Effects of Heat Stress on Post-Absorptive Metabolism and Bioenergetics in Lactating Dairy Cows

L.H. Baumgard & R.P. Rhoads

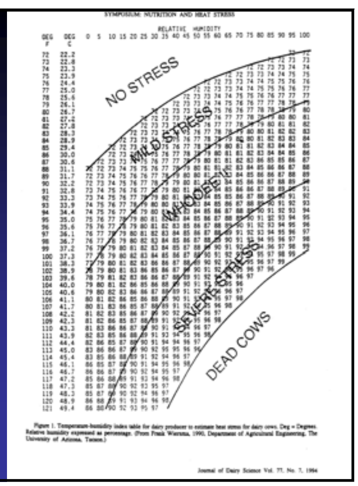
The University of Arizona
Department of Animal Sciences

Seminar Outline

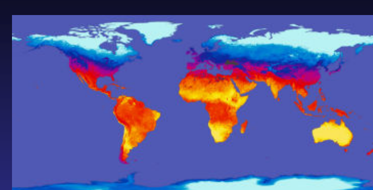
- Heat stress
  - Definition
  - Production effects
  - Effects on rumen health
- U of Arizona heat stress trials
- Heat Stress vs. Transition Period
  - (from an energetic stand point)
- Metabolic Summary
- Summary
- Conclusions

Temperature Humidity Index (THI)

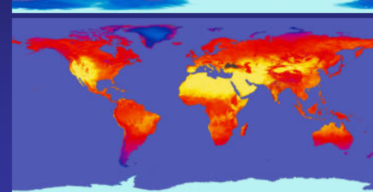
Easy way to measure and evaluate heat stress



Heat Stress is a Global Problem

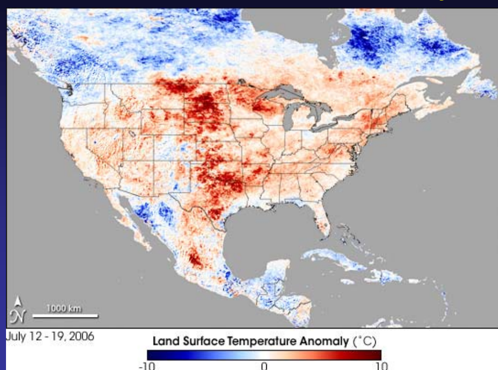


January 2003, NASA

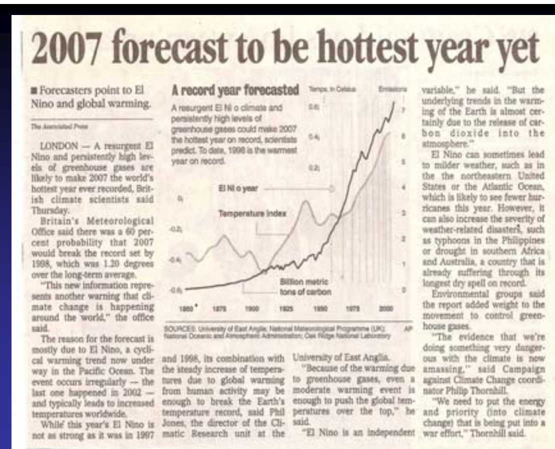


July 2003, NASA

July 2006 Heat Wave
$1 Billion Cost To California Dairy Industry



Collier, 2007 SWNC



2007 forecast to be hottest year yet

■ Forecasters point to El Nino and global warming.

The Associated Press

LONDON — A resurgent El Nino and persistently high levels of greenhouse gases are likely to make 2007 the world's hottest year ever recorded, British climate scientists said Thursday.

Britain's Meteorological Office said there was a 60 percent probability that 2007 would break the record set by 1998, which was 1.20 degrees over the long-term average.

"This new information represents another warning that climate change is happening around the world," the office said.

The reason for the forecast is mostly due to El Nino, a cyclical warming trend now under way in the Pacific Ocean. The event occurs irregularly — the last one happened in 2002 — and typically leads to increased temperatures worldwide.

While this year's El Nino is not as strong as it was in 1997 and 1998, its combination with the steady increase of temperatures due to global warming from human activity may be enough to break the Earth's temperature record, said Phil Jones, the director of the Climatic Research unit at the University of East Anglia.

"Because of the warming due to greenhouse gases, even a moderate warming event is enough to push the global temperatures over the top," he said.

"El Nino is an independent variable," he said. "But the underlying trends in the warming of the Earth is almost certainly due to the release of carbon dioxide into the atmosphere."

El Nino can sometimes lead to milder weather, such as in the the northeastern United States or the Atlantic Ocean, which is likely to see fewer hurricanes this year. However, it can also increase the severity of weather-related disasters, such as typhoons in the Philippines or drought in southern Africa and Australia, a country that is already suffering through its longest dry spell on record.

Environmental groups said the report added weight to the movement to control greenhouse gases.

"The evidence that we're doing something very dangerous with the climate is now amassing," said Campaign against Climate Change coordinator Philip Thornhill.

"We need to put the energy and priority (into climate change) that is being put into a war effort," Thornhill said.

A record year forecasted

A resurgent El Ni o climate and persistently high levels of greenhouse gases could make 2007 the hottest year on record, scientists predict. To date, 1998 is the warmest year on record.

SOURCES: University of East Anglia; National Meteorological Programme (UK); National Oceanic and Atmospheric Administration; Oak Ridge National Laboratory AP

Charlie Staples, U of FL

Bare ground surface temperature before and after shading at various times during the day[a]

Shaded time (min)	Temperature of Ground Surface (°F) 11 a.m.	12 noon	2 p.m.	4 p.m.
In sun	124.9	144.3	151.9	153.0
5	104.0	107.6	111.6	113.7
15	98.1	103.1	109.4	109.4
30	98.1	101.3	104.0	105.8
Air temp	91.9	95.0	98.1	104.0

[a]From Kelly et al. (1950).

Dairy Cows Respond to Heat in Several Ways:

- Reduced feed intake over 78° F (> 10 – 15%)
- Increased respiration rate (> 80 breaths per minute)
- Increased body temperature (> 102.5° F)
- Changed blood hormone concentration
- Increased water intake
- Increased evaporated water loss
- Reduced activity

Heat Stressed Cows

Results of Heat Stress

Decrease in milk production

Reduced body condition

Annual loss to American Dairy Industry is $897 MILLION!

St-Pierre et al., 2003 J. Dairy Sci. E52-E77.

Rumen acidosis

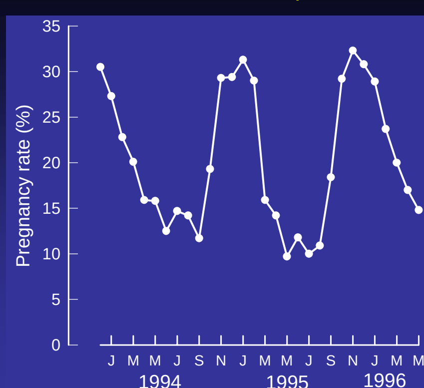
Significant drop in pregnancy rate

High incidence of abortions

High death loss

Added all up … costly!

Seasonal Effects on Reproduction



Dr. Peter Hansen, U of Fl

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Heat Stressed Cows

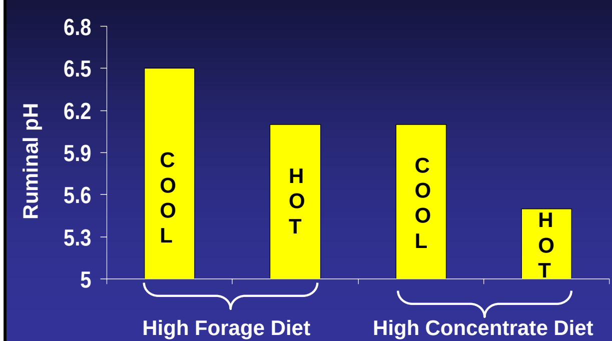
Results of Heat Stress

- Decrease in milk production
- Reduced body condition
- A
- R
- Si
- H
- High death loss

Rumen Acidosis:
- Reduced cellulose digestion
- Laminitis
- Milk fat depression
- etc…

Added all up … costly!

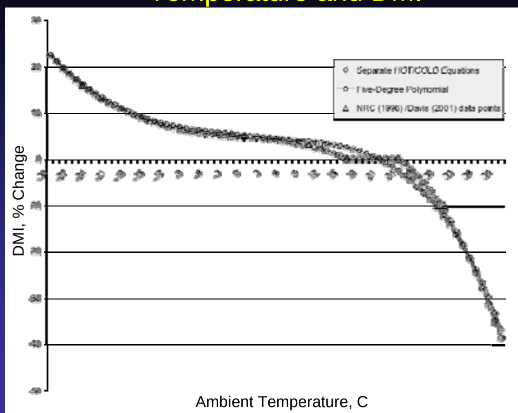
Effect of Heat Stress on Ruminal pH of Holstein Cows *(Mishra et al., JAS 30:1023)*



Heat Stress Induced Rumen Acidosis

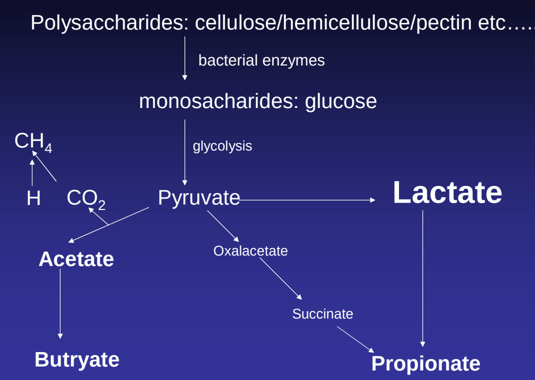
- Originates via:
  - 1) Altered respiration
    - Loss of systemic buffering capacity
  - 2) Changes in feed and feeding behavior
    - Reduced feed intake
    - Increased concentrates
    - “sorting”
    - “bout/slug” feeding
    - Drooling
    - Less saliva production

Temperature and DMI



Mader, 2003

Heat Stressed Rumen Fermentation



Dairy Cows Respond to Heat in Several Ways:

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Increased body temperature (> 102.5° F)

Changed blood hormone concentration

Increased water intake

Increased evaporated water loss

Reduced activity

Increased Respiration Rate

- Body requires 20:1 ratio of HCO_3:CO_2 in blood
- Increased expired CO_2
- To compensate, the kidney dumps HCO_3
- Therefore less HCO_3 to buffer the rumen

Summary

- ↑ Respiration = ↓ blood HCO_3
- ↓ Feeding = ↓ rumination = ↓ saliva production
- ↑ Drooling = wasted saliva
- Altered feeding habits and “hotter” rations

- Added all up = rumen acidosis

Seminar Outline

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- **U of Arizona heat stress trials**
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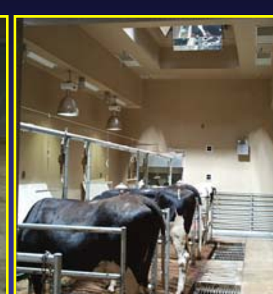
Environmental/metabolic Chambers

Heat Stress

Heat Stress + Solar Radiation



Heat Stress Questions??

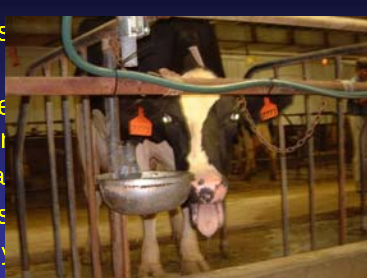
Does the decrease in feed intake explain the reduced milk yield when cows are heat stressed?

What dietary and management strategies can help alleviate some of the negative side effects of heat stress

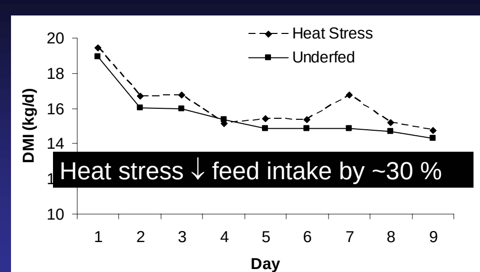
If we have a better understanding of the biological reasons WHY heat stress reduces milk yield, we'll have a better idea of how to alleviate it.

U of Arizona Trials Study 1

- Heat s … July day: cyclic
- Pair-fe … keep nutrien
  - 9 da
- Heat s
  - Body
  - Respiration rates went from 44 to 89 breaths/min

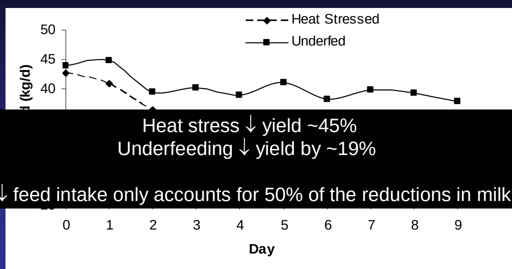


Effects of Heat Stress on Feed Intake



Rhoads and Baumgard, unpublished

Effects of Heat Stress on Milk Yield

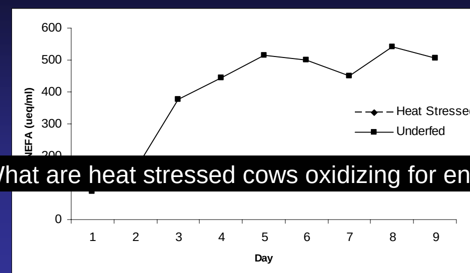


Heat stress ↓ yield ~45%
Underfeeding ↓ yield by ~19%

Thus, ↓ feed intake only accounts for 50% of the reductions in milk yield

Rhoads and Baumgard, unpublished

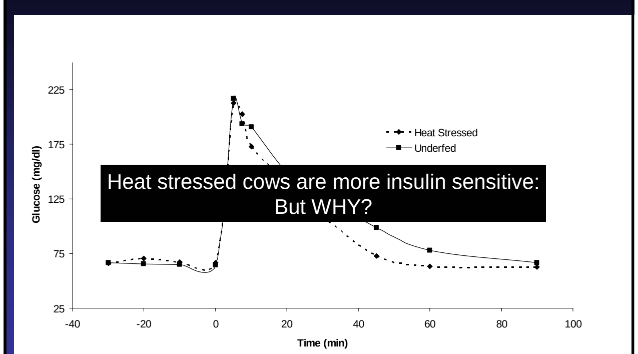
Effects of Heat Stress on Adipose Tissue Mobilization



What are heat stressed cows oxidizing for energy?

Rhoads and Baumgard, unpublished

Glucose Tolerance Test



Heat stressed cows are more insulin sensitive:
But WHY?

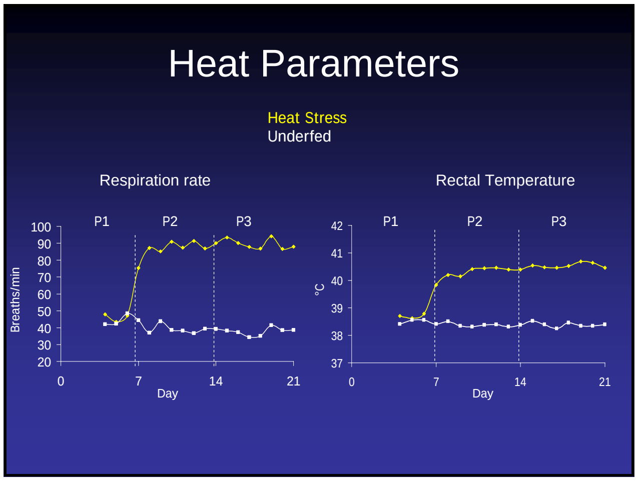
Wheelock and Baumgard, unpublished

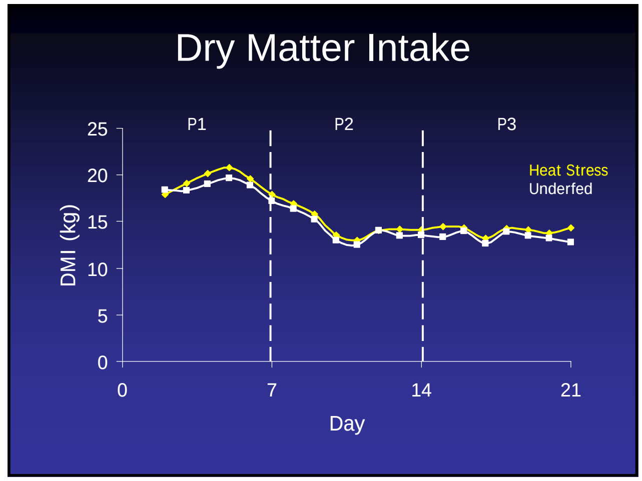
U of Arizona Trials
Study 2

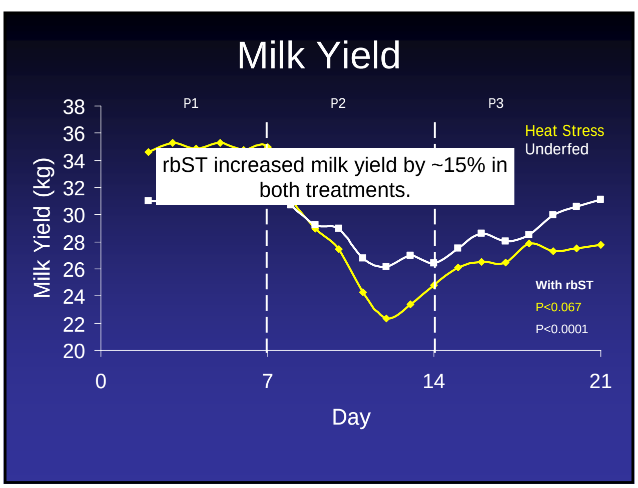
- 22 Multiparous Holstein cows (99.8 ± 20.2 DIM) were balanced for parity and production, and then randomly assigned to 1 of 2 trts
  - 1) Heat Stress (HS): cyclical temps (80-104°F)
  - 2) Underfeeding (UF): constant temp (70°C)

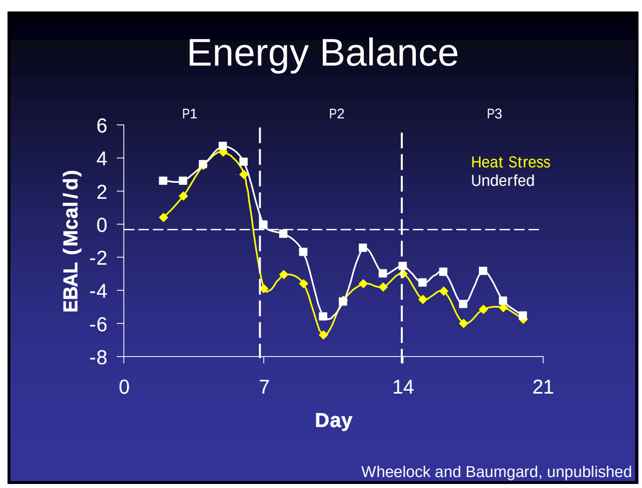
Objective:
Determine if heat-stressed cows respond to rbST

- dissimilar nutrient intake
- Cows underwent 3 periods (21 d total)
  - Acclimation (7 d)
  - HS or UF (7 d)
  - HS or UF with rbST supplementation (7 d)
    - rbST: POSILAC, Monsanto Inc., St. Louis MO

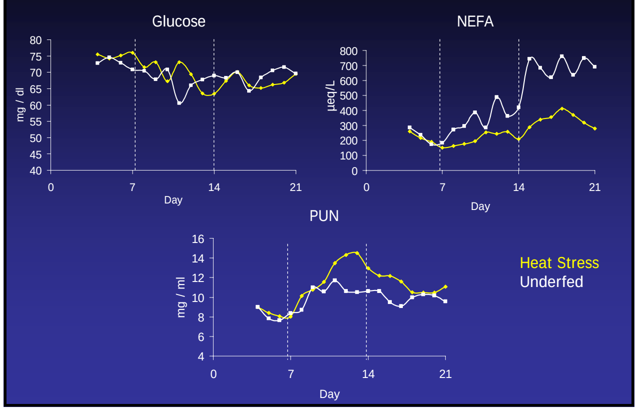

Heat Parameters
Heat Stress
Underfed
Respiration rate
Rectal Temperature
P1
P2
P3
Breaths/min
°C
Day


Dry Matter Intake
P1
P2
P3
Heat Stress
Underfed
DMI (kg)
Day

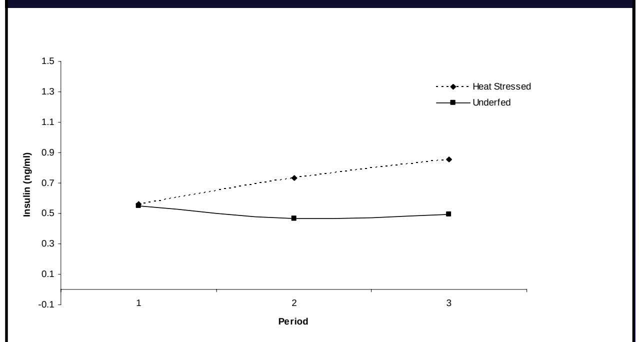

Milk Yield
P1
P2
P3
Heat Stress
Underfed
rbST increased milk yield by ~15% in both treatments.
With rbST
P<0.067
P<0.0001
Milk Yield (kg)
Day


Energy Balance
P1
P2
P3
Heat Stress
Underfed
EBAL (Mcal / d)
Day
Wheelock and Baumgard, unpublished

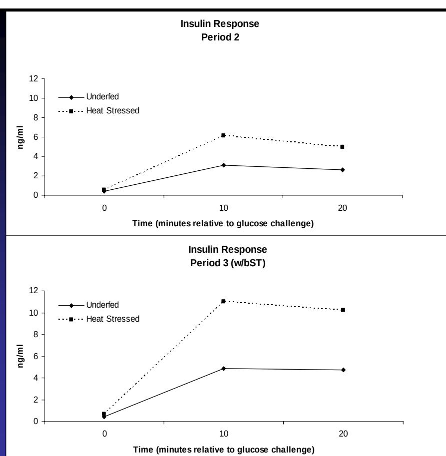
Daily Metabolites



Circulating Insulin



Wheelock and Baumgard, unpublished



Wheelock and Baumgard, unpublished

Energetic Summary

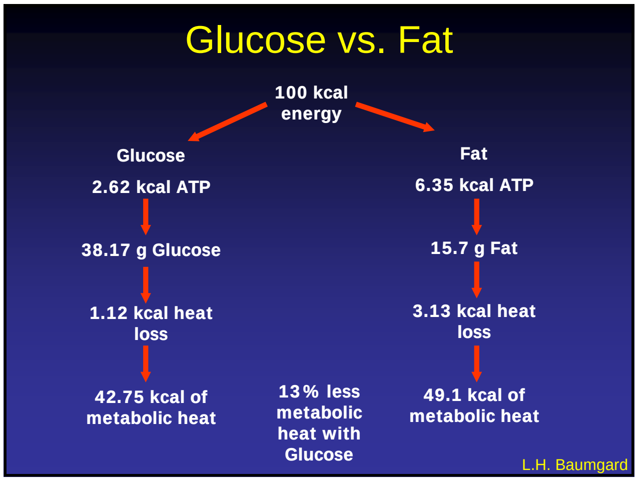
- Heat stress reduces milk yield (~40-50%)
- Decreased feed intake only accounts for ~50% of the reductions in milk yield
- Both underfeeding and heat stressed cows enter similar negative energy balances (~ -3.5 Mcal/d)
  - Ar
    av

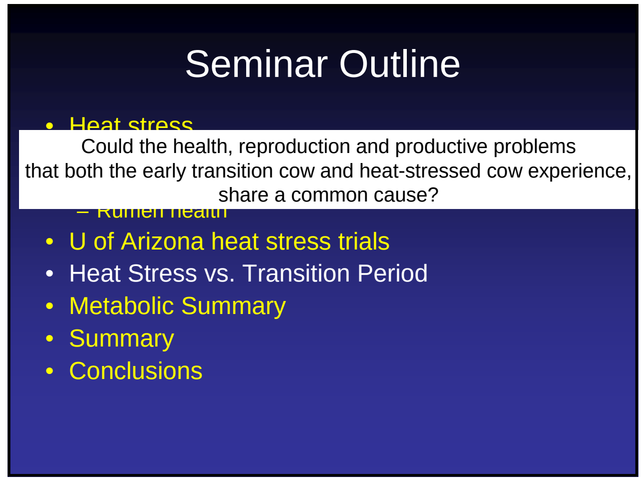
Why increase insulin action?

- Heat stressed cows become hypersensitive to insulin
  - Decreased NEFA
  - Increased glucose disposal

  } But why?
- Heat stressed cows require EXTRA ENERGY!
  - Especially glucose
    - Enhanced glucose utilization by the body may limit glucose availability to the mammary gland = ↓ lactose production

Rhoads and Baumgard, unpublished


Glucose vs. Fat
100 kcal energy
Glucose
2.62 kcal ATP
38.17 g Glucose
1.12 kcal heat loss
42.75 kcal of metabolic heat
13% less metabolic heat with Glucose
Fat
6.35 kcal ATP
15.7 g Fat
3.13 kcal heat loss
49.1 kcal of metabolic heat
L.H. Baumgard


Seminar Outline
• Heat stress
Could the health, reproduction and productive problems that both the early transition cow and heat-stressed cow experience, share a common cause?
• U of Arizona heat stress trials
• Heat Stress vs. Transition Period
• Metabolic Summary
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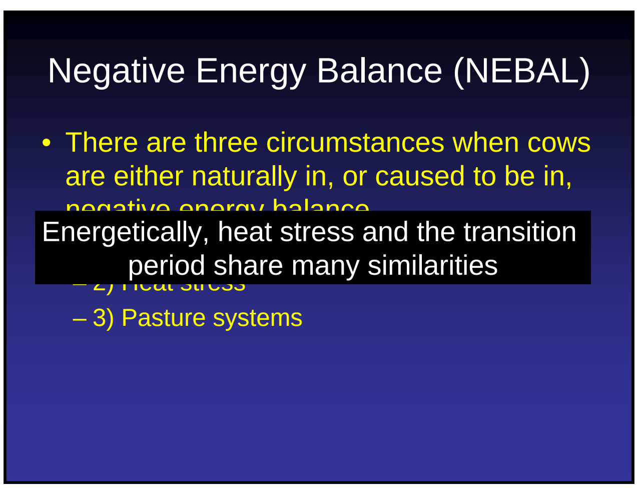
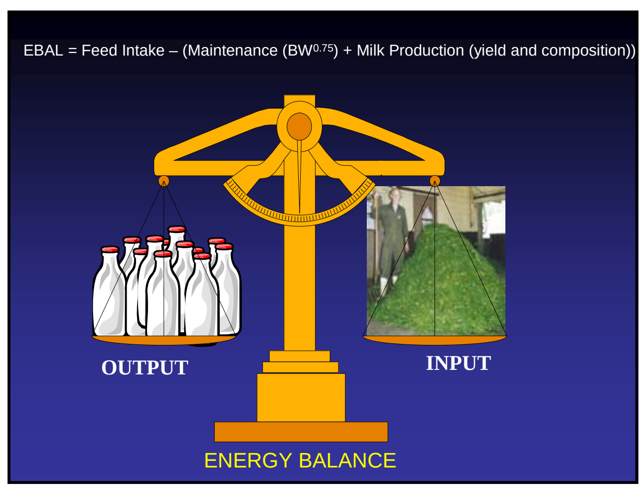
• Conclusions


Negative Energy Balance (NEBAL)
• There are three circumstances when cows are either naturally in, or caused to be in,
Energetically, heat stress and the transition period share many similarities
– 3) Pasture systems


EBAL = Feed Intake – (Maintenance (BW0.75) + Milk Production (yield and composition))
OUTPUT
INPUT
ENERGY BALANCE

Transition Period Disorders: Mediated Largely by NEBAL

- Dystocia
- Mi
- Re
- Metritis
- Ketosis
- Displaced abomasum
- Fatty liver
- Lameness
- Death

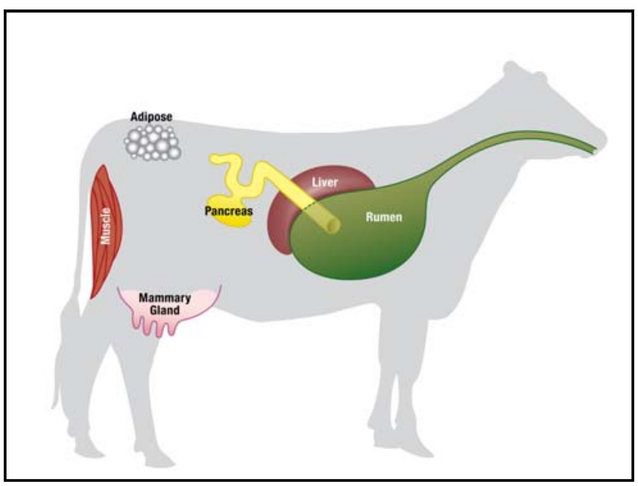
Heat stressed cows also have increased incidence of these disorders

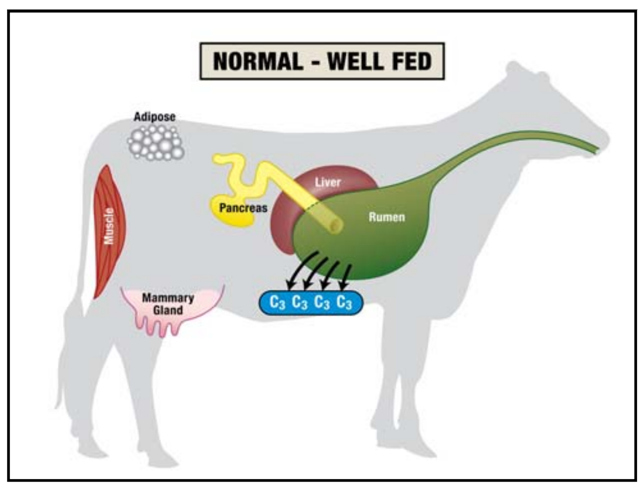
transition period without experiencing one of these problems

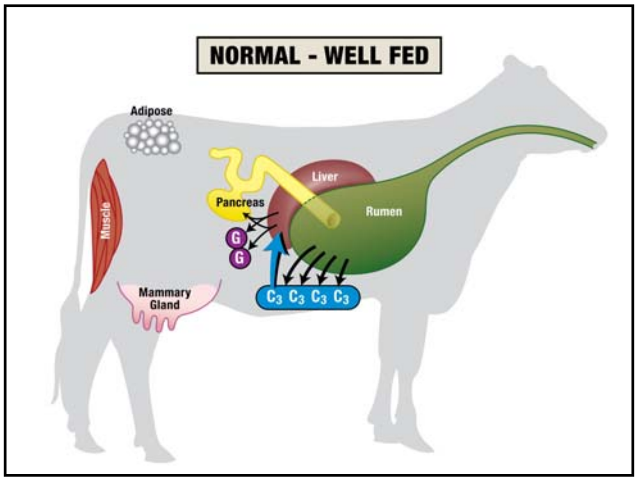
Drackley, 1999

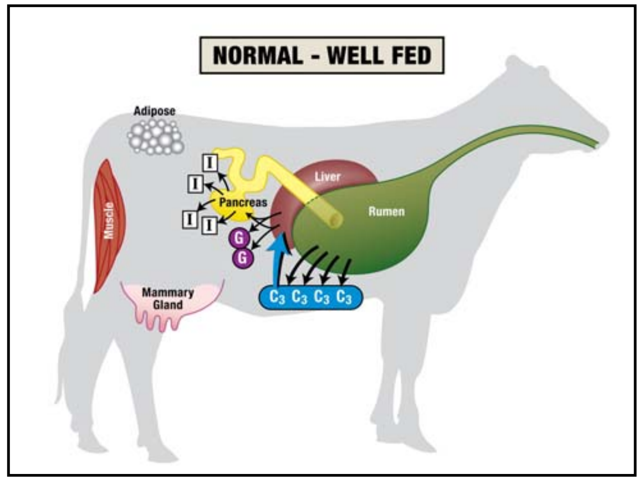
Metabolic Adaptation to Heat Stress

Summary






NORMAL - WELL FED
Adipose
Muscle
Pancreas
Liver
Rumen
G
G
Mammary Gland
C3 C3 C3 C3


NORMAL - WELL FED
Adipose
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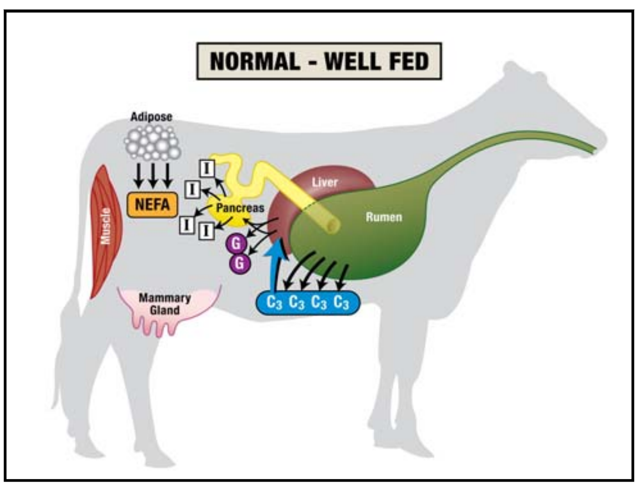
Pancreas
Liver
Rumen
G
G
Mammary Gland
C3 C3 C3 C3


NORMAL - WELL FED
Adipose
NEFA
Muscle
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Liver
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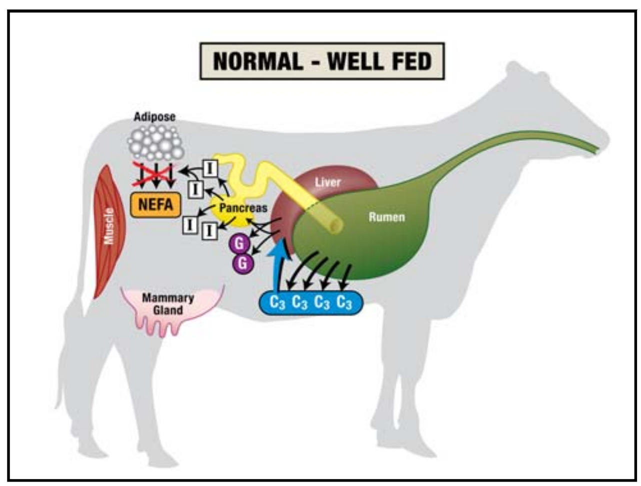
Mammary Gland
C3 C3 C3 C3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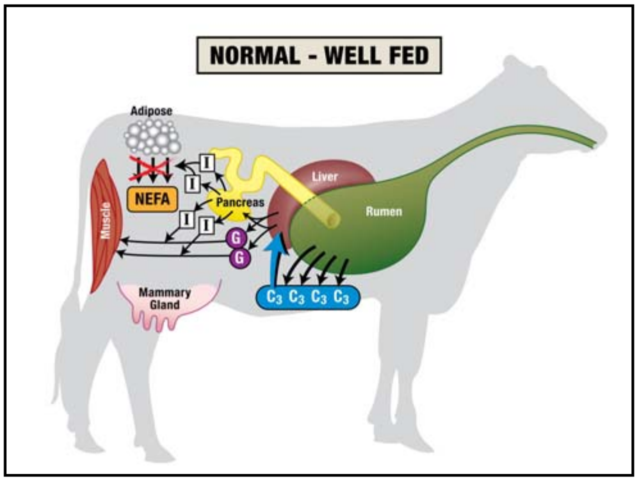
NORMAL - WELL FED
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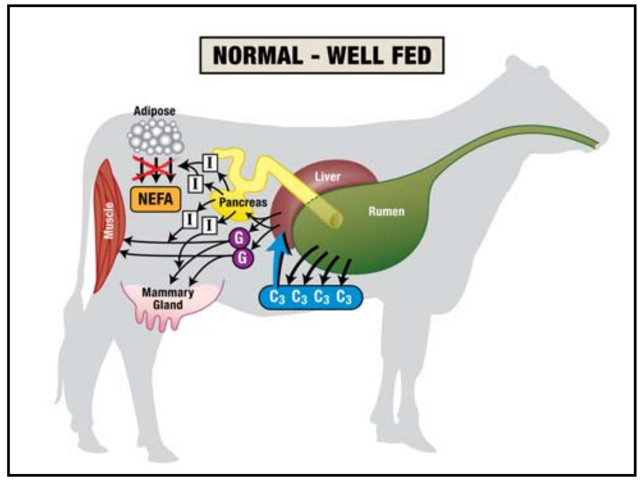
Mammary Gland


NORMAL - WELL FED
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Pancreas
Liver
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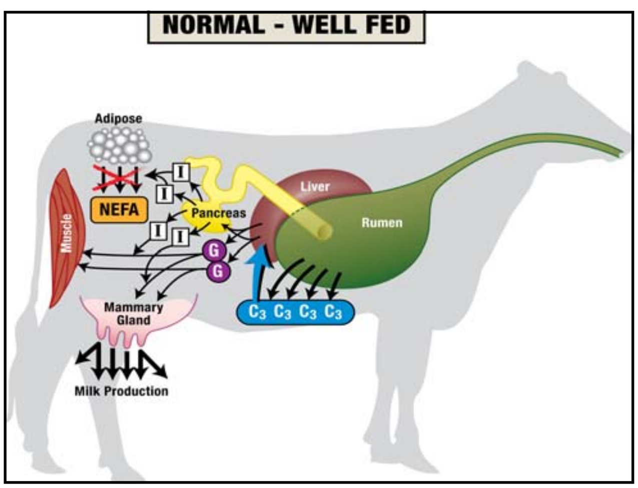
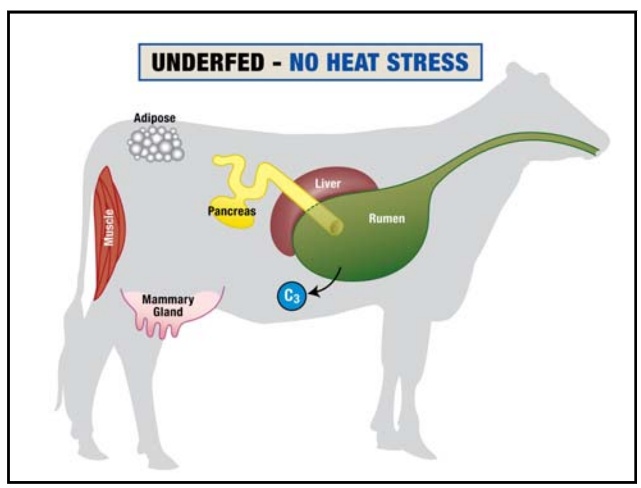
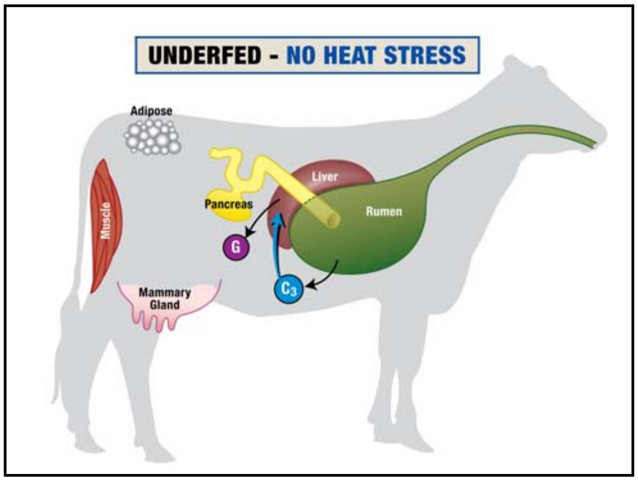
Mammary Gland


NORMAL - WELL FED
Adipose
NEFA
Muscle
Pancreas
Liver
Rumen
Mammary Gland
Milk Production


UNDERFED - NO HEAT STRESS
Adipose
Muscle
Pancreas
Liver
Rumen
Mammary Gland


UNDERFED - NO HEAT STRESS
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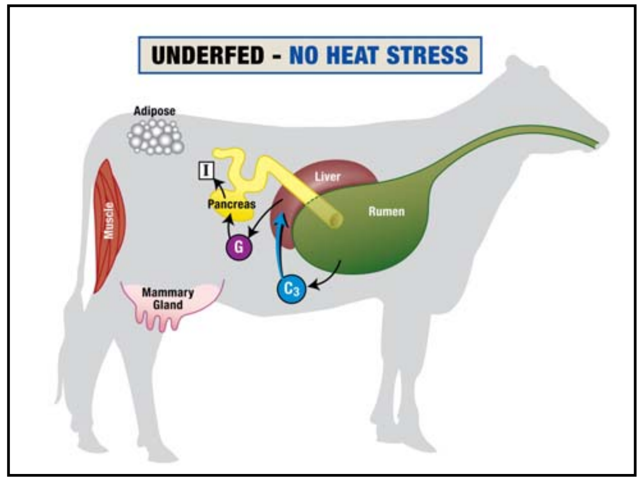
Pancreas
Liver
Rumen
G
C3
Mammary Gland


UNDERFED - NO HEAT STRESS
Adipose
Muscle
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Pancreas
Liver
Rumen
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C3
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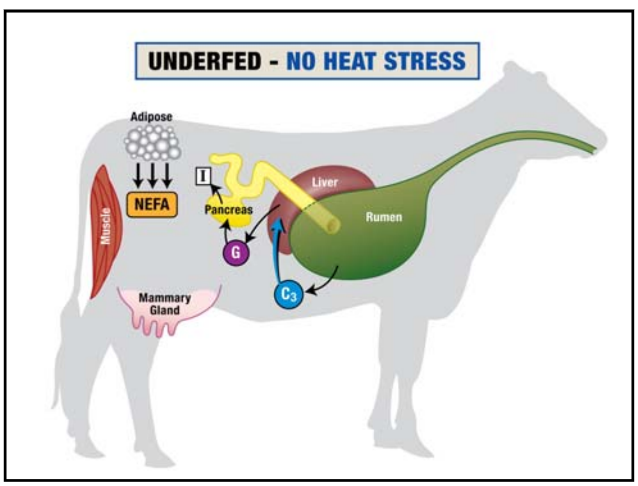
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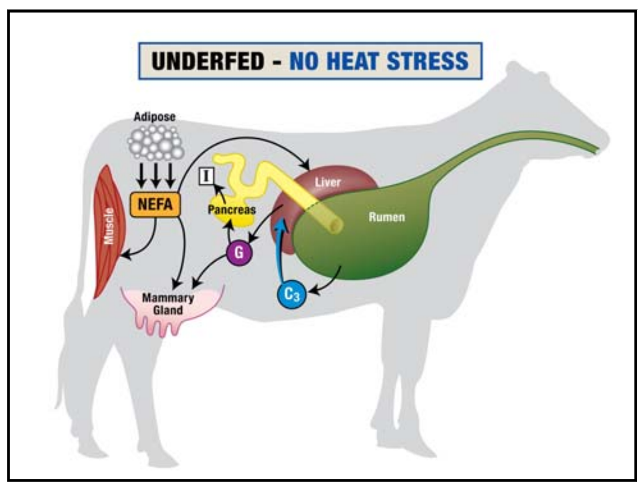
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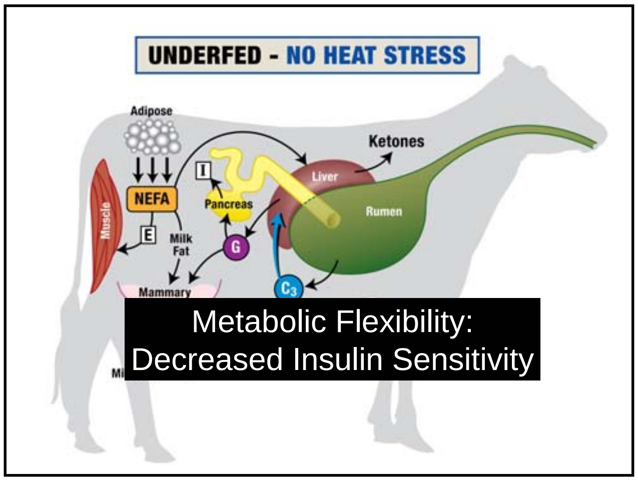
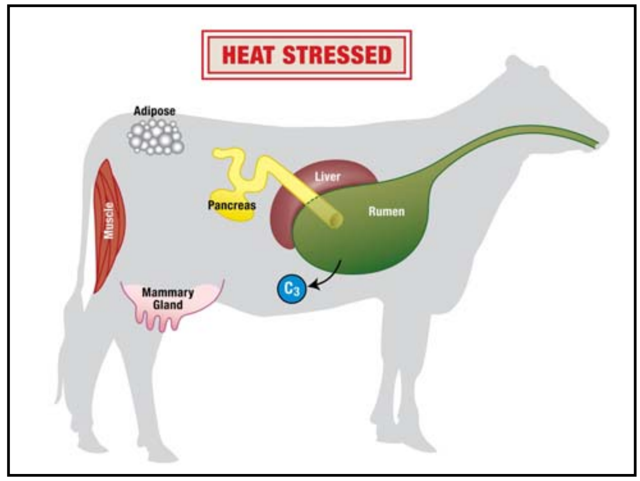
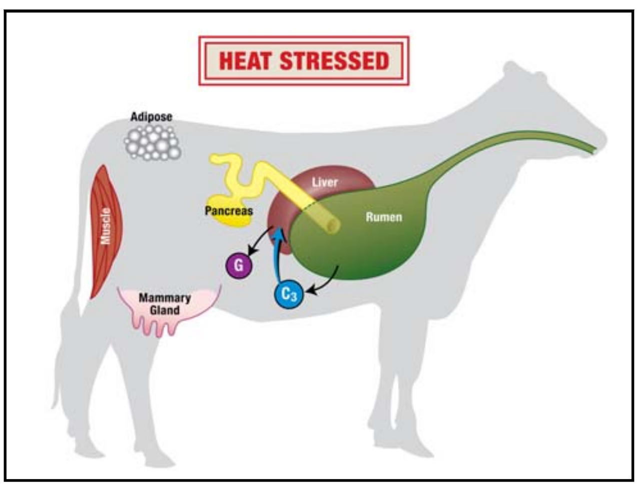
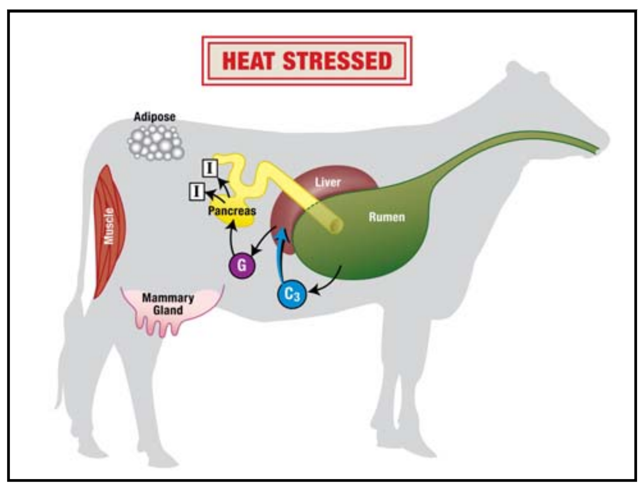

UNDERFED - NO HEAT STRESS
Adipose
Ketones
NEFA
I
Liver
Pancreas
Rumen
Muscle
E
Milk Fat
G
Mammary
C3
Metabolic Flexibility:
Decreased Insulin Sensitivity


HEAT STRESSED
Adipose
Liver
Pancreas
Rumen
Muscle
Mammary Gland
C3


HEAT STRESSED
Adipose
Liver
Pancreas
Rumen
Muscle
G
C3
Mammary Gland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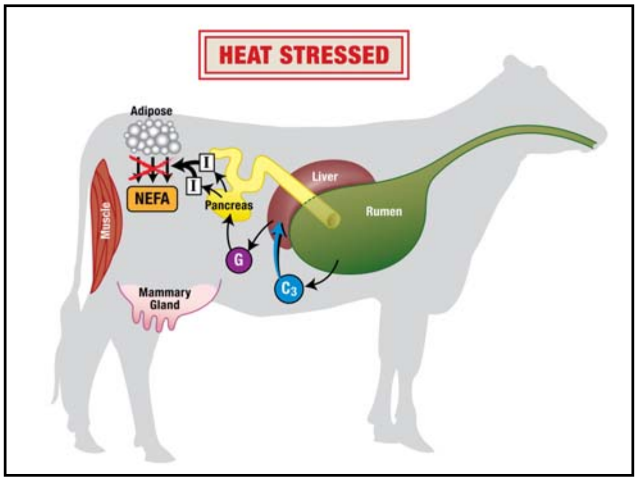
C3
Mammary Gland


HEAT STRESSED
Adipose
NEFA
Pancreas
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Rumen
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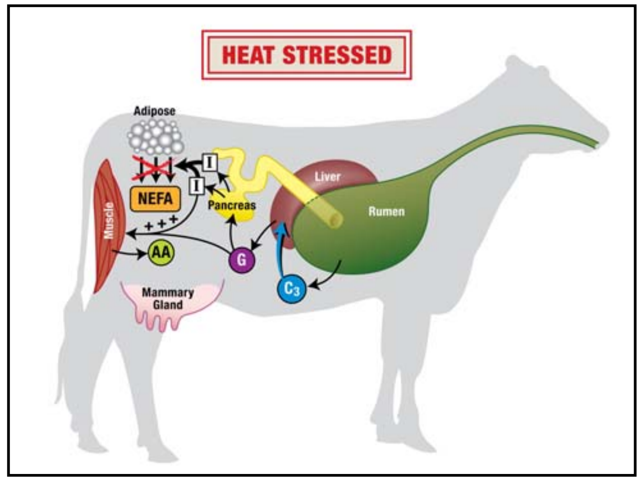
HEAT STRESSED
Adipose
NEFA
Pancreas
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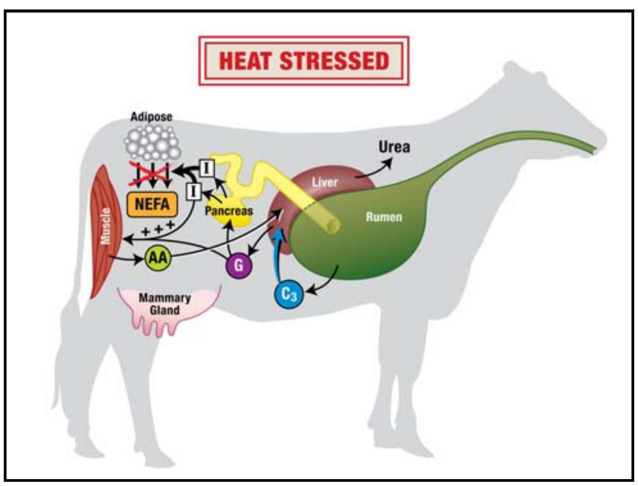
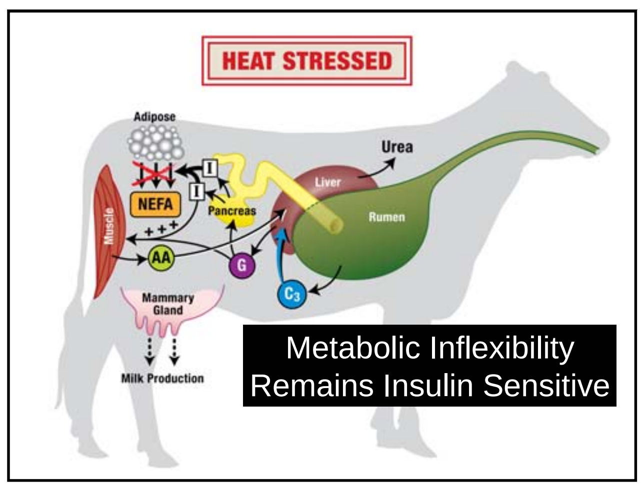
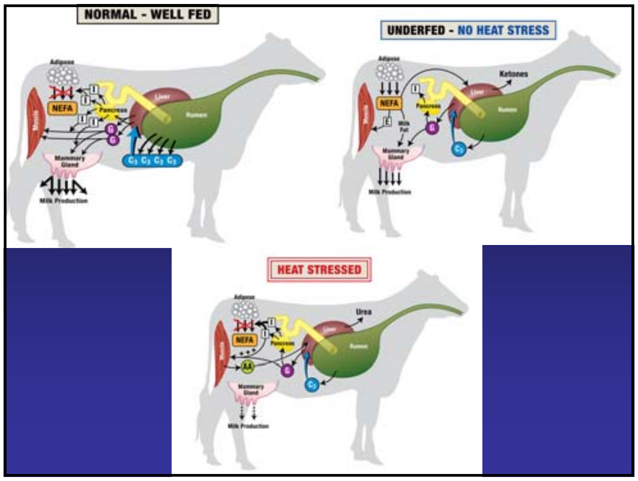
Mammary Gland


HEAT STRESSED
Adipose
Urea
NEFA
Pancreas
Liver
Rumen
Muscle
AA
G
C3
Mammary Gland


HEAT STRESSED
Adipose
Urea
NEFA
Pancreas
Liver
Rumen
Muscle
AA
G
C3
Mammary Gland
Milk Production
Metabolic Inflexibility
Remains Insulin Sensitive



Dietary and Management Strategies to Reduce the Negative Effects of Heat Stress

- Clean water tanks daily
  - Heat stressed cows become hyper-hydrated
- Dietary HCO_3
  - Helps prevent rumen acidosis
- **BUT the primary strategy to improve production during heat stress is shade and evaporative cooling**
  - ...eld and body condition
- Ionophores
  - Increases propionate and therefore overall liver glucose production
    - Cows prefer to oxidize glucose during heat stress
    - Studies indicate Monensin can stabilize rumen pH during periods of stress
- Direct fed microbials
  - A product that increases rumen digestion, stabilizes pH, increases propionate and increases DMI should benefit a heat stressed cow
    - The inconsistencies in the literature regarding these variables is of interest
- rbST
  - Reduces insulin sensitivity and partitions dietary nutrients towards milk production
    - The directing of glucose towards muscle during heat stress probably limits the glucose supply to the mammary gland

Typical reaction to one of my lectures.......thanks for your attention!

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- Laura Hernandez
- Sara Sanders
- Shannon Baker

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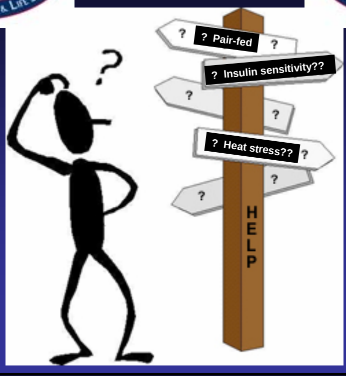
Questions?



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