trans* 18:1 Profile



trans-10 18:1 Has No Effect On Milk Fat



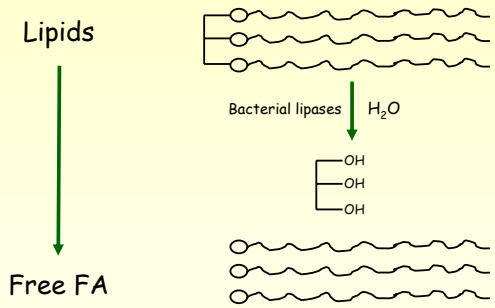
- Although *trans*-10 18:1 does not directly inhibit mammary synthesis of milk fat, it is relatively easy to analyze
- In general, it can serve as a surrogate marker for the type of alterations in rumen BH that characterize diet-induced MFD

Lock et al., 2007

DBM 0048

Digestion of Dietary Fats in the Rumen

Hydrolysis:



DBM 0048