Physiological limits of milk production in dairy cows

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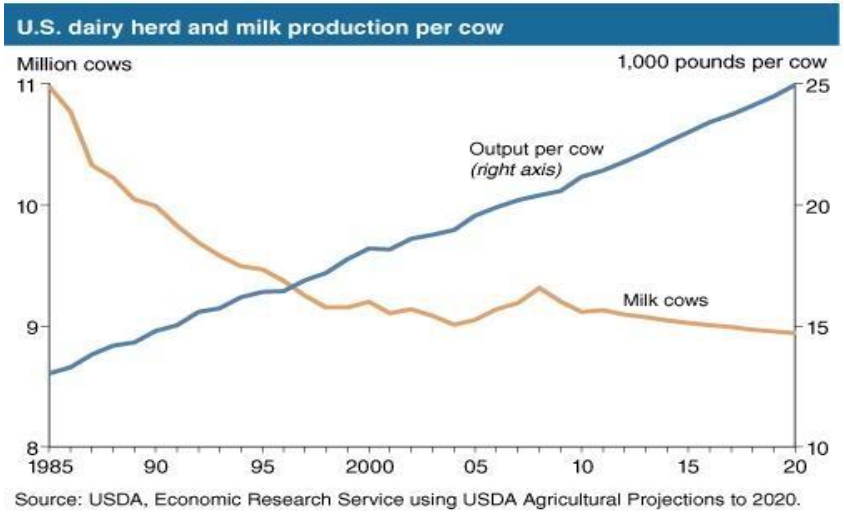
Milk production per cow continues to increase

High metabolic priority of milk production in maternal care:

⇒ successful breeding for high milk production

⇒ production limit of the mammary gland <u>not in sight</u>!



However:

- energy and nutrients must be provided for the udder

- exterior and metabolism of the cow must fit the udder

Where do limitations come from?

- Nature of ruminants – special digestive tract
- Limited feed sources for ruminants
- Consumer expectations
- Heat stress
- Metabolism and endocrine control
- Heterogenous production conditions

Limitations from "supply" via feed

Energy content of typical feed sources in dairy cow feeding

- Herbage/pasture	up to 6.3 MJ NEL/kg DM
- Grass silage/hay	5.7 to 5.9 MJ NEL/kg DM
- Maize silage	6.5 MJ NEL
- Straw	4 MJ NEL/kg DM
- Soy bean meal	7.9 MJ NEL/kg DM
- Wheat, barley	7.7 – 8.2 MJ NEL/kg DM

High lactation performance requires a high dietary energy density!

"Limits" of the rumen

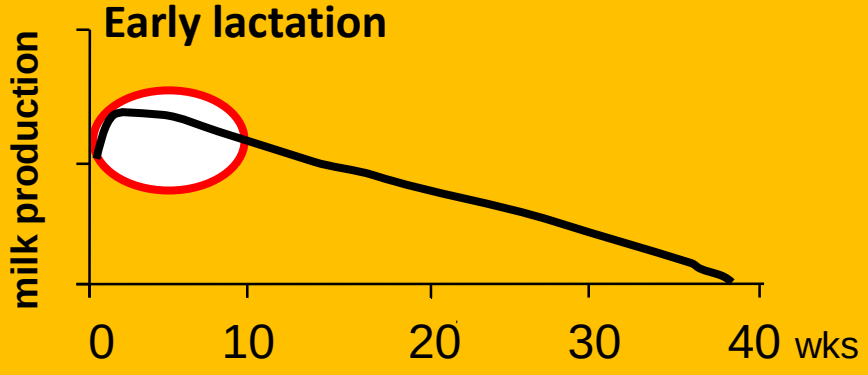
- Volume and function (depending on age, lactational stage, diet, passage kinetics, digestibility...)
- Dietary restrictions:
  - Sugar: max. 75 g/kg DM
  - Starch + sugar (- res. starch): 250 g/kg DM
  - Dietary fat: max. 5-6% in diet, rumen-protection!
  - Fiber content: > 18% in diet

Risk of rumen acidosis! Limited capacity of duodenal absorption!

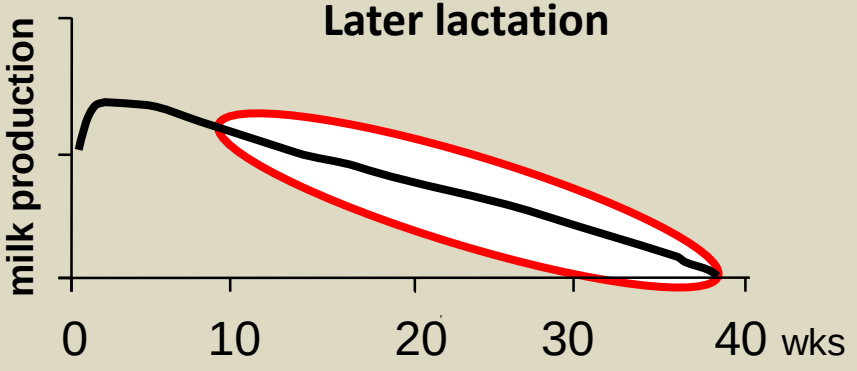
Mechanisms of metabolic and endocrine adaptation

- Different feeding situations
- Changes throughout the lactation cycle
- Interaction of metabolic and immune status

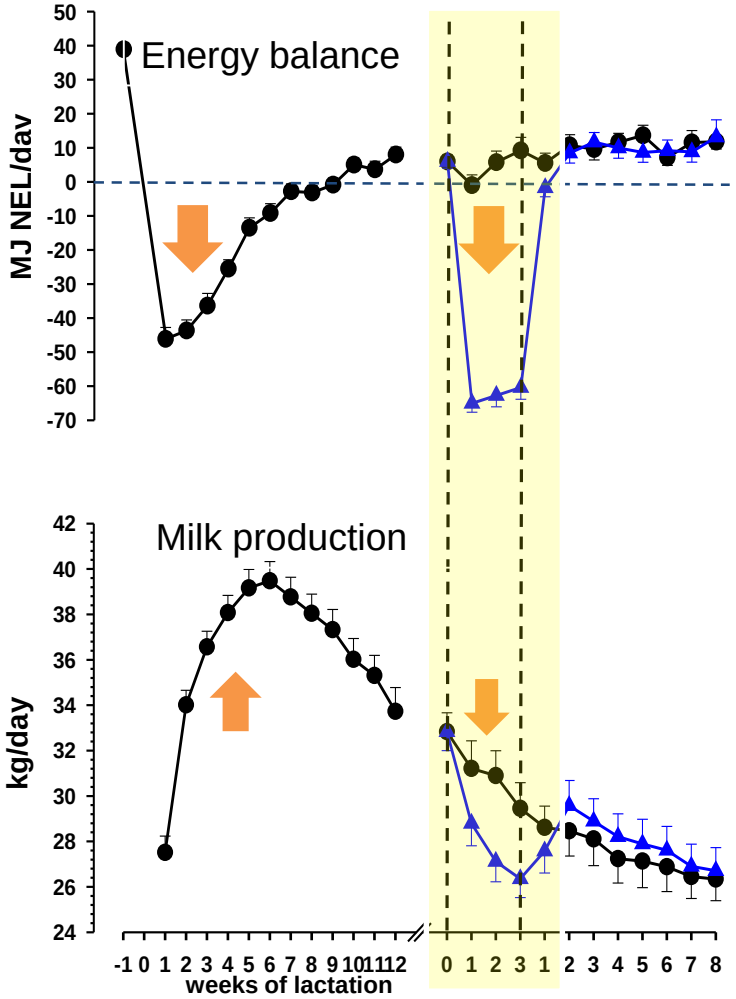
Ruminant Lactation in evolution:
Importance for the offspring in early and in later lactation



Milk is exclusive nutrient and energy source for the newborn calf.
Production increases after parturition because growing calf needs more milk.
Highest metabolic priority of milk production.
High selection success in the dairy industry.
Highest risk of metabolic disorders!



After a number of weeks the calf must feed on plant fibers to develop the ruminal system (**pseudo-monogastric → ruminant**)
Milk production decreases; mammary gland becomes part of the homeostatic regulation.
Lower risk of metabolic disorders.



Experimental study

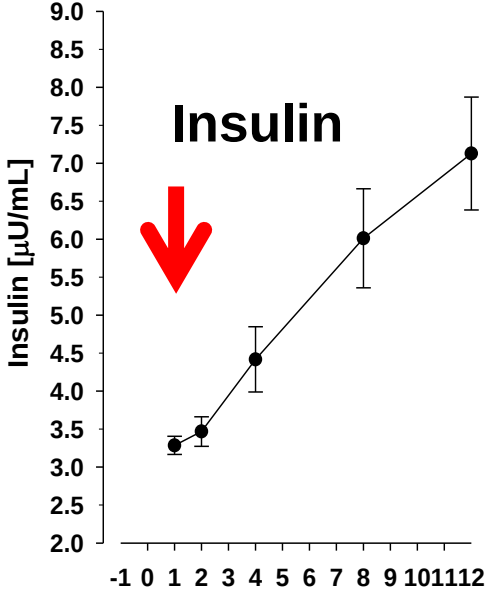
Negative energy balance in early lactation, and feed restriction after wk 14:

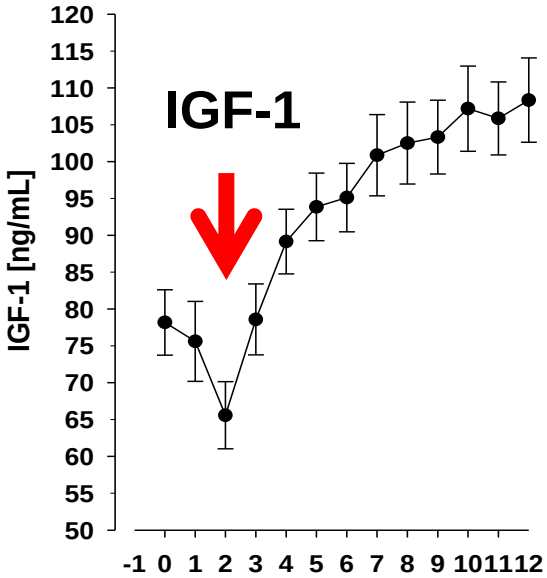
Early lactation: despite negative energy balance further increase of milk production.

Feed restriction after wk 14: immediate reduction of milk production to avoid negative energy balance.

Gross et al., J. Dairy Sci. 2011

Characteristic endocrine changes in early lactation





Low insulin:
- no deposition of nutrients
- lack of inhibition of lipolysis.

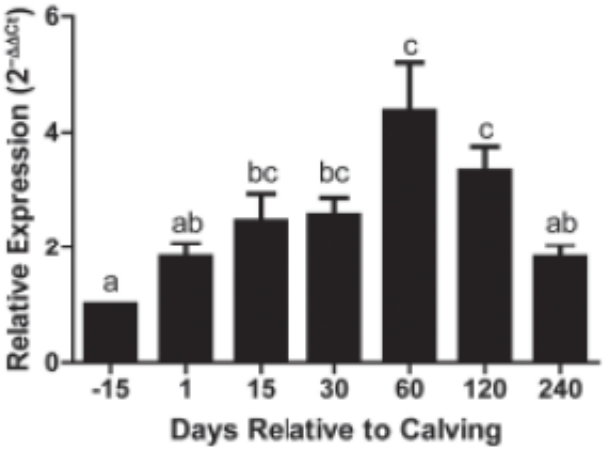
LIPOLYSIS

Low IGF-1:
- indicates catabolic situation
- missing neg. feedback for GH release
  ⇒high GH ⇒ lipolysis.

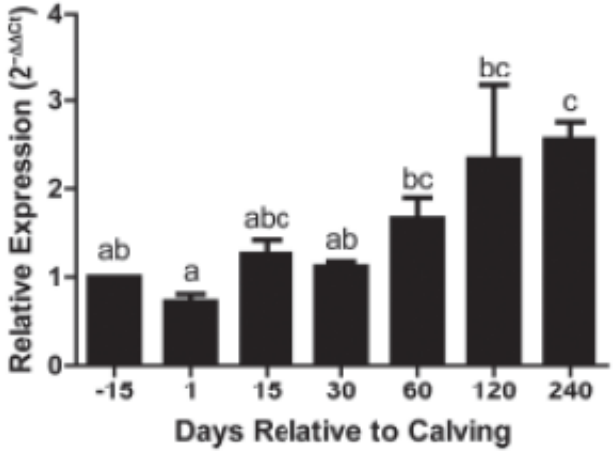
Glucose uptake into the mammary gland

- **Early lactation:** Directed nutrient flow towards the lactating mammary gland due to low insulin and simultaneous insulin resistance in peripheral tissues. Glucose uptake of the mammary gland by **GLUT1** is independent of insulin.
- **Later lactation: GLUT4** expression increases and glucose uptake becomes increasingly insulin dependent (homeostasis).

GLUT1: insulin independent

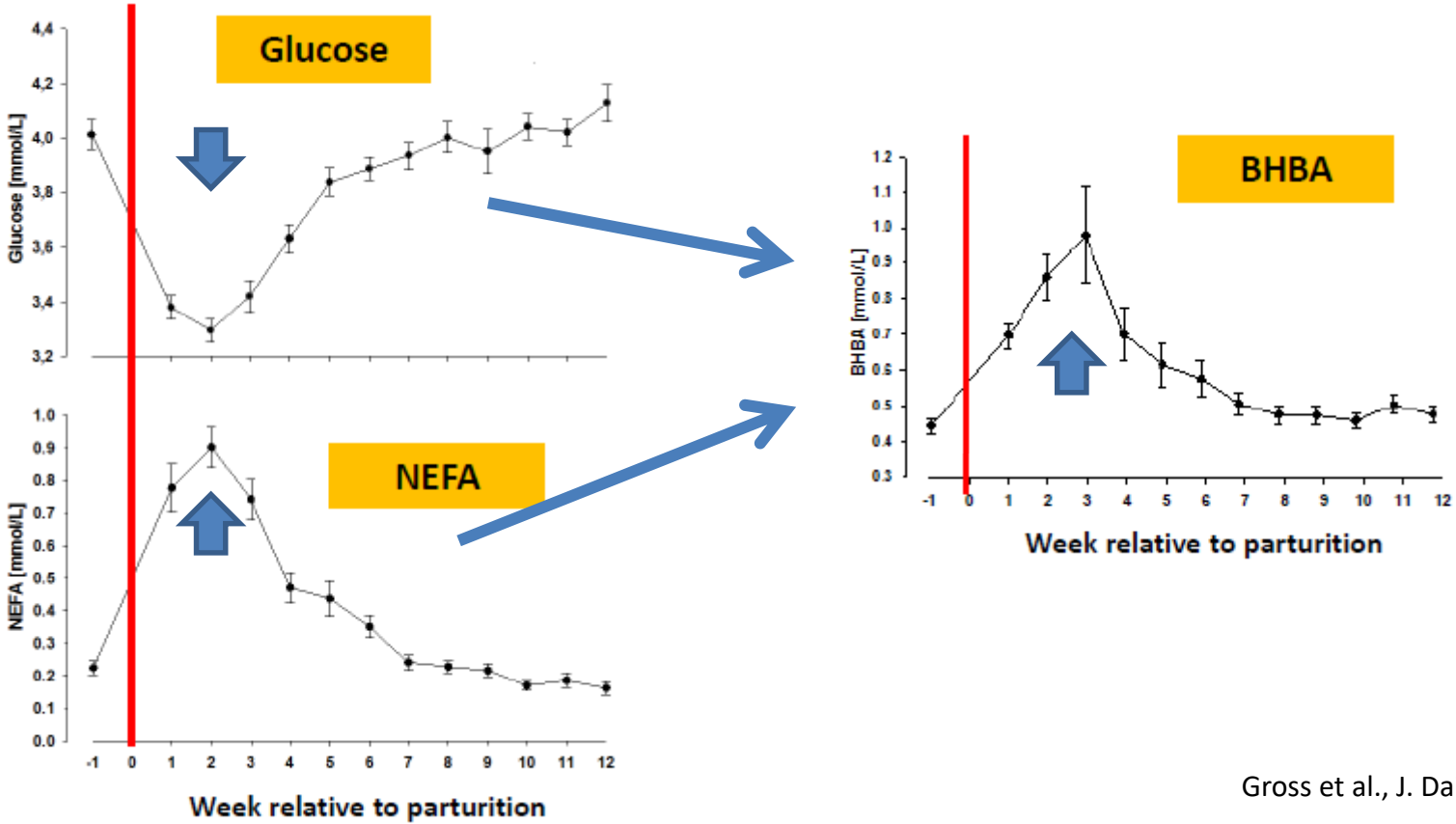


GLUT4: insulin dependent



Mattmiller et al., J. Dairy Sci. 2011

Characteristic metabolic changes in early lactation



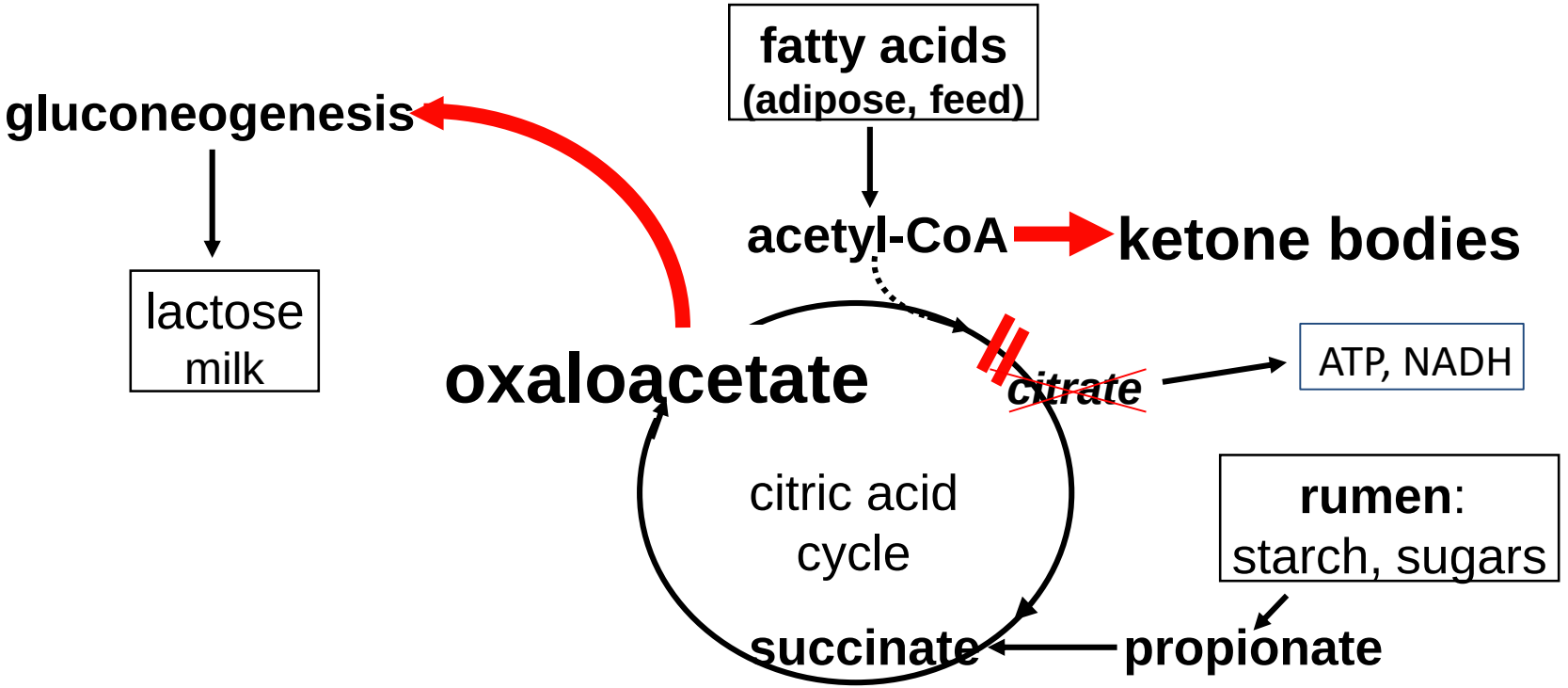
Gross et al., J. Dairy Sci. 2011

Studies presented in more detail

1. Infusion of BHBA: Effects on metabolism and mammary immune response
2. Study on herbage feeding with or without concentrate

Classical model of ketogenesis:

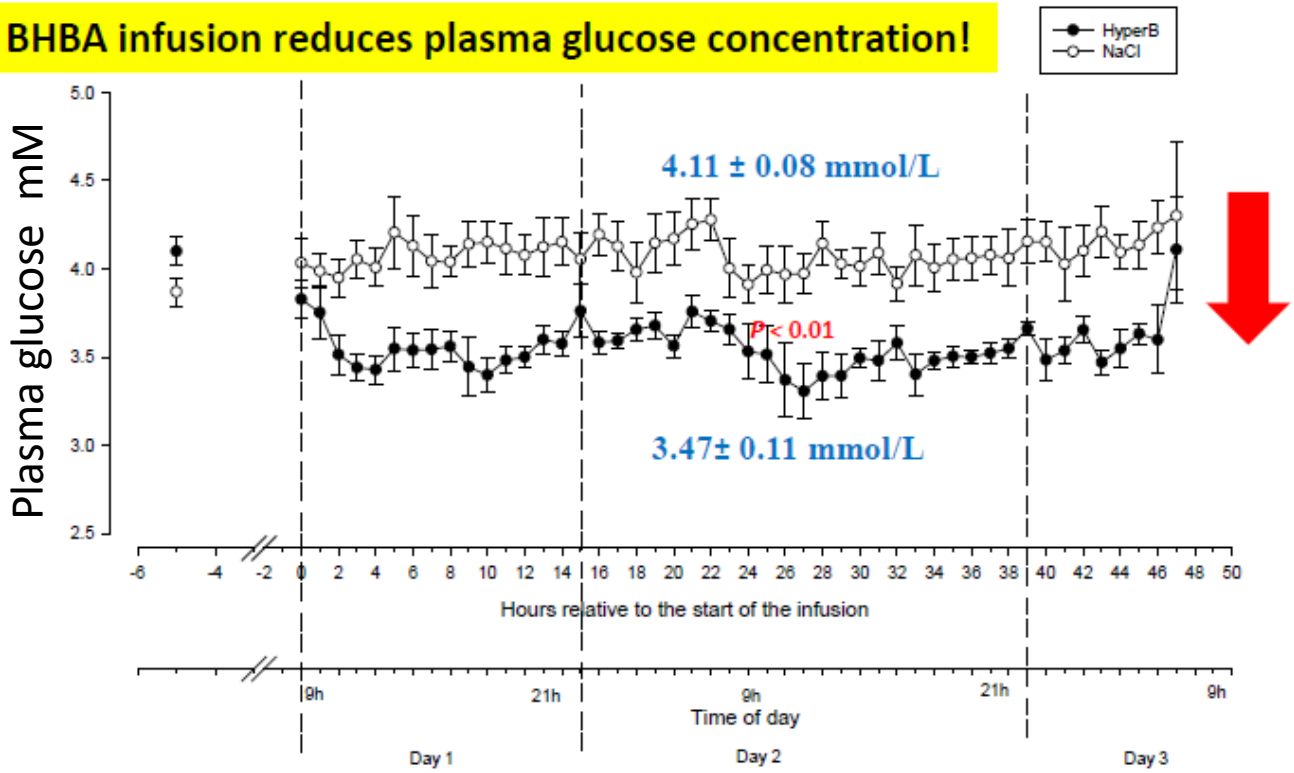
Ketone bodies are increasingly synthesized by hepatocytes because of depletion of the citric acid cycle through the use of oxaloacetate for gluconeogenesis.



How do ketone bodies feedback to the metabolism?

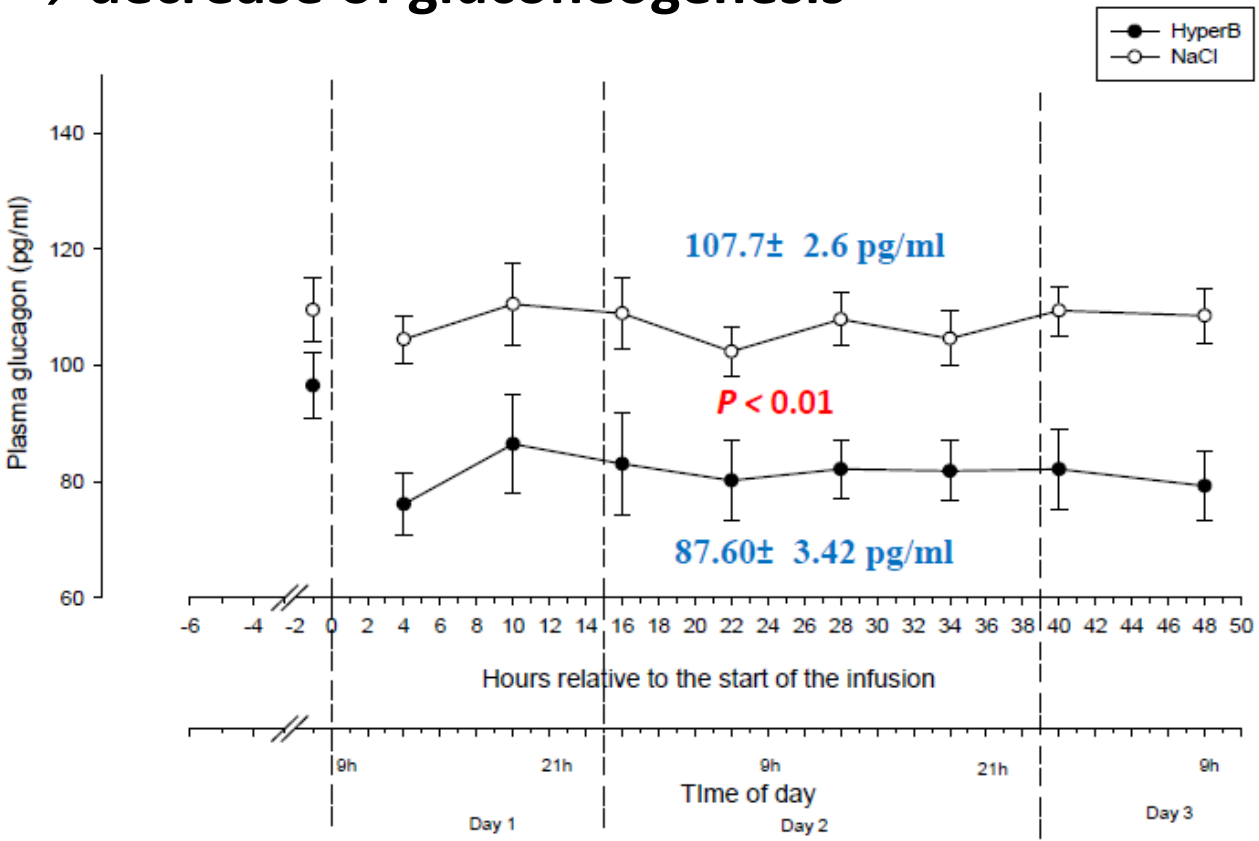
Infusion of BHBA to achieve 1.7 mM BHBA in plasma

Experiment 1:
during 2nd half of lactation.



Zarrin et al., J. Dairy Sci. 2013

Decrease of plasma glucagon
⇒ decrease of gluconeogenesis



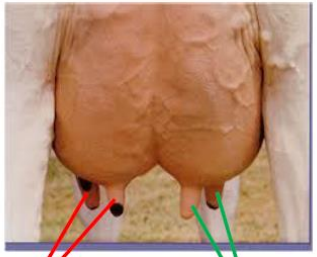
Zarrin et al., J. Dairy Sci. 2013

LPS-induced mastitis during BHBA infusion

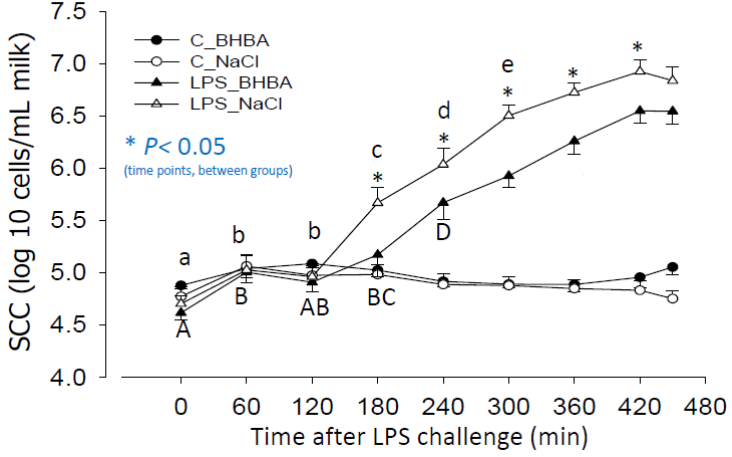
48-56 h of infusion:

Zarrin et al., J. Dairy Sci. 2014

200 µg of *Escherichia coli* LPS



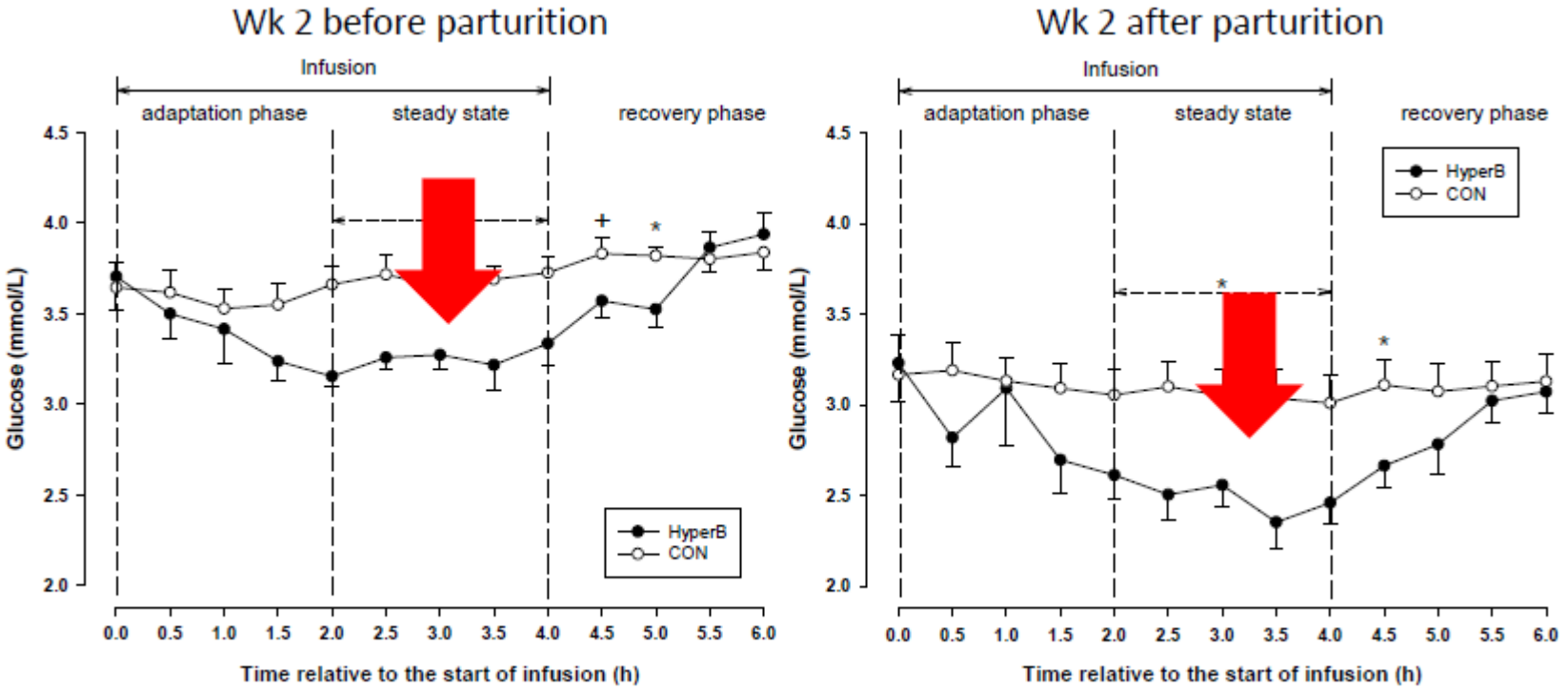
LPS **0.9% NaCl**



Main effects of high BHBA:

- Increased BHBA infusion rate to maintain plasma concentration
- Decrease of plasma BHBA in controls
- Fast decline of plasma glucose
- Reduced increase of glucagon
- No effect on increase of insulin
- Increased IL-8 and IL-10 in tissue
- Reduced increase of SCC

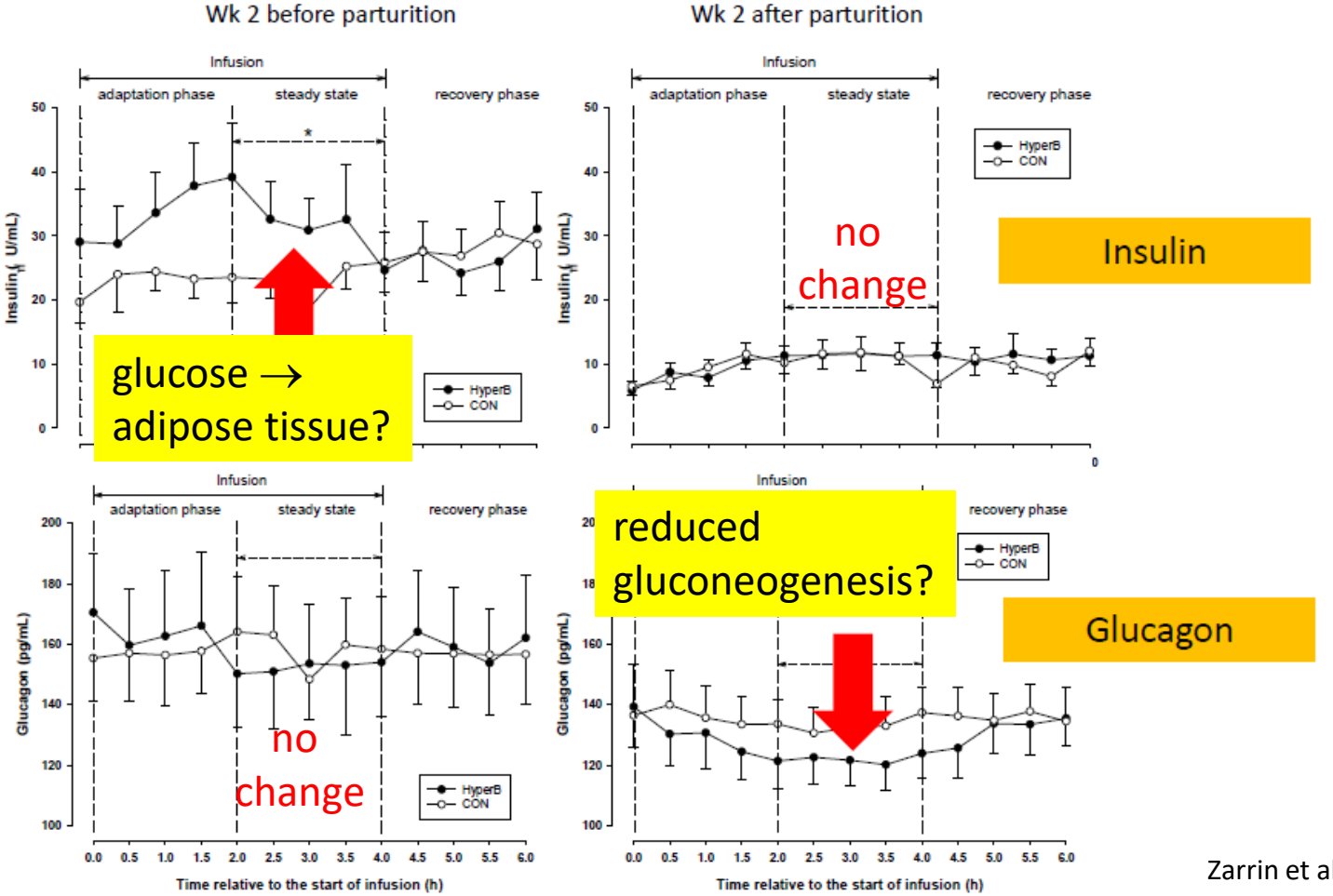
Experiment 2:
BHBA infusion during dry period and early lactation



Again, BHBA infusion causes reduced plasma glucose concentration.

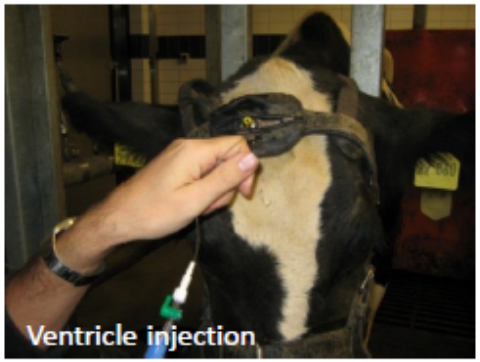
Zarrin et al., J. Dairy Sci. 2017

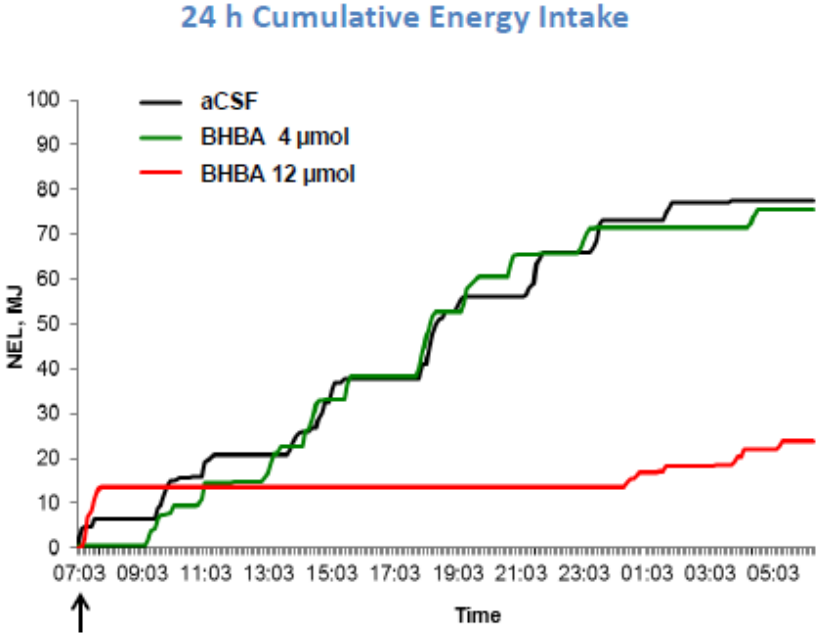
How is the endocrine regulation?



Zarrin et al., J. Dairy Sci. 2017

BHBA injection into lateral brain ventricle (in vivo)

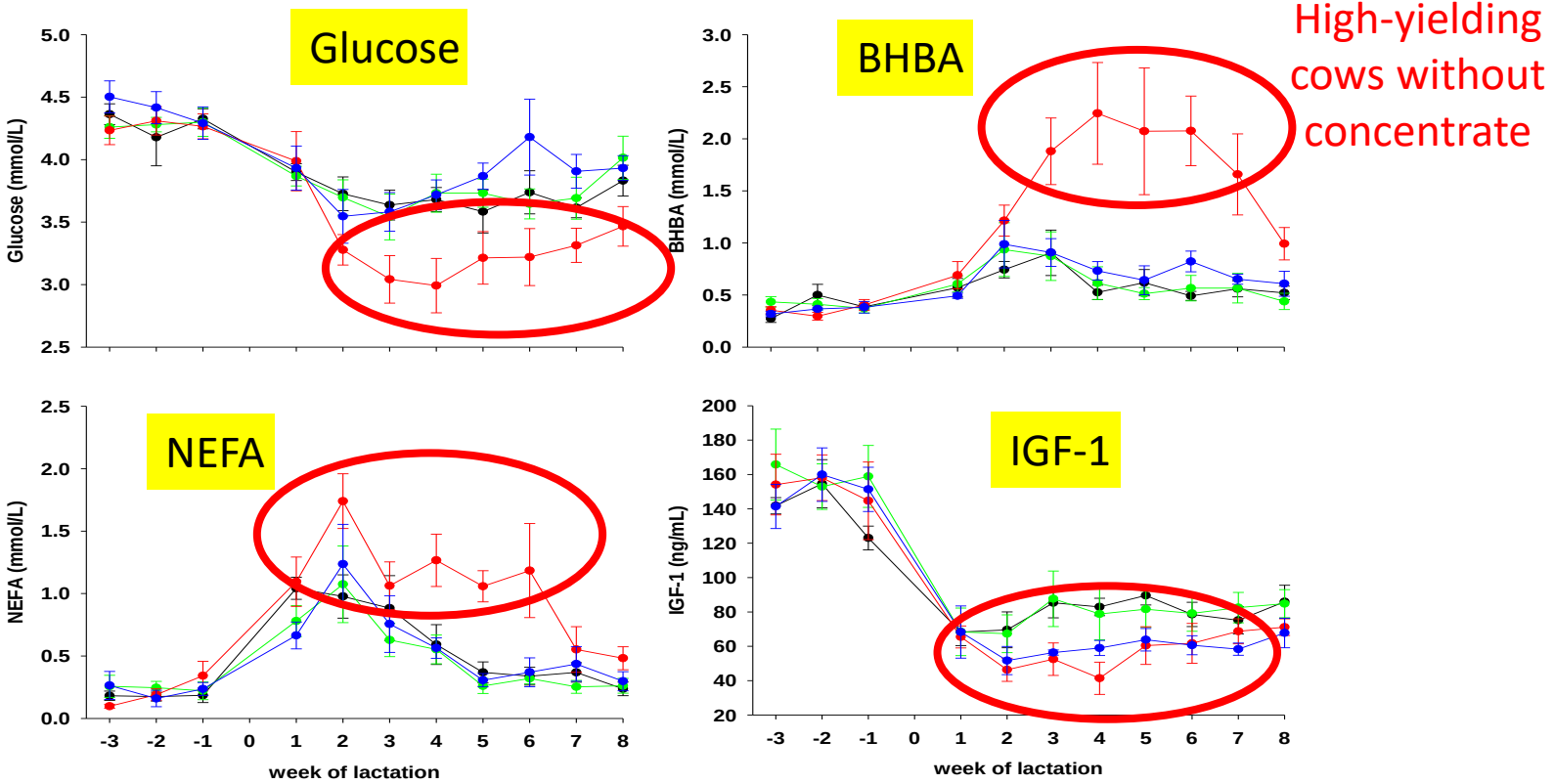




BHBA at a high dosage caused an inhibition of feed intake
(→ Negative effects on Agrp)

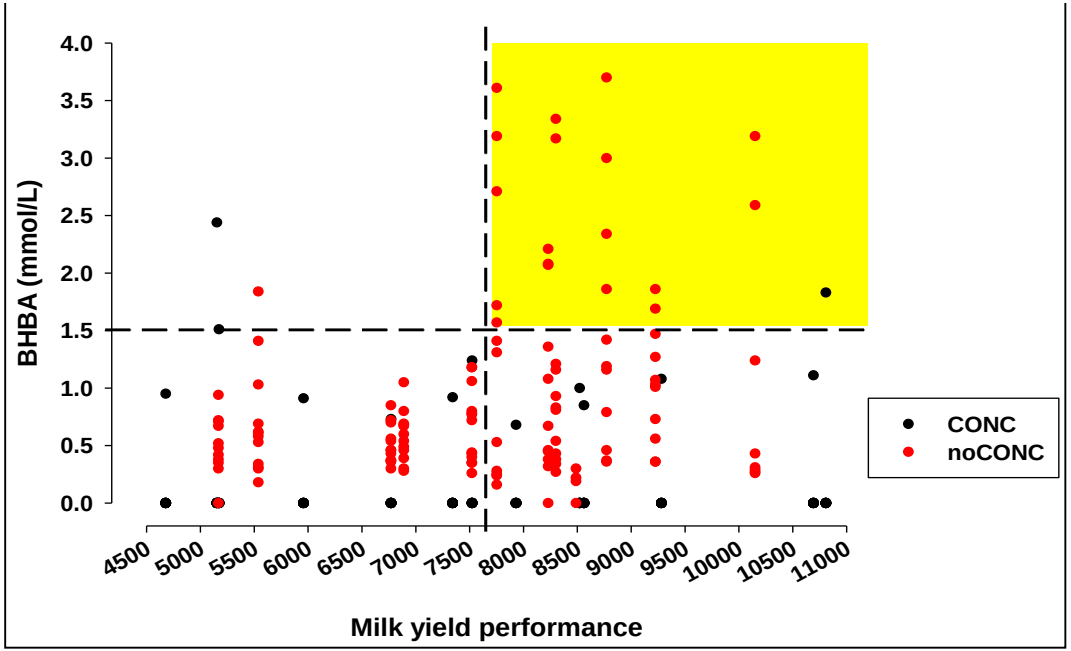
Laeger et al., J. Endocrinol. 2012

Herbage feeding with or without concentrate in low (L: <7600 kg) and high (H: >7600 kg) yielding dairy cows in early lactation



Zbinden et al., J. Anim. Physiol. Anim. Nutr. 2017

Elevated BHBA only in high yielding group without concentrate



Increased risk of production diseases!
Adequate feeding? Animal Welfare?

Zbinden et al., J. Anim. Physiol. Anim. Nutr. 2017

Approaches to meet limitations depend on genetic merit and metabolic robustness

- Dry period management
- Moderate start into lactation
- Persistency management
  - Milking frequency
  - Growth hormone and other hormones (banned in Europe!)
  - Manipulation of photoperiod
- Extended lactation (combined with semen sexing)
- Precision dairy farming

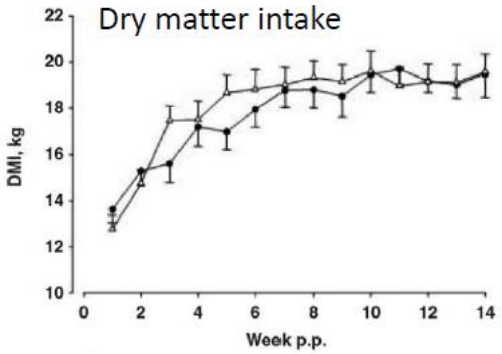
However, cows adapt differently to a similar negative energy balance

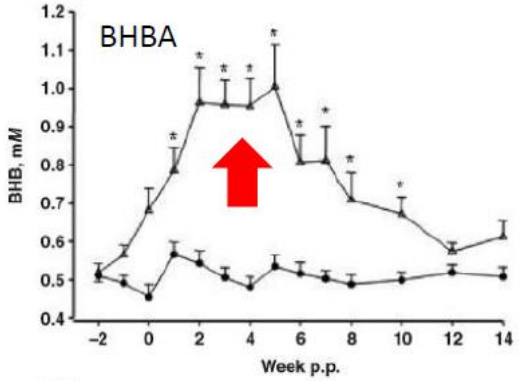
45 cows
weekly blood sampling
classified by BHBA
(> 1 mM at least once)

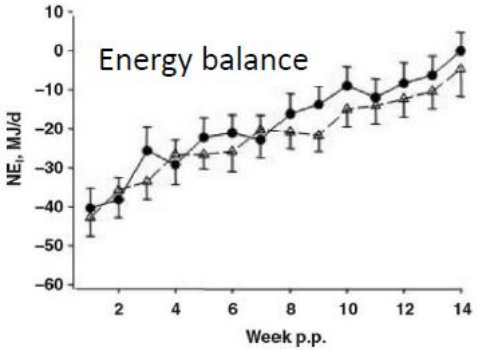
Mechanisms remain unclear!

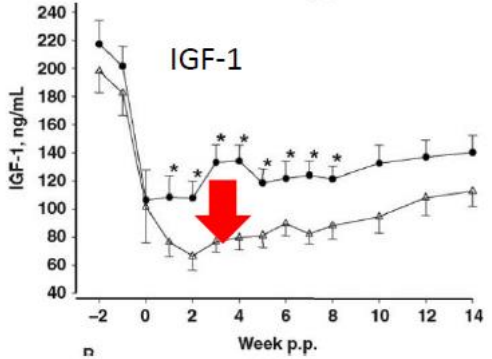
mRNA expression of hepatic key enzymes were mostly not correlated with metabolite concentrations.

IGF-1 may be the best indicator for success of metabolic adaption.









Kessel et al., J. Anim. Sci. 2008

Conclusions

- Mammary gland not limited in secretion capacity
- Limited nutrient and energy availability
- Variation!

Questions?