The Impact of Daily Rhythms on Milk and Component Yield

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College of Agricultural Sciences

Key principles that I hope to convince you of today!

- **There is a daily (circadian) pattern of intake that creates large changes in rumen fermentation across the day**
- **There is a daily pattern of milk synthesis**
- **Maximizing efficiency requires synchronizing nutrient absorption and mammary needs**
- **Considering daily patterns provides opportunities to optimize the rumen and milk production**

Milk fat and protein is affected by many nutritional and non-nutritional factors!

Nutritional Factors

Fat

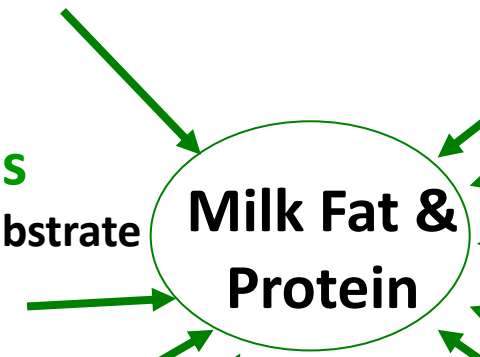
Decreased by milk fat depression
- Unsaturated fat
- Fermentability
- Acidosis
- **Feeding strategies**

Increase by additional substrate
- Acetate from forages
- Fat supplement
  - Palmitic acid

Protein

Energy Supply
- Starch level
- Fat supply

Amino Acid Supply
- Microbial protein
- Amino acid balance



Non-nutritional Factors

- **Genetics**
- **Season**
- **Time of day**
- **Stage of lactation**
- **Parity**

Circadian/Daily Rhythms in the Dairy Cow

- **Circadian rhythms are 24 hour repeating cycles controlled endogenously**

- **Many biological functions follow a 24 cycle**
  - Activity and Alertness
  - Nutrient Metabolism
  - **Milk Synthesis**
  - **Intake**

Why??

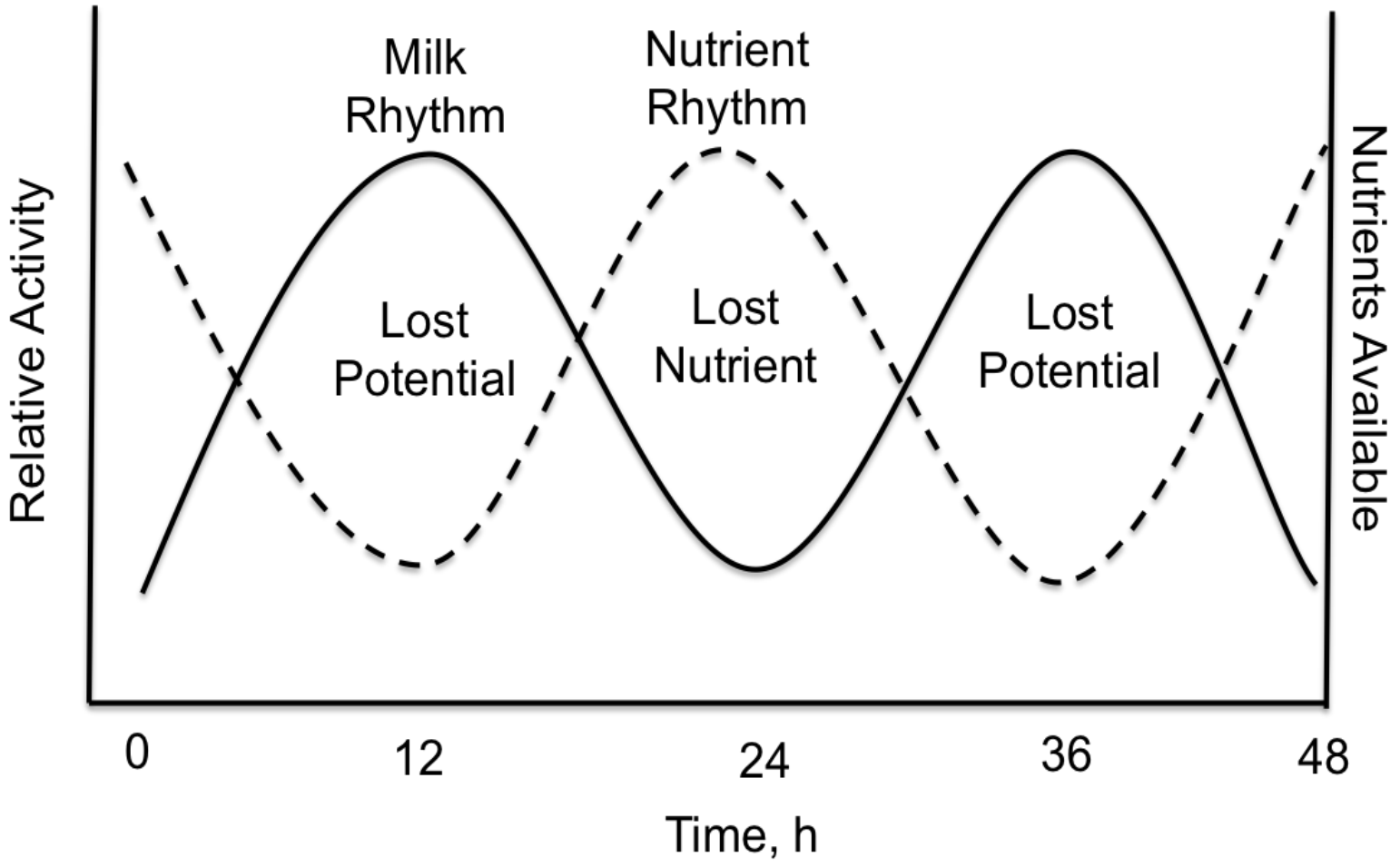
Allows the animal to anticipate changes and adapt before they occur

Remember, we talk about daily intake and production, but the cow lives second to second and minute to minute!

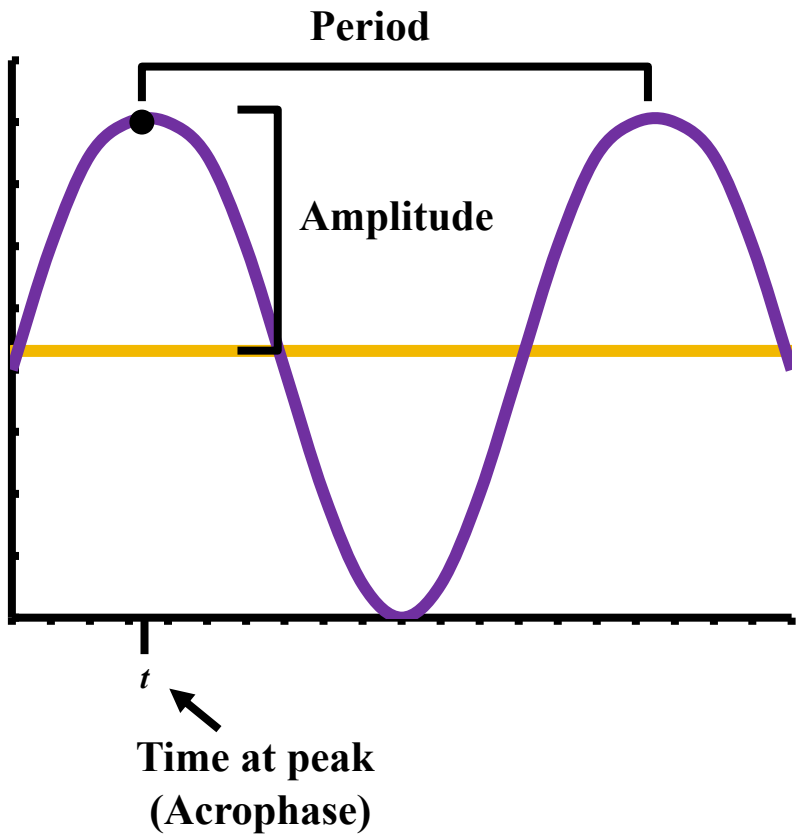
- **Feed is consumed through meals across the day**
  daily intake = # meals * size meals
  (5 to 12 meals/day)

- **Milk is synthesized continuously across the day**

Are the daily patterns of nutrient absorption and milk synthesis synchronized?

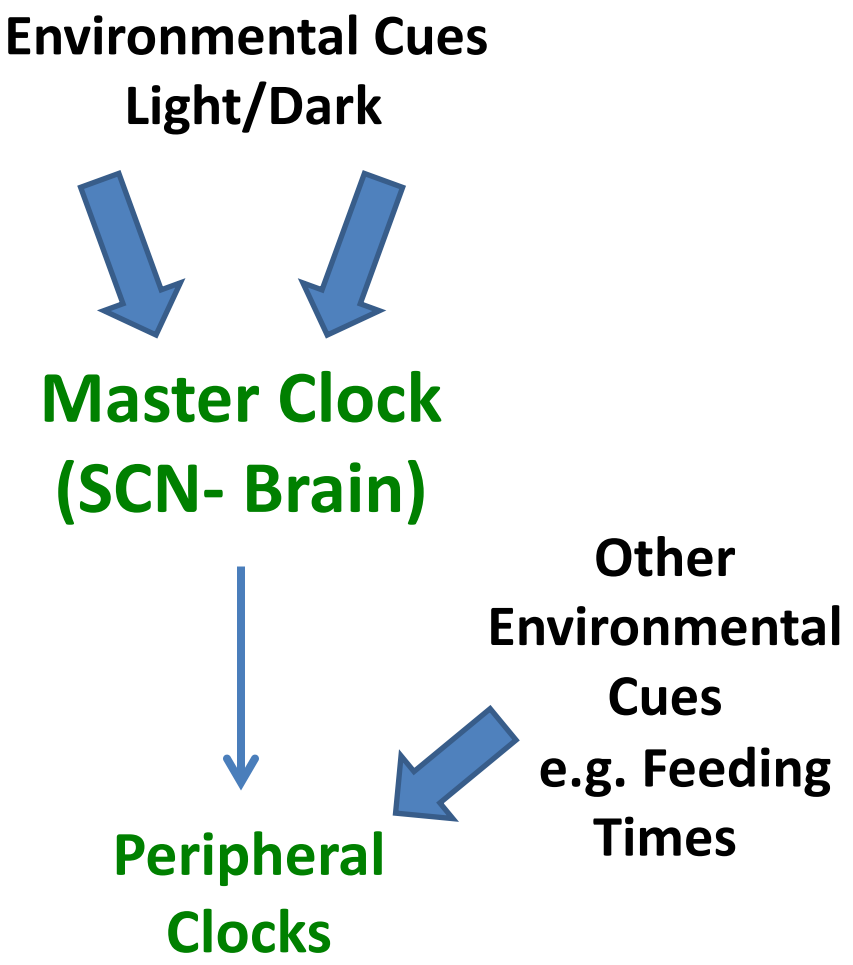


Biological rhythms are repeating cycles that are driven by a time keeping mechanism in the animal and can be reset (entrained) by external factors, like timing of lighting



- Will be maintained if animal is put under constant conditions
- Are helpful as they allow the animal to prepare for upcoming changes

How does the cow know what time of day it is?

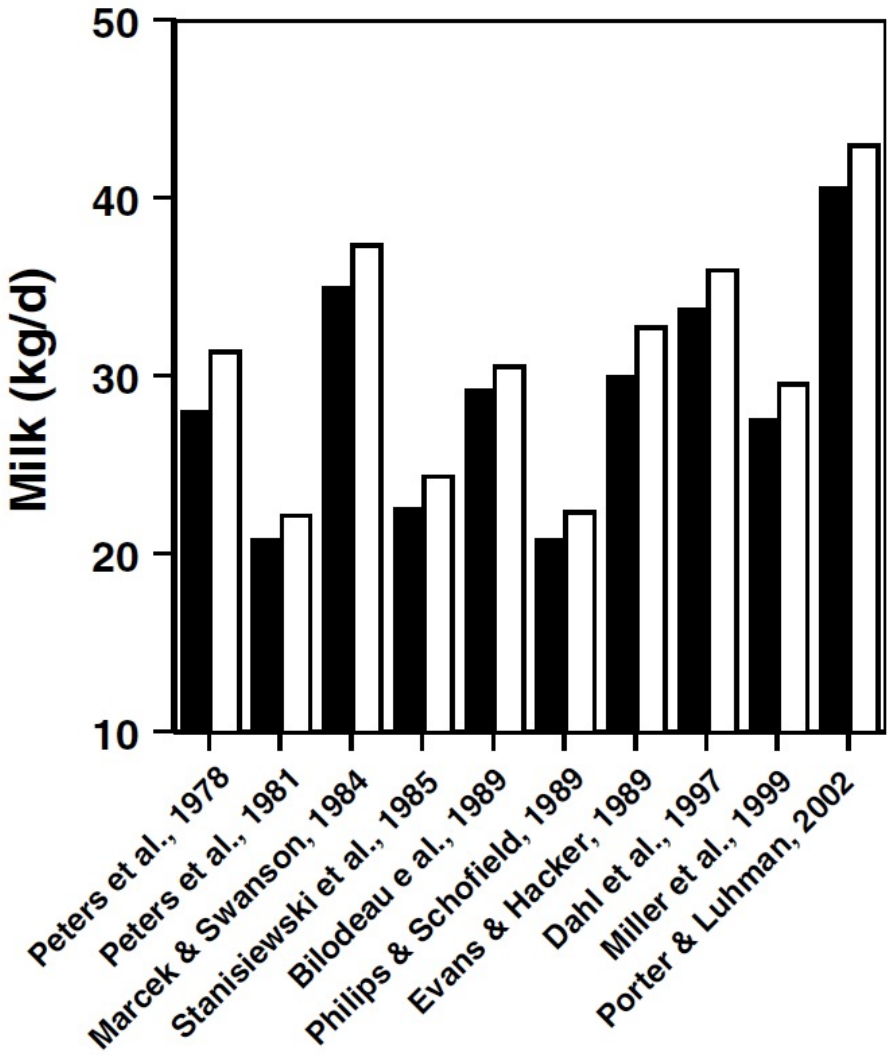


- **Main environmental cues:**
  - Light/Dark

  Peripheral rhythms
  - Feeding Times
  - Milking Time?
- **A breakdown in the daily system creates jetlag!**
- **A disconnection between lighting and feeding can cause metabolic issues in humans and rodents**

- Example is night shift work in humans (Asher, Schibler 2011)

We know "Photoperiod" has a large impact on milk yield



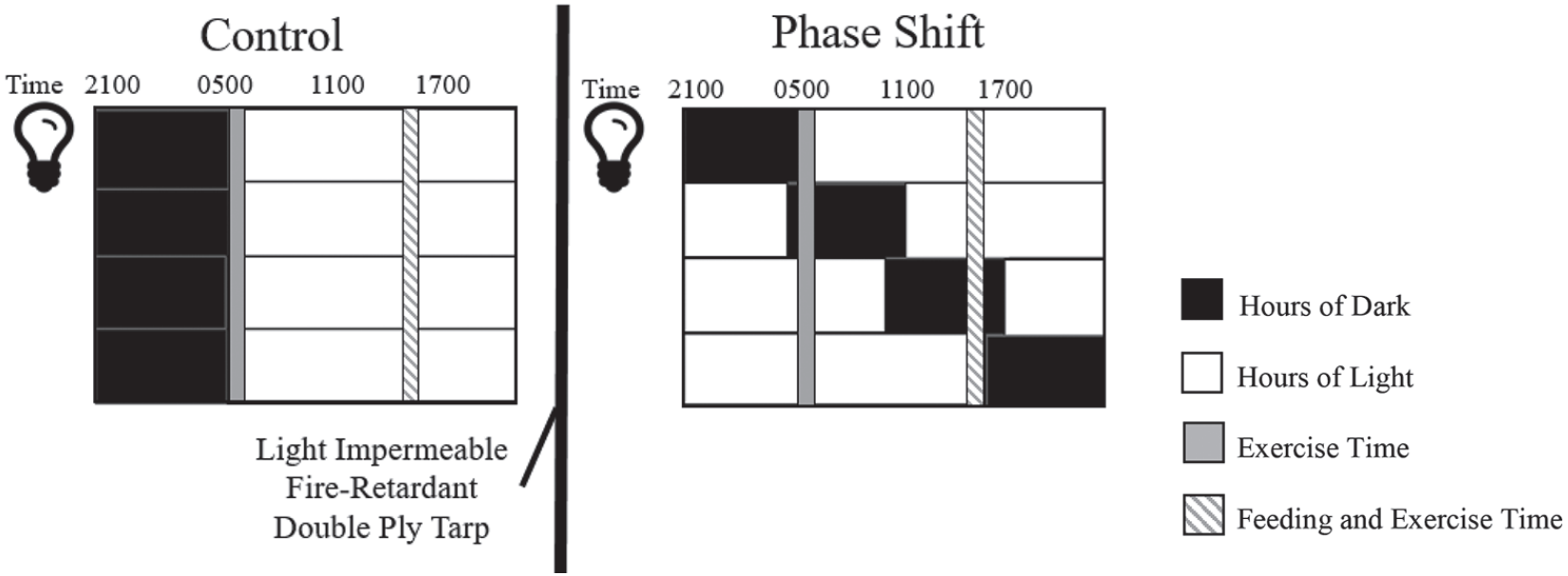
Constant 16 to 18 h vs. 8 to 10 h light

- ~5 to 10% increase in milk yield and no change in milk composition
- Additional effect of short days in dry period
- Eliminated by constant light

-Basic mechanism of photoperiod is through same signaling as circadian rhythms

Dahl and Petitclerc., 2003

Lighting ”Phase Disruption” during the dry period impact physiology of the cow

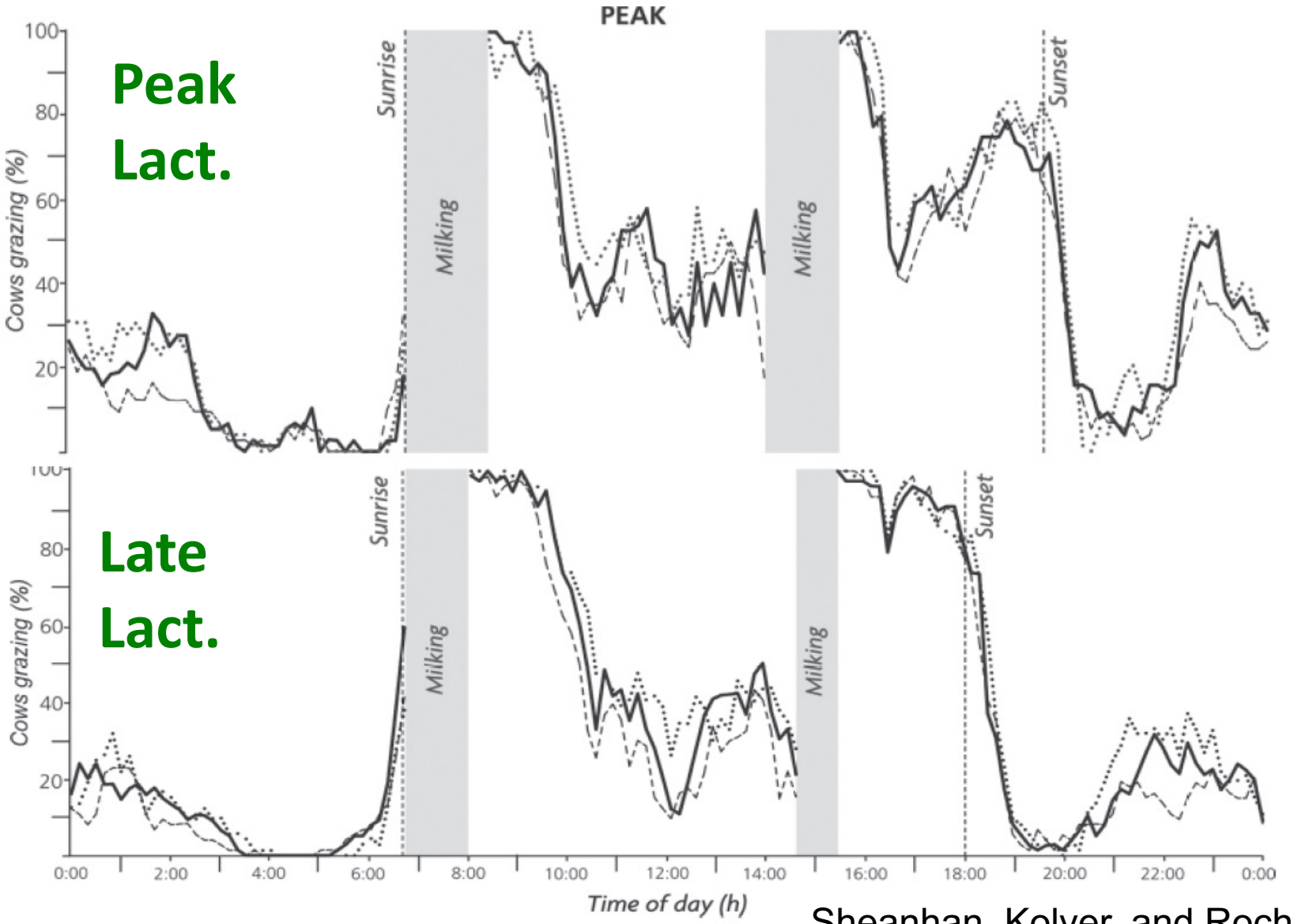


Phase shifting light during the dry period

- **Reduced milk yield in Casey et al. 2014**
- **Decreased blood glucose and increased milk yield in Suarez-Trujilo et al. 2020**
- **Increased insulin, reduced mammary development, and milk yield in subsequent lactation in McCabe et al. 2020.**

Is there a daily pattern of feed intake?

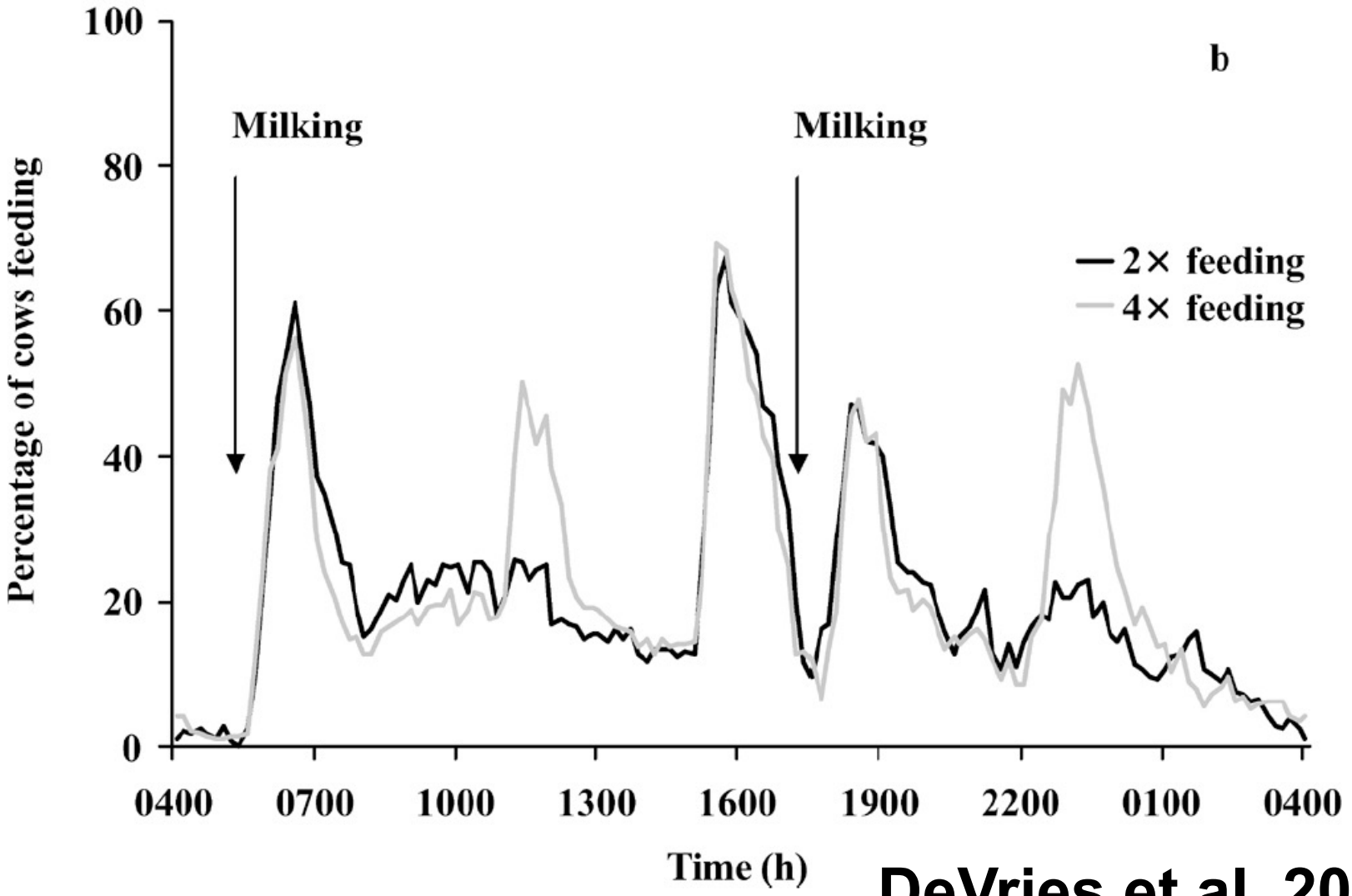
Pasture Fed Cows



Sheanhan, Kolver, and Roche, 2011

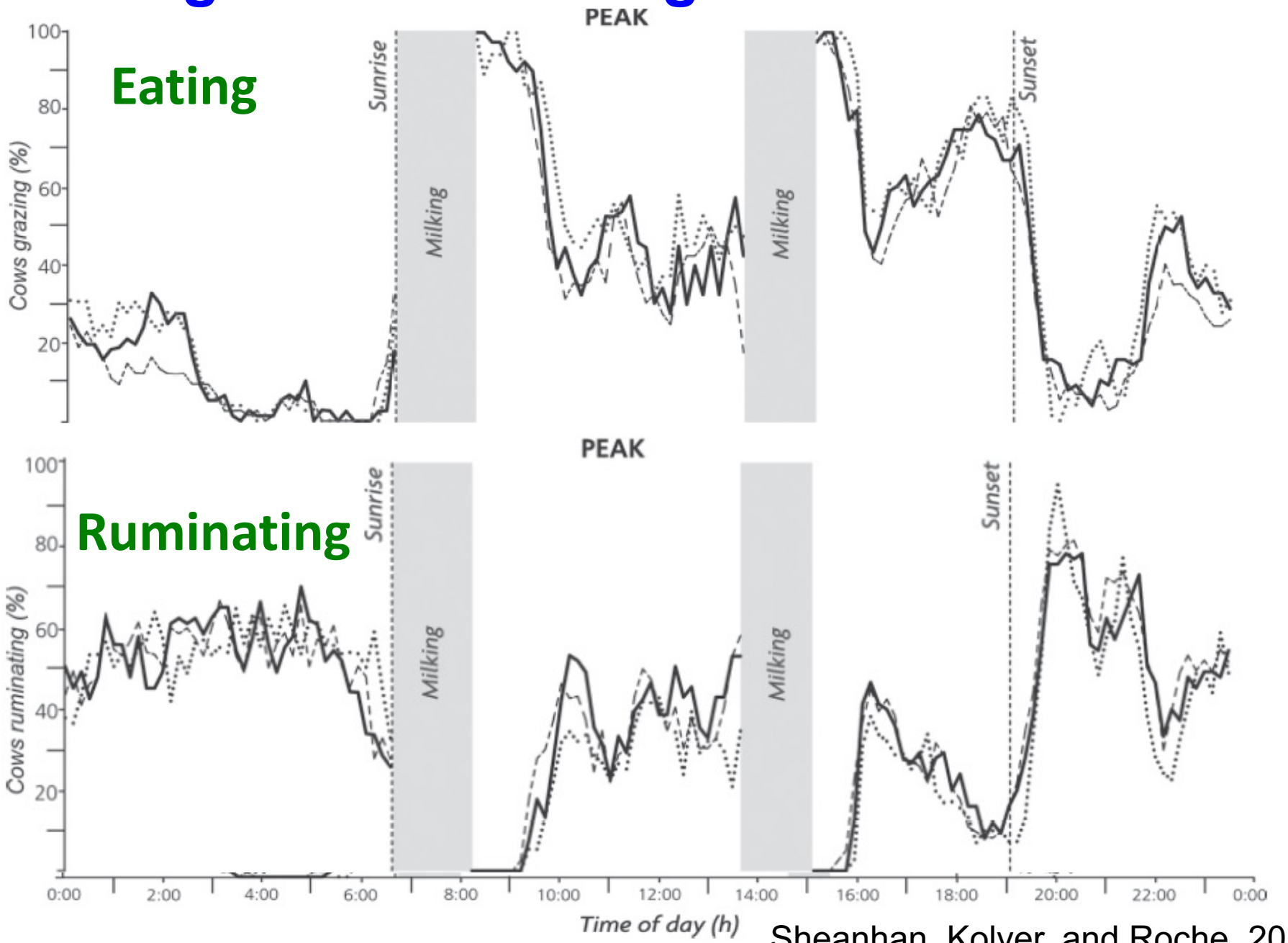
TMR Feeding: Feeding and milking times are most important

Feeding and milking commonly both near dawn & dusk in experimental data



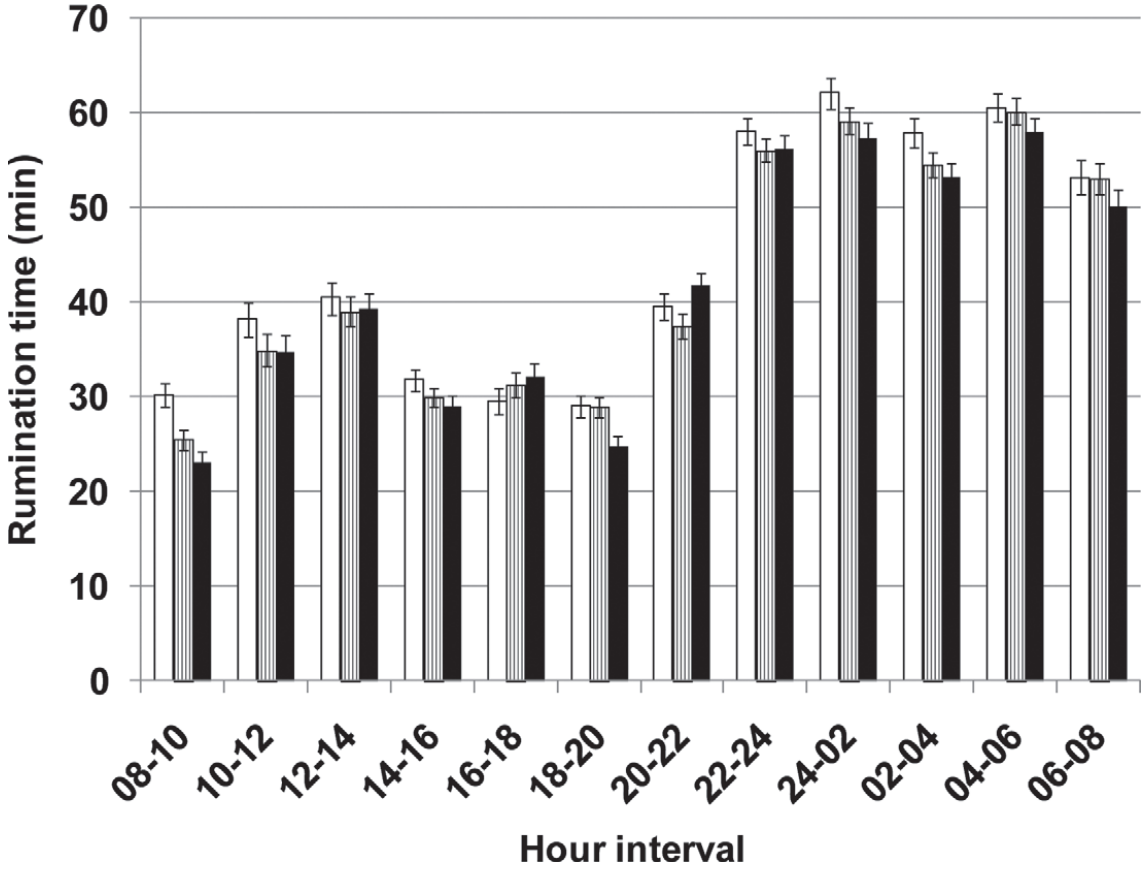
DeVries et al. 2005

Eating and Ruminating tend to be inverse



Sheanhan, Kolver, and Roche, 2011

Rumination pattern is conserved even during heat stress



Low, Medium, and high Temperature-Humidity Index

Daily pattern of rumination time expressed in minutes per 2 h in 3 levels of daily maximum temperature-humidity index (THI).
White bars = THI <80; bars with vertical lines = THI from 80 to 85; black bars = THI >85.

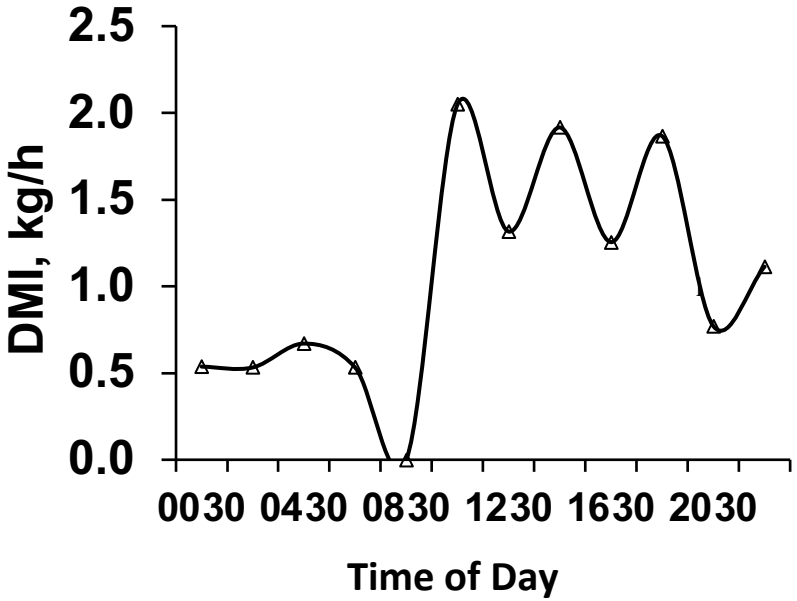
Soriani et al. JDS 2014

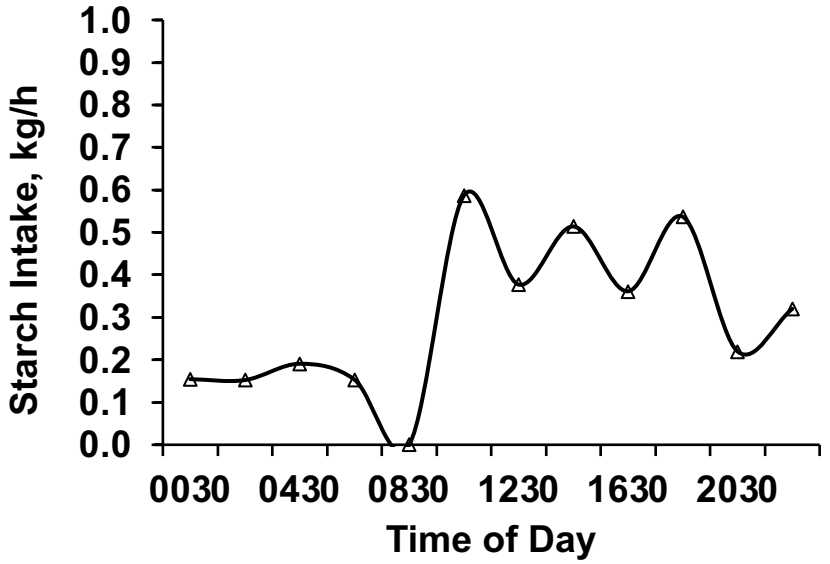
PSU Feeding Behavior System

MooMonitor+ Dairymaster

(Image Dairymaster.ie)

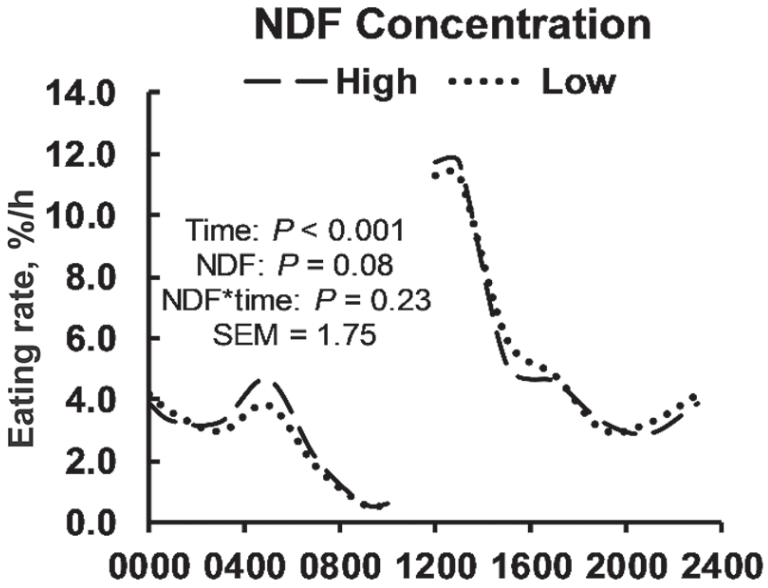
Feed intake is highest after feeding and in the afternoon

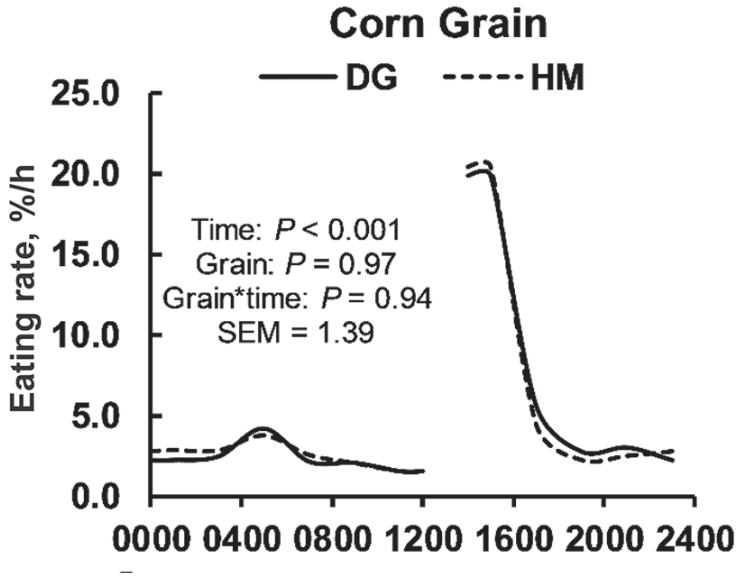


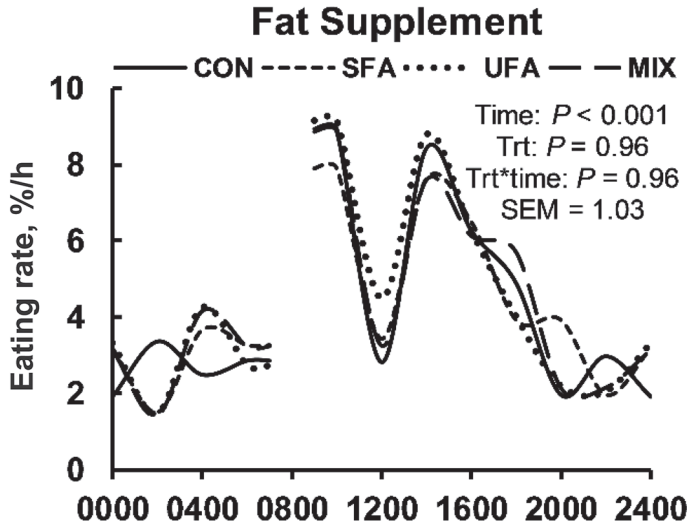


Ying et al. 2015

The feeding pattern is consistent across NDF, starch, and fat levels and types







Salfer et al. 2018

What is the impact of the daily pattern of intake?

Intake =

Entrance of fermentable feed into the rumen for microbes to digest

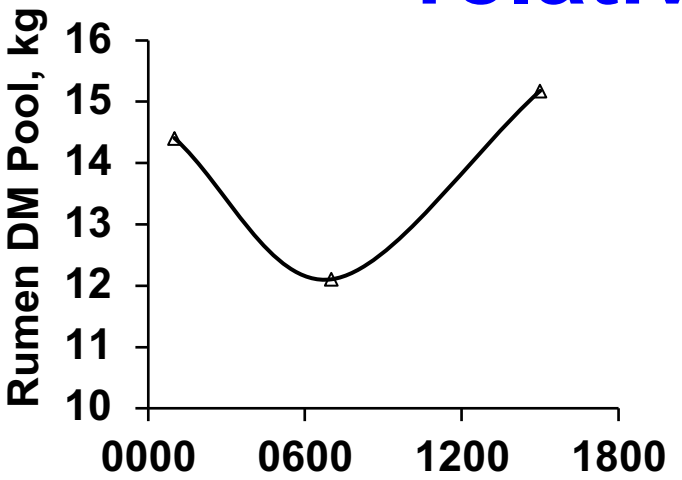
Fermentable feed =

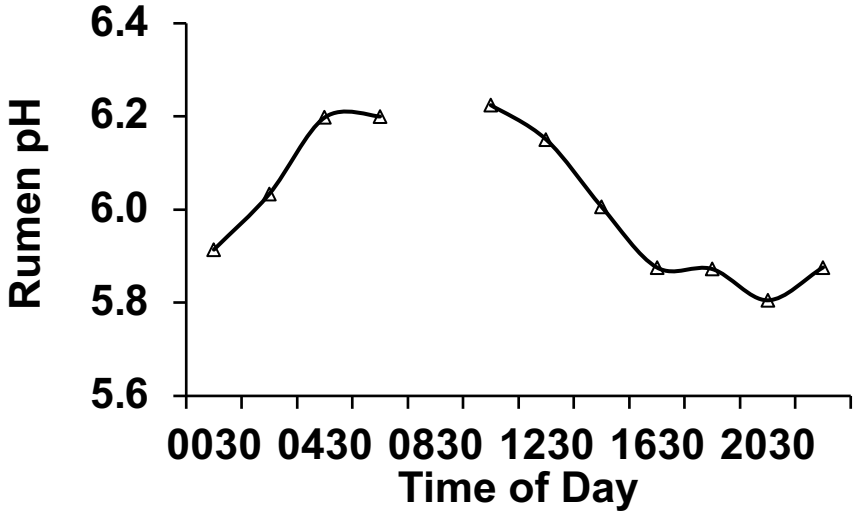
Synthesis of VFA's (acids) & microbial protein

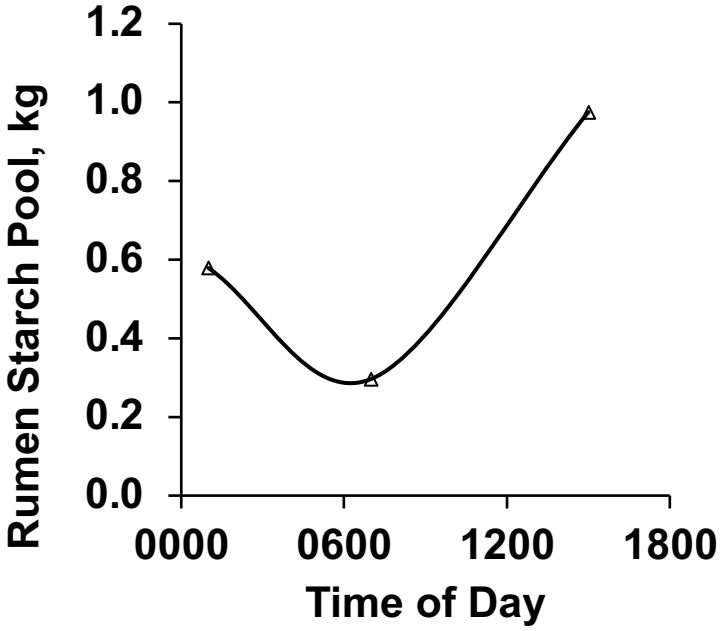
VFA's =

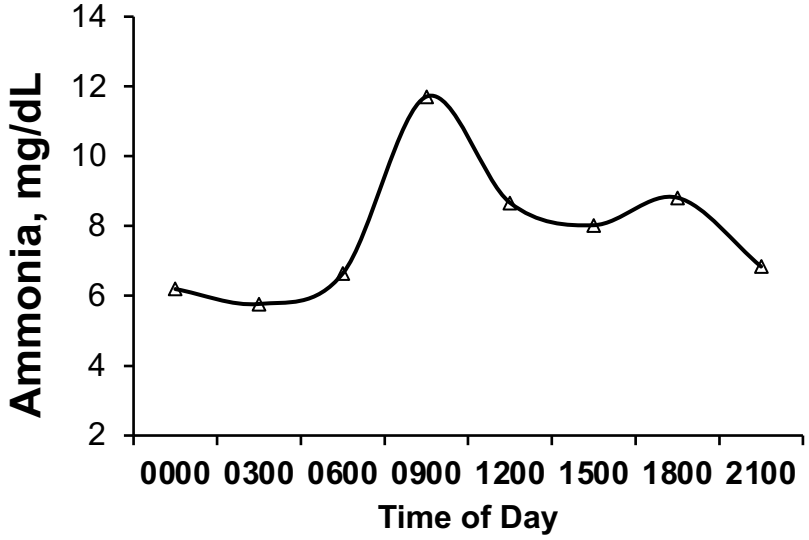
Acid load for rumen
Nutrient supply for cow

What are the rumen changes relative to feeding



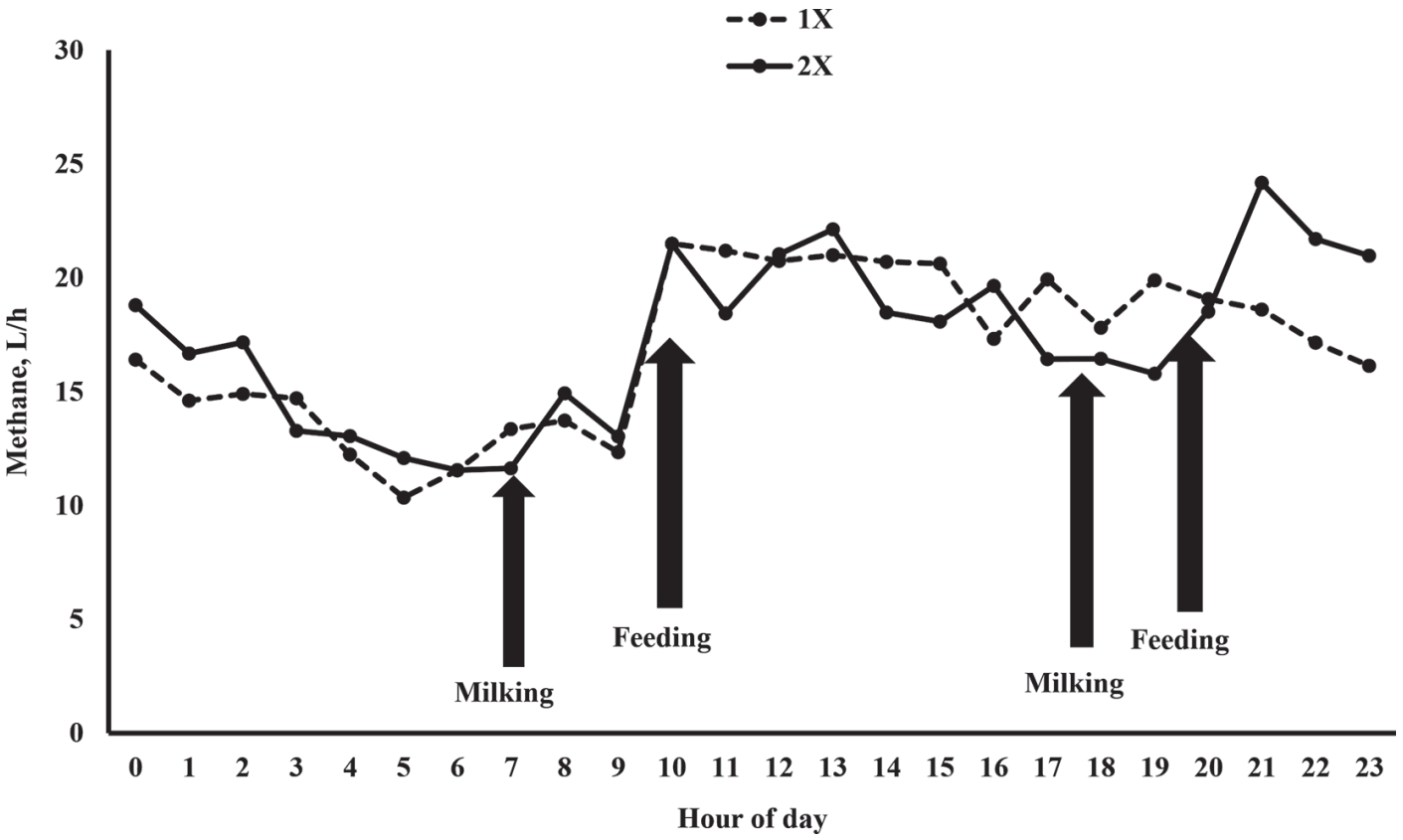






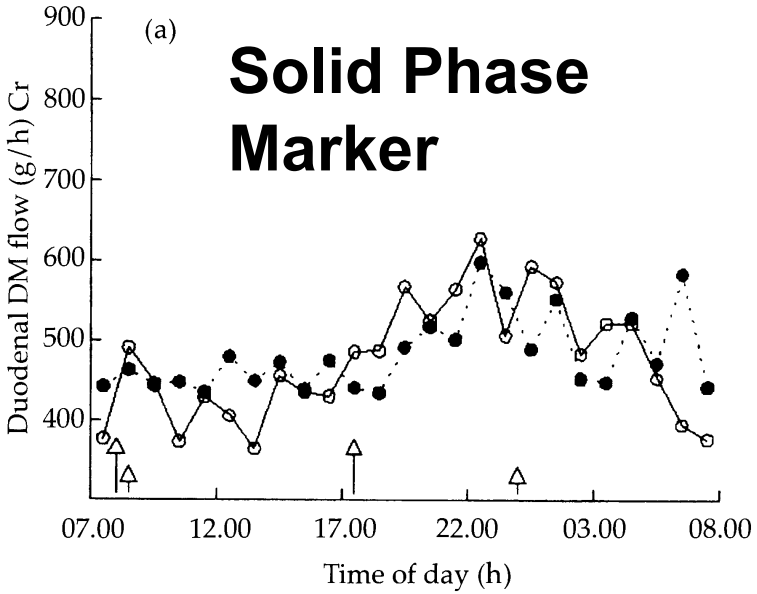
Ying et al. 2015

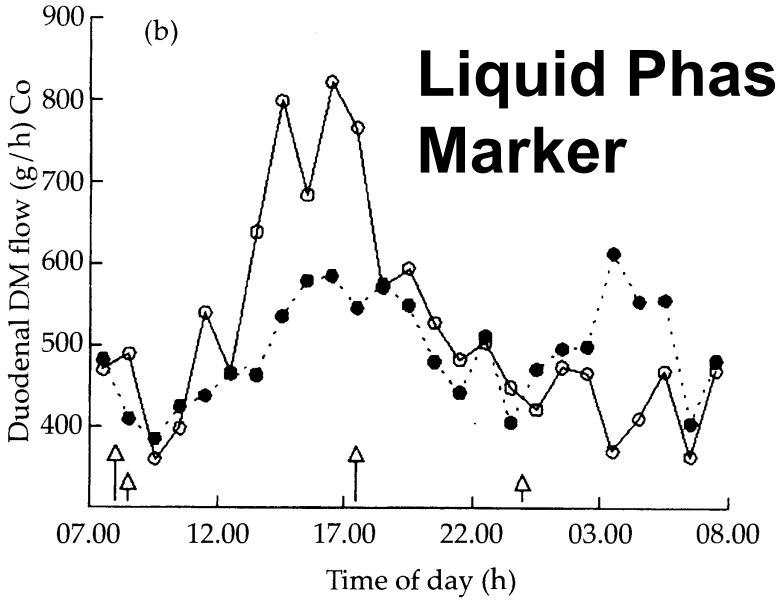
Rumen methane also follows a daily pattern: Jersey cows fed 1 vs 2x/d



Judy et al. 2018

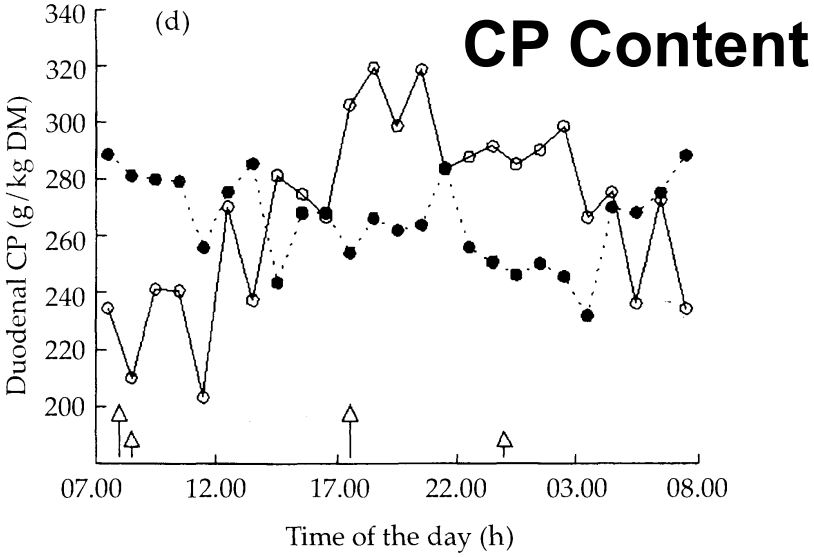
And.. Duodenal flow and composition varies across the day



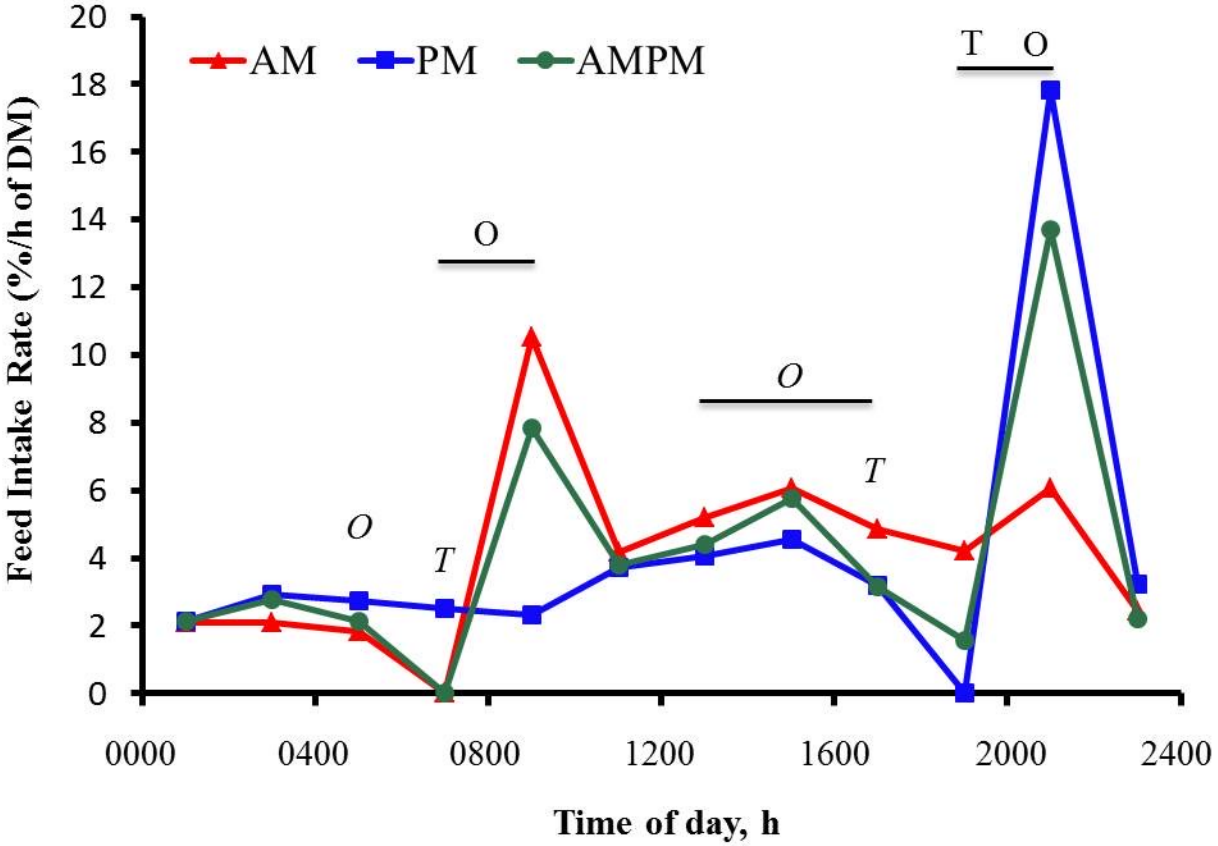


- No feed from 0000 to 0800. Treatment was protein supplement at 0830 (open marker) vs 0030 (solid marker)

Gill et al. 1999



How flexible is the pattern? Evening feed delivery increased feed intake after feeding by >50%!



➢ ANOVA

Effect	*P*-value
Treatment	0.78
Time	<0.01
Treatment x Time	<0.01

➢ Circadian Parameters

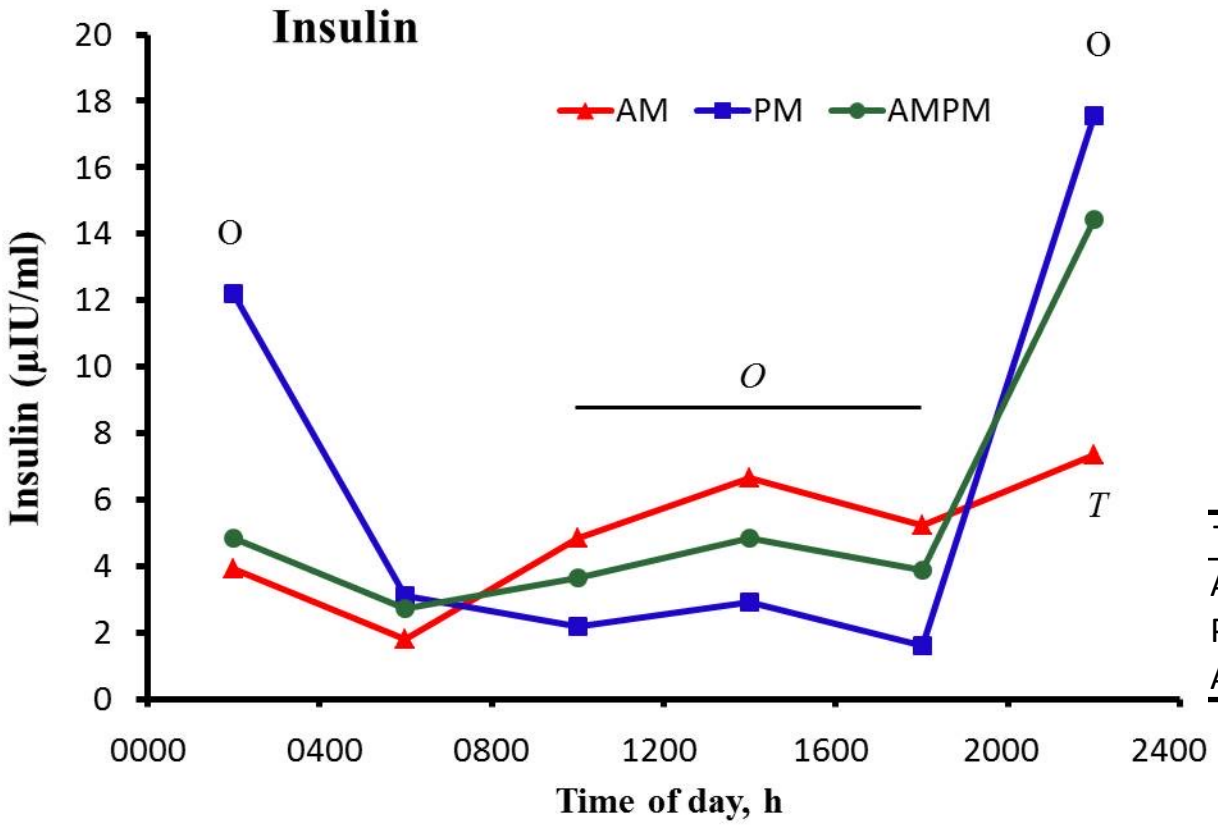
Treatment	Phase/h	Amplitude	*P*-value
AM	1654	2.0	<0.01
PM	1638*	0.6*	<0.01
AMPM	1448*	1.1*	<0.01

*Significantly ($P < 0.05$) different from AM

❖AM vs.PM ($^{O=}P < 0.01$, and $^{O}= P < 0.05$); AM vs. AMPM ($^{T}P < 0.01$, and $^{T}P < 0.05$)

- Conditional meals were larger at the evening feeding
- Modestly higher intake rate in the early afternoon for **AM**

Increase intake in the evening spikes insulin



➢ ANOVA

Effect	*P*-value
Treatment	0.76
Time	<0.01
Treatment x Time	<0.01

➢ Circadian Parameters

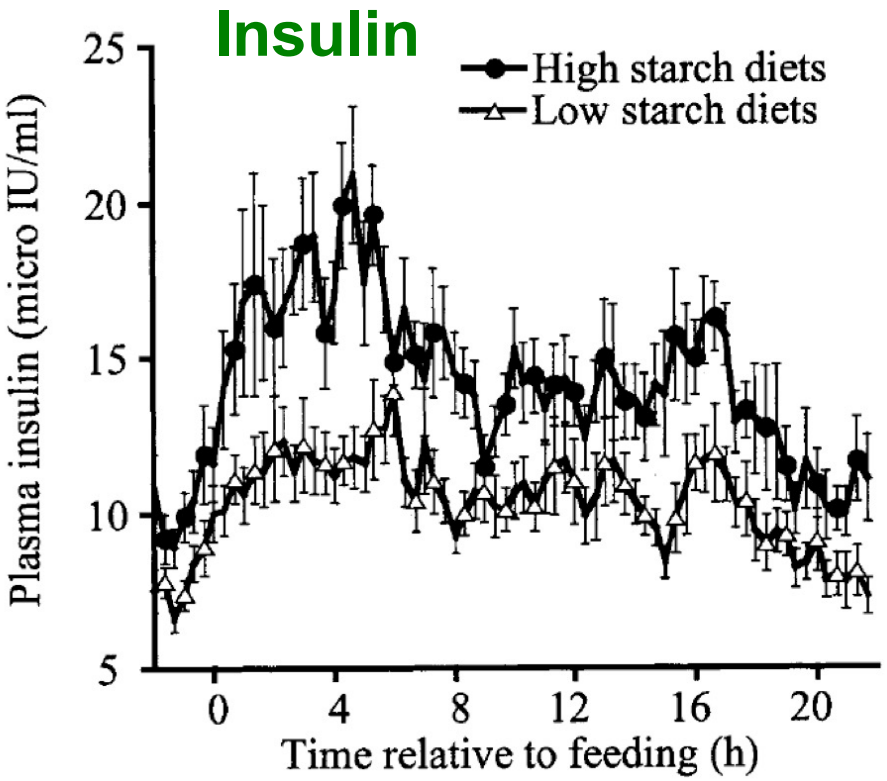
Treatment	Phase/h	Amplitude	*P*-value
AM	1844	1.8	0.07
PM	0031*	8.3*	<0.01
AMPM	2220*	4.8*	<0.01

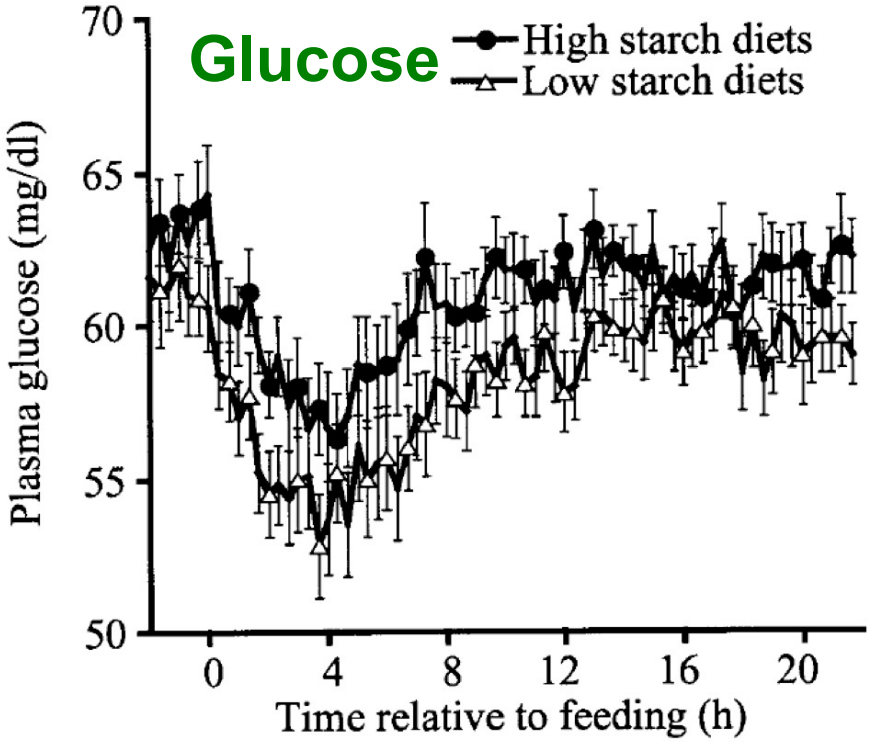
*Significantly ($P < 0.05$) different from AM

❖AM vs.PM ($^{O=}P < 0.01$, and $^{O}P < 0.05$); AM vs. AMPM ($^{T}P < 0.01$, and $^{T}P < 0.05$)

- Fresh feed delivery at night resulted in greater insulin secretion
- Morning feeding moderately increased insulin in the early afternoon

Intake pattern creates a circadian pattern of plasma metabolites and hormones

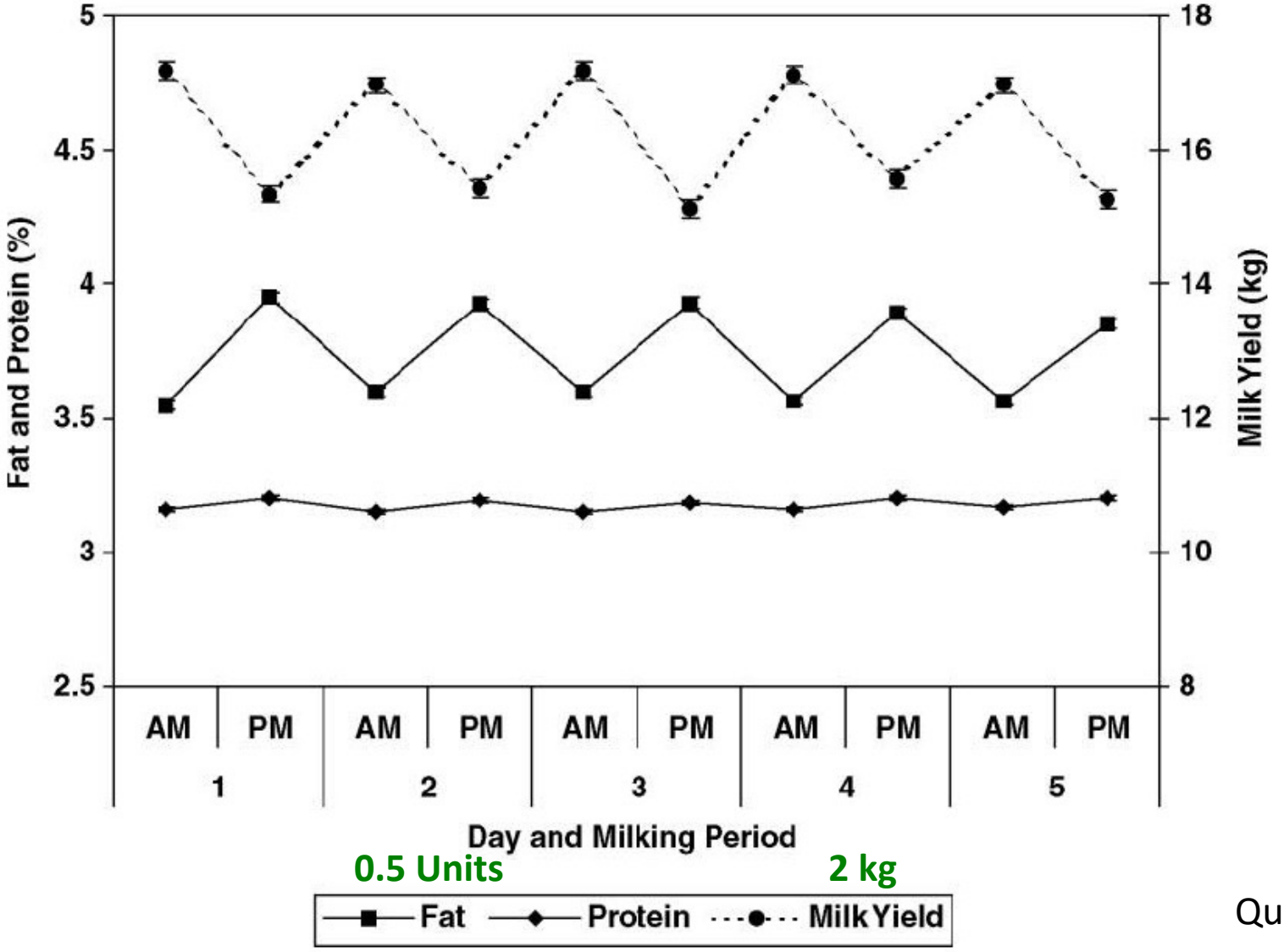




Oba and Allen, 2003

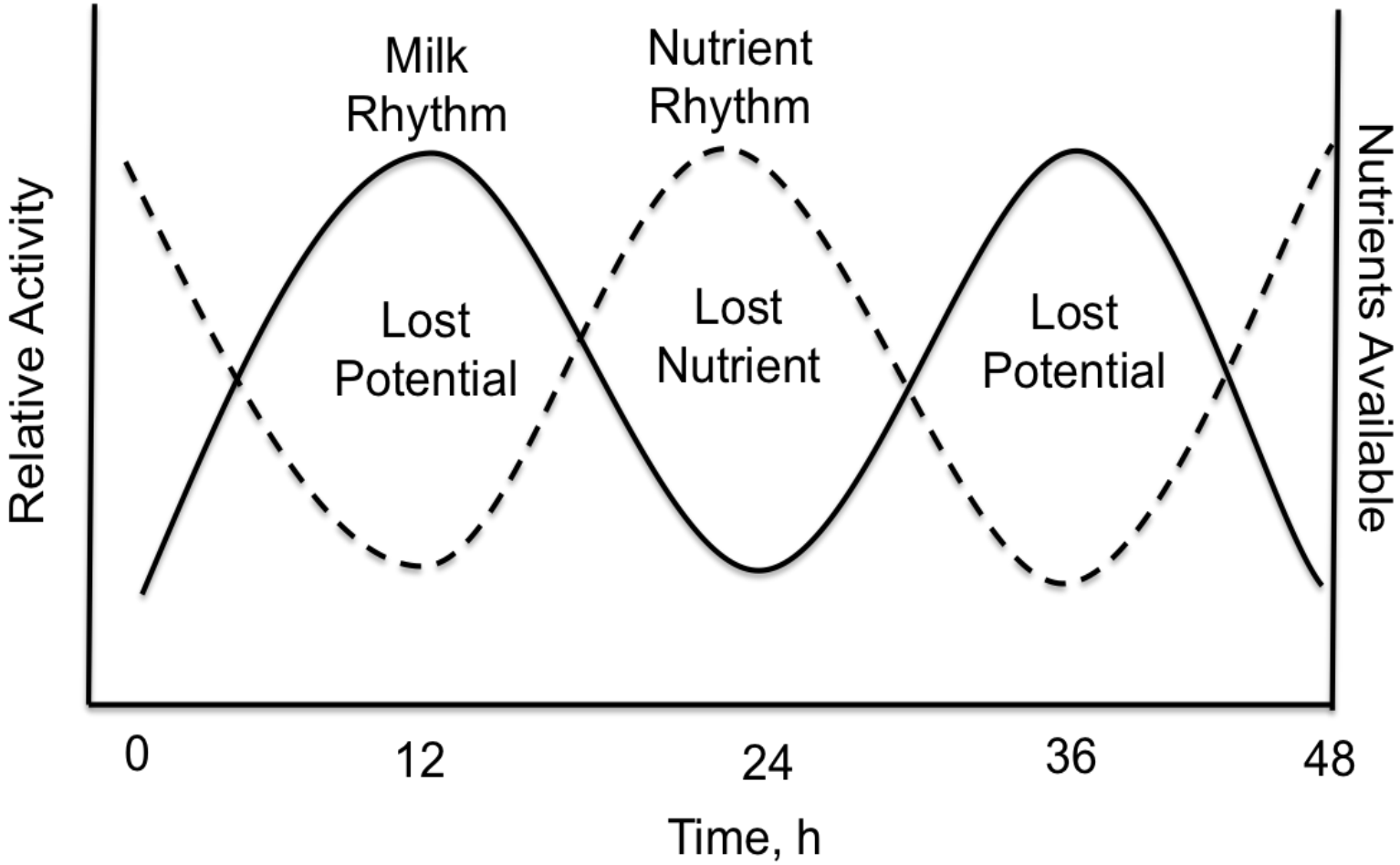
Milk synthesis is variable over the day

2x Milked Herds



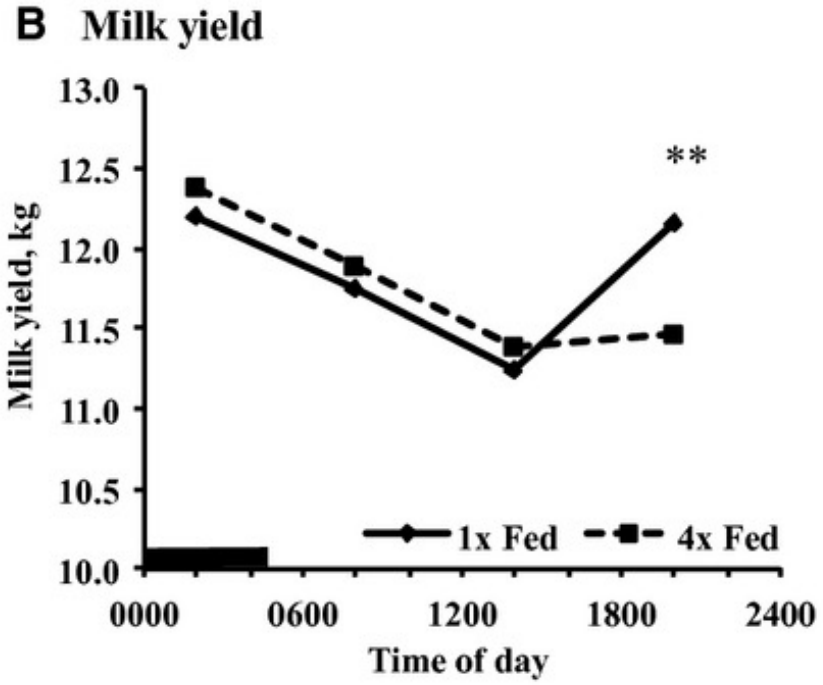
Quist et al. 2008

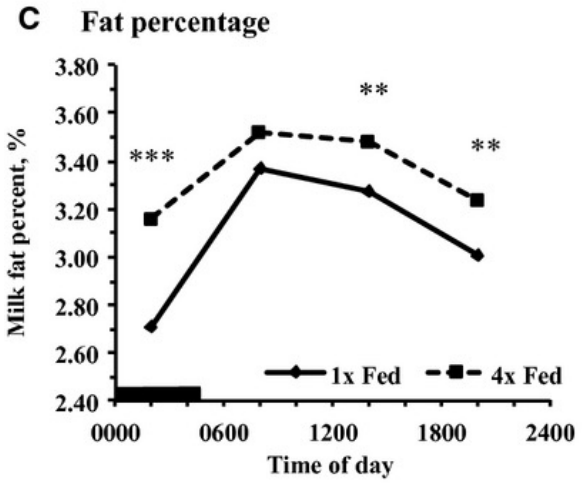
Theoretical de-synchronization of intake and mammary metabolism

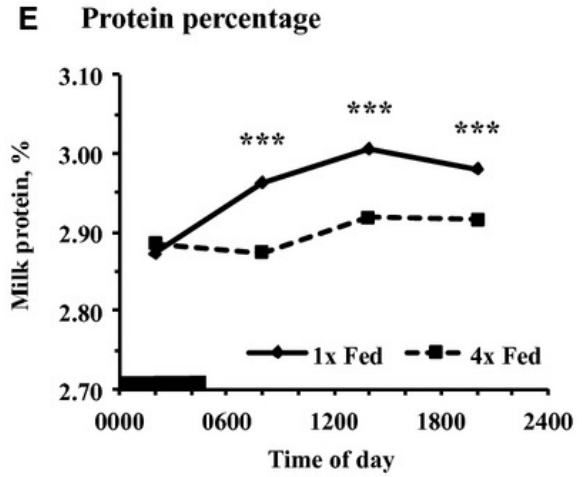


First test: Fed cows 1x/d or 4x/d in equal feedings

Feeding cows 1x/d vs 4x/d changed milk yield over the day at one milking





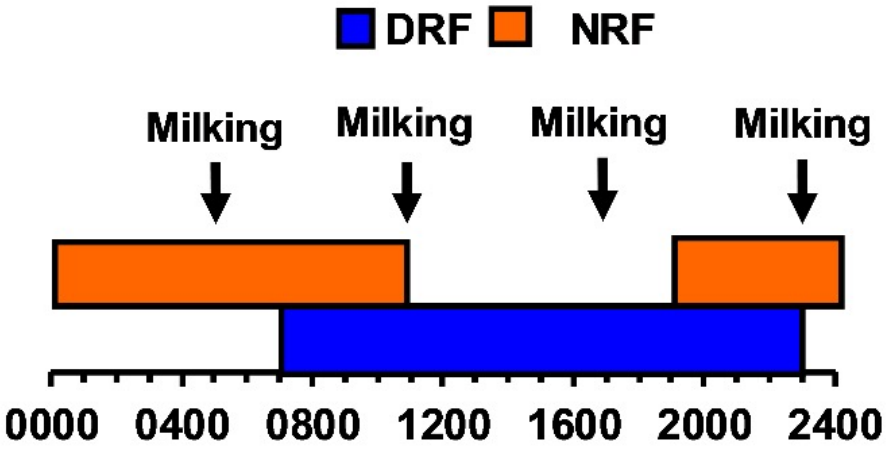


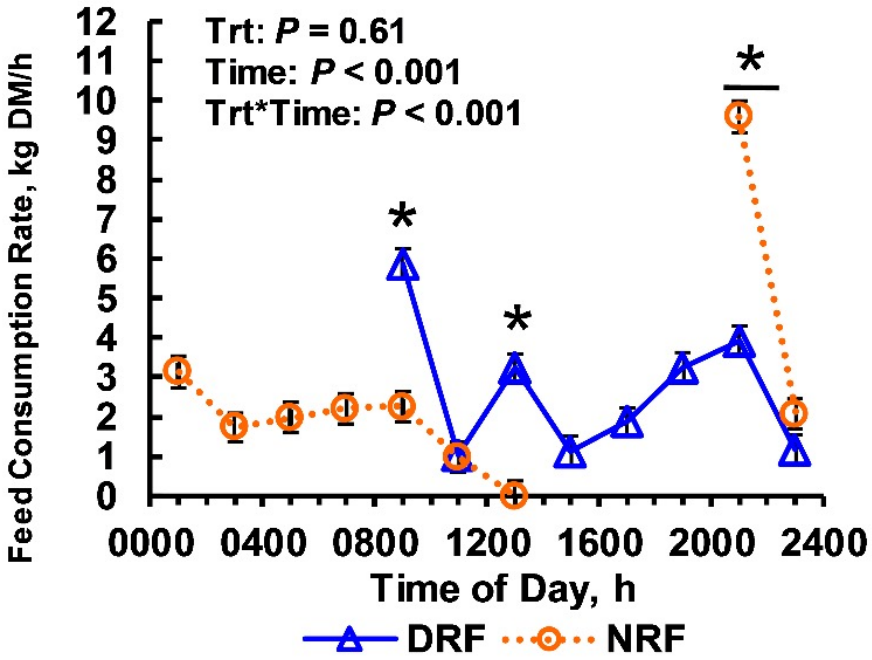
Cows were fed either 1x or 4x/d

Morning: High volume, low fat and protein%
Evening: Low volume, high fat and protein %

Rottman et al. (2014) *Physiol. Rep.* 2:1-12

How does the time of feed restriction affect the daily rhythms of milk synthesis?





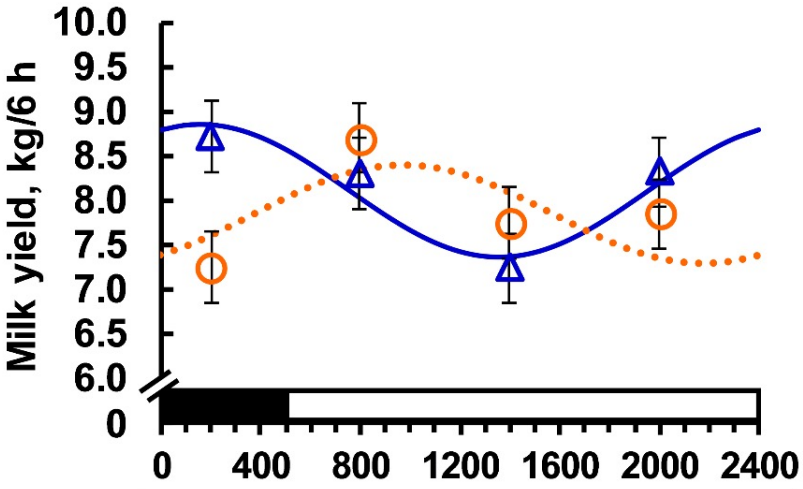
- 16 Cows
- Crossover design
- 17 d period
- 7 d of 4x/d milking

DRF: Fed 16 h/d during day (7 AM to 11 PM)

NRF: Fed 16 h/d overnight (7 PM to 11 AM)

Salfer et al. Bri. J. Nutr. 2020

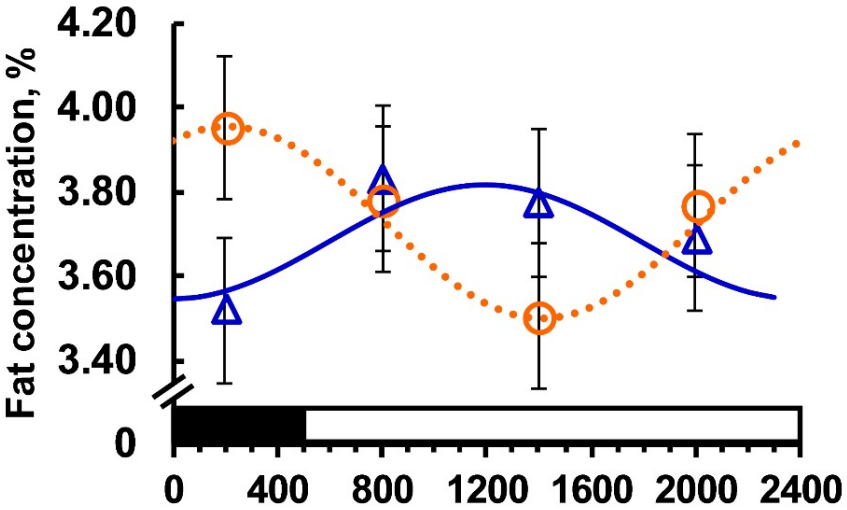
Milk yield and fat and protein concentration were shifted by night-restricted feeding



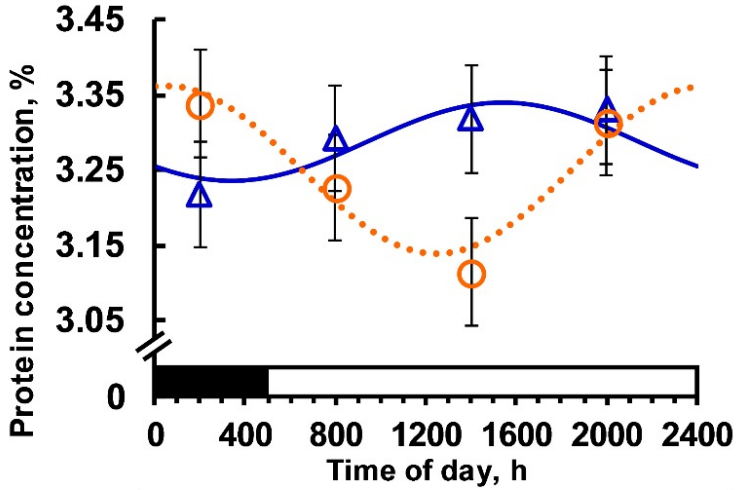
Trt	Mean	Amp[1]	Acro[2]	*P*-value[3]
DRF	8.14	0.74[a]	0134[a]	<0.0001
NRF	7.19	0.56[b]	0944[b]	<0.0001

DRF: Fed 16 h/d during day (7 AM to 11 PM)

NRF: Fed 16 h/d overnight (7 PM to 11 AM)



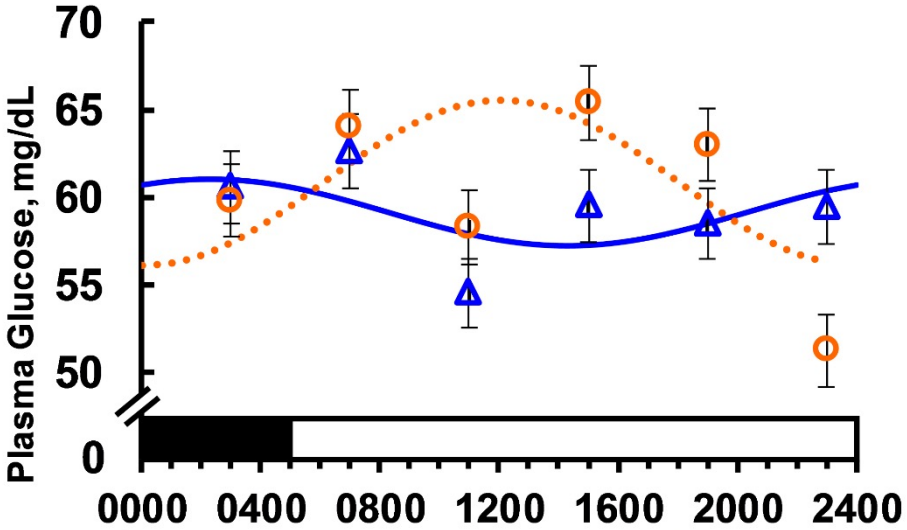
Trt	Mean	Amp[1]	Acro[2]	*P*-value[3]
DRF	3.68	0.14[b]	1156[b]	0.06
NRF	3.73	0.23[a]	0207[a]	< 0.0001



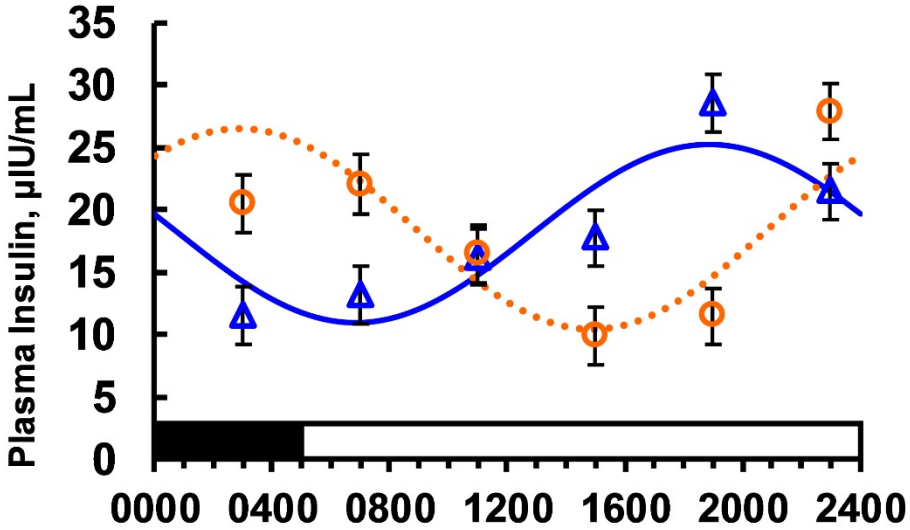
Trt	Mean	Amp[1]	Acro[2]	*P*-value[3]
DRF	3.29	0.05[b]	1525[b]	0.02
NRF	3.25	0.11[a]	0029[a]	< 0.0001

Salfer et al. Bri. J. Nutr. 2020

Plasma glucose and insulin concentrations were shifted by the time of feed restriction



Trt	Mean	Amp[1]	Acro[2]	*P*-value[3]
DRF	59.1	1.90[b]	0218[a]	0.03
NRF	60.8	4.74[a]	1205[b]	< 0.001

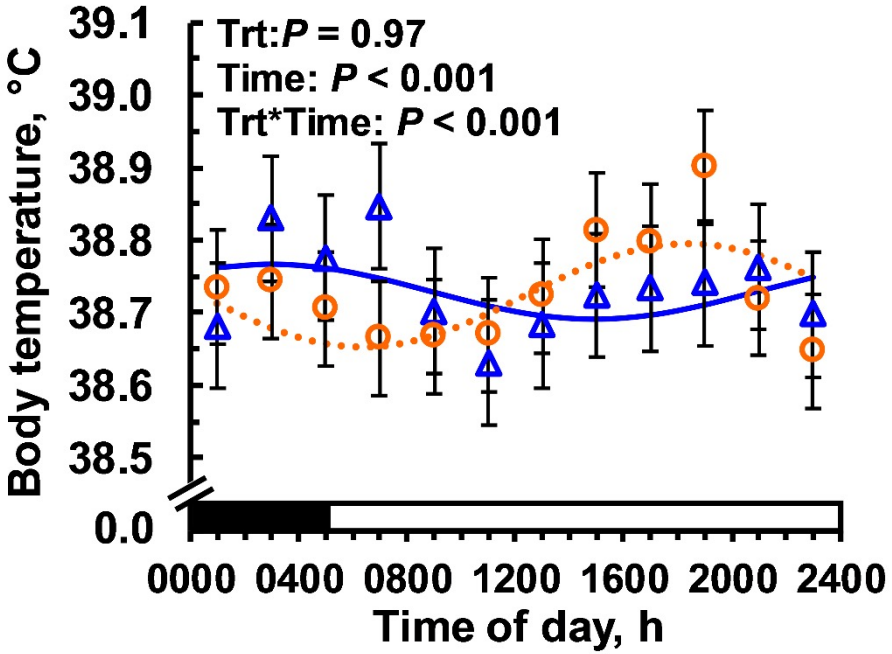


Trt	Mean	Amp[1]	Acro[2]	*P*-value[3]
DRF	18.1	7.08[b]	1851[b]	< 0.001
NRF	17.3	8.00[a]	0253[a]	< 0.001

DRF: Fed 16 h/d during day (7 AM to 11 PM)
NRF: Fed 16 h/d overnight (7 PM to 11 AM)

Salfer et al. Bri. J. Nutr. 2020

The daily rhythm of body temperature was shifted 8 h by night-restricted feeding



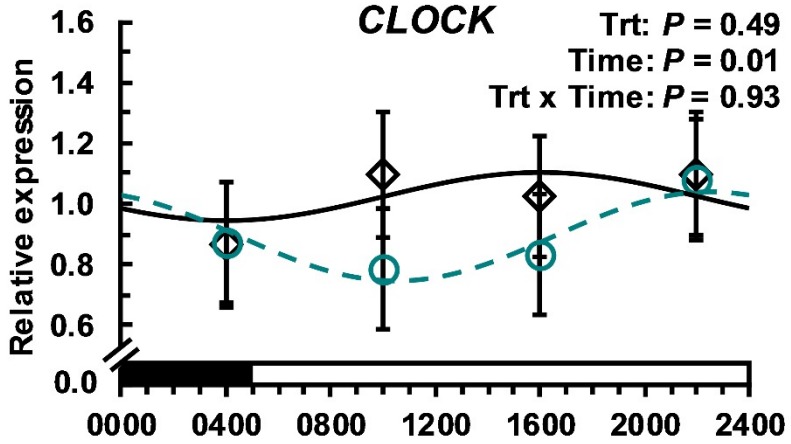
Trt	Mean	Amp[1]	Acro[2]	*P*-value[3]
DRF	38.7	0.04[b]	0154[a]	< 0.0001
NRF	38.7	0.07[a]	1724[b]	< 0.0001

DRF: Fed 16 h/d during day (7 AM to 11 PM)

NRF: Fed 16 h/d overnight (7 PM to 11 AM)

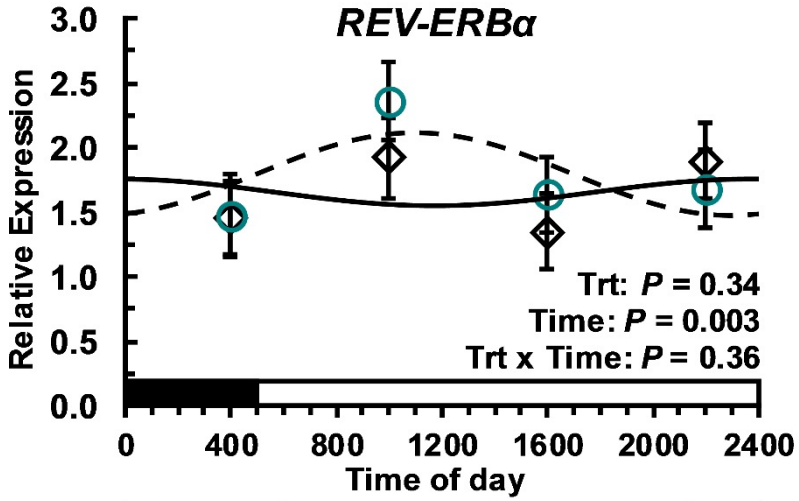
Salfer et al. Bri. J. Nutr. 2020

Mammary expression of some of the core clock genes was shifted by night-restricted feeding

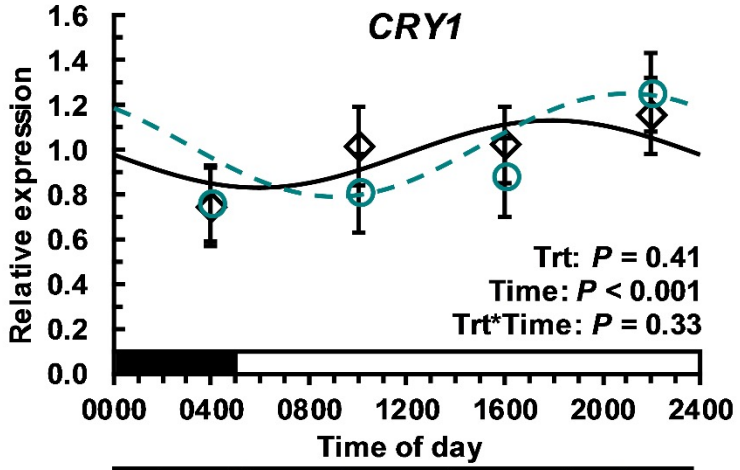


Trt	Mean	Amp	Acro	*P*-value
CON	0.94	0.08	1603[a]	< 0.001
NR	0.89	0.14	2232[b]	0.06

CON: Fed continuously 24 h/d
NR: Feed restricted to 16 h at night (8 PM to 12PM)



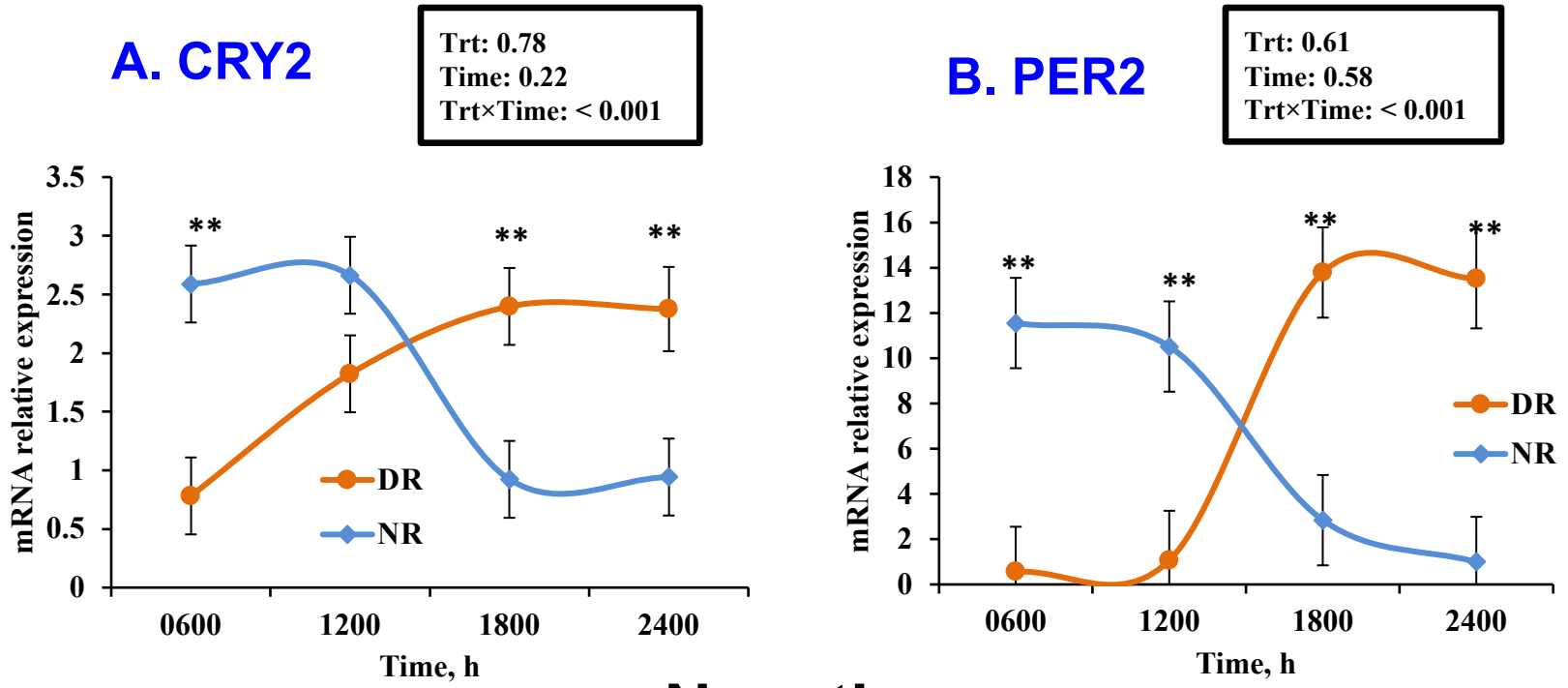
Trt	Mean	Amp	Acro	*P*-value
CON	1.65	0.10[b]	1143[a]	0.62
NR	1.79	0.32[a]	2258[b]	0.06

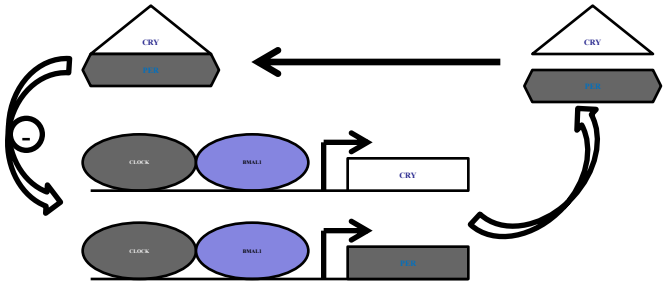


Trt	Mean	Amp	Acro	*P*-value
CON	0.94	0.15	1756[a]	0.006
NR	0.90	0.23	2104[b]	0.02

Salfer et al. Unpublished

The mammary core clock was robustly inverted in day vs night fed mice



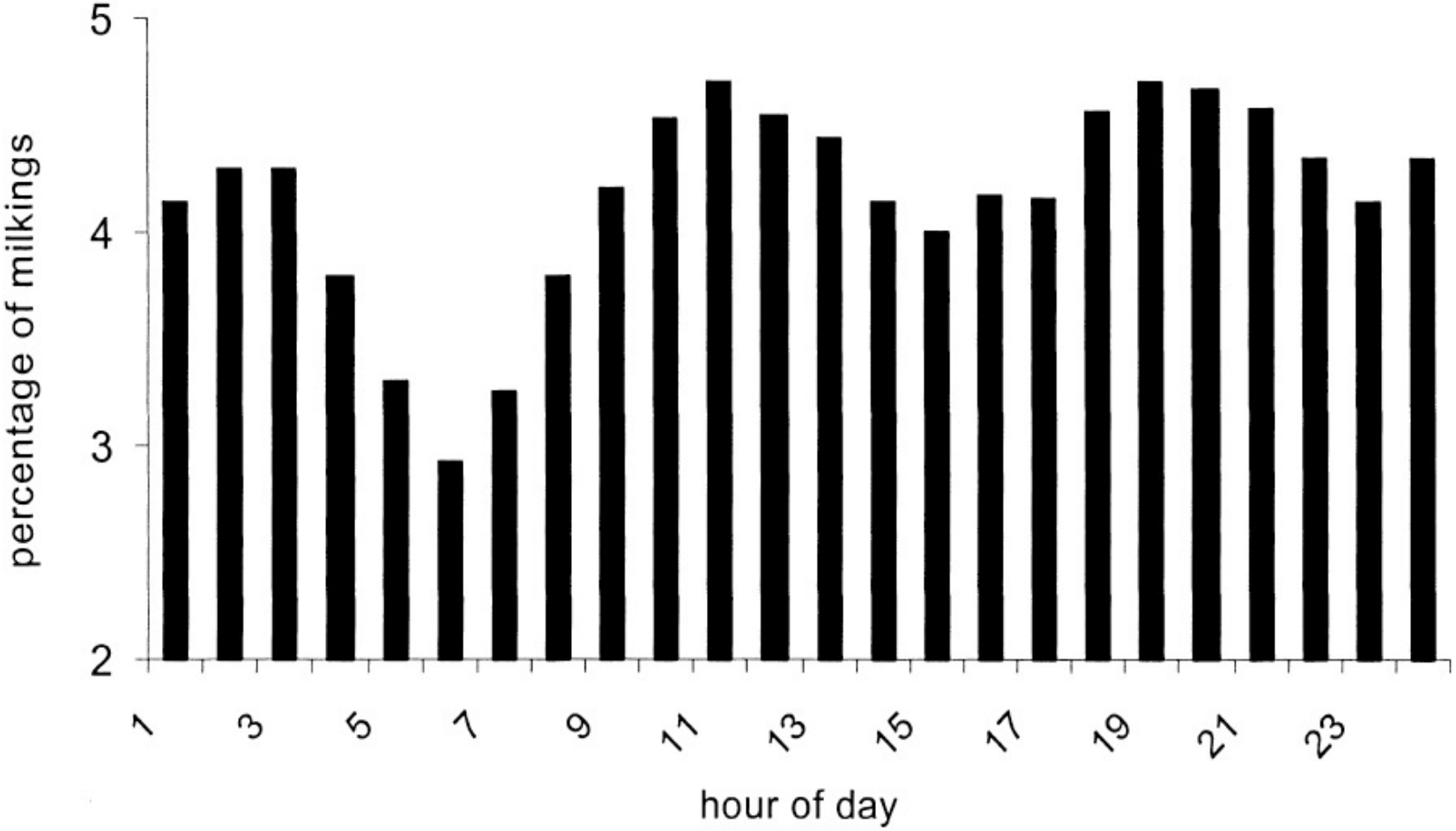


- **Negative arm**
  - Phase inverted
  - ↑ when food available
- **Positive arm**
  - BMAL1 also phase shifted

Ma et al. Unpublished

When do cows prefer to be milked??

Automated Milking System



Hogeveen et al., 2001

How can we use this information??

Think not just about the diet we are feeding, but how we are feeding it and how the cows are eating it!

We need to watch the cows and see what they are doing!

1st… Think of the rumen

- **Can we stabilize the amount of fermentable feed entering the rumen over the day?**
  - **Take out some of the slugs and fill in during some of the low points**

How do we do this?

- **Feed delivery is a strong signal for feeding which can be used to increase intake during low intake periods of the day**

- **Make sure feed is available when return from parlor……, but**
  - **Delivery of feed 2-3 h before or after milking may spread intake more across the day (King et al. 2018)**

What else can we do?

- **Feeding different diets across the day might also work**
  - **Feed same ration to entire herd in morning**
  - **Return to “top-off” high groups**

Feeding multiple rations over the day

- **Three diets were used**
  - Control (Con): 30.1% NDF
  - High fiber (H): 31.8% NDF
  - Low fiber (L): 26.9% NDF

70% of H & 30% of L = Control

- **Three Treatments**
  - **Fed control TMR once per day at 0900**
  - **High-Low Treatment (HL)**
    - 70% of feed fed as High Fiber Diet at 0900 h
    - 30% of feed fed as Low Fiber Diet at 2200 h
  - **Low-High Treatment (LH)**
    - 30% of feed fed as Low Fiber Diet at 0900 h
    - 70% of feed fed as High Fiber Diet at 1300 h

Rottman et al. 2015; Ying et al. 2015

Milk yield and composition

	Treatment				*P*-value
	CON	HL	LH	SEM	Trt
DMI, lbs/d	58.0	53.7[c]	56.0	2.4	0.01
Milk, lbs/d	87.3	84.9	90.2	5.3	0.14
Milk Fat					
Percent	3.44	3.39	3.45	0.25	0.73
Yield, lbs/d	2.99	2.82[LH]	3.10	0.11	0.07
Milk Protein					
Percent	3.08	3.10	3.10	0.09	0.86
Yield, lbs/d	2.68	2.64	2.79	0.15	0.19

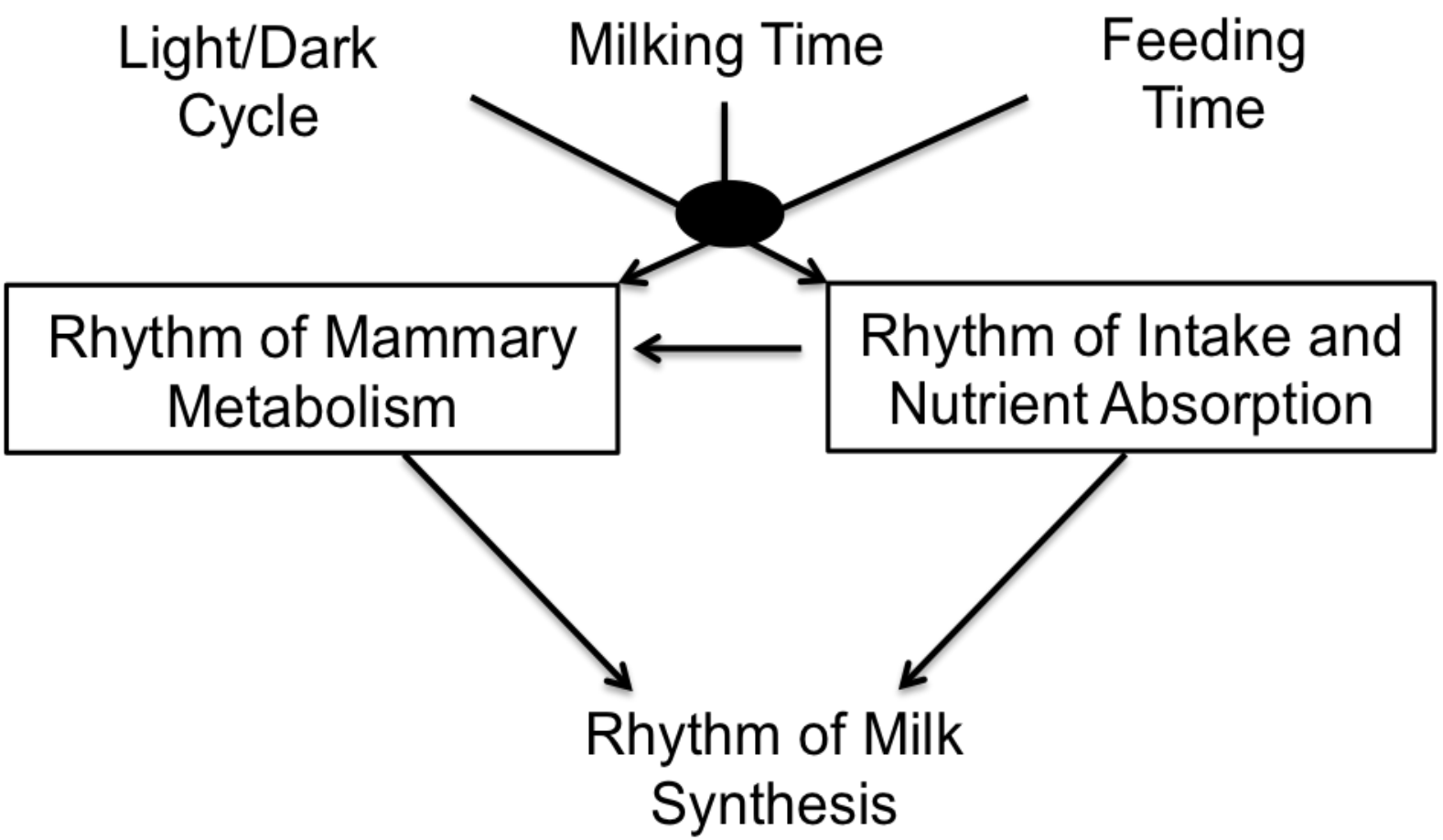
What did we learn?

- **Its complicated!**
- **Have to be very careful with the effect of timing of feed delivery changing feeding behavior**
- **Demonstrates we don't have to have the same TMR across the day and there are times that feeding different diets might be advantageous**

Interesting Call From the Field

- One pen of cows on a large farm consistently 0.3 to 0.5 units lower in milk fat than peer pen in another barn fed same diet
- Moved fifteen cows from the pen to another pen and they increased milk fat
- Normal MFD troubleshooting turned up no clues
- Cows being fed later in the day (11:30 AM)
- Switched milking and feeding order so feed delivered earlier and before milking.
- Milk fat increased equal to peer pen

Must consider multiple factors that have an impact on behavior and physiology



Key Principles

- There is a daily (circadian) pattern of intake that has a major impact on the rumen
- There is a daily pattern of milk synthesis
- We need to manage the daily pattern of intake and our best tools for this are through feeding and milking schedules
- Don’t be afraid to feed multiple diets per day, but be careful with late afternoon and evening feedings (early morning may be safer)

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Thank You!