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Technical Symposium
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California Animal Nutrition Conference

PURDUE UNIVERSITY

Understanding subclinical hypocalcemia to set up the fresh cow for success

Rafael C. Neves, DVM, MSc, PhD
Assistant Professor, Food Animal Production Medicine
Department of Veterinary Clinical Sciences
College of Veterinary Medicine

2025 California Animal Nutrition Conference | Visalia, CA

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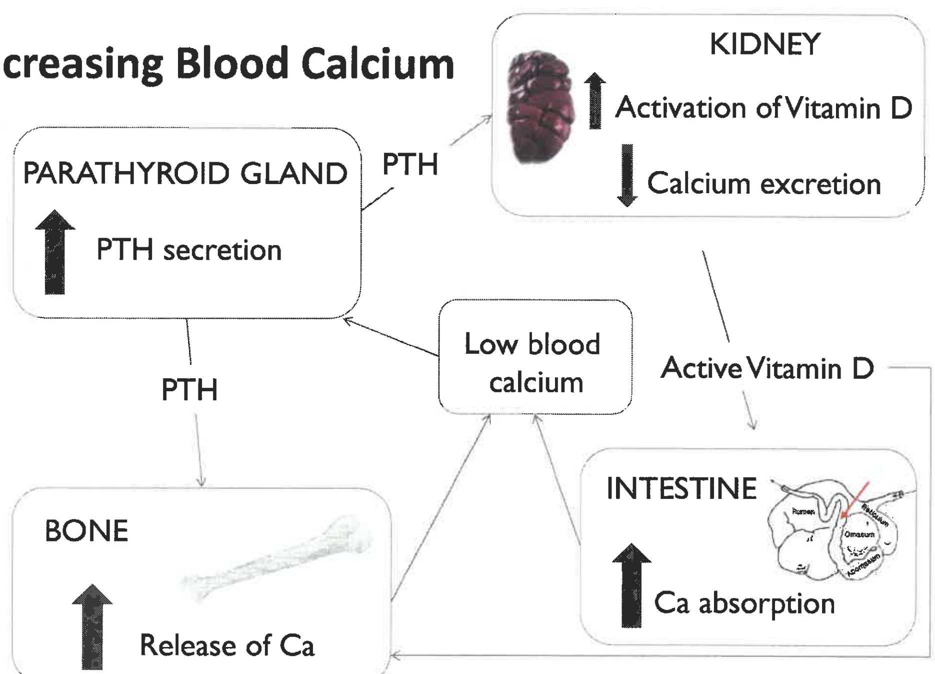
Increasing Blood Calcium



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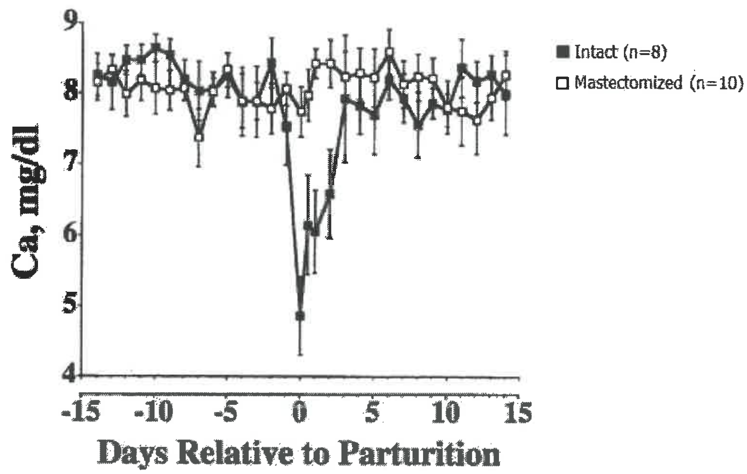
Ca demands for lactation



Source: Goff et al., 2002

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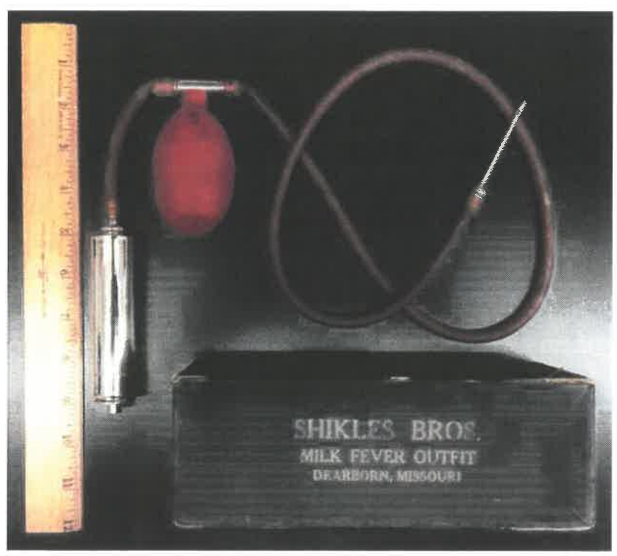

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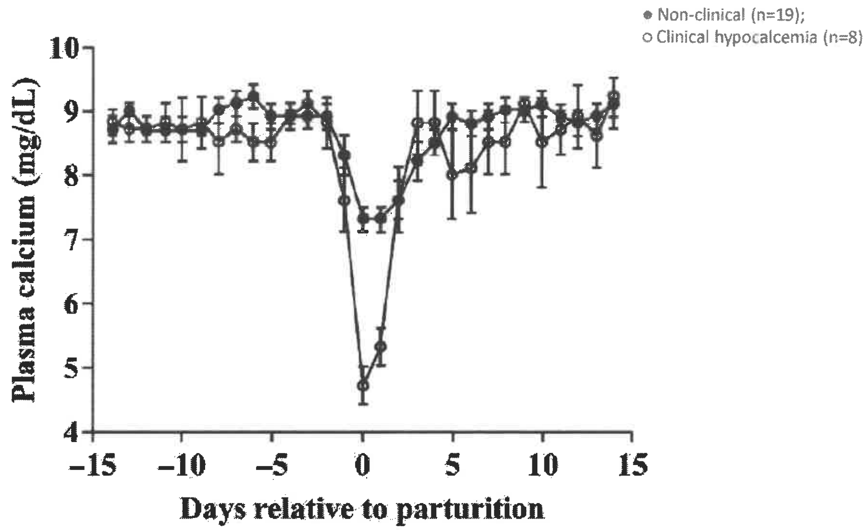
Calcium dynamics in clinical hypocalcemia



Source: Kimura et al., 2006

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Subclinical hypocalcemia history

J Dairy Sci. 1988 Dec;71(12):3302-9.

Ammonium chloride and ammonium sulfate for prevention of parturient paresis in dairy cows.

Oetzel GR[1], Olson JD, Curtis CR, Fettman MJ.

- Classification of subclinical hypocalcemia (SCH) based on ionized Ca <1.0 mmol/L

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J Am Vet Med Assoc. 1996 Sep 1;209(5):958-61.

Effect of calcium chloride gel treatment in dairy cows on incidence of periparturient diseases.

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- Classification of SCH based on total Ca <8.0 mg/dL

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J Dairy Sci. 1996 Mar;79(3):378-83.

Field trials of an oral calcium propionate paste as an aid to prevent milk fever in periparturient dairy cows.

Goff JP[1], Horst RL, Jardon PW, Borelli C, Wedam J.

- Classification of SCH based on total Ca ≤7.5 mg/dL

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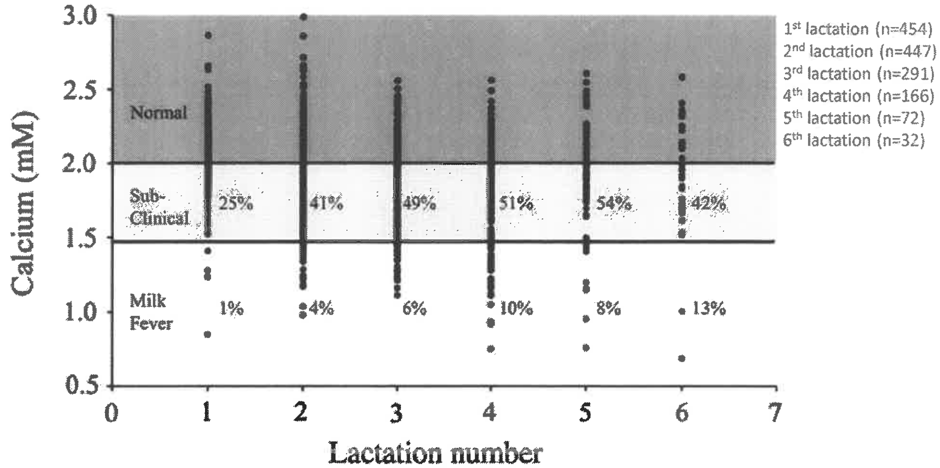
Prevalence of SCH in U.S. dairy herds



Sampling source: 480 herds from 21 states

Source: Reinhardt et al., 2011

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Subclinical hypocalcemia history

J Dairy Sci. 2011 Oct;94(10):4897-903. doi: 10.3168/jds.2010-4075.

The association of serum metabolites with clinical disease during the transition period.

Chapinal N[1], Carson M, Duffield TF, Capel M, Godden S, Overton M, Santos JE, LeBlanc SJ.

J Dairy Sci. 2012 Mar;95(3):1301-9. doi: 10.3168/jds.2011-4724.

The association of serum metabolites in the transition period with milk production and early-lactation reproductive performance.

Chapinal N[1], Carson ME, LeBlanc SJ, Leslie KE, Godden S, Capel M, Santos JE, Overton MW, Duffield TF.

Sampling source: 55 herds across the U.S. and Canada

Lower serum [tCa] after dichotomization at wk 1 was associated with:
- increased odds of displaced abomasum
- impaired reproduction (↓ CR 1st AI) and milk production (-3.2 kg/d);

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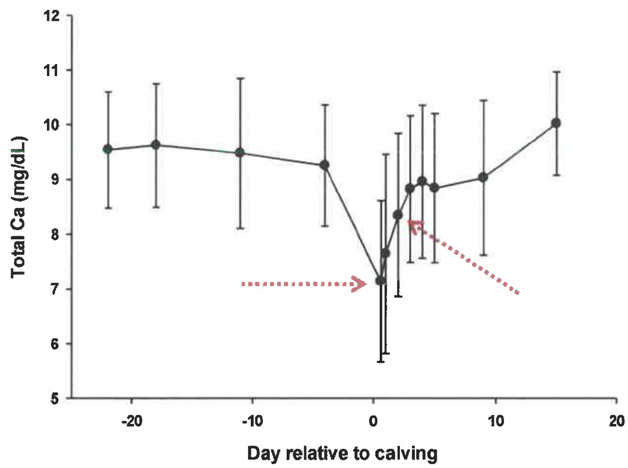
Average blood Ca concentration in the transition period



Adapted from: Ramos-Nieves et al., 2007

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Association of plasma [tCa] with health, production, and reproduction

- Prospective cohort study in 5 dairy herds in NY
- Inclusion criteria: primiparous and multiparous with a blood sample collected within 12 h of parturition
- 1,412 Holstein cows

- **No association of immediate postpartum plasma tCa concentration with:**
  - RP (*P* = 0.52)
  - Metritis (*P* = 0.21)
  - Clinical mastitis within 60 DIM (*P* = 0.61)
  - Pregnancy to 1st service (*P* = 0.88)

- **No association of immediate postpartum plasma tCa concentration in primiparous cows with:**
  - Culling risk (*P* = 0.45)
  - Milk production over 9 DHIA tests (*P* = 0.46)

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▪ **No association of immediate postpartum plasma tCa concentration in multiparous cows with:**

- RP ($P = 0.52$)
- Metritis ($P = 0.21$)
- Clinical mastitis within 60 DIM ($P = 0.61$)
- Pregnancy to 1st service ($P = 0.88$)

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- Milk production over 9 DHIA tests ($P = 0.46$)

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The effect of plasma [tCa] and DA

Parameter	Estimate	SE	*P*-value	RR	95% CI
Parity group	–	–	0.32	–	–
Uterine disease					
Healthy	Ref	–	–	–	–
Retained placenta, metritis or both	0.92	0.34	0.008	2.51	1.29 to 4.94
Ca concentration within 12 h of parturition					
>1.85 mmol/L	Ref	–	–	–	–
≤1.85 mmol/L (7.4 mg/dL)	1.04	0.37	0.006	2.82	1.35 to 5.87

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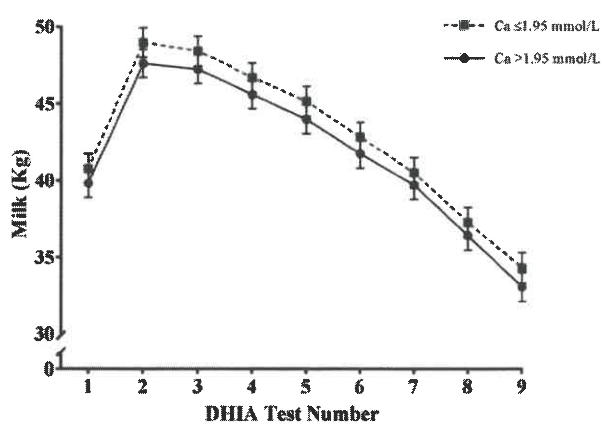
Milk production across 9 DHIA tests for 1,063 multiparous cows according to plasma tCa dichotomization. Cows with plasma tCa ≤1.95 mmol/L produced, on average, 1.08 kg more milk per test-day. Error bars represent the SEM.



P = 0.002

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The effect of plasma [tCa] and milk production

- Cohort study in Germany (n = 1,289; 107 herds)

  → cows with [tCa] <2.1 mmol/L within 48 h of parturition tended to produce more milk (+ 0.80 kg/d; *P* = 0.058) (Venjakob et al., 2018)

- Retrospective data from 3 feeding trials (n = 78 multiparous cows)

  → cows having a transient SCH state produced more milk compared to other Ca dynamic groups (Seely et al., 2021)

- Cohort study in TX using Jersey cows (n = 380; 1 herd)

  → cows with [tCa] ≤1.84 mmol/L at 1 DIM had increased milk production across the first 9 wk of lactation (Menta et al., 2021)

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Epidemiology of subclinical hypocalcemia in early-lactation Holstein dairy cows: The temporal associations of plasma calcium concentration in the first 4 days in milk with disease and milk production

R. C. Neves,* B. M. Leno,† K. D. Bach,‡ and J. A. A. McArt‡[1]
*Department of Veterinary Sciences, Texas Tech University, Lubbock 79409
†Department of Animal Science, and
‡Department of Population Medicine and Diagnostic Sciences, Cornell University, Ithaca, NY 14853

- Prospective cohort study in 2 dairy herds in NY
- Blood samples collected at 1, 2, 3, and 4 DIM
- 389 animals included in the analyses
- Associations were dependent on parity

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Plasma [tCa] association and its temporal association

- Association of plasma [tCa] and the risk of metritis in primiparous cows

DIM of plasma [tCa]	AUC	Cut point mmol/L (mg/dL)	Sn	Sp	RR
2	0.78	≤2.15 (8.6)	72.2	68.6	4.0
3	0.80	≤2.1 (8.4)	70.6	79.7	5.2
4	0.80	≤2.15 (8.6)	71.4	79.1	6.8

- Association of plasma [tCa] and the risk of metritis/DA in multiparous cows

Parity	DIM of plasma [tCa]	AUC	Cut point mmol/L (mg/dL)	Sn	Sp	RR
2	2	0.67	≤1.97 (7.9)	44.4	88.8	3.5
≥3	4	0.70	≤2.2 (8.8)	72.7	60.5	2.9

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Plasma [tCa] association at 4 DIM and milk production across 15 wk of lactation in multiparous cows

Item	Estimate	SE	*P*-value
Parity group			
2	Ref.	–	–
3	1.97	0.73	0.01
Herd			
1	Ref.	–	–
2	3.37	0.81	<0.0001
Calving season			
0	Ref.	–	–
1	-1.66	0.73	0.02
Clinical diseases			
Healthy	Ref.	–	–
RP, and/or metritis, and/or DA, and/or CM	-4.08	1.02	<0.0001
SCH-classification			
Plasma [tCa] >2.2 mmol/L (8.8 mg/dL)	Ref.	–	–
Plasma [tCa] ≤2.2 mmol/L (8.8 mg/dL)	-1.80	0.78	0.02

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Hypothesis

The appropriate physiological response to sudden Ca deficit is transient whereas persistent or delayed are evidence of maladaptation of Ca homeostasis.

Objective

To evaluate the association of Ca status cohorts with:

- Risk of early lactation adverse events
  - - Metritis, displaced abomasum, herd removal within 60 DIM
  - - Hyperketonemia (HYK) at 3, 5, 7, or 10 DIM
- Average daily milk yield for first 10 weeks

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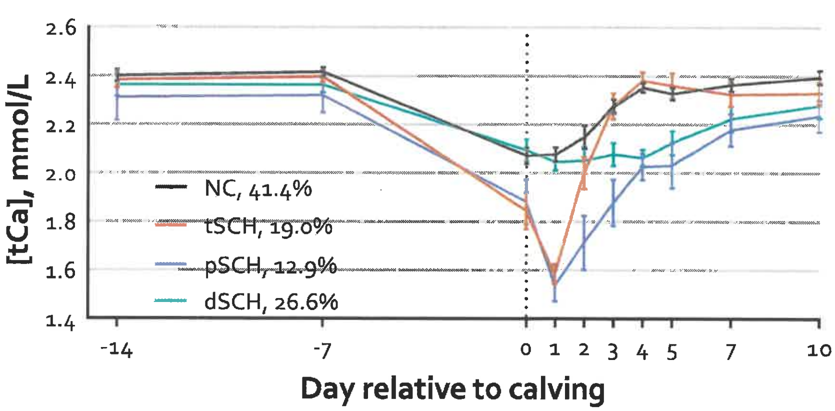
Suboptimal Ca concentration by 4 DIM is detrimental to health and production



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Risk of disease or herd removal within 60 DIM

Ca status group	n (%)	Estimate	SE	*P*-value	RR	95% CI
Primiparous (n = 144)						
Normocalcemic	67 (46.5)	Ref.	–	–	–	–
Transient SCH	25 (17.4)	0.23	0.47	0.63	1.3	0.5 to 3.2
Persistent SCH	33 (22.9)	1.40	0.34	<0.001	4.1	2.1 to 7.7
Delayed SCH	19 (13.2)	1.27	0.40	0.003	3.2	1.5 to 7.0
Multiparous (n = 263)						
Normocalcemic	109 (41.4)	Ref.	–	–	–	–
Transient SCH	50 (19.0)	0.33	0.20	0.09	1.4	0.9 to 2.1
Persistent SCH	34 (12.9)	0.57	0.21	0.006	1.8	1.2 to 2.7
Delayed SCH	70 (26.6)	0.62	0.17	<0.001	1.9	1.3 to 2.6

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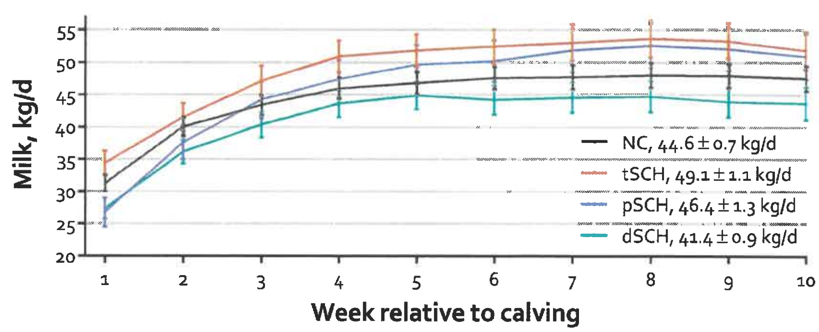
Milk yield by cohort: multiparous



Error bars represent 95% confidence intervals.

Cohort x time: *P* = 0.009
Herd: *P* = 0.22

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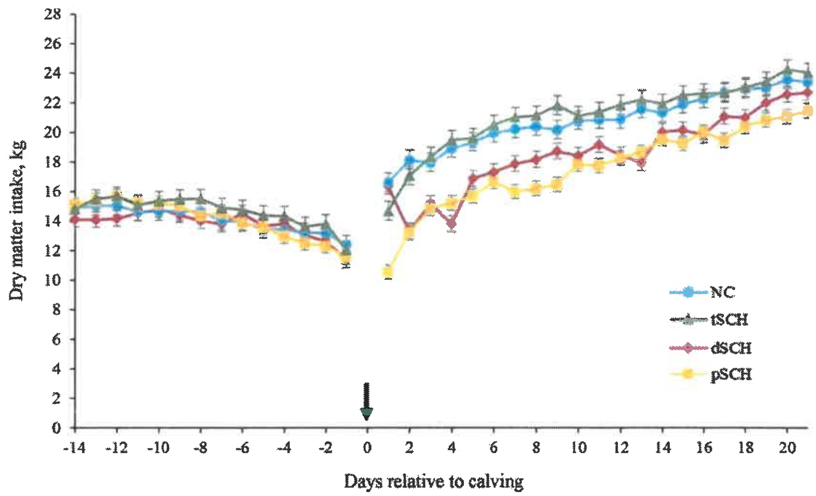
Decreased DMI is a component of SCH



Source: Seely et al., 2021

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Current recommendations on SCH surveillance

- In real-world, defining cows into different SCH patterns are unlikely to help with management decisions
- Lack of large studies attempting to define herd-level thresholds
- Personal recommendation:
  - Blood sampling at 4 DIM
  - Primiparous SCH: [tCa] ≤ 2.15 mmol/L
  - Multiparous SCH: [tCa] ≤ 2.20 mmol/L
- What should we do with those cows?

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Impact of delayed Ca bolus administration on milk yield and health events

Table 3. Final model mean milk yield for the first 10 wk of lactation, incidence of health events, and serum total Ca (tCa) for multiparous Holstein cows (milk and health analysis; n = 931, blood total Ca (tCa) analysis; n = 920) from 4 farms in New York randomly assigned to 1 of 3 treatments at calving: 1) control; no supplemental Ca at or around parturition (CON), 2) conventional bolus; an oral Ca bolus containing 43 g Ca at calving and 24 h later (BOL-C), or 3) delayed bolus; an oral Ca bolus containing 43 g Ca at calving and 24 h later (BOL-D). Brackets indicate 95% confidence intervals

	Treatment			P - value					
Item	CON[1]	BOL-C[2]	BOL-D[3]	Treatment	Farm	Parity group	Time	Treatment × time	Treatment × parity group
Milk yield, kg/d	48.8 [48.0, 49.6]	48.2 [47.4, 49.6]	49.2 [48.4, 50.0]	0.2	<0.001	0.003	<0.001	0.7	0.002
Dyscalcemic[4], % (n)	26 (85)	28 (83)	32 (95)						
Metritis, % (n)	6.3 (20)	5.4 (17)	7.0 (21)						
DA, % (n)	1.9 (6)	0.6 (2)	2.3 (7)						
Herd removal[5], % (n)	4.4 (14)	2.9 (9)	4.3 (13)						
Adverse event[6], % (n)	10.8 (34)	8.0 (25)	11.5 (35)	0.4	0.2	0.1	—	—	0.08
tCa, mmol/L	2.11 [2.09, 2.13]	2.11 [2.09, 2.13]	2.09 [2.07, 2.11]	0.2	<0.001	<0.001	<0.001	0.2	0.1

[1]Milk and health; n = 315; tCa n = 320.
[2]Milk and health; n = 314; tCa n = 301.
[3]Milk and health; n = 302; tCa n = 299.
[4]Serum tCa <2.20 mmol/L at 4 DIM.
[5]Culled or died before 30 DIM
[6]Metritis, DA, and/or herd removal before 30 DIM

Source: Seely et al., 2024

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Impact of delayed Ca bolus administration on milk yield

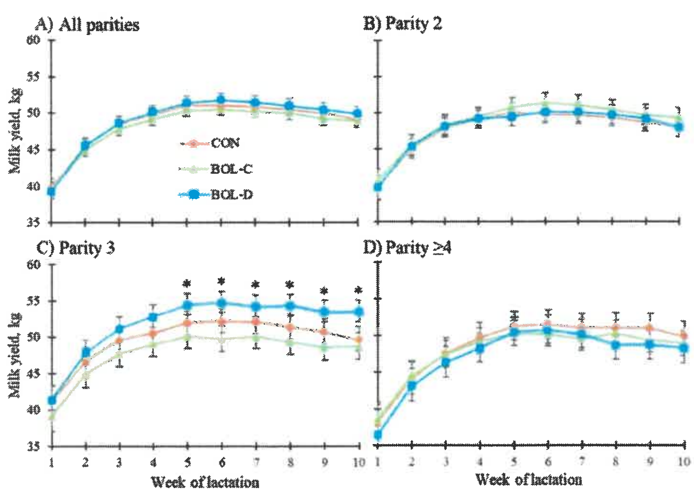

Figure 1. Final model least squares means of average weekly milk yield for multiparous Holstein cows (n = 931) from 4 farms in New York state randomly assigned to 1 of 3 treatments at calving: 1) control; no supplemental Ca at or around parturition (CON; n = 315), 2) conventional bolus; an oral Ca bolus containing 43 g Ca at calving and 24 h later (BOL-C; n = 314), or 3) delayed bolus; an oral Ca bolus containing 43 g Ca at calving and 24 h later (BOL-D; n = 302). (A) all cows, (B) parity 2, (C) parity 3, and (D) parity ≥ 4. Solid orange circles represent CON, dotted green triangles represent BOL-C, and dashed blue squares represent BOL-D. Asterisks represent differences between BOL-D and BOL-C using the Tukey-Kramer studentized adjustment where $P < 0.05$. Error bars represent 95% confidence intervals.

Source: Seely et al., 2024

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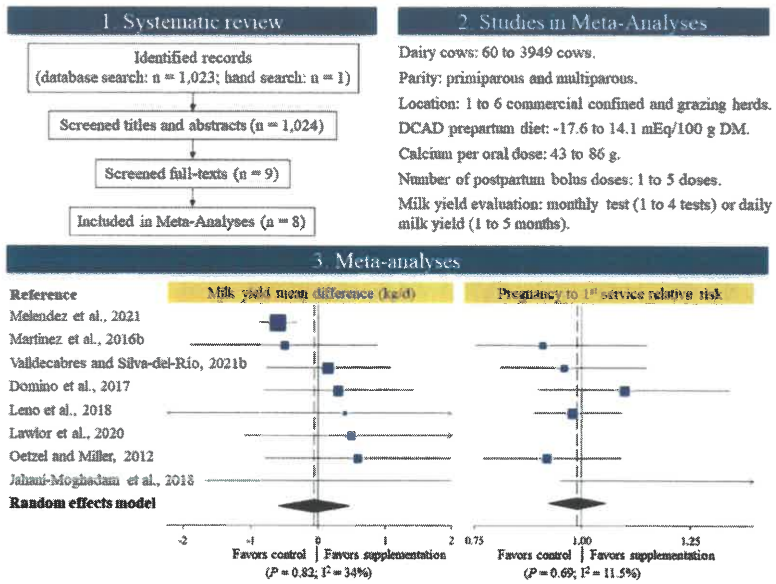
Meta-analysis on Ca supplements



Source: Valldecabres et al., 2023

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Nutritional strategies to modulate Ca balance in the immediate postpartum

- Negative DCAD feeding – reviewing the latest data available
- Impact of P on Ca balance

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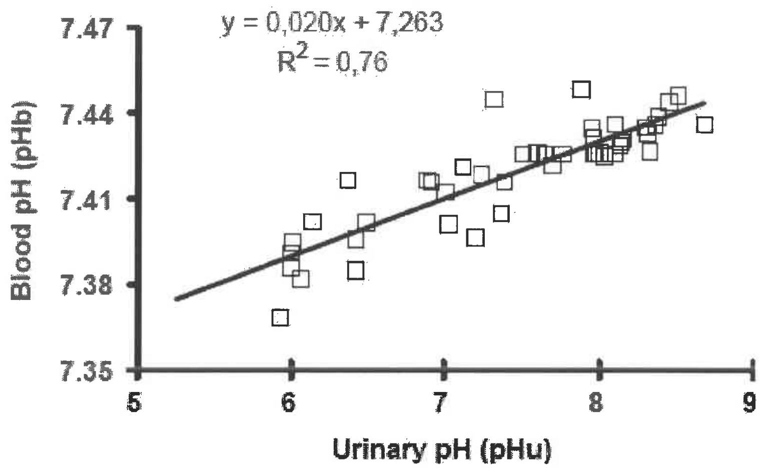
Relationship of urinary pH and blood pH



Source: Spanghero, 2004

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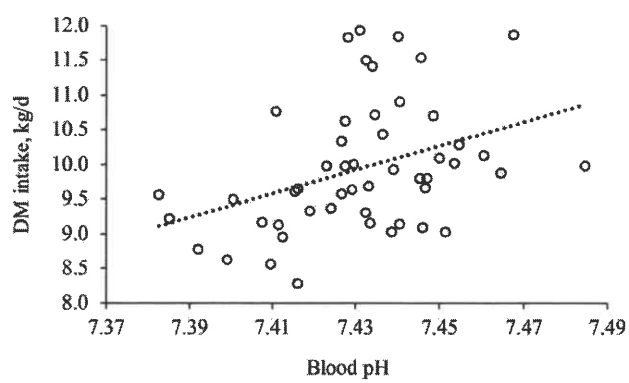
The relationship of blood acid-base balance and DMI



Source: Zimpel et al., 2018

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DCAD Success

- DCAD success (easier said than done):

  - Ability to successfully deliver the formulated TMR (PMR)

  - Correct prediction of TMR DCAD level (NIR versus wet chemistry on minerals)

  - Correct intake prediction

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DCAD "yo-yo" effect

- Forage change without correct wet chemistry analysis of minerals
- Improper chopping of straw and hay that allows sorting behavior
- Overcrowding (bunk space/stalls and water access issues)
- Frequent pen moves (social stress)
- Ingredient errors
  - Use of the wrong mineral mix
  - Use of untested forages
- Mixing errors
  - Residual feed from previous diets
  - Inaccurate weighing of ingredients
  - Batch sizes below the range of the mixer

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Case-study discussion

- Contacted on January 2023 by a private nutritionist to help on a herd-level issue
  - Herd size: 12,200 cows/2x milking
  - Breed: 90% Holstein-Jersey crosses, 10% Holstein
  - Milk production: ~ 82-83 lbs (37 kg)
- Herd feeding a negative DCAD via HCl liquid molasses
- Major complaint: Increase in milk fever cases (and increased use of injectable Ca solutions)

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Case-study discussion

FDAT	FRESH	MF	% MF
Jan22	786	25	3%
Feb22	679	6	1%
Mar22	680	8	1%
Apr22	548	4	1%
May22	547	13	2%
Jun22	630	3	0%
Jul22	818	3	0%
Aug22	781	21	3%
Sep22	640	30	5%
Oct22	805	69	9%
Nov22	771	49	6%
Dec22	814	35	4%
Jan23	162	9	6%

- HCl concentration variations from supplier – corrected end of May 2022
- Silage changes – August 2022
- Mixing errors by feeders – corrected on August 2022
- Noticed high inclusion rates of HCl decreased DMI and rumination – limited HCl inclusion into diets
- Added CaCl to reduce urine pH and targeted maximum HCl at 1 lb (0.45 kg)
- Moved HCl to 0.2 lbs (0.09 DM on January 8, 2023 – urine pH averaging 6.10

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Ingredient Name	Close Up 2 Nov 22	Close Ration 15 Dec 2022	Close 8 Jan 23
Close Up Mineral Phos Mg 2 Jan 23	0.500	0.500	0.500
TM PAK MICRO 1.17.19	0.005	0.005	0.005
Alf Hay #2	3.900	3.900	3.900
Corn Silage Pit #2 2021	11.599	12.899	12.919
Corn, Steamed Rolled	4.750	4.900	4.900
Soybean Meal 48	2.750	3.000	3.000
HCL 35% modified Liq.	0.870	1.100	1.000
Wheat Silage #2 2022	1.750	1.850	1.850
Distillers Grains	2.200	2.410	2.410
Sorghum #1 2021	1.750	2.000	2.000
Zinpro 120	0.002	0.002	0.002
CALCIUM CL 94%			0.200
Total	30.076	32.566	32.687

Nutrient		2 Nov 22	15 Dec 22	8 Jan 23
DM Conc	%	51.622	51.077	51.144
ME	Mcal/lb	1.325	1.319	1.315
NEl	Mcal/lb	0.744	0.740	0.737
Crude Protein	%	16.128	15.991	15.937
MP	%	11.014	10.972	10.935
MET LYS	%	0.701	0.697	0.695
MET MET	%	0.195	0.194	0.193
Lys/Met	-	3.598	3.600	3.600
Sol P (%CP)	-	29.523	29.308	29.308
mRDP (%DM)	%	8.673	8.536	8.506
ADF	%	19.272	19.240	19.182
NDFom	%	30.611	30.712	30.620
Forage NDF	%	25.202	25.326	25.254
Forage ADF	%	16.909	16.863	16.834
Forage Dry Matter	%	63.176	63.413	63.241
NDFd (%NDF)	-	54.609	54.772	54.772
Sugar (%DM)	%	2.574	2.568	2.560
Starch (%DM)	%	28.602	28.518	28.438
NFC	%	42.586	42.726	42.741
Fat (EE)	%	3.600	3.642	3.629
Calcium	%	0.657	0.626	0.844
Phosphorus	%	0.535	0.518	0.516
Magnesium	%	0.483	0.458	0.456

39

Diet Name	As Fed Consumption	Feed Additive	IU or mg Per Head per day	Micro System IU or Mcg Per Head per day
Dry Cows		Zinpro 120	0.001	453.59
		Vanderham NEW TM PAK MICRO	0.0045	2041.17
		Rumensin 90	200	200 mg of Monensin
		Vitamin A	85000	85000 IU
		Vitamin D	25000	25000 IU
		Vitamin E	900	900 IU
		ClariFly .67		
Diet Name	As Fed Consumption	Feed Additive	IU or mg Per Head per day	Micro System IU or Mcg Per Head per day
Close Up Cows		Zinpro 120	0.0015	680.39
		Vanderham NEW TM PAK MICRO	0.005	2267.96
		Rumensin 90	450	450 mg of Monensin
		Diamond V XPC	0.03087	14002.40
		Vitamin A	120000	120000 IU
		Vitamin D	32000	32000 IU
		Vitamin E	1200	1200 IU
		ClariFly .67		

Code	Name	Stored	Min.	Max.	Per.
018200	CALCIUM CARB 38%	615.0000			30.75
019850	MONOCALCIUM PHOS	615.0000	615.0000		30.75
019500	MAG OX	575.0000	575.0000		28.75
020110	PROMG 95 (DOLOMITE)	95.0000	95.0000		4.75
020200	SALT (BULK)	85.0000	85.0000		4.25
018250	CALCIUM SULFATE	15.0000	15.0000		0.75
		2,000.0000			

What is the problem?

40

Diet Name	As Fed Consumption	Feed Additive	IU or mg Per head per day	Micro System IU or Mcg Per head per day
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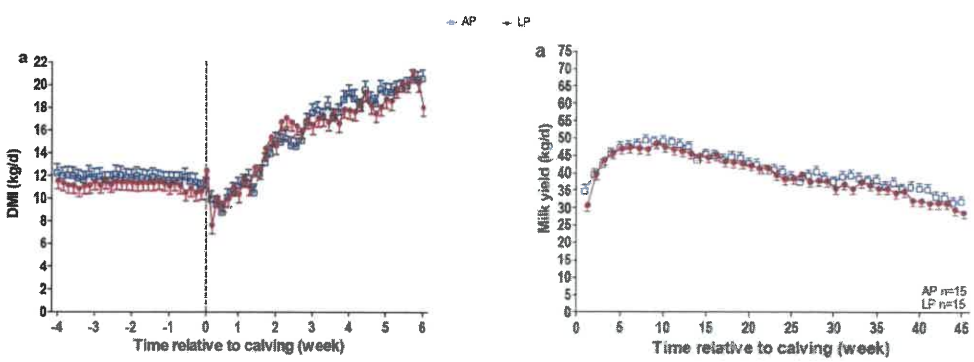
020110	PROMG 95 (DOLOMITE)	95.0000	95.0000		4.75
020200	SALT (BULK)	85.0000	85.0000		4.25
018250	CALCIUM SULFATE	15.0000	15.0000		0.75
		2,000.0000			

What is the problem?

- High P in the diet (with a highly available source)

41

Dietary P in close-up diets



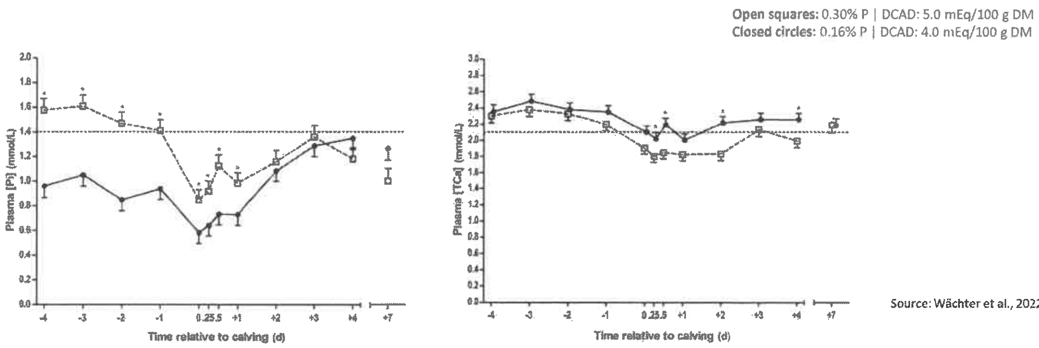
Source: Adapted from Wächter et al., 2022

- Increased FGF23 suppresses PTH mRNA and protein secretion of bovine parathyroid glands under *in vitro* conditions (Krajisnik et al., 2007)
- Good evidence from humans and murine models showing that FGF23 reduces 1 alpha-hydroxylase (Perwad et al., 2007)

42

Dietary P in close-up diets

- Fresh cow diets contained 0.46% P



- Other nutritional studies support the concept that decreased P intake in the prefresh period positively impacts Ca balance in the early postpartum (example: Cohrs et al., 2018)
- Increased P intake in the prefresh increase the odds of clinical hypocalcemia (Lean et al., 2006)
- What %P DM should we use in negative DCAD diets???

43

44

A Different Perspective on Metabolic Acidosis: Impacts on Glucose Metabolism

Dr. Heather White
University of Wisconsin-Madison
Professor, Nutritional Physiology
Associate Dean for Faculty Affairs

ANIMAL & DAIRY SCIENCES
University of Wisconsin-Madison

1

A few caveats.....

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1. *I am not a mineral expert.*
2. *I am not a DCAD expert.*
3. *This talk isn't about how to feed DCAD diets.*

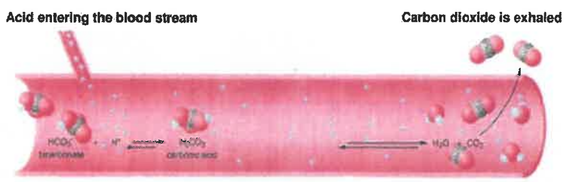
This is a thought exercise!

2

DCAD Dietary Strategies

- DCAD as a dietary strategy has long been used to manage mineral balance as a method to mitigate postpartum health disorders
- Prepartum the goal is to induce metabolic acidosis by shifting blood pH, a very tightly regulated physiological state

Maintaining Blood pH



$$HCO_3^{1-} + H^+ \rightleftharpoons H_2CO_3 \rightleftharpoons H_2O + CO_2$$

Bicarbonate ion circulates in the blood stream where it is in equilibrium with H^+ and OH^-. In the lungs, bicarbonate ions combine with a hydrogen ion and lose a water molecule to form carbon dioxide, which is exhaled.

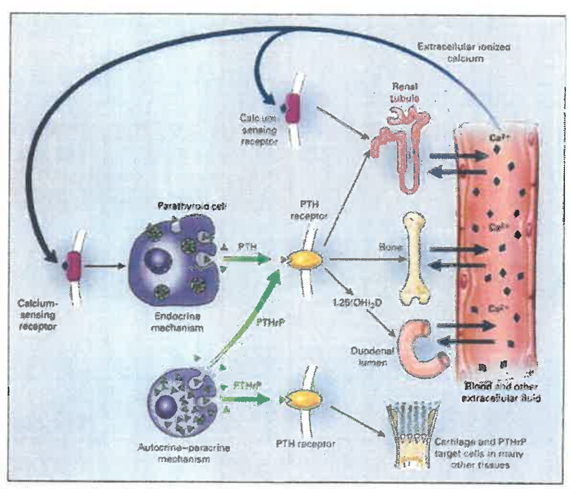
Kelter, Carr, Scott, Chemistry A World of Choices. 1999.

3

Calcium Metabolism

Metabolic acidosis has been demonstrated to improve Ca homeostasis

- ↑ sensitivity of bone and kidney parathyroid hormone (PTH) receptors
- ↑ Ca reserve mobilization from bone
- ↑ Ca reabsorption from kidney
- ↑ Ca absorption from small intestine



Medical Lecture Notes Online: Parathyroid Disease

Goff et al., 2004 and 2019

4

DCAD Dietary Strategies

- Prepartum the goal is to induce metabolic acidosis
- Detected on farm by urine pH
  - Mild metabolic acidosis: 6.0 to 6.8
  - Moderate acidosis: <6.0
- Results in maintained/improved blood Ca and iCa postpartum

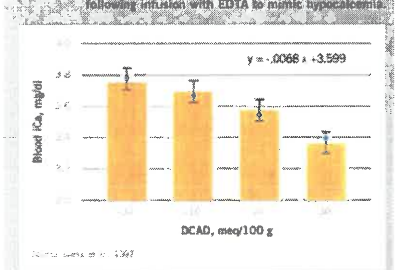


FIGURE 5. Blood-ionized Ca response to four levels of DCAD following infusion with EDTA to mimic hypocalcemia.

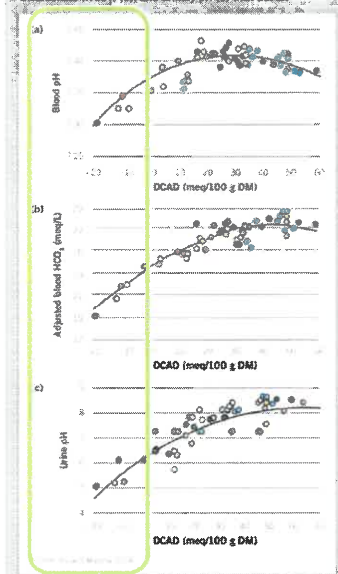


FIGURE 4a, b, c. The relationship between blood pH (a), bicarbonate (HCO_3) (b), and urinary pH (c) with DCAD.

Melendez and Chelikani, 2022; Hu and Murphy, 2004; Giesy et al., 1997

gfdgbhvhdufkvxp p du|3sq#dkirrqfkdb1frp

5

Metabolic Acidosis and Milk Fever

Table 6. Effect of reducing the DCAD from +200 to −100 mEq/kg on estimated urine pH and blood concentrations of minerals in Holstein cows according to parity group (LSM ± SEM)

Item	Means (Exp.)[1]	Nulliparous +200	Nulliparous −100	Parous +200	Parous −100	P-value[2] DCAD	P-value[2] DCAD × parity
Urine pH prepartum	104 (31)	8.21 ± 0.21	6.46 ± 0.21	8.04 ± 0.16	6.51 ± 0.16	<0.001	0.43
Blood Ca, m*M*							
Prepartum	113 (35)	2.465 ± 0.048	2.460 ± 0.048	2.320 ± 0.039	2.344 ± 0.039	0.77	0.58
Day of calving	107 (33)	2.295 ± 0.065	2.394 ± 0.065	1.860 ± 0.046	2.044 ± 0.046	<0.001	0.15
Postpartum	115 (36)	2.363 ± 0.056	2.440 ± 0.056	2.104 ± 0.050	2.224 ± 0.050	<0.001	0.31
Blood Mg, m*M*							
Prepartum	69 (22)	0.957 ± 0.048	0.919 ± 0.048	0.896 ± 0.028	0.885 ± 0.028	0.80	0.79
Day of calving	47 (15)	0.920 ± 0.052	0.923 ± 0.052	0.987 ± 0.039	0.970 ± 0.039	0.82	0.77
Postpartum	66 (21)	0.901 ± 0.033	0.929 ± 0.033	0.916 ± 0.022	0.884 ± 0.022	0.65	0.19
Blood P, m*M*							
Prepartum	77 (24)	1.755 ± 0.073	1.745 ± 0.073	1.757 ± 0.045	1.779 ± 0.045	0.92	0.79
Day of calving	51 (17)	1.695 ± 0.106	1.737 ± 0.106	1.118 ± 0.055	1.370 ± 0.055	0.15	0.37
Postpartum	74 (23)	1.737 ± 0.080	1.732 ± 0.080	1.665 ± 0.072	1.703 ± 0.072	0.62	0.53

[1]Number of treatment means and number of experiments (Exp.) that contributed with data for the analyses.

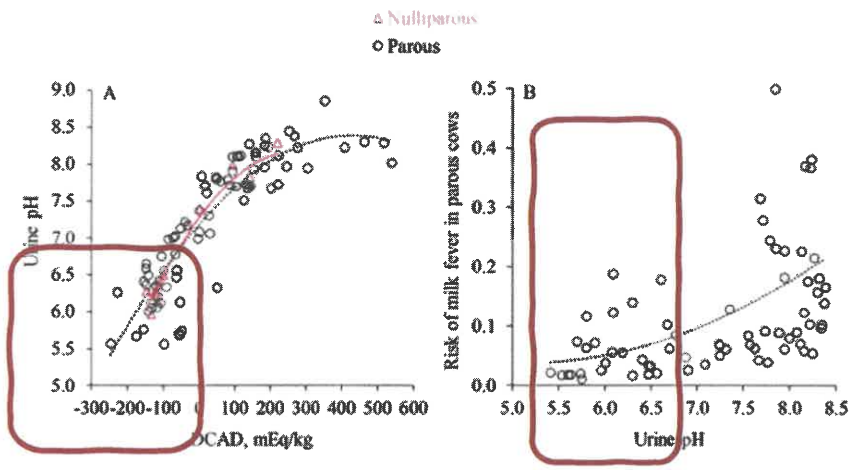
[2]DCAD = linear effect of altering the DCAD; DCAD × parity = interaction between the linear effect of altering the DCAD and parity (nulliparous or parous).

Prepartum negative DCAD diet, verified by reduced urine pH, results in greater blood calcium on the day of calving and postpartum

Santos et al., 2019

6

Metabolic Acidosis and Milk Fever



Effective strategy to mitigate milk fever

Santos et al., 2019

7

If something (i.e. blood pH) is so tightly regulated, wouldn't there be other changes when blood pH is shifted?

In other words, what are the unintended impacts of metabolic acidosis

8

Metabolic Acidosis and Milk Production

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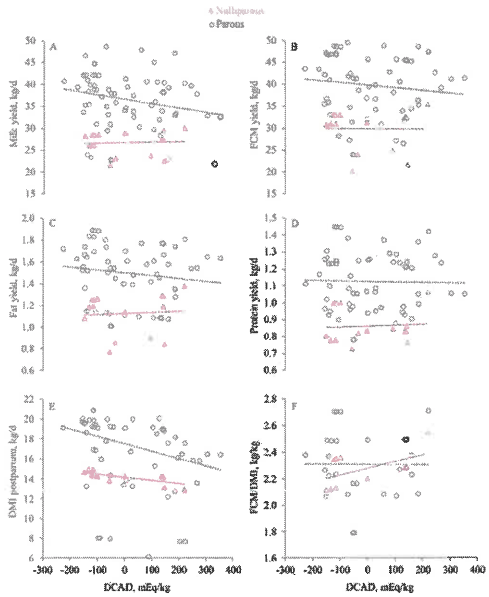


- Meta-analysis of 42 experiments, lines are significant differences
- Feeding negative DCAD prepartum increased milk yield and fat-corrected milk yield in multiparous cows

Santos et al., 2019

9

Metabolic Acidosis and DMI

ANIMAL & DAIRY SCIENCES
University of Wisconsin-Madison

- DCAD can decrease prepartum DMI, tends to increase DMI postpartum (Santos et al., 2019)

Item	Means (Exp.)[1]	Nulliparous +200	Nulliparous −100	Parous +200	Parous −100	P-value[2] DCAD	P-value[2] DCAD × parity
DMI, kg/d							
Prepartum	115 (36)	10.3 ± 0.5	9.6 ± 0.5	12.4 ± 0.4	12.0 ± 0.4	0.02	0.49
Postpartum	86 (26)	13.9 ± 0.9	13.7 ± 0.9	17.7 ± 0.7	18.7 ± 0.7	0.08	0.98
Milk yield, kg/d	90 (28)	25.9 ± 1.3[c]	24.5 ± 1.3[c]	36.2 ± 1.1[b]	37.9 ± 1.1[a]	0.74	0.03
FCM yield, kg/d	84 (25)	26.6 ± 1.9[c]	24.5 ± 1.9[d]	38.5 ± 1.8[b]	39.9 ± 1.8[a]	0.90	0.002

Santos et al., 2019

- Decreasing urine pH from 7.0 to 6.0 or lower led to a modest decrease in the incidence of milk fever but markedly increased the risk of decreased DMI in the prepartum period (Charbonneau et al., 2006).

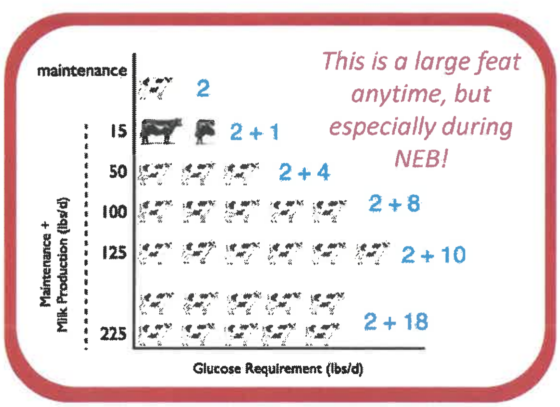
10

How is milk production increased with decreased blood pH?

11

Potential limiters for milk production

- **Glucose metabolism is different in ruminants ….** ***The rumen makes cows special!***
  - Glucose is spared for obligate glucose using tissues (ie, fetus and mammary gland)
  - Glucose is made primarily in the liver and 90% of glucose must be made de novo in ruminants
  - Glucose fuels milk lactose synthesis



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Potential limiters for milk production

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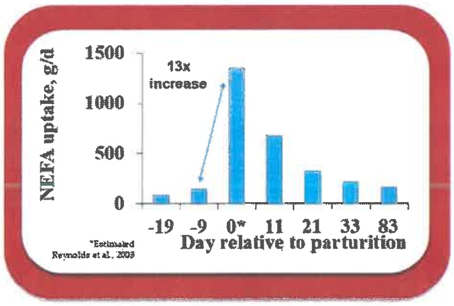
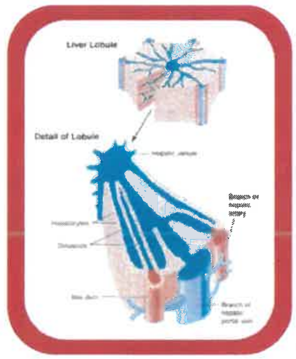
- Glucose metabolism is different in ruminants
  - Glucose is spared for obligate glucose using tissues (ie, fetus and mammary gland)
  - Glucose is made primarily in the liver and 90% of glucose must be made de novo in ruminants
  - Glucose fuels milk lactose synthesis
- **Lipid metabolism is dynamic during the transition to lactation period ....** ***Cows milk off their back!***
  - TG are mobilized during negative energy balance and provide energy (fatty acids) and glucose (glycerol) precursors
    - Oxidation of NEFA generates ATP for *cellular* use to make glucose, metabolize amino acids, etc.
  - NEFA are milk fat precursors





13

Potential limiters for milk production

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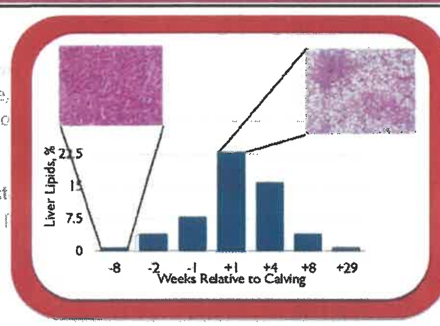
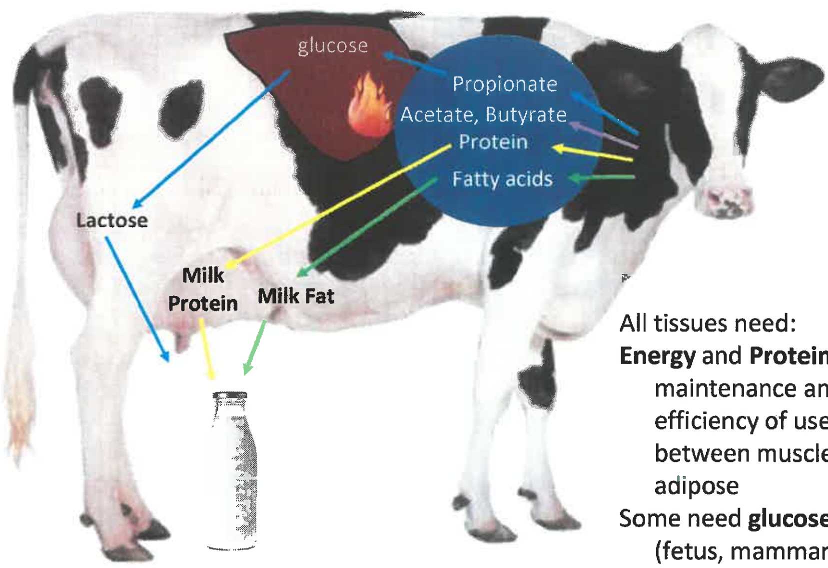
- Glucose metabolism is different in ruminants
  - Glucose is spared for obligate glucose using tissues (ie,
  - Glucose is made primarily in the liver and 90% of gluco
  - Glucose fuels milk lactose synthesis
- Lipid metabolism is dynamic during the transition to lact
  - TG are mobilized during negative energy balance and p precursors
    - Oxidation of NEFA generates ATP for *cellular* use
  - NEFA are milk fat precursors



- **Ketogenesis and TG storage are alternatives to complete oxidation of FA ....** ***Cows adapt to NEB!***
  - Ketone bodies are an exportable energy source that can be used by some tissues
    - if liver production exceeds tissue use cows can develop hyperketonemia (aka, sub-clinical ketosis)
  - NEFA that exceed oxidative capacity can be storage as TG. They can be used later but they can also contribute to transient or chronic fatty liver

14

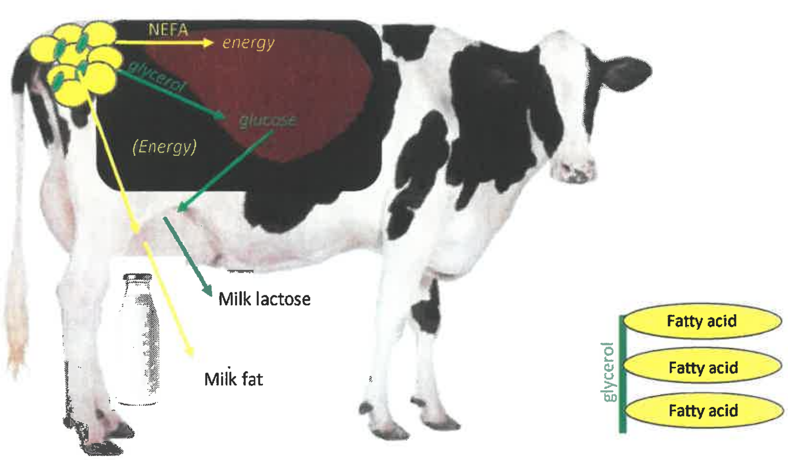
Nutritional Support of Lactation



All tissues need:
Energy and **Protein** for
maintenance and growth
efficiency of use varies between muscle and adipose
Some need **glucose**
(fetus, mammary gland)

15

Nutritional Support of Lactation



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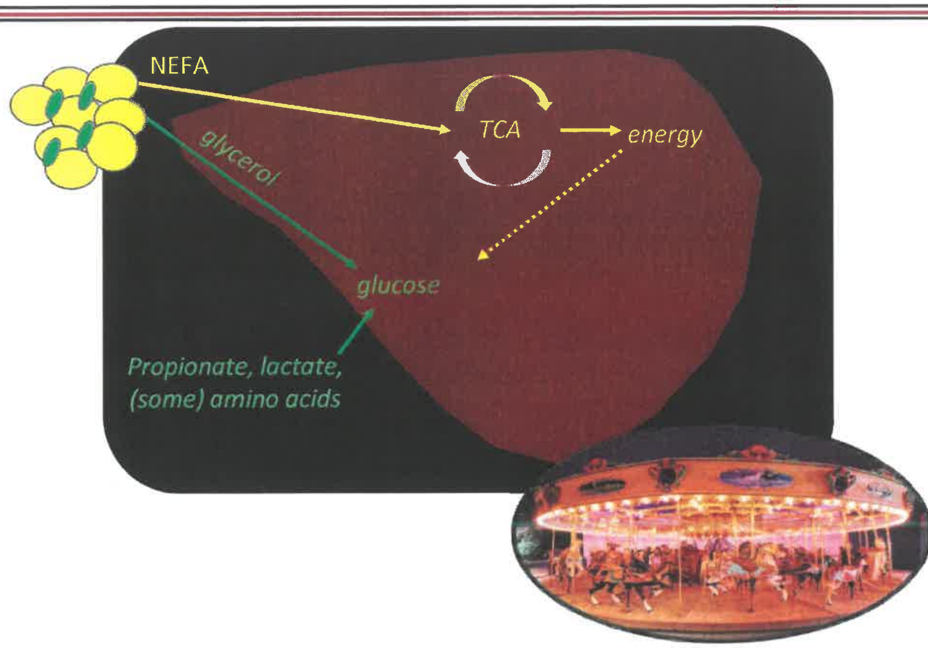
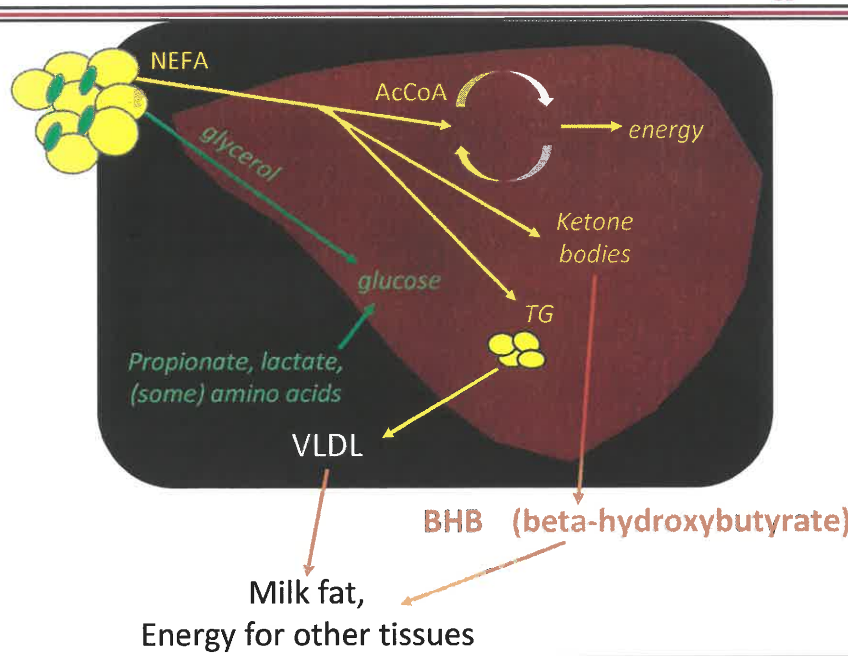
Hepatic Nutrient Partitioning



17

Hepatic Nutrient Partitioning



18

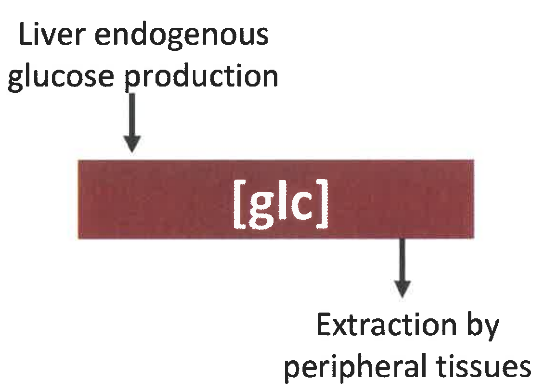
If DCAD diets are sometimes associated with greater milk production, are they influencing these pathways?

This is an involved question because we can't just measure blood glucose....

19

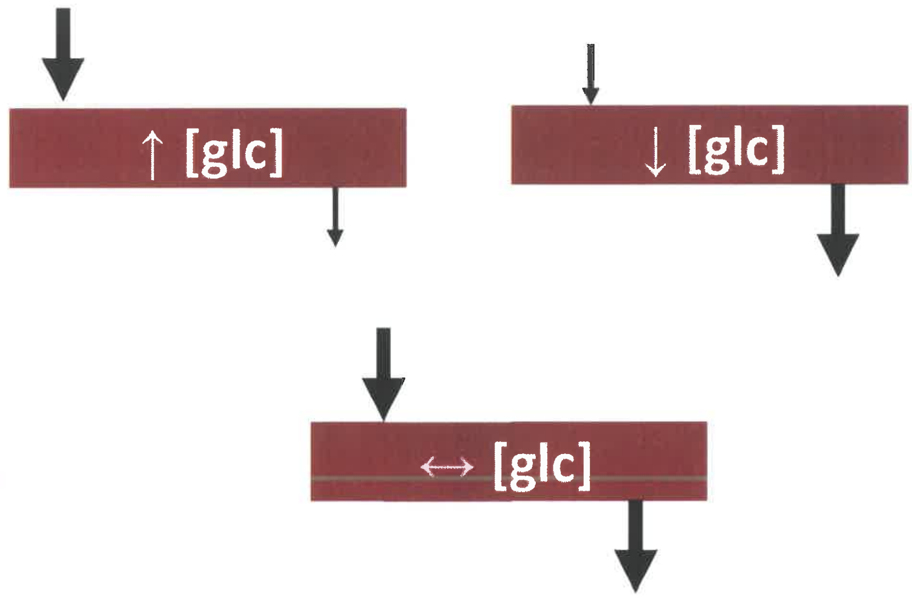
Pool Concentration

- Concentration of any pool is a product of appearance into the pool and disappearance out of the pool



20

Pool Concentration



21

If DCAD diets are sometimes associated with greater milk production, are they influencing these pathways?

22

Glucose Metabolism with DCAD diet

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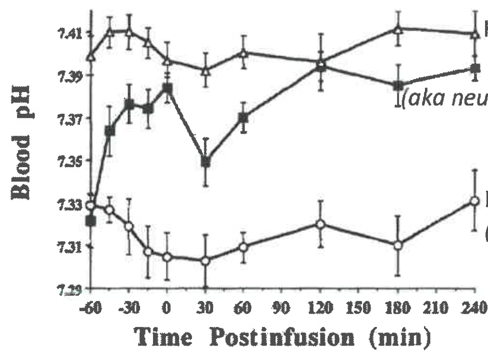
- Metabolic acidosis was induced in nonpregnant, nonlactating Jersey cows for 7d
- Glucose tolerance tests to determine if metabolic acidosis altered glucose metabolism



Bigner et al., 1996

23

Glucose Metabolism with DCAD diet

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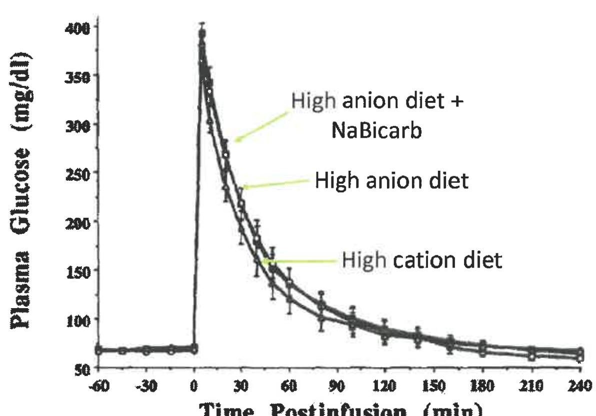
Glucose tolerance test

Metabolic acidosis impaired glucose disappearance

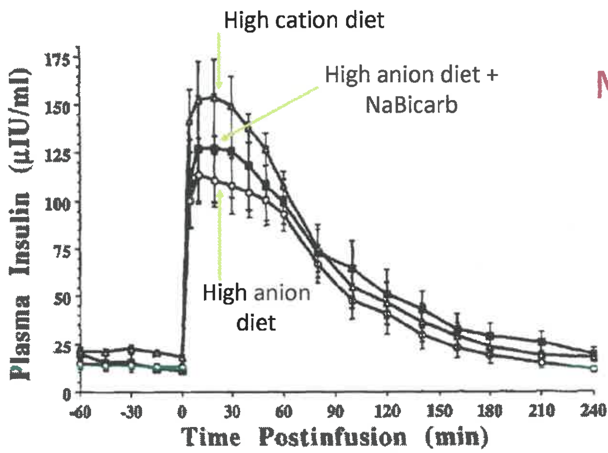


Bigner et al., 1996

24

Glucose Metabolism with DCAD diet

Glucose tolerance test



Metabolic acidosis impaired insulin release

Bigner et al., 1996

25

Glucose Metabolism with DCAD diet

- Insulin response to a glucose load was altered with high anion diet and partially recovered by treatment with sodium bicarbonate neutralization of the metabolic acidosis.
- Interestingly, this was not a DCAD study per se
  - the research team used DCAD to induce metabolic acidosis as a model of ketosis-induced metabolic acidosis
- Partial recovery of insulin sensitivity with bicarbonate neutralization has also been demonstrated in humans

Bigner et al., 1996; Cuthbert and Alberti, 1978; Walker et al., 1963; Schade et al., 1981; Bellasi et al., 2016; Guardia et al., 2018

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Glucose Metabolism with DCAD diet

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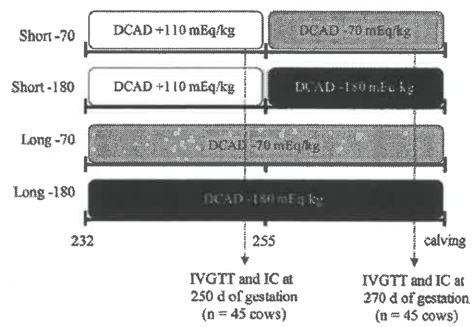
- Likely dependent on the extent of acidosis induced
- Mild acidosis that did not alter blood pH or other acidotic markers did not reduce insulin release or alter IR (GTT)

- 2 degrees of DCAD diet for two lengths of time prepartum
  - Cows with moderate metabolic acidosis had reduced insulin sensitivity, potentially through both blighted insulin release from the pancreas and dampened response to insulin



Grünberg et al., 2011; Vieira-Neto et al., 2021

27

Potential limiters for milk production

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- **Glucose metabolism is different in ruminants ….** *The rumen makes cows special!*
  - Glucose is spared for obligate glucose using tissues (ie, fetus and mammary gland)
  - Glucose is made primarily in the liver and 90% of glucose must be made de novo in ruminants
  - Glucose fuels milk lactose synthesis

Moderate metabolic acidosis may shift glucose metabolism.

What is the impact of this?

To answer this, we need to dig a little deeper into glucose metabolism and insulin resistance.

28

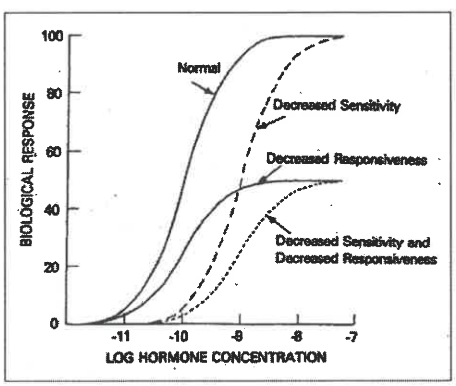
Glucose Metabolism with DCAD diet

- In cows, metabolic acidosis impacts insulin sensitivity
- In humans, metabolic acidosis classically dampens insulin sensitivity through decreased insulin release and responsiveness
  - Interfering with insulin binding to the insulin receptor or interfering with the subsequent signaling cascade
  - Recent epidemiological data supports that mild acidosis is associated with impaired insulin response

Bigner et al., 1996; Cuthbert and Alberti, 1978; Walker et al., 1963; Schade et al., 1981; Bellasi et al., 2016; Guardia et al., 2018

29

Insulin Responsiveness



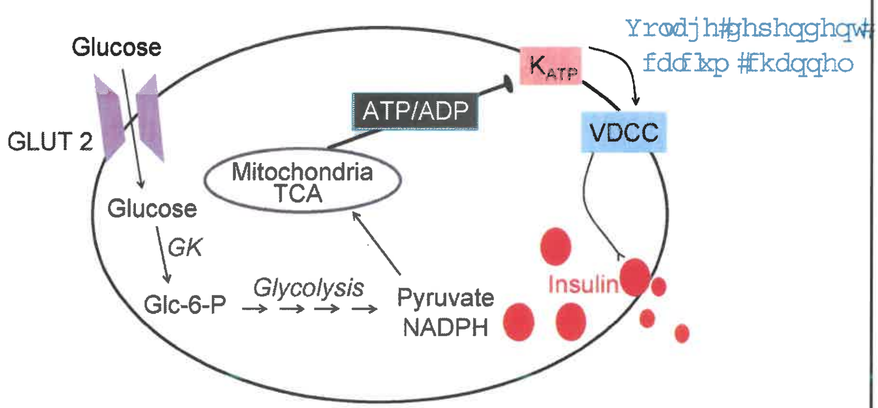
- Decreased Sensitivity
  - maximal response is unchanged
  - greater concentration of insulin is needed to elicit a normal response
- Decreased Responsiveness
  - reduced maximal response

Kahn, 1978

30

Pancreatic Insulin Release

Glucose Sensing by Pancreatic βcells

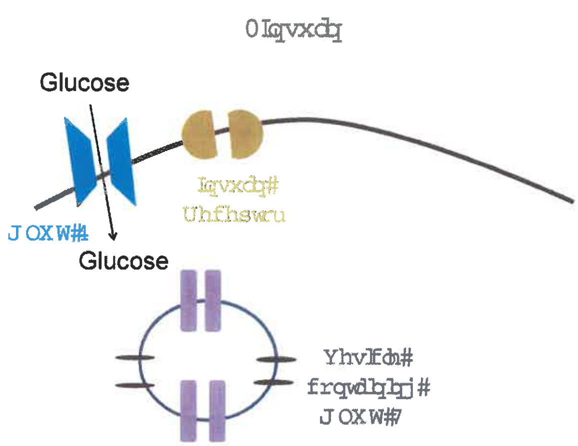


Adapted from MacDonald et al, 2005.

31

Insulin-Mediated Glucose Uptake

insulin-independent transporters are always "on"
insulin-dependent transport requires insulin activation

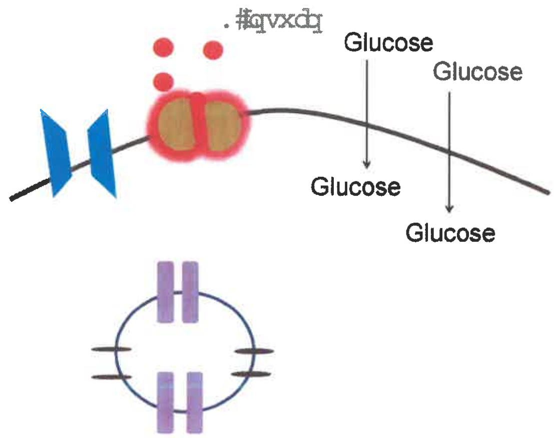


Brown 2000.

32

Insulin-Mediated Glucose Uptake

GLUT 4 Transport

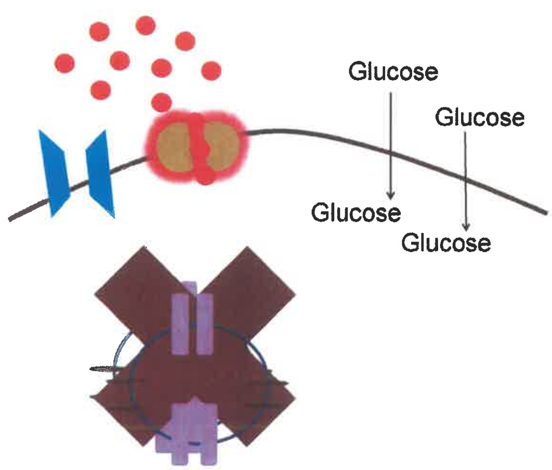


Brown 2000.

33

Insulin-Mediated Glucose Uptake

Insulin Resistance

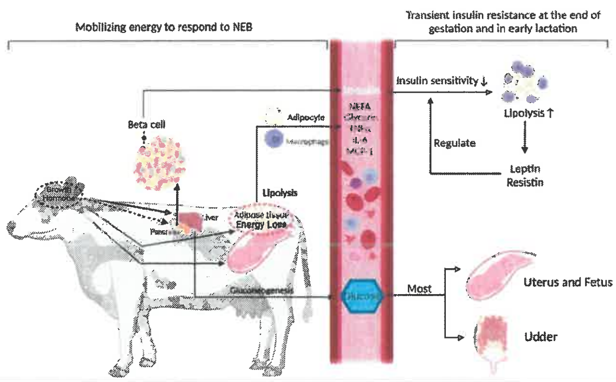


Brown 2000.

34

What about in cows?

- Insulin resistance is not a new concept in dairy cattle and has been of increased interest as we continue to select and manage for higher production, longevity, and health
- Insulin resistance allows for glucose to be prioritized (even more) to obligatory glucose-utilizing tissues
  - Less insulin release in response to glucose load or less insulin responsiveness



Qiao et al., 2024

35

Metabolic Acidosis and Glucose

- In humans, metabolic acidosis classically dampens insulin sensitivity
  - Ex. diabetic individuals with ketoacidosis are not as insulin responsive as those who are not in an acidotic state
- Of recent interest given
  - prevalence of Type II Diabetes and insulin resistance
  - Use of ketogenic diets to combat obesity and metabolic health challenges
- Ketone bodies (e.g. ketoacids) decrease blood pH
- As early as 1978, clinically ketotic or fasted (48-hr feed restriction) cows had impaired insulin responses to glucose infusion

Ketosis is a natural case study of metabolic acidosis

Hove, 1978

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Ketosis and Metabolic Acidosis

ANIMAL & DAIRY SCIENCES University of Wisconsin-Madison

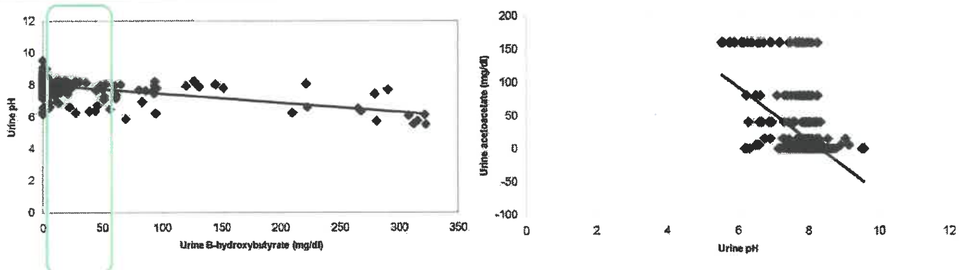

Table 4-4. Correlations of urine parameters for cows fed diets with different prepartum energy concentrations with or without supplemental calcium propionate.

Parameter	Normal Energy (-) Ca-prop	Normal Energy (+) Ca-prop	High Energy (-) Ca-prop	High Energy (+) Ca-prop
BHBA (mg/dl) / pH	-0.14924	-0.65243	-0.71848	-0.28798
BHBA (mg/dl) / Acetoacetate (mg/dl)	0.88339	0.81087	0.91610	0.77630
pH / Acetoacetate (mg/dl)	-0.34659	-0.63855	-0.70034	-0.42665

Table 4-4. Correlations of urine parameters for cows fed diets with different prepartum energy concentrations with or without supplemental calcium propionate.

Beem, 2003

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Ketosis and Insulin Response

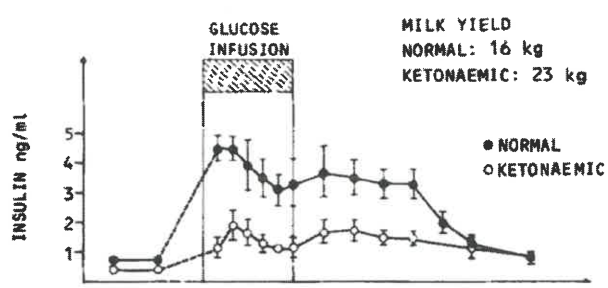
ANIMAL & DAIRY SCIENCES University of Wisconsin-Madison

TABLE 1. Milk production (average and range), stage of lactation, and pre-infusion concentrations in plasma of the measured metabolites (average and standard deviation).

Group	Days post-partum	Milk production (kg/day)	Sugar (mg/100 ml)		Plasma Acac (mg/100 ml)		Insulin (ng/ml)	
Normal	13–240	16 13–23	73.7	7.7	.4	.3	.75	.30
Ketonemic	15–54	23 18–27	50.8	12.7	14.0	3.6	.40	.10
Starved	57–148	19 14–24 (4–11)[a]	70.0	6.8	2.5	2.7	.33	.06

[a]Range of milk yields during the last 24 h of the starvation period.

Reduced insulin response to glucose challenge in ketotic cows



Hove, 1978

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Ketone bodies may also reduce urine pH and influence glucose metabolism.

Are there similar impacts on milk yield?

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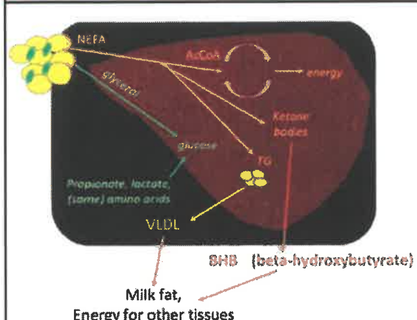
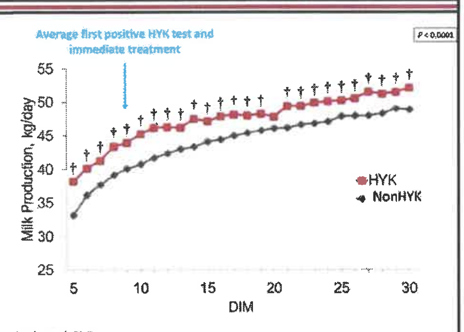
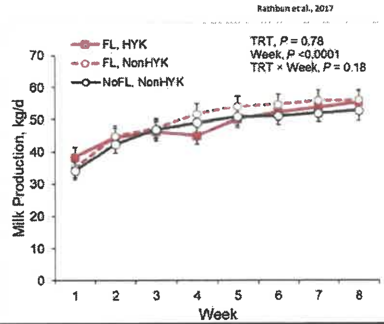
Cows with HYK Can Remain High Producers







Praisler et al., White Lab
unpublished data

40

Insulin Resistance is Bad, Right?

- Extremes of anything can be negative but IR is innately part of the glucose-sparing mechanisms that support lactational glucose demands
- Optimal balance of insulin sensitivity, inflammation, and milk production is nuanced
- Ketotic cows often exhibit altered insulin sensitivity, increased peripheral tissue utilization of ketone bodies, and presumably acidosis (although blood and urine pH is rarely reported in ketosis research)
- Although there are negative impacts associated with ketosis, the shift in nutrient partitioning has a purpose…

Vieira-Neto et al., 2021; McArt et al., 2012a,b

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What else might the change in insulin sensitivity impact?

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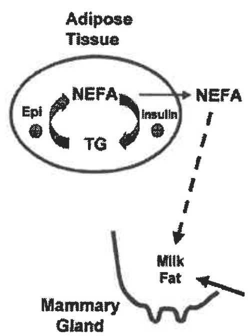
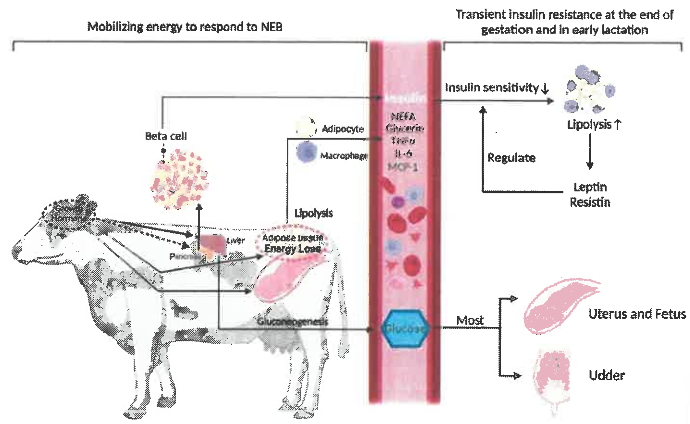
Other Impacts of Insulin

Peripartum Lipolysis





Insulin resistance means it takes more insulin to inhibit lipolysis

Drackley, 1999 Qiao et al., 2024

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DCAD and Lipolysis

- DCAD impact on plasma FA is variable

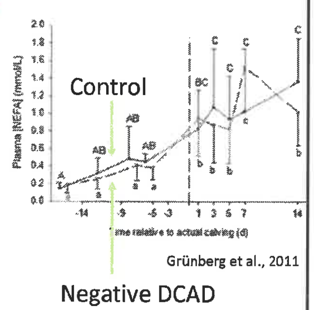
Item	Means (Exp 1)[1]	Nulliparous +200	Nulliparous −100	Parous +200	Parous −100	P-value[2] DCAD	P-value[2] DCAD × parity
Blood glucose, mM							
Prepartum	40 (10)	3.923 ± 0.133	3.797 ± 0.133	3.528 ± 0.128	3.480 ± 0.128	0.02	0.30
Postpartum	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Blood fatty acids, mM							
Prepartum	55 (15)	0.249 ± 0.040	0.224 ± 0.040	0.253 ± 0.036	0.261 ± 0.036	0.51	0.29
Postpartum	51 (15)	0.654 ± 0.117	0.636 ± 0.117	0.772 ± 0.115	0.863 ± 0.115	0.50	0.02
Blood BHB, mM							
Prepartum	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Postpartum	48 (13)	0.595 ± 0.099	0.441 ± 0.099	0.802 ± 0.086	0.843 ± 0.086	0.02	0.21

Santos et al., 2019

Variable[1]	Treatment[3] CON	Treatment[3] ND	Treatment[3] NDCA	SEM	Contrast[4] C1	Contrast[4] C2
NEFA, mEq/L						
Prepartum	0.28	0.30	0.35	0.02	0.01	0.03
At calving	0.83	1.00	0.79	0.08	0.49	0.04
Immediate postcalving	0.66	0.69	0.66	0.07	0.81	0.61
Postpartum	0.66	0.57	0.60	0.05	0.06	0.83

C1 = control vs. both negative DCAD (ND)
C2 = NDCA vs. ND

Zhang et al., 2022



Grünberg et al., 2011

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Increased blood fatty acids are typically associated with negative energy balance.

Are these cows eating less?

sometimes

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DCAD and Lipolysis

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- DCAD can decrease prepartum DMI (Santos et al., 2019)

Item	Means (Exp.)[1]	Nulliparous +200	Nulliparous −100	Parous +200	Parous −100	P-value[2] DCAD	P-value[2] DCAD × parity
DMI, kg/d							
Prepartum	115 (36)	10.3 ± 0.5	9.6 ± 0.5	12.4 ± 0.4	12.0 ± 0.4	0.02	0.49
Postpartum	86 (26)	12.9 ± 0.9	13.7 ± 0.9	17.7 ± 0.7	18.7 ± 0.7	0.08	0.08
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FCM yield, kg/d	84 (25)	26.6 ± 1.9	24.5 ± 1.9	38.8 ± 1.8	39.9 ± 1.8	0.90	0.002

Santos et al., 2019

- Decreasing urine pH from 7.0 to 6.0 or lower led to a modest decrease in the incidence of milk fever but markedly increased the risk of decreased DMI in the prepartum period (Charbonneau et al., 2006).

So we have to watch intakes…

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Summary

- Utilization of DCAD interventions to manage metabolic health peripartum has numerous benefits, but it is very likely that there are impacts on physiology and metabolism that reach beyond mineral metabolism
- Metabolic acidosis influences glucose metabolism and insulin resistance
  - At least if not over-exacerbated, may support the adaptive mechanisms associated with glucose sparing and permit maintained or increased milk production
  - Could present challenges if metabolic acidosis becomes severe
- DCAD diets may alter regulation of lipolysis can could confound responses, especially in cases when DMI is decreased, and likely reflects extent of insulin resistance

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Take Home Messages

- Herds or individual cows may respond differently to dietary DCAD strategies dependent on:
  - Different metabolic baselines (i.e., over-conditioned, insulin-resistant, etc.)
  - Extent of metabolic acidosis achieved (note, this is not the same as amount of DCAD fed)
  - Impact on DMI
  - Extent of postpartum adipose tissue lipolysis
- Taken together, these potential interactions may explain the non-mineral benefits, and differences in responses, to DCAD strategies

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Acknowledgments

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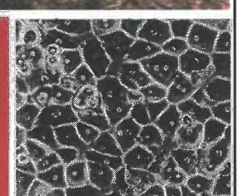

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Non-Nutritional Stressors During Transition

Ashley Niesen, Ph.D., PAS
Dairy Technical Service Manager

Phibro

1

The Invisible Threat: Stress and Its Devastating Effects on Health

Non-Nutritional Stressors During Transition

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2

Hidden Dangers: Recognizing Chronic Stress Symptoms and Preventing Health Catastrophes

Non-Nutritional Stressors During Transition

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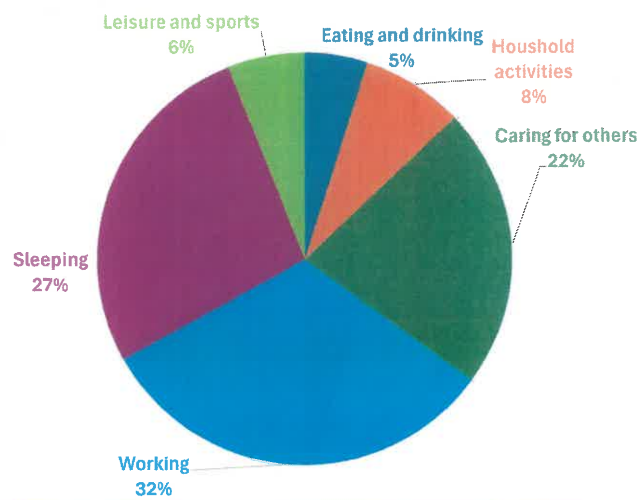
3

American Time Use Survey

Non-Nutritional Stressors During Transition



ADAPTED FROM: U.S. Bureau of Labor Statistics. Bls.gov. Accessed April 21, 2025. https://www.bls.gov/tus/latest-numbers.htm

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Time Budget on Commercial Herds
Non-Nutritional Stressors During Transition

Typical daily time budget for lactating dairy cow.

Activity	Time devoted to activity per day
Eating	3 to 5 h (9 to 14 meals/d)
Lying/resting	12 to 14 h
Social interactions	2 to 3 h
Ruminating	7 to 10 h
Drinking	30 min
Outside pen (milking, travel time)	2.5 to 3.5 h

SOURCE: Grant, R. 2003. Stocking Density and Time Budgets. Western Dairy Management Proceedings.

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5

Time Budget on Commercial Herds
Non-Nutritional Stressors During Transition

Typical daily time budget for ~~lactating~~ dry dairy cow.

Activity	Time devoted to activity per day
Eating	3 to 5 h (9 to 14 meals/d)
Lying/resting	12 to 14 h
Social interactions	2 to 3 h
Ruminating	7 to 10 h
Drinking	30 min
Outside pen (milking, travel time)	2.5 to 3.5 h

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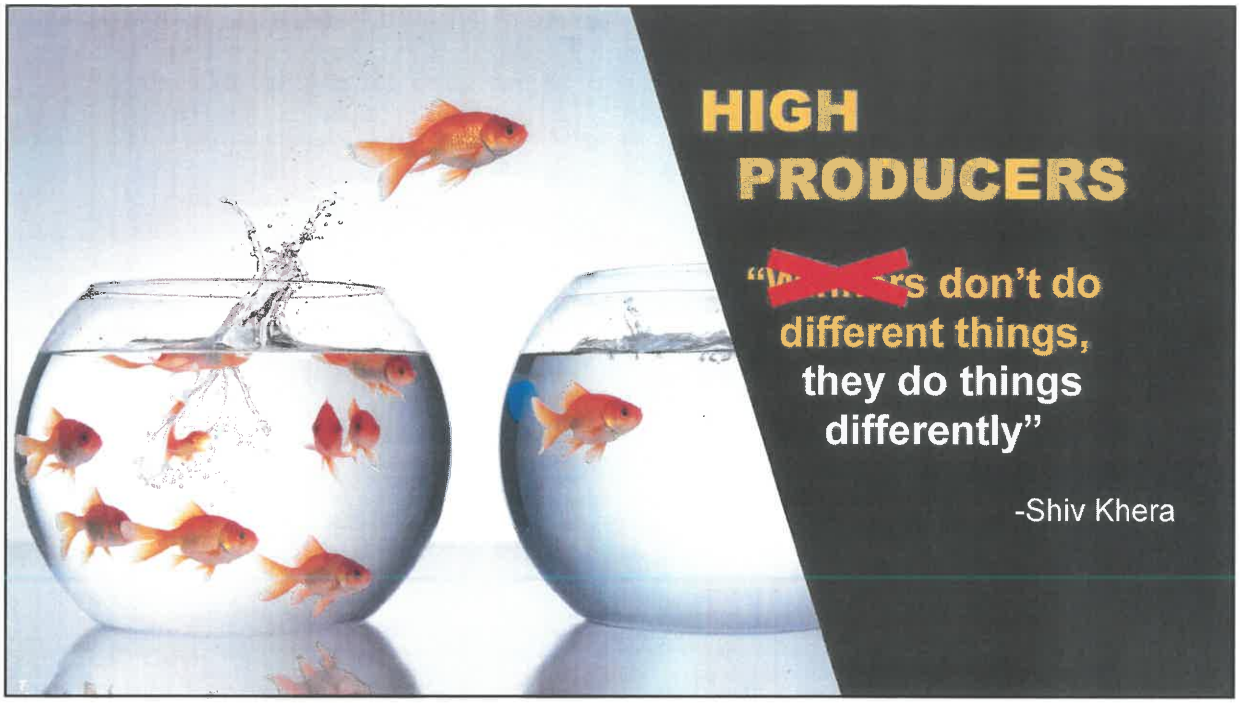
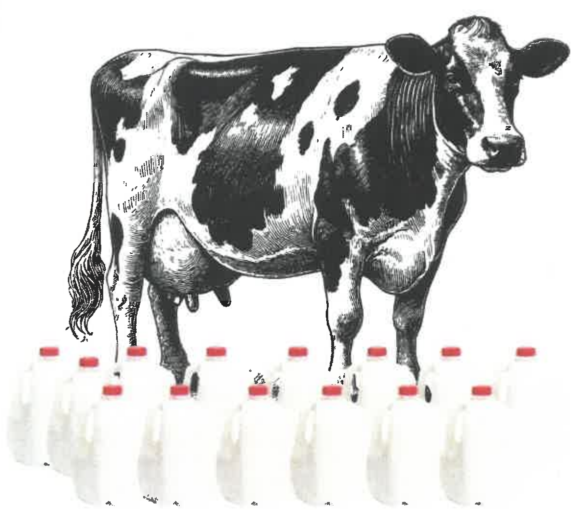


7

Time Budget of High Production

Non-Nutritional Stressors During Transition



- **Beecher Arlinda Ellen**
- **First cow to break 22,676 kg of milk/yr (i.e., 50,000 lb/yr)**
- **She spent approximately 6 h/d eating and nearly 14 h/d lying down**
- **Spent 7.5 h/d ruminating, 93% of that rumination occurring while lying down**

SOURCE: Grant, R. 2023. What We've Learned from Cows: A Tale of Two Decades of Management Research at Miner. Pages 109-120 in Cornell Nutrition Conference Proceedings.

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Time Budget for Top 10% of Cows

Non-Nutritional Stressors During Transition

Daily behavioral time budget for top-10% of cows by milk production and average milk production cows (h/d).[1]

Activity	Top-10%	Average
Eating at manger	5.5	5.5
Resting	14.1[a]	11.8[b]
Standing in alleys	1.1[b]	2.2[a]
Perching in stalls	0.5[b]	1.4[a]
Drinking	0.3	0.4

[ab]Means within a row differ ($P < 0.05$).
[1]Adapted from Matzke (2003).

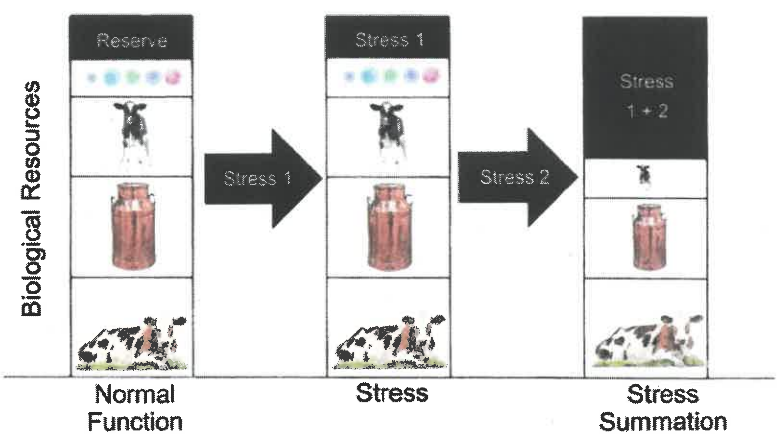
- **Comparable to what was observed with Beecher Arlinda Ellen's time budget (6 h/d eating and nearly 14 h/d lying down)**

SOURCE: Grant, R. 2003. Stocking Density and Time Budgets. Western Dairy Management Proceedings.

9

Summation of Multiple Stressors

Non-Nutritional Stressors During Transition

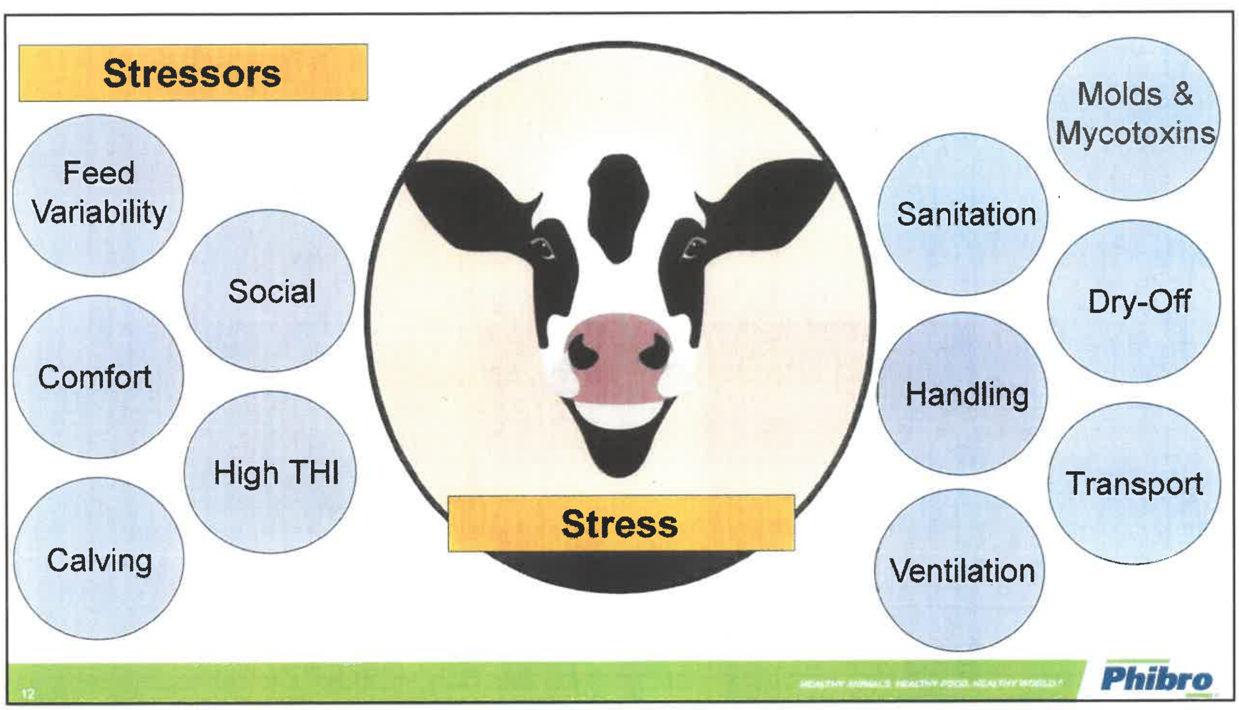


ADAPTED FROM Moberg G.P. 2000. *Biological Response to Stress: Implications for Animal Welfare*. CAB International.

10


Summation of Multiple Stressors
Non-Nutritional Stressors During Transition
Health
Production
Reproduction
Phibro

11


Stressors
Feed Variability
Social
Comfort
High THI
Calving
Stress
Sanitation
Molds & Mycotoxins
Dry-Off
Handling
Transport
Ventilation
Phibro

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Social Turmoil - Causes

Non-Nutritional Stressors During Transition

- Limited resources

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Social Turmoil - Causes

Non-Nutritional Stressors During Transition

- **Limited resources**
- **Tight conditions**

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Social Turmoil - Causes

Non-Nutritional Stressors During Transition

- **Limited resources**
- **Tight conditions**
- **Regrouping**

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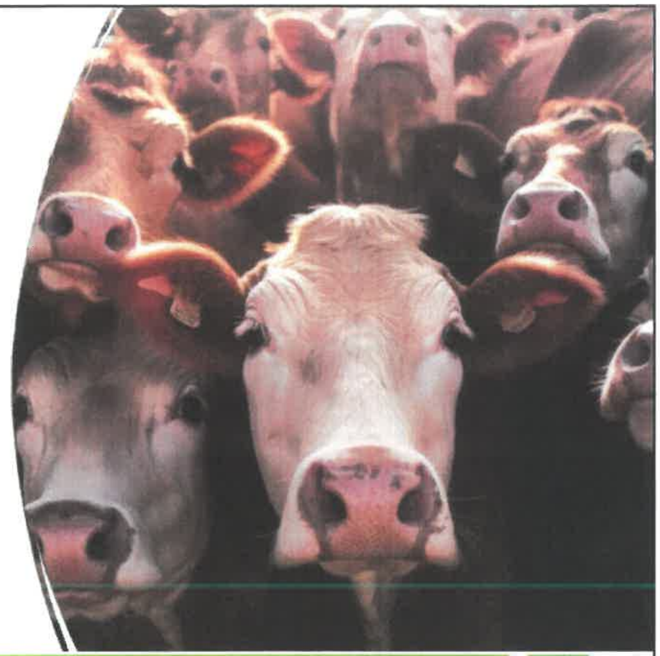
Social Turmoil - Causes

Non-Nutritional Stressors During Transition

- **Overcrowding**
- **Mixed parity groups**
- **Frequently moving cows**



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Social Turmoil - Effects

Non-Nutritional Stressors During Transition

- **Social instability**
- **Competition for feeding and resting space**
- **Aggression**
- **Social defeat / subordination**
- **Inability to retreat**
- **Balance biological needs vs. conflict**

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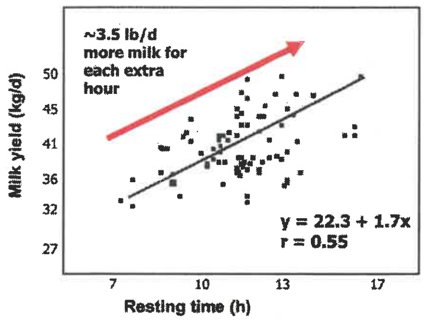
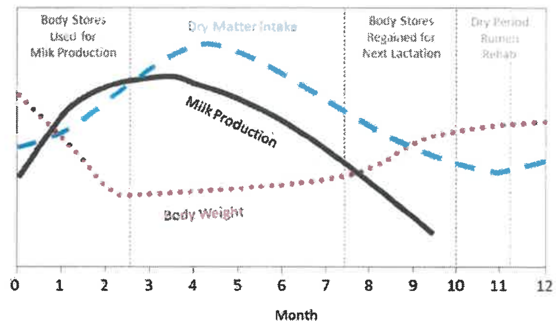
Rest More, Eat More, Milk More

Non-Nutritional Stressors During Transition





Relationship between resting time and milk yield in dairy cows

SOURCE: Grant, R. 2009. Stocking Density and Time Budgets. Western Dairy Management Proceedings.

SOURCE: Body Condition Scoring as a Tool for Dairy Herd Management. extension.psu.edu. Updated January 23, 2023. Accessed April 21, 2025. https://extension.psu.edu/body-condition-scoring-as-a-tool-for-dairy-herd-management.

19

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When we allow behavior to follow biologically necessary routines, production outcomes are improved.

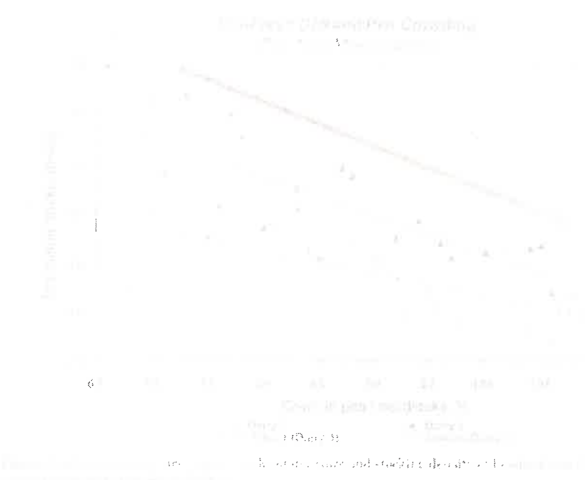
Let's look at what happens when social stressors disrupt behavioral time budgets.

20

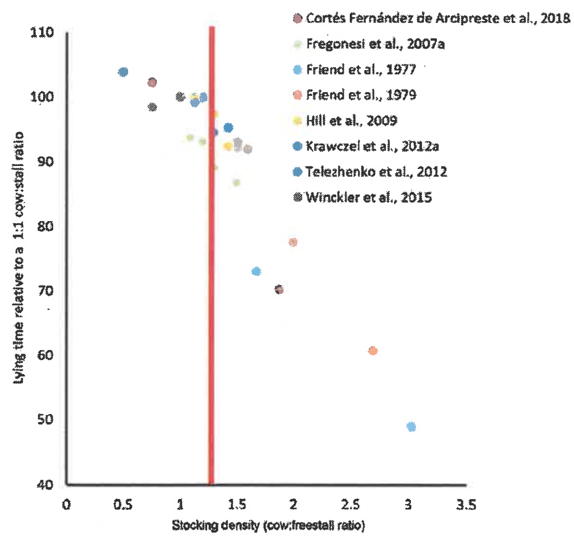
20

Resting and DMI

Non-Nutritional Stressors During Transition



SOURCE: Norlund, et al. Comingling Dairy Cows: Pen Moves, Stocking Density and Health. Proceedings of the American Association of Bovine Practitioners, 39:36-42.



SOURCE: Tucker et al. 2021. J. Dairy Sci. 104:20-46.

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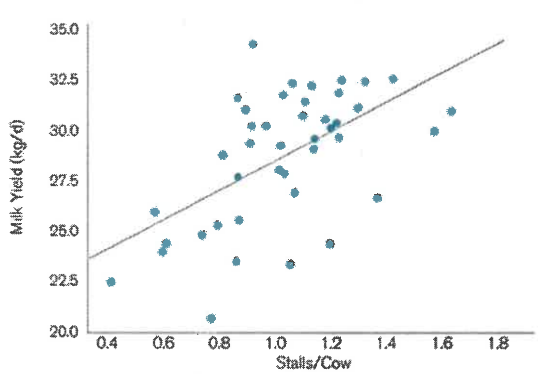
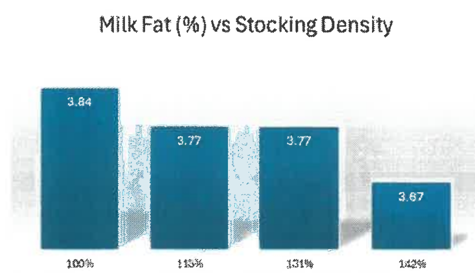
Milk Production and Quality

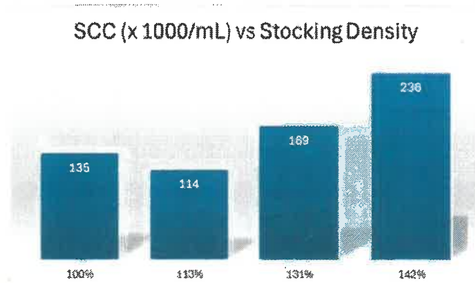
Non-Nutritional Stressors During Transition



Milk yield = 20.4+(7.5 x stalls/cow) R^2 = 0.32

SOURCE: Bach, A. 2008. J. Dairy Sci. 91:3259-3267.





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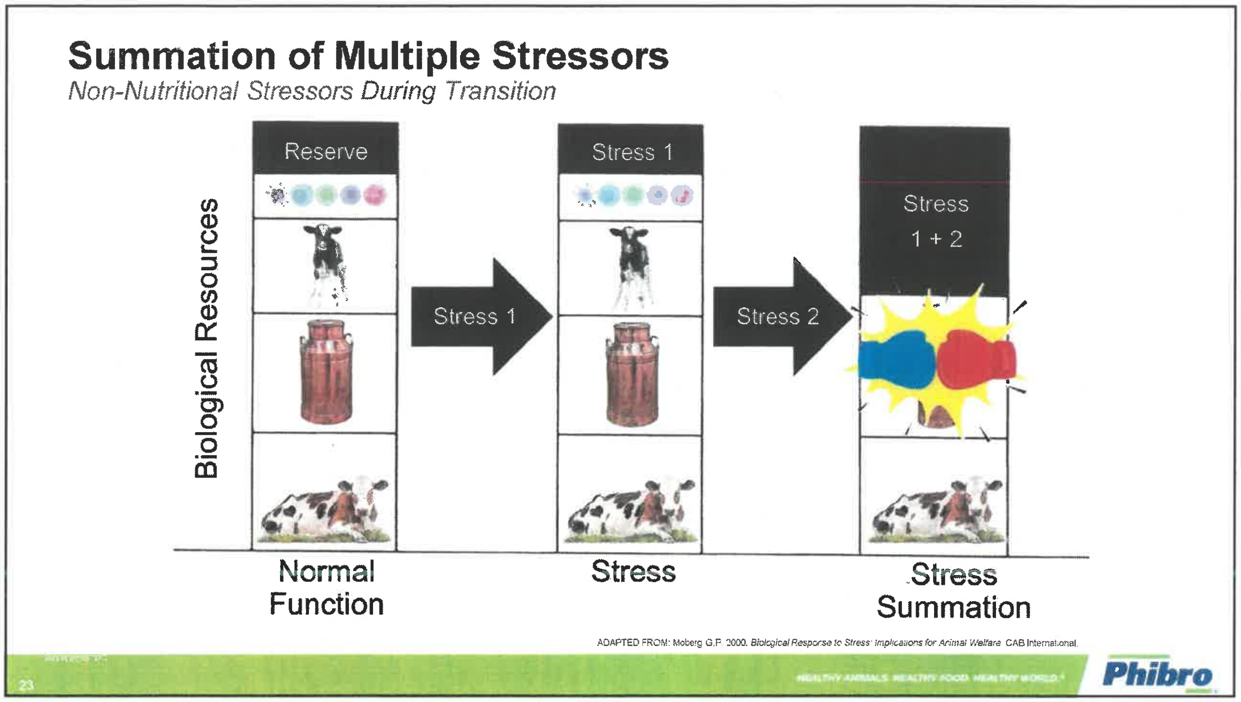
Summation of Multiple Stressors
Non-Nutritional Stressors During Transition
Biological Resources
Reserve
Stress 1
Stress 1
Stress 2
Stress 1 + 2
Normal Function
Stress
Stress Summation
ADAPTED FROM: Moberg G.P. 2000. Biological Response to Stress: Implications for Animal Welfare. CAB International.
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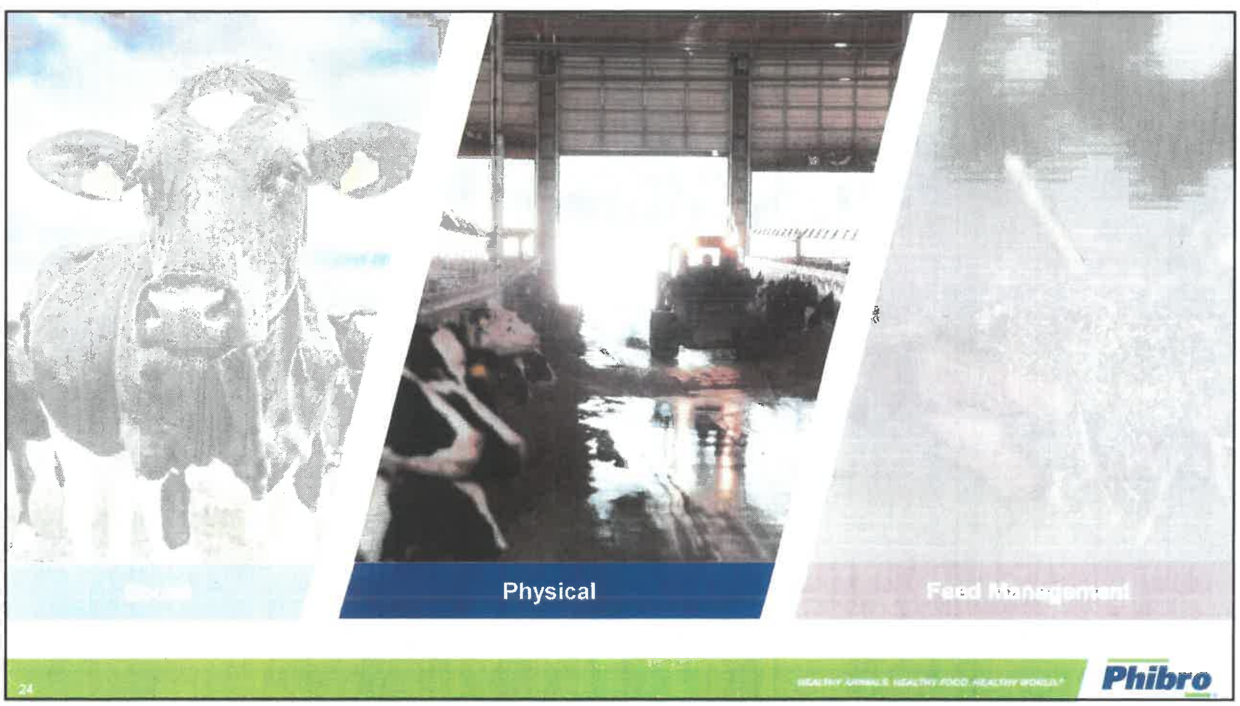
Physical
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Physical Stressors - Causes
Non-Nutritional Stressors During Transition

- Temperature and humidity

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Physical Stressors - Causes
Non-Nutritional Stressors During Transition

- Temperature and humidity
- Exposure to elements

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Physical Stressors - Causes
Non-Nutritional Stressors During Transition

- Temperature and humidity
- Exposure to elements
- Bedding comfort & cleanliness

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Physical Stressors - Causes
Non-Nutritional Stressors During Transition

- Temperature and humidity
- Exposure to elements
- Bedding comfort & cleanliness
- Excessive walking & standing

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Physical Stressors - Effects

Non-Nutritional Stressors During Transition

- Heat stress
- Cold stress
- Lesions & lameness
- Time lost eating and resting

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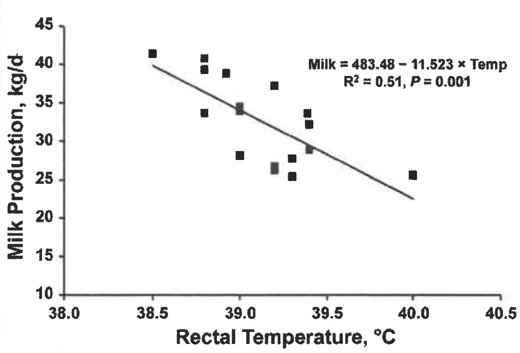
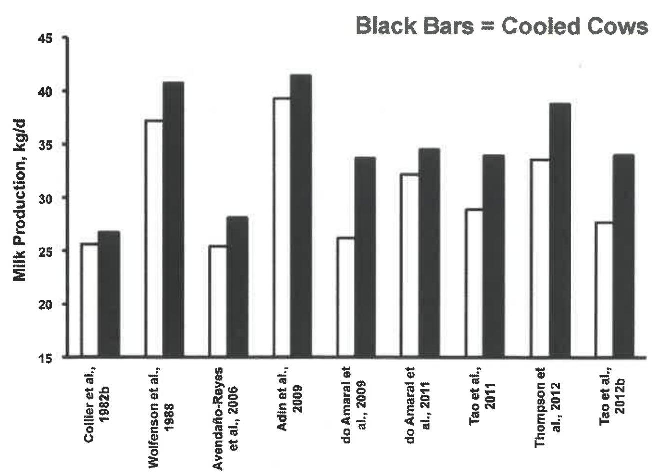
Heat Stress and Production

Non-Nutritional Stressors During Transition





SOURCE: Tao et al. 2013. J. Dairy Sci.96:4079-4093.

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Excessive Standing and Walking

Non-Nutritional Stressors During Transition

- Standing and walking in alley estimated at 2-3 hr/day
- Headlocks recommended ≤ 1hr/d
- Parlor time and travel 2.5 – 3.5 hr/d

Where do your herds stand?

SOURCE: MSU Extension. Accessed April 21, 2025. https://www.canr.msu.edu/news/time_management_for_dairy_cows.

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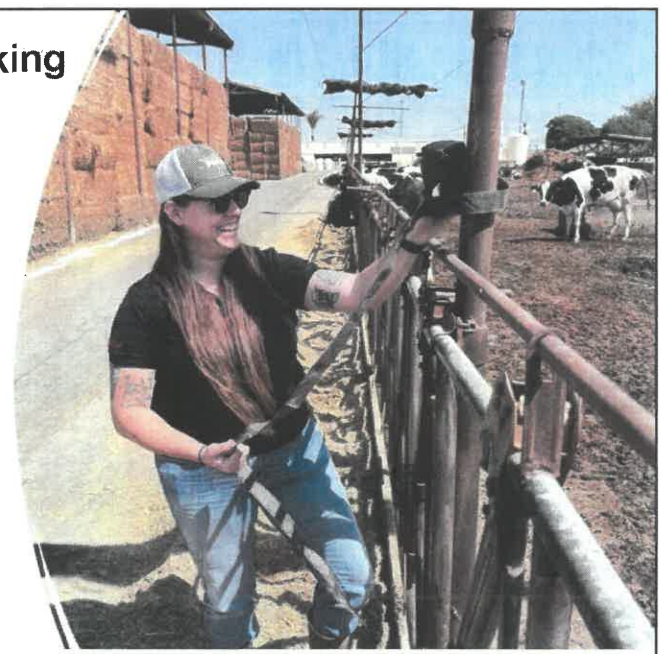
Excessive Standing and Walking

Non-Nutritional Stressors During Transition



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Excessive Standing and Walking

Non-Nutritional Stressors During Transition

1/18/2025	1:39	Pushup	1
1/18/2025	3:02	Out	1
1/18/2025	5:58	Feeding #1	1
1/18/2025	6:00	Locked	1
1/18/2025	6:56	Pushup	1
1/18/2025	8:08	Unlocked	1
1/18/2025	8:35	Feed Ridge	1
1/18/2025	10:47	Milking	1
1/18/2025	11:07	Pushup	1
1/18/2025	13:00	Feed Ridge	1
1/18/2025	14:03	Feeding #2	1
1/18/2025	16:41	Feed Ridge	1
1/18/2025	17:18	Pushup	1
1/18/2025	23:00	Pushup	1

~2 hr locked

~1.5 hr for single milking

Time lost eating and resting

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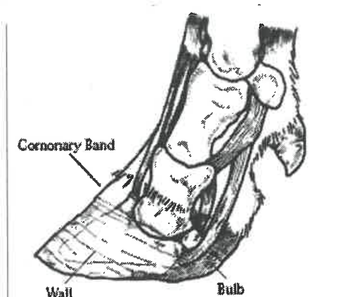
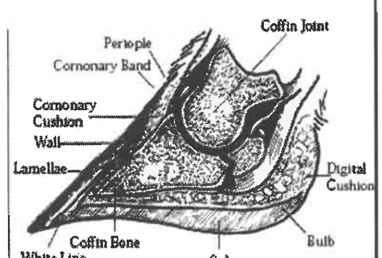
Excessive Standing and Walking

Non-Nutritional Stressors During Transition

- **Strain on feet & legs and softening of the hoof**
- **Lameness is one of the top conditions observed in slaughtered dairy cattle (76,886 cattle slaughtered in 13 countries)**
- **Cow comfort and management directly impact lameness i.e cow survival**
- **Compounding effect with social stressors like stocking density**





SOURCE: Dahl-Pedersen et al. 2018. Livestock Sci.218:108-113.

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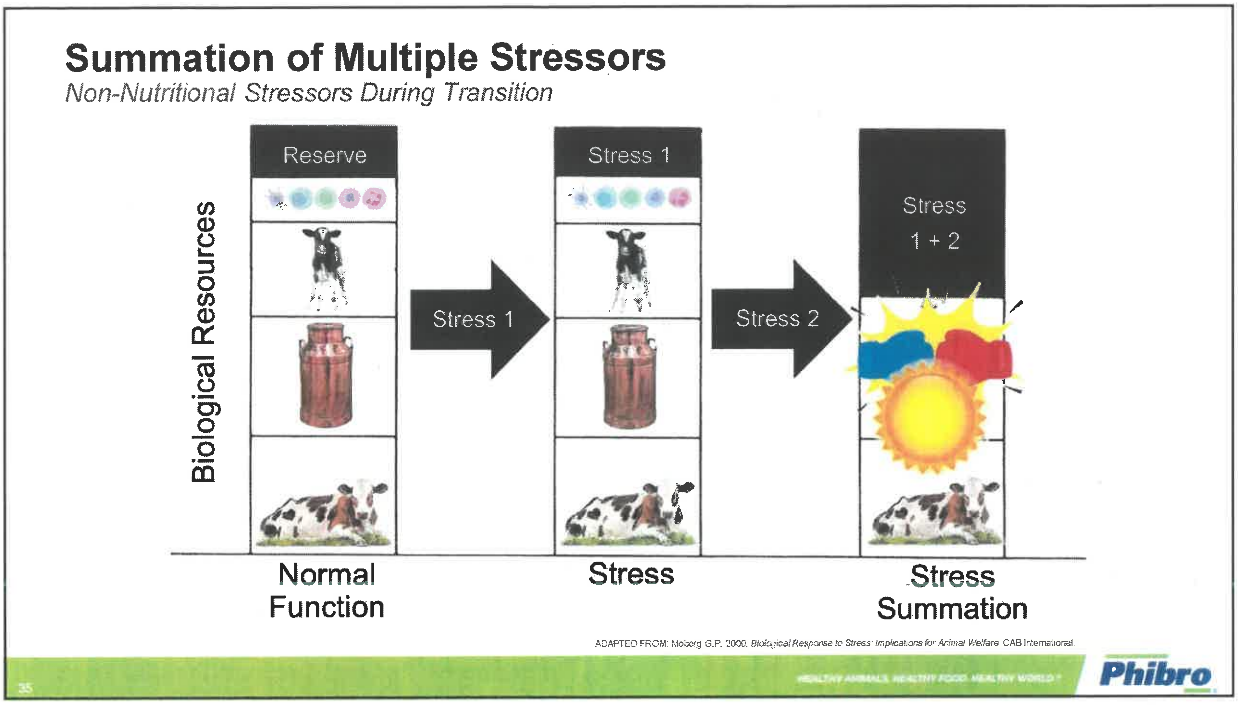
Summation of Multiple Stressors
Non-Nutritional Stressors During Transition
Biological Resources
Reserve
Stress 1
Stress 1
Stress 2
Stress 1 + 2
Normal Function
Stress
Stress Summation
ADAPTED FROM: Moberg G.P. 2000. Biological Response to Stress: Implications for Animal Welfare. CAB International.
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Physical
Feed Management
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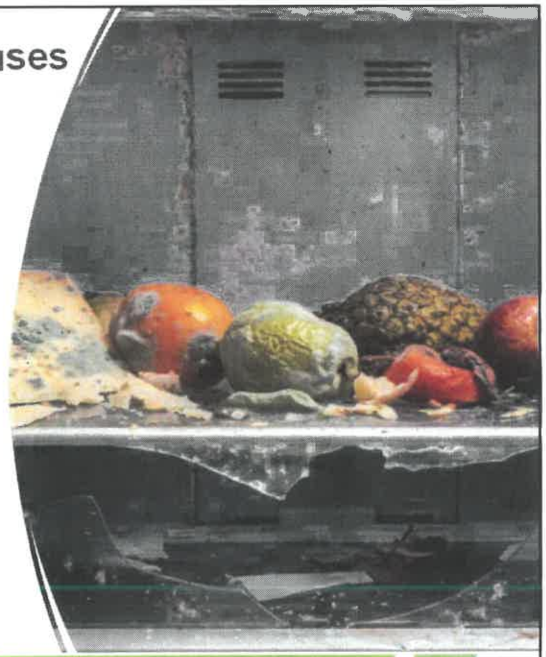
36

Disrupted Feed Management - Causes
Non-Nutritional Stressors During Transition

- Feed storage & turnover



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Disrupted Feed Management - Causes
Non-Nutritional Stressors During Transition

- Feed storage & turnover
- Mixing & delivery of the diets

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Disrupted Feed Management - Causes

Non-Nutritional Stressors During Transition

- Feed storage & turnover
- Mixing & delivery of the diets
- Feed bunk and water trough maintenance

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Disrupted Feed Management - Causes

Non-Nutritional Stressors During Transition

- Feed storage & turnover
- Mixing & delivery of the diets
- Feed bunk and water trough maintenance
- Feed availability and push-ups

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Disrupted Feed Management - Effects

Non-Nutritional Stressors During Transition

- Variability
  - Reduced intake
  - Rumen upset
  - Short term deficiencies
- Exposure to toxins
- Feed sorting
- Dehydration

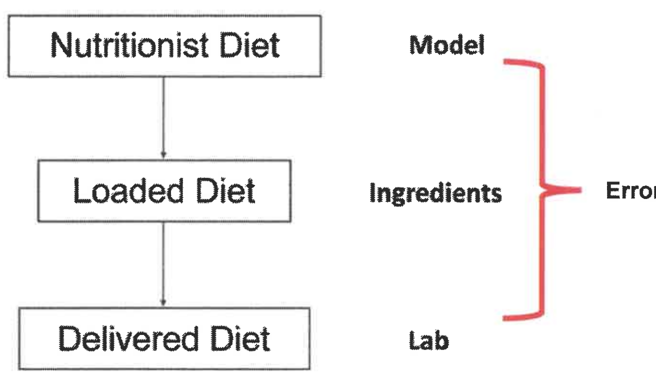
41

Feed Management and Variation

Non-Nutritional Stressors During Transition

5 Commercial Dairies

- Sampled 7 to 12wk
- 4 pens: close-up, fresh, high, low
- Assessed multiple points of variability on farm and effects on production



SOURCE: Rossow et al. 2013. J. Dairy Sci.96 7371-7381.

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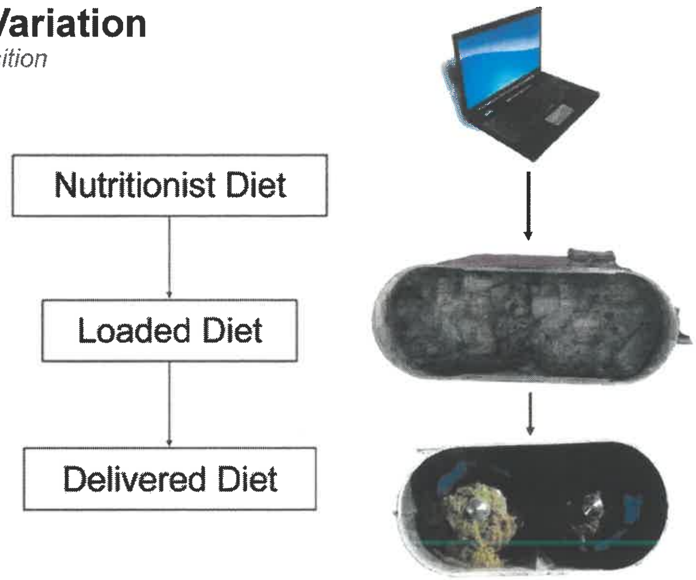
Feed Management and Variation

Non-Nutritional Stressors During Transition

5 Commercial Dairies

- Sampled 7 to 12wk
- 4 pens: close-up, fresh, high, low
- Assessed multiple points of variability on farm and effects on production



SOURCE: Rossow et al. 2013. J. Dairy Sci.96:7371-7381.

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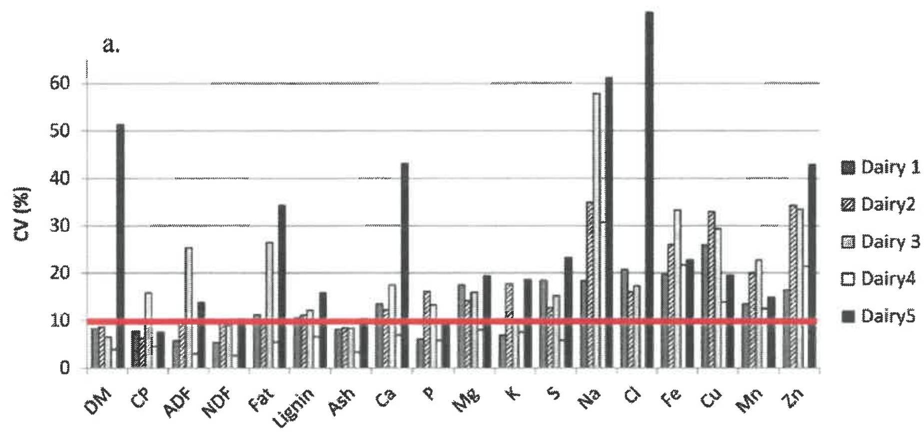
Feed Management and Variation

Non-Nutritional Stressors During Transition

- Could this be impacting your transition cow strategy?

Coefficients of variation for Close-up TMR nutrients from weekly bunk samples



SOURCE: Rossow et al. 2013. J. Dairy Sci.96:7371-7381.

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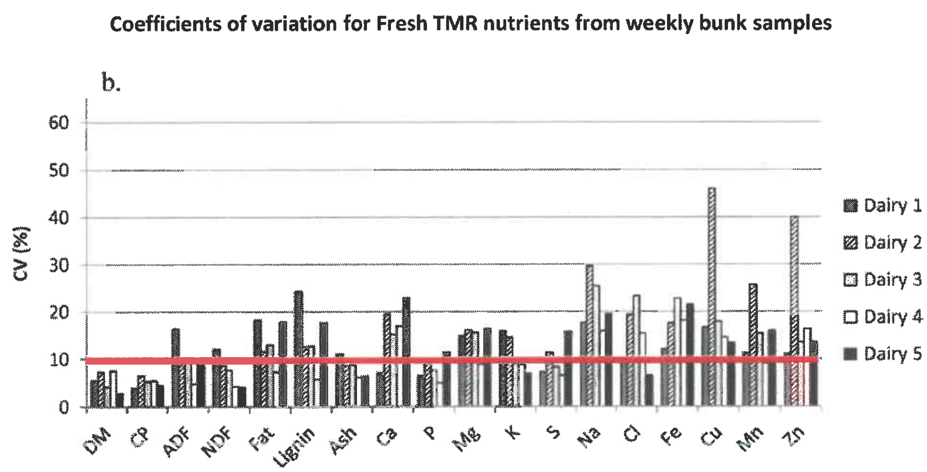
Feed Management and Variation

Non-Nutritional Stressors During Transition

- Repeated for all pens
- Looked at variation vs production outcomes
- Suggested milk yield may be the outcome most sensitive to nutrient variability



SOURCE: Rossow et al, 2013, J. Dairy Sci. 96:7371-7381

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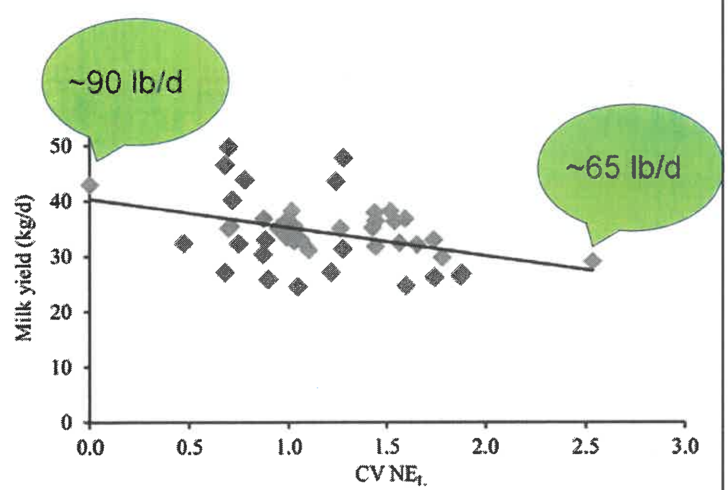
Feed Management and Variation

Non-Nutritional Stressors During Transition

22 commercial dairies

- Variability over 7 consecutive days
- Collected in summer & winter months
- 0.5% increase in CV ≥ ~2.5 lb milk loss



SOURCE: Sova et al, 2013, J. Dairy Sci. 96:4759-4770.

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Management and Production

Non-Nutritional Stressors During Transition

47 Herds in Spain surveyed to determine the effect of nondietary factors on performance

General Management	Calf Care	Heifer Care	Dry Cow Care	Lactating Cow Care
• Number of workers • Age of owner(s) • Daily working hours/worker • Working days/week • Recent investments • Future plans (willingness to continue)	• Number of animals • Colostrum feeding • Type and amount of milk • Weaning age • Weaning method • Forage availability • Water availability • Mortality rate • Housing method	• Number of animals • Age at first breeding • Age at first calving • Mortality rate • Fertility rate	• Number of animals • Duration of dry period • Animals per group • Mastitis treatment • Close-up management • Hoof trimming	• Number of animals • Housing system • Number of stalls per cow • Stall maintenance • Number of waterers per cow • Feedbunk space per cow • Waterer & feedbunk management • Number of daily milkings • Milking time, h/d • Milking settings • Milking routine • Cull rate/reasons

ADAPTED FROM: Bach, A. 2008. J. Dairy Sci. 91:3259-3267

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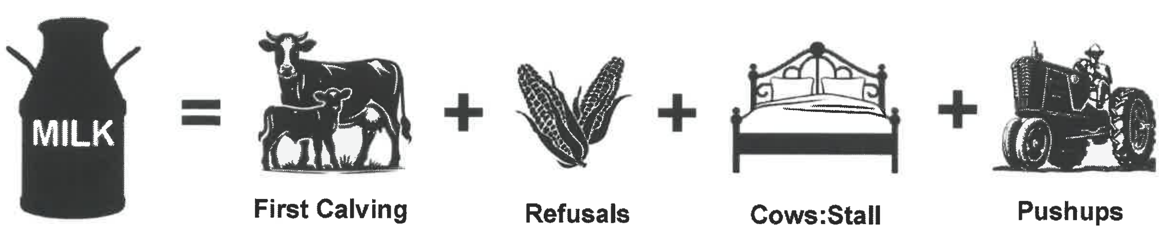
Management and Production

Non-Nutritional Stressors During Transition



Explained 56% of the variation in milk production

Management Stressors

ADAPTED FROM: Bach, A. 2008. J. Dairy Sci. 91:3259-3267

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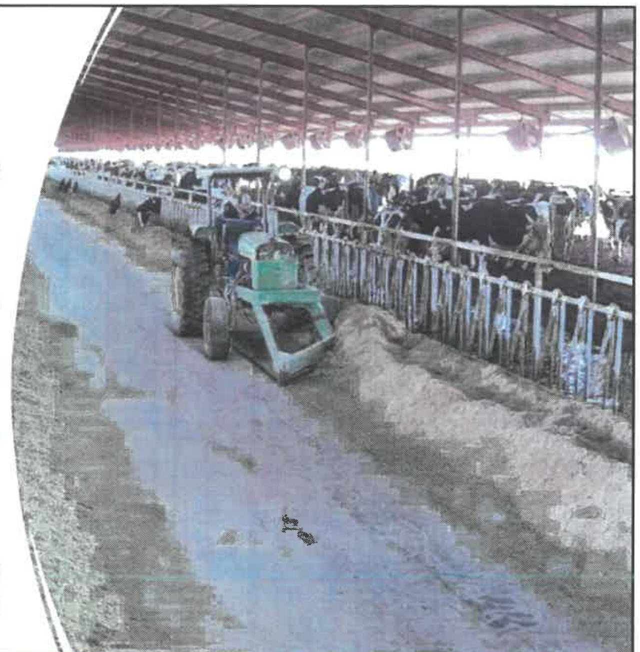
Pushups and Refusals

Non-Nutritional Stressors During Transition

1/18/2025	1:39	Pushup	1
1/18/2025	3:02	Out	1
1/18/2025	5:58	Feeding #1	1
1/18/2025	6:00	Locked	1
1/18/2025	6:56	Pushup	1
1/18/2025	8:08	Unlocked	1
1/18/2025	8:35	Feed Ridge	1
1/18/2025	10:47	Milking	1
1/18/2025	11:07	Pushup	1
1/18/2025	13:00	Feed Ridge	1
1/18/2025	14:03	Feeding #2	1
1/18/2025	16:41	Feed Ridge	1
1/18/2025	17:18	Pushup	1
1/18/2025	23:00	Pushup	1



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Pushups and Refusals

Non-Nutritional Stressors During Transition

1/18/2025	1:39	Pushup	1
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1/18/2025	14:03	Feeding #2	1
1/18/2025	16:41	Feed Ridge	1
1/18/2025	17:18	Pushup	1
1/18/2025	23:00	Pushup	1

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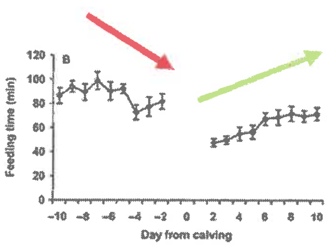
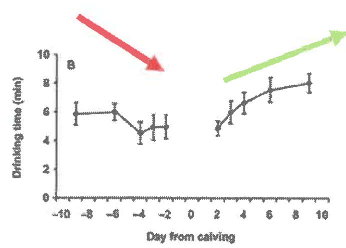
Water the Solvent of Life

Non-Nutritional Stressors During Transition

Feeding time



Drinking time



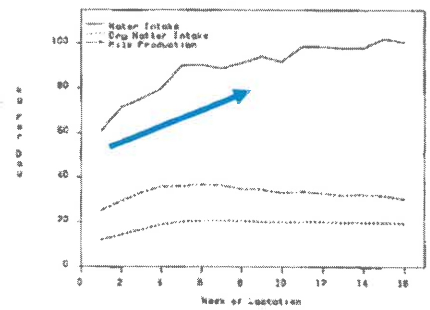


Figure 1. Water intake, dry matter intake, and milk production of dairy cows for the first 16 wk of lactation.

SOURCE: Huzzey, J. 2005. J. Dairy Sci. 88:2454-2461.

SOURCE: Murphy, M. 1983. J. Dairy Sci. 66:35-38.

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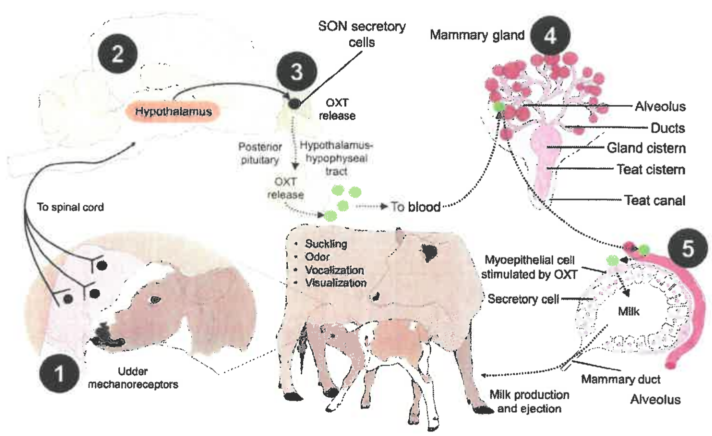
Water the Solvent of Life

Non-Nutritional Stressors During Transition

Human literature

- **Link between milk ejection, oxytocin and thirst** (Moberg et al., 2020. Plos One.15(8).)
- **Link between dehydration and aging, disease and premature mortality** (Dmitrivea et al., 2023. eBioMedicine. 87:104404.)



SOURCE: Mota-Rojas et al., 2023. Animals. 13:1207.

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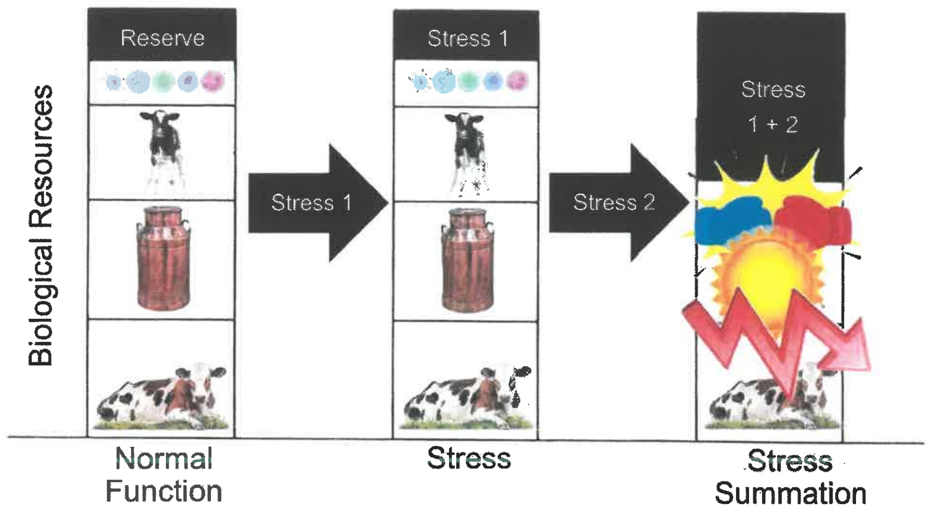
Summation of Multiple Stressors

Non-Nutritional Stressors During Transition



ADAPTED FROM: Moberg G.P. 2000. *Biological Response to Stress: Implications for Animal Welfare.* CAB International.

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Ashley Niesen, Ph.D., PAS

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559-880-0092

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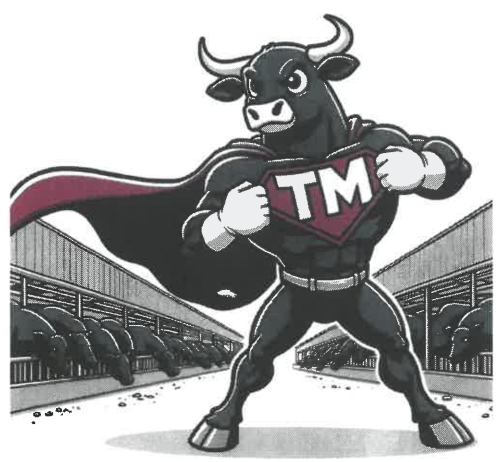
Re-examining trace mineral roles in transition cows

Stephanie L. Hansen
Department of Animal Science
Iowa State University

1

Hansen Laboratory Goal

To improve our understanding of trace mineral and vitamin requirements to optimize cattle performance and producer profit



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Feed Intake
Recover from calving
Immune function
Energy Metabolism
Antioxidants

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NASEM TM Requirements

- Recommendations are total diet, not supplemental
- But often we ignore feed contributions because they are variable (or unknown)
- Factorial approach accounts for the average cow's needs:
  - Maintenance
  - Fetal accrual
  - Milk production
  - Growth (calves, developing heifers, etc)

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Finding the balance

For the average cow, so feeding 20% extra to cover the top end makes sense. Feeding 2 or 3 x might not.

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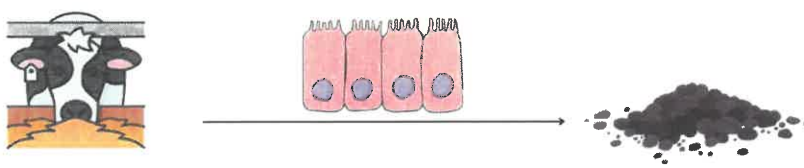
Increasing supplementation by 50%



Zn	Absorption of ~20%	@50 mg/kg *22 kg *0.8= 880 mg/d @75 mg/kg *22 kg *0.8= 1320 mg/d
Cu	Absorption of ~4-10%	@12 mg/kg *22 kg *0.95= 250 mg/d @18 mg/kg *22 kg *0.95= 376 mg/d
Mn	Absorption of ~0.5%	@30 mg/kg *22 kg *0.995= 656 mg/d @45 mg/kg *22 kg *0.995= 985 mg/d

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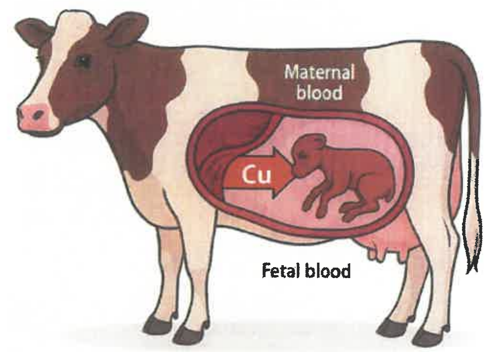
A Quick Reminder on Placental Transfer

TM supplementation in gestation not only affects the cow (health, growth) but also impacts the calf's start in life

Placental Transfer of Copper in a Dairy Cow to Her Calf



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Trace Minerals Vs. Fat Soluble Vitamins from Cow to Calf

- Trace Minerals
- Cu, Zn, Fe readily cross the placenta, accumulating in the fetal liver to provide the calf with TM early in life as cow's milk has very low TM concentrations
- Neonatal reference ranges are higher than juveniles/adults

- Fat Soluble Vitamins
  - Vitamin A and E are greatest in colostrum and calf born with almost no A & E
  - Colostrum consumption critical to give calf these essential vitamins
  - Blood taken a birth will give false negative on status

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How do we give cows the minerals they deserve?

9

Mineral sources

- Plants may not fully meet needs, or be fully available
- Inorganic sources
  - Sulfates, carbonates, oxides
  - Often highly water soluble
- Organic sources
  - Complexed or chelated to amino acid, or other ligand
  - May protect against antagonist interaction (solubility?)
- Hydroxy sources
  - Minerals (Cu, Zn, or Mn) tightly bound to hydroxy groups
    - Insoluble in water, but soluble in acids
- Injectable sources (Cu, Zn, Mn, Se) or (Se, Vit E)

10

Effects of partial replacement of inorganic chlorides with amino acid complex TM

- 69 multiparous Holstein cows, from 50–57 days prepartum through 154 DIM
- **Treatments**: (total TM supply equal between trts)
  - Control: Inorganic hydroxychloride TM (75 ppm Zn, 65 Mn, 10 Cu, 1 Co)
  - Test: Partially replaced with amino acid complex TM (Availa-Dairy; 40 Zn, 20 Mn, 3.5 Cu, 1 Co)
- **Key findings**:
  - +1.5 kg/day **more milk** ($P = 0.05$)
  - **Better liver health** early postpartum (higher LHI at 4 DIM)
  - **Calves grew faster** (higher ADG through 9 weeks)- relatively low power
- Trace mineral source influenced cow productivity and calf growth, even when total TM levels were equal.

Kerwin et al., 2023

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Selenium (and vitamin E)

- Retained placenta and somatic cell counts, mastitis often decrease with supplementation
- Partner with vitamin E
- Ruminant liver accumulates Se, caution against "stacking" Se products

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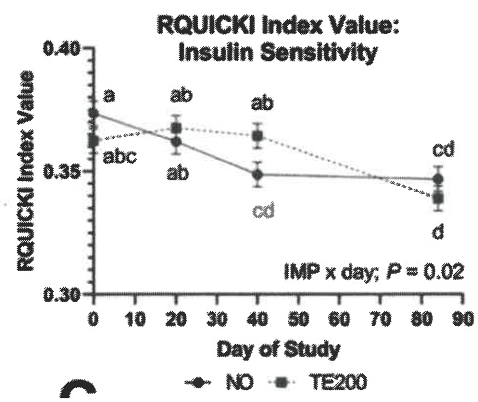
Chromium

- No established requirement but more often than not, studies show improvements in milk yield during this transition period
- Cr may reduce cortisol
- Proposed to enhance insulin sensitivity, by increasing glucose uptake through stimulation of activity of insulin receptor

Insulin sensitivity

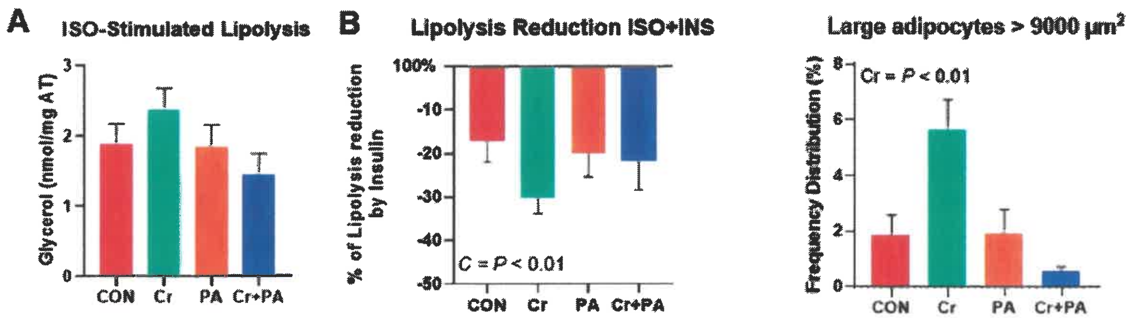
Item	HIGH	HIGHCR	MAN	SEM	*P*-value
Weekly collections[2]					
Serum glucose, mg/dL	95.6[a]	91.1[b]	92.7[ab]	1.3	0.09
Serum NEFA, mmol/L	0.176[a]	0.139[b]	0.144[ab]	0.012	0.08
RQUICKI	0.578[a]	0.780[b]	0.841[b]	0.072	0.05
Glucose tolerance test[3]					
Glucose (area under the curve, mg/dL·min)	18,638	17,708	16,971	1,650	0.45
Insulin (area under the curve, mg/dL·min)	6,324[a]	3,668[b]	4,918[ab]	1,394	0.04
Glucose clearance rate, %/min	0.949	1.163	1.049	0.173	0.61
Glucose half-life, min	101.7	77.4	78.1	21.9	0.68

Leiva et al., 2014 JAS 92:775-782



Smerchek et al., 2024

Chromium propionate for 24 DIM decreased markers of lipolysis and increased markers of lipogenesis



Chirivi et al., 2025; JDS

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Zinc

- Well studied in transition- but maybe mostly in shorter durations
- Immune system support, "tamping down" of inflammatory response
- Sources other than inorganics in particular seem beneficial here
  - Zinc sulfate can knock back fiber digestion
- Helping with feed recovery and increasing intakes after parturition?

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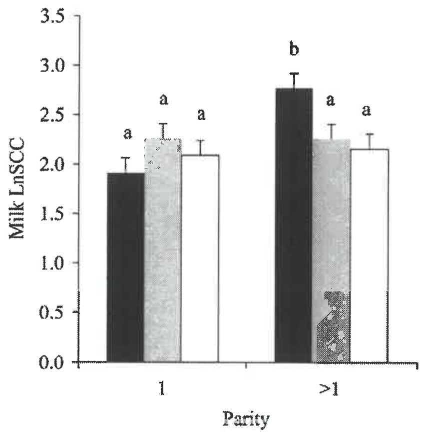
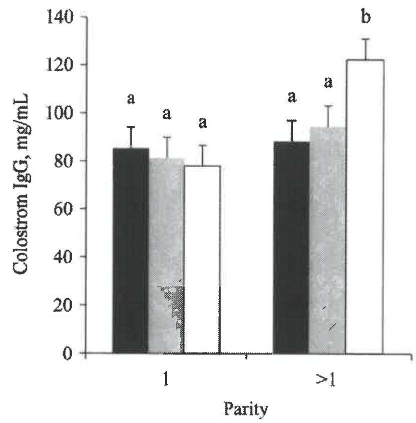
Increasing from 0 to 16 to 40 ppm Zn-AA complex linearly increased efficiency (MY, FCM, and SCM/DMI)





Nayeri et al., 2014

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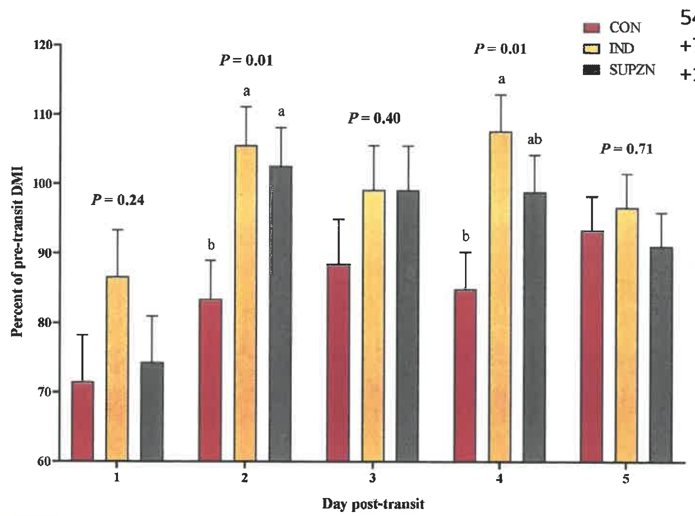
Zn supplemented cattle recover DMI post-transit more quickly



54 mg Zn/kg DM basal
+70 mg/kg
+120 mg/kg

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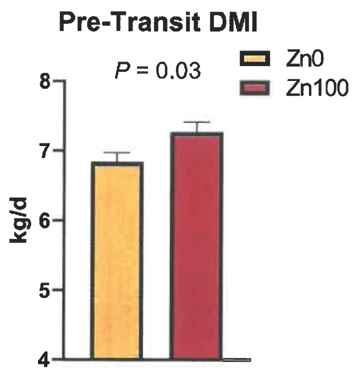
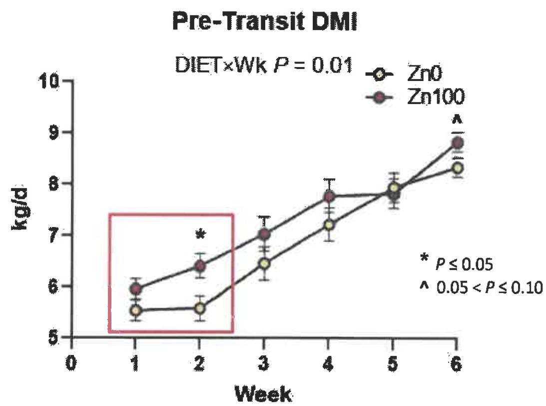
Pre-Transit: Performance





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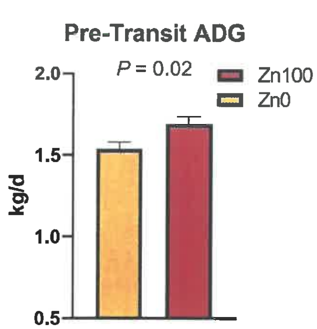
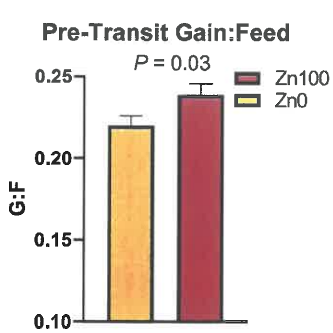
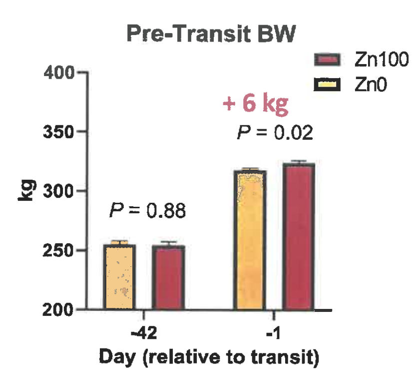
Pre-Transit: Performance







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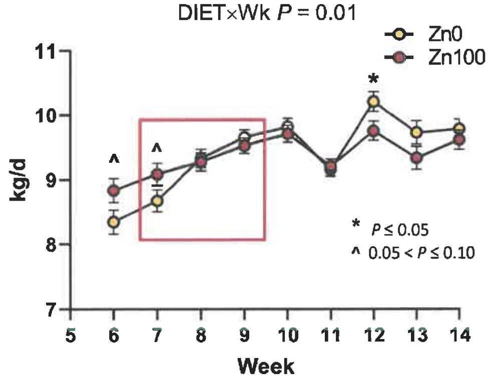
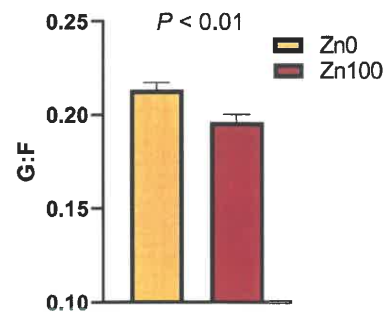
Post-Transit: Performance

All treatments receiving Zn100 diet





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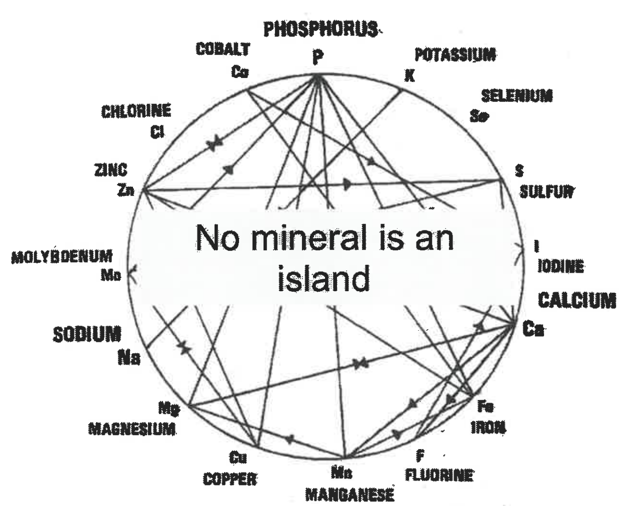

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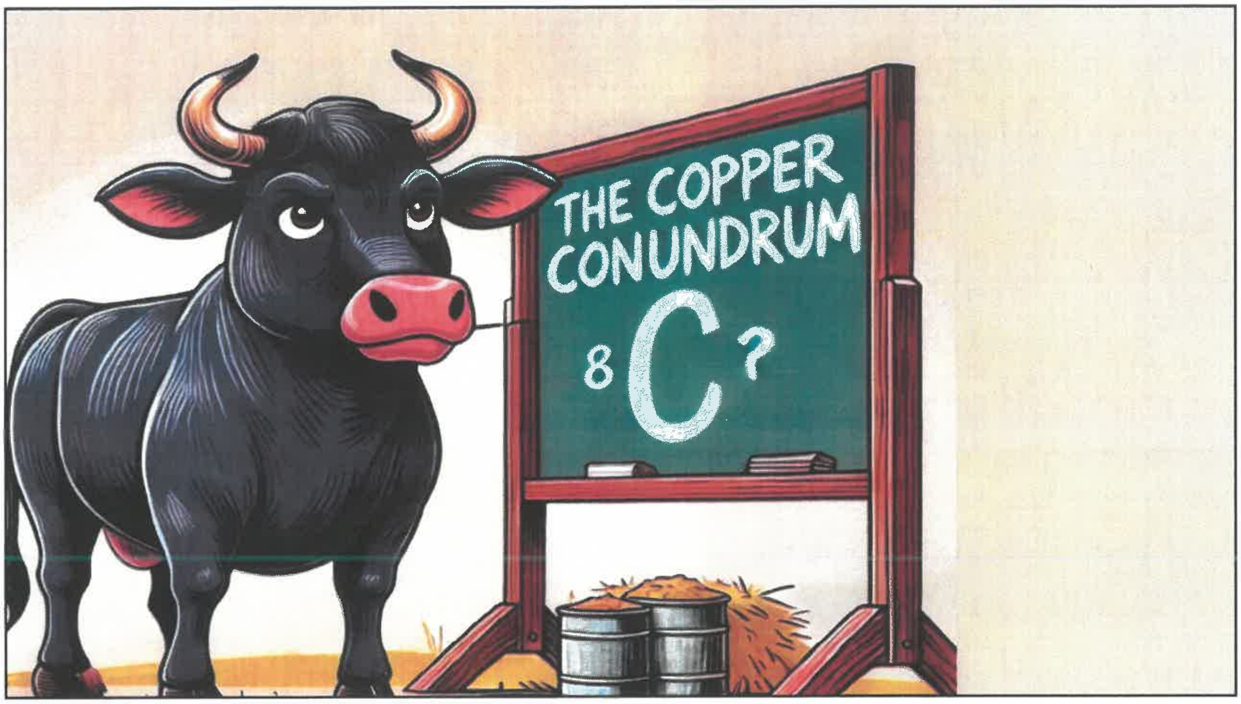

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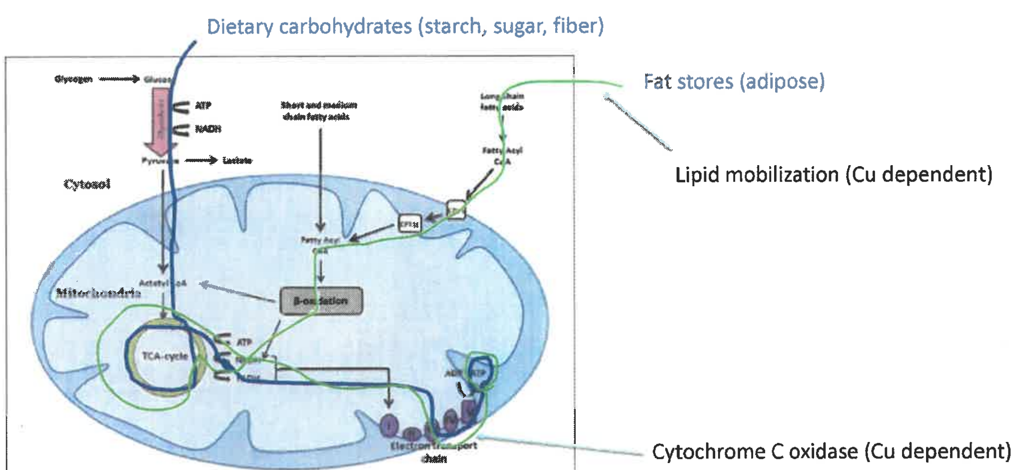
Copper is essential for energy metabolism



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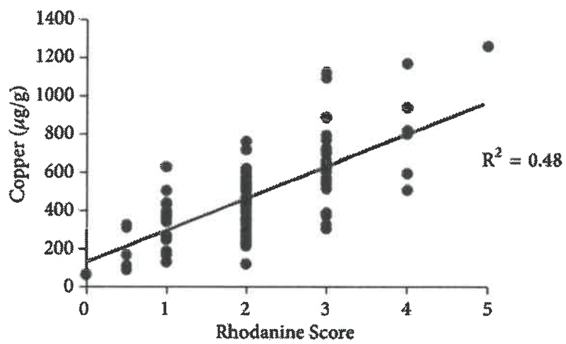
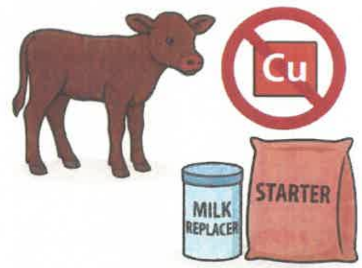
But in excess....

- Liver crude fat inversely correlated with liver Cu
- High liver Cu not associated with inflammation, but associated with oxidative stress



Strickland et al., 2019

Excessive Copper Supplementation in Calves



- Copper accumulation in the liver
- Oxidative stress

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The impact of excess liver copper on response to bovine respiratory disease

Jacob Henderson, Stephanie Hansen, Jodi McGill

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Experimental Design

- Beef-on-dairy steers weighing 209 ± 15 lb, 8 wk of age
- Two treatments: adequate (**ADE**) and **HIGH**
  - 13 steers per treatment
- Pelleted starter diet fed for 47 d, plus ad libitum hay
  - ADE: 10 mg Cu/kg DM
  - HIGH 20 mg Cu/kg DM
- Steers transitioned to TMR, fed for another 73 d
  - ADE 0 mg Cu/kg DM
  - HIGH: 10 mg Cu/kg DM

Table 1. Composition of common total mixed ration.

Ingredient	% of diet DM
Hay	15
Corn	15
Corn Silage	15
Dried distillers grains	18.06
Sweet Bran	35
Cu premix	5
Trace mineral premix	0.0204
Limestone	1.5
Salt	0.31
Vitamin A & E premix	0.1
Rumensin 90	0.0135
Analyzed Composition	
Crude protein, %	18.4
Neutral detergent fiber, %	33.1
Ether extract, %	5.2
Sulfur, %	0.31
Molybdenum, mg/kg DM	0.97
Copper, mg/kg DM	4.8
Zinc, mg/kg DM	67.5
Iron, mg/kg DM	211

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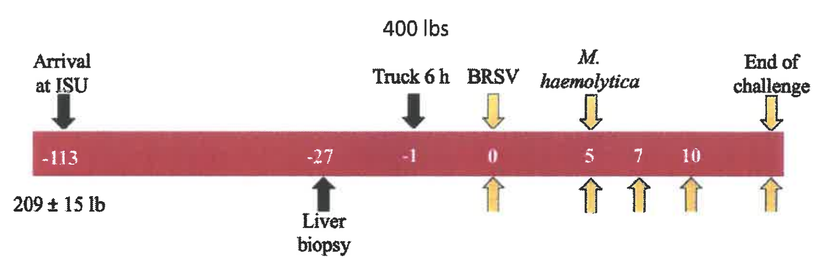
Experimental Timeline



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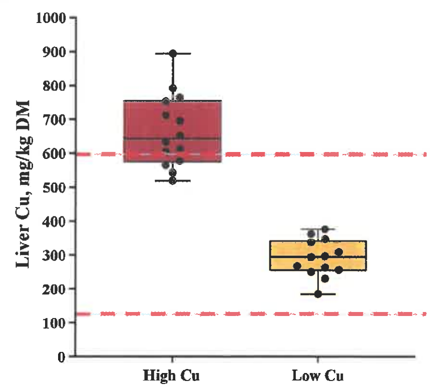
Liver Cu Concentration

- High Cu: 665 ± 23 mg Cu/kg liver DM
  - Range 519-893 mg/kg DM
- Low Cu: 291 ± 24 mg/kg DM
  - Range 240-376 mg/kg DM

Kincaid (1999) "adequate" range:
125-600 mg Cu/kg liver DM



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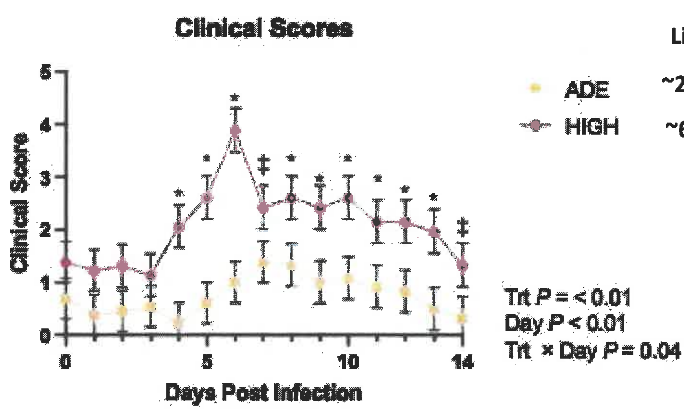
Liver Cu of 600 mg/kg DM results in sicker calves at feedlot entry



Liver Cu
~250 mg Cu/kg DM
~600 mg Cu/kg DM

Henderson et al., unpublished

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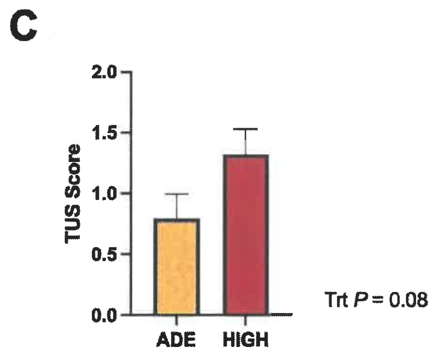
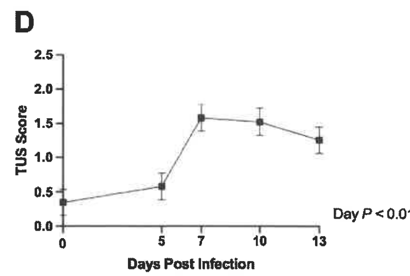
Lung consolidation is worse with high Cu status





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Conclusions

Excess liver Cu resulted in heightened severity of disease and an impaired nutritional immunity response, **indicating that excess liver Cu may be a contributing factor to the poor health of beef on dairy calves in the feedlot**

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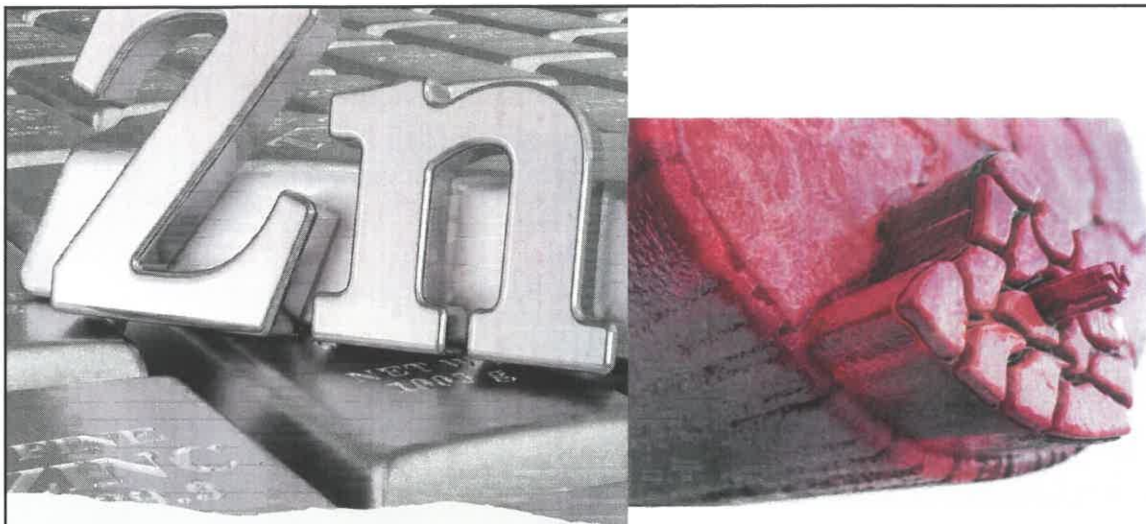

Zinc

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Impact of clinical and subclinical BRD on tissue-specific regulation of Zn and vitamin A metabolism and apparent absorption and retention of trace minerals

Emma Rients, Stephanie Hansen, and Jodi McGill

IOWA STATE UNIVERSITY

Department of Animal Science

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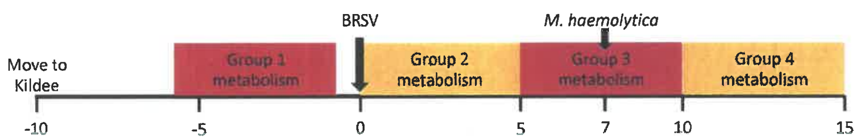
Methods – animals and infection model

- Protocols approved by IACUC (IACUC-21-003) and IBC (IBC-21-001)
- Dairy × Beef crossbred steers (n = 29; BW = 230 ± 12.1 kg)
- 10 d prior to infection steers were moved to the metabolism facility in Kildee Hall
- Co-infection model:
  - Aerosol inoculation with 10^4 $TCID_{50}$ BRSV strain 375 (d 0)
  - Intratracheal inoculation with 9.3 x 10^9 CFU *Mannheimia haemolytica* strain D153 (d 7)



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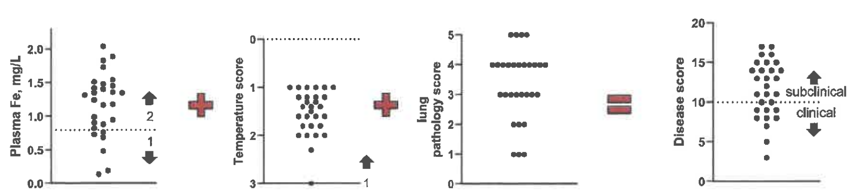
Methods – disease classifications

- Steers were grouped into clinical or subclinical disease using the following criteria:
  - Plasma Fe > 0.8 mg/L was assigned a 2; Plasma Fe ≤ 0.8 mg/L was assigned a 1
  - Rectal temperature scores were averaged and ranked
  - Lung pathology score
- Plasma Fe score + lung pathology score + rectal temp score = disease score

  Clinical = scores < 10 (n = 9)   Subclinical = scores ≥ 10 (n = 20)



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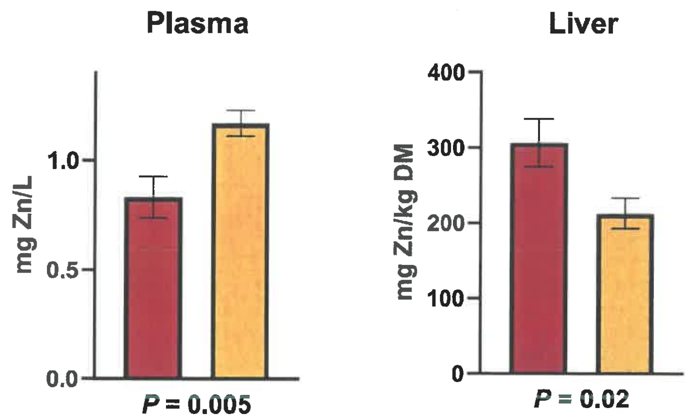
Tissue Zn changes during illness



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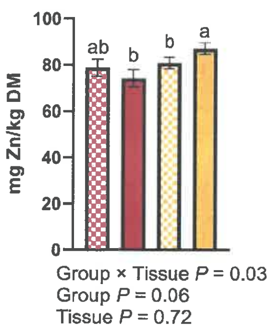
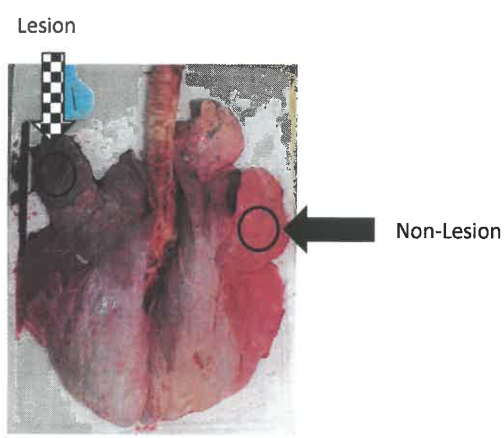
Zinc in the lung

Clinical Lesion
Clinical Non-Lesion
Subclinical Lesion
Subclinical Non-Lesion





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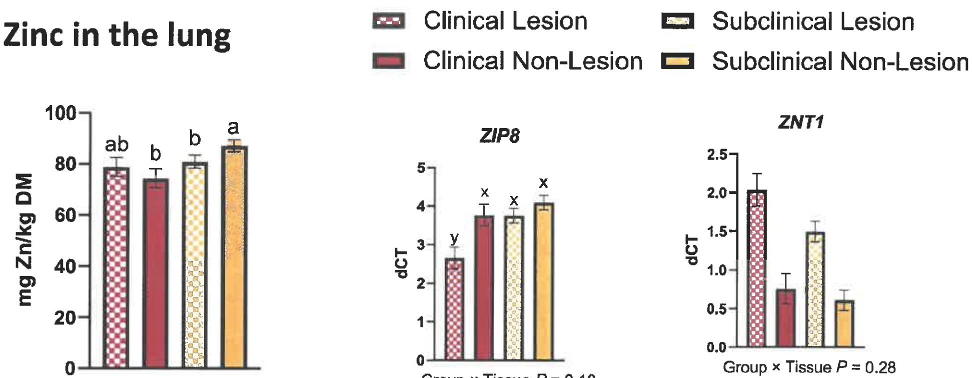
Zinc in the lung



Group × Tissue $P = 0.03$
Group $P = 0.06$
Tissue $P = 0.72$

Group × Tissue $P = 0.10$
Group $P = 0.01$
Tissue $P = 0.003$

Group × Tissue $P = 0.28$
Group $P = 0.04$
Tissue $P = 0.0001$

Diseased lung is looking for zinc

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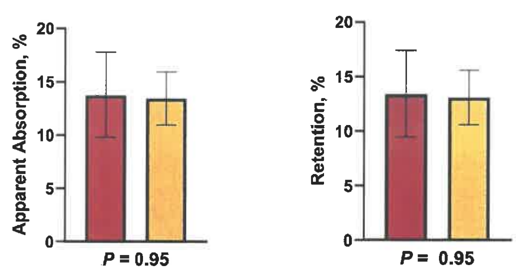
But Zn apparent absorption and retention are not different due to disease



Also, no difference in

- Urinary Zn excreted (mg/day and % of intake)
- Fecal Zn (% of intake)
- Zn retention (mg/day; $P \geq 0.24$)

$$AA\% = \frac{Zn\ intake - fecal\ Zn}{Zn\ intake} \times 100$$

$$\text{Retention } \% = \frac{Zn\ intake - (fecal + urine\ Zn)}{Zn\ intake} \times 100$$

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Change in mineral concentration in clinical disease relative to subclinical disease

Liver
Zn +43.9%**
Fe +53.5%**

Kidney
Zn +15.1%*

Lesion Lung
Fe +41.4%**

Non-Lesion Lung
Zn -14.8**

Pancreas
Mn -26.1%**

Thymus
No differences

Tracheobronchial Lymph Node
Zn -5.1%*
Cu +14.7%**
Fe +64.5%**
Mn +20.9%**

Spleen
Cu +9.2%**

Plasma
Zn -29%**
Cu +28.8%**
Fe -44.2%**

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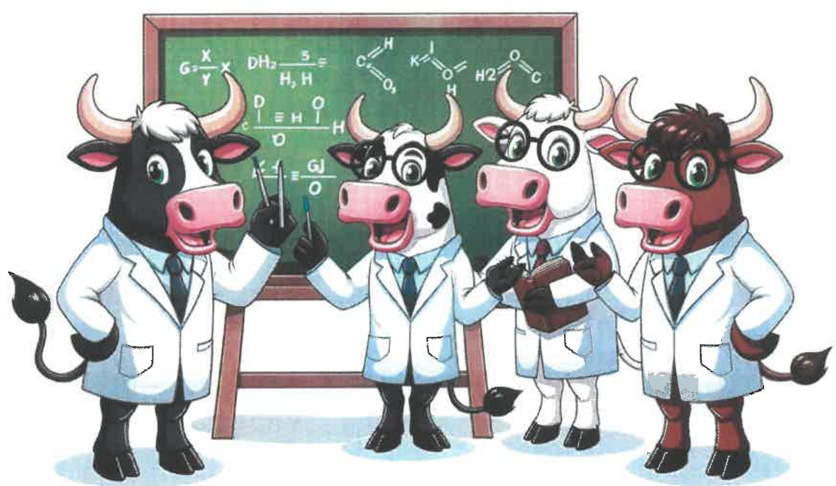
What's next?



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Conclusions

- Transition period = critical window to get trace mineral nutrition right (Duplessis & Royer, 2023)
- Trace minerals support increased production and increase resiliency to disease and other stressors
- But "more is not always better" — excess can harm cow health, calf outcomes, and nutrient management
- Precision feeding supports health, performance, and responsible stewardship

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Acknowledgments

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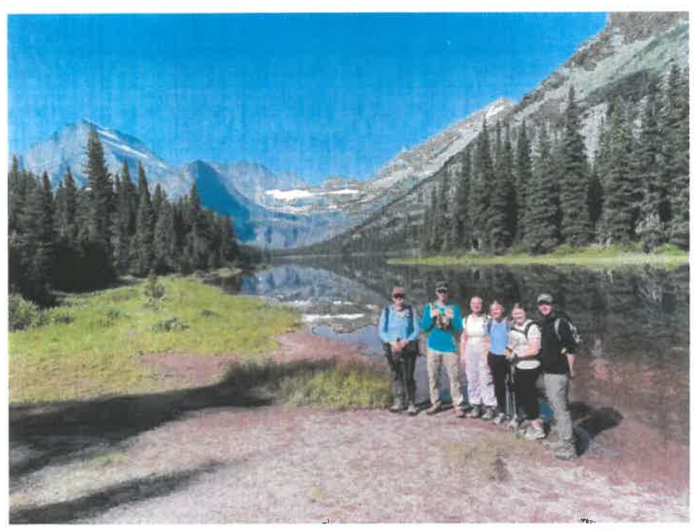
Phytobiotics

Elanco, Zoetis (product donation)

Iowa Beef Checkoff

Hansen Ruminant Nutrition Lab



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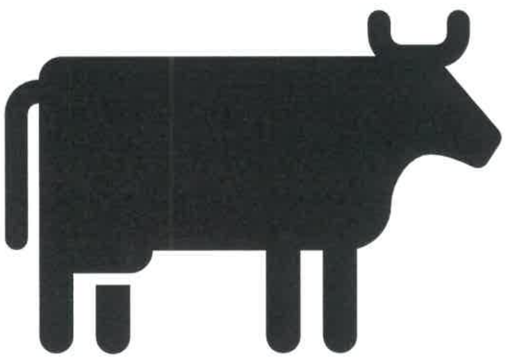
Strategic Decision Making:
Drivers of Farm Strategy and Adopting Precision Technologies

Brady Brewer
Department of Agricultural Economics
Kansas State University

California Animal Nutrition Conference
May 7th, 2025

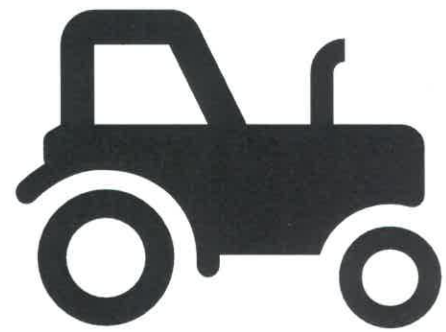
KANSAS STATE UNIVERSITY | Agricultural Economics

Overview



How should we think about farm strategy?

How do farmers approach strategy?



How does adoption of precision technologies impact farm strategy and profitability?

The Five Managerial Levers a Farmer Can Pull

Output Price	Yield	Costs	Assets	People
Manage price you get for what you produce.	Manage how much output you produce.	Manage how much it costs you to produce.	Manage your balance sheet/What tools you use to produce.	Manage the people that help you with the four levers above.

Feed Management Survey

- Survey of dairy feed managers and employees
- Most questions on a scale from 1 to 5
  - 5=Always
  - 4=Most of the Time
  - 3=About Half of the Time
  - 2=Some of the Time
  - 1=Never
- Answers to questions then compared to dairy herd performance metrics
- In partnership with Phibro Animal Health Corporation

Feed Management Survey

Average Daily Milk (lbs of milk per cow)		
Score on Metric	"Our Dairy has an attitude of excellence"	"My dairy fills the TMR Mixer to capacity and avoids overfill"
3 or less	62.00	64.33
4	65.66	70.11
5	71.96	71.75

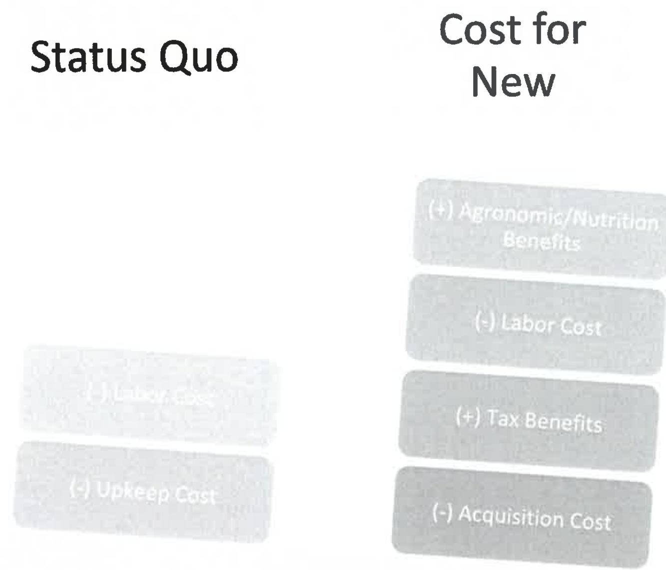
Scale is from 1 to 5 where 1 is the negative response and 5 is the most positive response. Source: Phibro, Vital Insight Feeder Survey
1=Never, 2=Some of the time, 3=About half of the time, 4=Most of the time, 5=Always

Feed Management Survey

- Positively correlated with milk yield per cow
  - "I receive feedback on the work I do as a feeder"
    - Manage People
  - "Accuracy and consistency are high priorities"
    - Manage Costs/Yield
  - "Our feed equipment works well and achieves what we need it to do"
    - Manage Assets

Must Answer

Will the new equipment cost less than existing equipment?



Equipment Decision Checklist

Questions that need answered at the beginning

- ❑ What are the tasks that need to be performed?
- ❑ What tools/implements are necessary for accomplishing the work?
- ❑ What are the minimum horsepower requirements for those implements?
- ❑ How many acres or number of head can this purchase be divided over?

What specific equipment (and size) do I need?

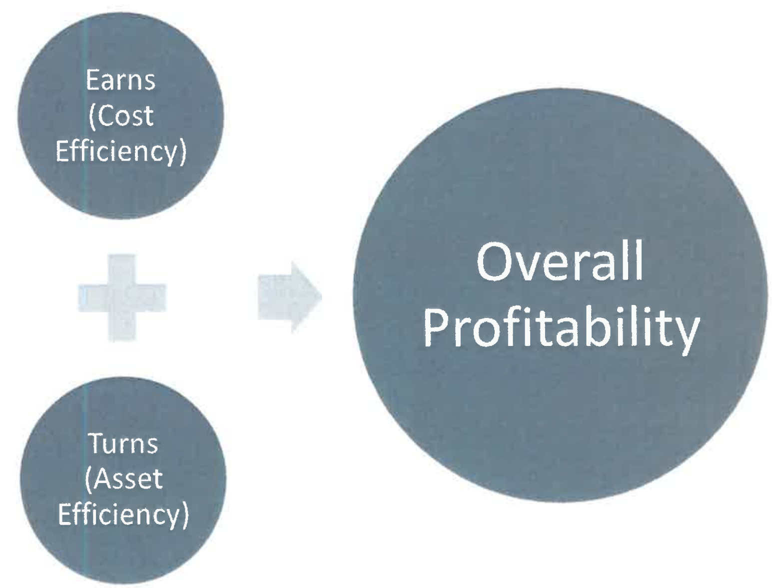
- ❑ What will owning those implements cost?
- ❑ What will owning the tractors with the minimum hp and features requirements cost?
- ❑ How much does a custom operator charge to perform the same task?
- ❑ How much do you anticipate the regular maintenance will cost?

What will be the financial implications of this purchase?

Source: Iowa State University

Why Focus on Efficiency?

- Two key inputs to profitability: Costs and Assets
  - Earns
    - How cost efficient a business is
  - Turns
    - How asset efficient a business is
  - These sometimes work together, but often are at odds with each other.
    - Tradeoffs are key to understand.



Benchmarking

	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Interest Expense Ratio	18.8%	10.8%	7.9%	6.0%	4.7%	3.6%	2.5%	1.6%	0.6%	0%
Operating Profit Margin	-53.8%	-18.8%	-8.1%	-0.9%	4.2%	9.1%	13.6%	19.3%	26.3%	39.2%
Asset Turnover Ratio	.094	.16	.211	.251	.28.9	.337	.39	.467	.593	.91

Source: FINBIN, University of Minnesota

Precision means more efficiency and decision making

- More efficient with other costs
  - Fuel
  - Fertilizer
  - Crop Protection
  - Time and labor
- Increase in plant health and yield
- Data for better decision making

What farmers benefit most from technology?

(RESEARCH): Fiechter, Brewer, Ifft

- Four types of efficiency that we studied
  - Pure Technical: Ability to turn inputs into farm output
  - Scale: Are you the right size. E.g. would you be more efficient if you "scaled up"
  - Allocative: Are you using the right mix of inputs
  - Overall: Could you produce the same amount of farm output for lesser cost

- Minimal returns to single technology implementation
- Higher returns to bundles of technology

- Impact of technology different based on the efficiency of the farm
  - Already efficient farms did not benefit from further technology adoption
  - Inefficient farms benefited the most from technology adoption

What farmers benefit most from technology?

(RESEARCH): Fiechter, Brewer, Ifft

- Most of the efficiency gain was because of better allocation of inputs.
  - Not using too much of one input or not enough of another

- When considering buying equipment, specially Ag Tech:
  - Already efficient farms: actual efficiency gains may be lower than expected
  - Less efficient farms: actual efficiency gains will be higher than expected

- Highest Overall Efficiency Gain in Study: ~8.5%

Importance of Retaining Employees

$1,678

Average DIRECT cost to train a new employee in 2022

3x – 4x of Salary

$35k=

Total Costs to Train an Employee

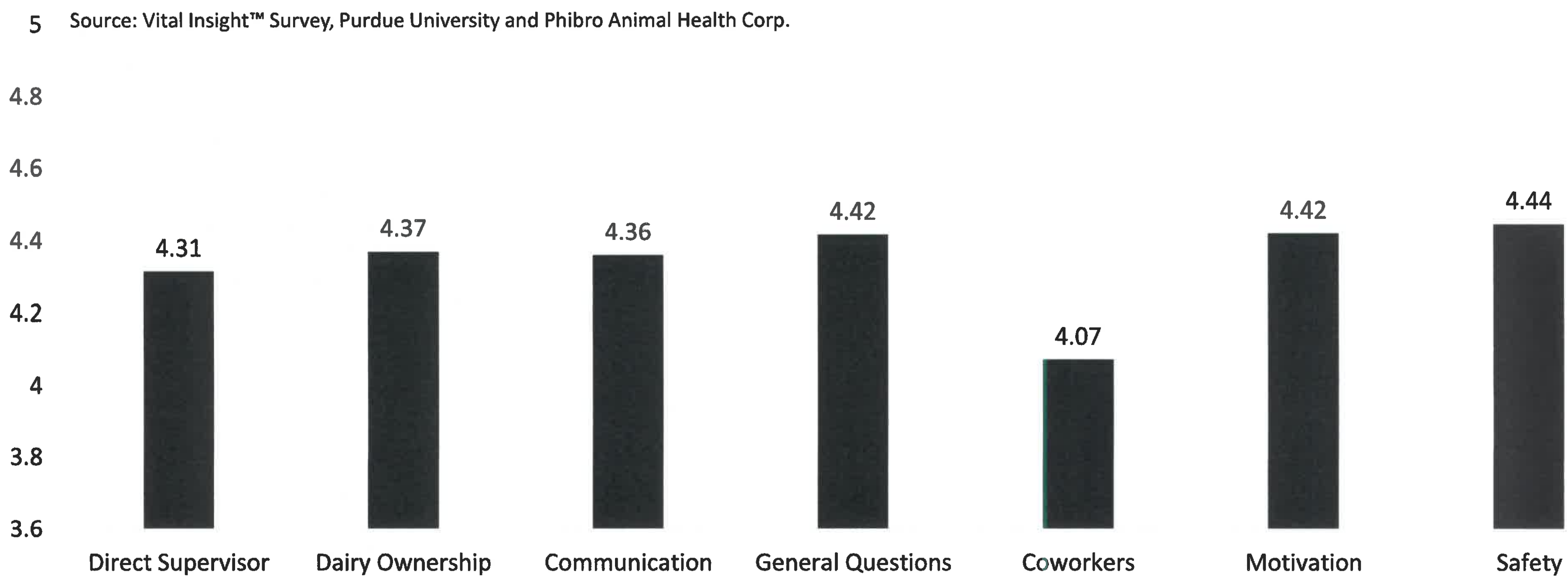
Lost Efficiency

Mistakes

Other employee time

Dairy Employee Engagement Category Scores

Source: Vital Insight™ Survey, Purdue University and Phibro Animal Health Corp.



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Dairy Employee Engagement Category Scores

Source: Vital Insight™ Survey, Purdue University and Phibro Animal Health Corp.

Strategic Decision Making:

Drivers of Farm Strategy and Adopting Precision Technologies

Brady Brewer
Department of Agricultural Economics
Kansas State University

California Animal Nutrition Conference

May 7th, 2025

Weaning with Less Distress in Dairy Calves

James K. Drackley[1]
Department of Animal Sciences
University of Illinois Urbana-Champaign

Introduction

Knowledge of and interest in calf nutrition and management has exploded in the last 25 yr. Calf nutrition has progressed from a simple, one-size-fits-all approach to a more sophisticated understanding of the role that early nutrition plays in growth, health, and future productivity. The industry has moved away, slowly, from the idea that calf nutrition is "one bag of milk replacer per calf and all the starter they'll eat" to evaluating the desired performance objectives and designing a feeding program to achieve the goals.

The milk-feeding period is certainly a front and center welfare concern, as well as a huge economic opportunity for producers and calf specialists alike. The old "convention" of feeding a pound or a pound and a quarter of milk replacer to calves is slowly being replaced by intakes of more nutritious milk replacer that perhaps are twice as great, which approach "natural" intake levels. The last National Animal Health Monitoring system {NAHMS) study conducted in 2014 found that the average amount of milk fed on US dairy farms was 5.7 L/d per calf, which equates to about 740 g/d (1.6 lb) of milk solids (Urie et al., 2018). That average likely has continued to increase in the decade since the survey was performed, with many farms feeding 6 to >8 L of milk or milk replacer daily. NASEM (2021} stated that the minimum amount of milk solids to be fed should be 1.5% of birth body weight (BW}, which for a 95-lb (43 kg) Holstein heifer would be >1.4 lb (0.64 kg} of solids or more than 11 lb (5 kg) of whole milk. Clearly, many farms surpass this minimum amount.

While progress has been made on improving welfare of calves during the milk feeding period, the situation often falls apart at weaning. Calves may struggle at weaning with decreases in average daily gain (ADG) and increases in diseases such as bovine respiratory disease (BRD) and coccidiosis. Much of this difficulty lies in the failure to adjust our systems of weaning for the practice of feeding more milk or milk replacer.

---

[1] Contact at 1207 W. Gregory Dr., 260 Animal Sciences Laboratory, Urbana, IL 61802, (217) 244-3157, email: drackley@illinois.edu.

My aim is to discuss the weaning transition and factors that influence it. Current views on nutritional management during the weaning transition as supported by key research are presented and discussed. The paper is not complete or exhaustive in its coverage of the extensive amount of research conducted within the last 25 yr.

Changes around weaning

By definition there are marked changes in nutrition around weaning as the liquid feed (milk or milk replacer) is withdrawn and the calf becomes wholly dependent on starter feed and free water. In addition to the nutritional change, there is often a change in environment and housing, as calves are moved from a hutch to a group setting. Calves must learn to compete and coexist with herdmates for the first time. The feeder stops coming twice a day with the delicious warm liquid feed. All of these factors constitute stressors on the calf.

Weaning distress weakens the immune system and decreases nutrient intake for growth. Behavioral changes include increased vocalization and decreased resting. Slumps in growth are common and the calf is susceptible to infections such as BRD and coccidiosis. Growth and health are impaired because of the decreased nutrient intake and the effects of the stressors. Holstein calves in the 2014 NAHMS survey had respectable ADG before weaning of 0.73 kg/d. However, after weaning until 90 d the ADG slumped to 0.60 kg/d. Gains of withers height followed the same pattern. This loss of performance represents lost potential growth and a greater presence or likelihood of disease.

The most important factor in preparing the calf for weaning is developing the rumen so that the ruminal microbiome can ferment solid feeds and VFA can be absorbed. Fermentable carbohydrates lead to butyrate and propionate production that stimulate rumen epithelial development. Starter intake therefore plays the key role in rumen development. The amount of milk or milk replacer fed is inversely related to starter intake (Hodgson, 1971; Stamey Lanier et al., 2022).

When the calf is a functioning nonruminant, the digestive tract contents represents a relatively small proportion of BW compared with the mature ruminant. As the calf continues to increase solid feed intake, gut fill increases. Weaning, therefore, results in a decrease of empty BW (EBW) as a proportion of live BW. The NASEM (2021) system set EBW at 94% of BW for a milk-fed calf, and 93% for a calf consuming milk and small amounts of starter. However, EBW for a weaned calf is considered to be only 85% of BW. The remaining proportion of BW is gut fill, which increases as the calf approaches and goes through weaning. We conducted a study where some calves were sacrificed at 5 wk and the remainder were weaned at 6 wk and sacrificed at 10 wk of age. The increase of gut fill from 5 wk of age when calves were consuming milk replacer and starter for ad libitum intake to postweaning at 10 wk of age alone provided 0.21 to 0.28 kg/d contribution to measured ADG of BW, while EBW gain was much less (Stamey Lanier et al., 2021). Thus, gut fill can be approximated to account for 25 to 30% of ADG at 10 wk of age. Gain of body tissue, or true growth, is much less than measured ADG.

A key physiological challenge for young calves is stabilization of rumen pH within a range where fiber digestion can proceed, generally considered to be >6.0 {Williams and Frost, 1992). Examples of ruminal pH from the literature show that most of the values of pH are< 6.0, and the simple average of the mean pH values from a sample of studies is 5.70, which is below the threshold for subacute rumen acidosis for calves {5.8) defined by Laarman and Oba (2011). Indeed, a number of values were below 5.2, which is used as a threshold for acute ruminal acidosis {Laarman and Oba, 2011). While it is hard to discern dietary, age, or management factors that may have an influence on ruminal pH without conducting a formal meta-analysis and meta-regression, it is evident that ruminal pH is often much lower in calves than in mature ruminants.

The normal pH of the rumen is around 6.0 at 1 wk of age (Anderson et al., 1987a,b; Suarez-Mena et al., 2016) but decreases thereafter as starter intake increases, to a nadir of <5.0 to ~5.6, depending on starter characteristics and forage availability. In calves fed starter and chopped straw and weaned at 6 wk of age, preweaning pH was below 5.8 for approximately 936 min/d, increasing to 1204 min/d at 2 wk postweaning before beginning to lessen by wk 12 (van Niekerk et al., 2021). Such low pH would represent subacute to acute acidosis in mature cattle {Plazier et al., 2022), but in many cases calves do not show signs of acidosis. Nevertheless, low pH is inhibitory to voluntary feed intake (Williams and·Frost, 1992) and increases the variation in dry feed intake (Frost, 1989). Given that calves cannot substitute adequate amounts of dry feed to compensate for decreased milk intake, low rumen pH may be an important factor in difficult weaning. Ruminal pH begins to increase after stabilizing following weaning, but still remains <6.0 at 12 wk {Anderson et al., 1987a,b) to 16 wk (Quigley et al., 1992; Gelsinger et al., 2020).

Calf starters

Calf starters play a hugely important role in early calf nutrition. They supply additional nutrients, but more importantly provide the fermentation substrate for rumen microbes to produce the volatile fatty acids (VFA), of which butyrate and propionate are the most important for rumen epithelial (papillae) development (Sander et al., 1959). At birth the rumen and reticulum are undeveloped, but VFA (propionate and butyrate) stimulate the growth and differentiation of epithelial structure. The functional epithelium absorbs the VFA, in turn helping to increase the pH in the rumen. As pH increases to 6.0, fiber-digesting microbes are able to survive and function, initiating the digestion of forages and non-forage fiber sources (Williams and Frost, 1992).

Consequently, the most important property of a calf starter is that the calf wants to eat it. Palatability and acceptability are influenced by both the ingredient composition and the physical form of the starter. Although differences are small, a well-texturized starter generally favors greater intake than an all-pelleted starter (Porter et al., 2007). Pellet quality is important in either case, as calves do not like fines in the starter. Ground (mash or meal) starters also can be well utilized, although initial intake may be slower. Small particle size does not seem to be an issue if the particle size is uniformly small rathe� than dusty (Bateman et al., 2009).

Corn and wheat promoted greater starter intakes than oats and barley (Khan et al., 2008), with rice and sorghum also being less effective than corn (Khan et al., 2016). Soybean meal was the best-consumed protein source (Miller-Cushen et al., 2014). Corn byproducts such as corn gluten feed or corn gluten meal were less acceptable than other ingredients. While corn distillers grain was highly acceptable by calves (Miller-Cushon et al., 2014), its low lysine content makes it a poor ingredient for young calf nutrition.

Calf growth has generally been greatest on high starch (>35% of the DM) formulas, but the resultant rumen pH is very low, often averaging slightly above 5.0 for much of the day (Quigley et al., 1992). Concern about these effects on rumen health has resulted in many calf starter formulas now being 18% to 28% starch, more similar to diets for functioning ruminants. Content of NDF should be above 13% (NASEM, 2021). Protein content of the starter has been considered adequate at 18% as fed (20% of DM), but recent studies have shown benefits to calf growth when higher CP starters (22% as fed or 25% of DM) were fed with greater intakes of milk (Stamey et al., 2012; Stamey

Lanier et al., 2021). A sugar content of 10 to 12% is favorable for rumen development because sugars ferment to a high proportion of butyrate (NASEM, 2021). Sugars can be provided from molasses, dextrose, and milk by-products such as whey.

Small amounts (<5% of total DM or -0.3 lb/d [-150 g/d)) of chopped forage can be offered to calves before weaning, particularly those fed a pelleted starter and not bedded on straw (NASEM, 2021). This forage can be something like wheat straw or grass hay, which have been shown to improve total starter intake and ADG (Castells et al., 2012) even when consumed in small amounts. Free-choice access to alfalfa hay should NOT be provided, because calves may consume enough hay (which is poorly digested) to decrease intake of the easily fermentable starter grains. Calves fed ad libitum alfalfa hay consumed 14% of their total DMI as hay, resulting in a decrease in starter consumption (Castells et al., 2012). Avoid free-choice alfalfa until the calf is about 6 mo of age.

The weaning transition

While the housing and social stressors around weaning may be somewhat unavoidable, the nutritional stressors can be minimized by ensuring that the calf is able to consume and digest sufficient starter before complete weaning. Preweaning starter intake is strongly related to postweaning growth (Stamey et al., 2012). To minimize growth slumps and health challenges around weaning, calves should be consuming 3 lb/d (1.3 kg/d) of starter before weaning. Maintenance intake for a newly weaned Holstein calf is around 2.2 lb (1 kg) of starter daily (NASEM, 2021). Insufficient starter intake means that the rumen has not had adequate time to develop the absorptive papillae of the rumen and a microbial population able to digest fiber (Terre et al., 2007).

Many factors affect the intake of calf starter around weaning. One of the most important is starter composition and quality, and its management, which was discussed in the previous section. Common problems are excessive starch content, unpalatable ingredients, and excessive fines or poor pellet quality.

Greater rates of milk feeding decrease starter intake (Jasper and Weary, 2002; Rosenberger et al., 2017; Stamey Lanier et al., 2022), which is not surprising since calves have a maximum dry matter intake (DMI) just like older ruminants. Increased milk solids will therefore decrease the amount of starter consumed. This has created problems with on-farm adoption of greater milk feeding rates, where producers still have the mindset to wean early. With increased milk feeding, we need to re-evaluate the historical emphasis on early weaning. Weaning at 8 wk of age instead of 6 wk will allow calves to increase their intake of starter to adequate levels before the weaning transition (Eckert et al., 2015; de Passille et al., 2011).

It *is* important to provide a gradual reduction in milk offered, and "cold" weaning should be avoided (Sweeney et al., 2010). With automated feeders it *is* simple to program a gradual decrease in milk offered. With manual high milk feeding programs, providing at least two weekly steps down *in* amounts offered will smooth out the weaning transition (Henrichs et al., 2021).

Providing ad libitum access to alfalfa should be avoided as it may decrease starter intake (Castells et al., 2012). As mentioned earlier, forage is poorly digested in the young rumen and contributes very little to nutrient supply. Small amounts of forage (ca. 5% of total DM) may help to increase total starter intake, ADG, and feed efficiency (NASEM, 2021). When allowed ad libitum access to various forages, except alfalfa and oat hay, consumption was only about 5% of the total DM consumed (Castells et al., 2012). Providing small amounts of chopped forage rather than ad libitum access also will minimize wastage and save feed costs.

Another problem is water availability and its management. Milk bypasses the rumen whether fed by nipple or bucket. Calves need free water, which enters the rumen, to support microbial growth and fuel lean tissue growth. Calves should have water available from birth, and it should be kept clean and fresh. Calves need about 3-4 L of water for every 1 kg of starter **intake (NASEM, 2021)**.

Avoid "stacking" stressors on the calves. Separate weaning from other management tasks such as dehorning and vaccination. Do not move the calves at the time of weaning. Pay attention to environmental stressors (extreme heat or cold) at the time of weaning.

Ruminal acidosis

Ruminal acidosis is a common factor in complicating the period around and after weaning. Acidosis is caused by excessive accumulation of VFA and lactate, exceeding the underdeveloped capacities for absorption and buffering in the young rumen. Signs of acidosis include decreased starter intake, decreased growth, lethargy, diarrhea characterized as forming "lakes" with bubbles, rough hair coat, and abdominal discomfort. Risk factors for development of acidosis in young calves include higher starch and lower NDF contents *in* starter, small feed particle size, pelleted rather than texturized starter, ground vs. unground starter ingredients, lack of forage feeding, no straw bedding, higher starter intakes, and slug feeding caused by feeding limited amounts of starter once daily. Usually signs of acidosis are not observed in calves before weaning, but may become apparent shortly after weaning as intake of starter increases rapidly.

Although in many cases no signs of acidosis are observed despite pH< 5.4, acidosis signs have been observed in situations of extremely low pH (Suarez-Mena et al., 2016). Gelsinger et al. (2020) attempted to create acidosis *in* young calves by feeding a pelleted starter containing 42.7% starch and 15.1% NDF, compared with calves fed a texturized starter containing 35.3% starch and 25.3% NDF. No forage was fed to either group and calves were housed on rubber mats to prevent ingestion of bedding. Rumen pH for the calves fed the texturized starter fell gradually after feeding from about 5.8 to 5.5 at 12 h post-feeding, whereas in the calves fed the pelleted starter rumen pH decreased to 5.4 after 2 hand continued to fall to about 4.9 at 12 h post-feeding. Starter intake was less for the calves fed the pelleted starter and they also ate it more slowly than calves fed the texturized starter. The BW was lower for calves fed the pelleted starter. The calves fed the pelleted starter had a greater ruminal lesion score than calves fed the texturized starter. In a study with limited calf numbers, Porter et al. (2007) recorded a pH of 4.95 for calves fed a high starch diet compared with pH of 5.50 for calves fed a higher fiber starter, and a pH of 5.03 for pelleted starters vs. 5.43 for calves fed textured mash starters. No forage was fed and calves were not bedded on straw. Many studies have not extended far enough post-weaning to detect occurrence of acidosis.

Forage supplementation in many cases has increased starter intake and growth rates (Thomas and Hinks, 1982), and may improve the rumen environment to help prevent acidosis. Castells et al. (2013) fed a control group only pelleted starter and fed 2 other groups starter plus alfalfa hay or oat hay. Calves were bedded on sawdust. Feeding forage increased ADG post-weaning but preweaning differences did not reach significance because of low animal numbers. Rumen pH was greater and total VFA concentration was lower for calves fed forage than for the controls. Rumen and total tract digesta fill did not differ among diets. Kim et al. (2016) compared calves fed forage and starter to those fed starter only. Ruminal pH was greater for the hay-supplemented group. In contrast, Quigley et al. (1992) compared 16-wk-old calves fed hay or not, and showed no differences between groups in rumen pH. Reasons for the differences among trials are not easy to discern.

Post-weaning nutrition

Much less is known about nutrition during the postweaning period, as research in this area has been limited. Intake of calf starter will increase rapidly after weaning, reaching an intake level of about 3.0% of BW as DM (NASEM, 2021). After adjustment to the weaning transition, calves can gain as much as 2.6 to 3.1 lb/d (1.2 to 1.4 kg/d). Continue feeding starter for 2 wk post-weaning, with a small amount of forage (5-10% of total DMI). Following this, calves can be switched to a lower-cost grower ration with small amounts of forage (10-15% of total DMI). Calves will respond to a greater intake of concentrate with greater ADG (Rosadiuk et al., 2021). A TMR can be introduced when the calf is about 4 mo old. Now the calf is ready to progress through the heifer growth scheme.

Conclusions

The last 25 yr has seen huge advancements in calf nutrition and management. Adopting higher rates of milk or milk replacer feeding brings tremendous biological advantages to the calf, both in the short-term and later in life as a milking cow. We now understand how to implement such programs without compromising weaning and post-weaning growth. We need to work with producers to implement such practices correctly and efficiently. Much of the on-farm challenges in implementation seem to be related to a lack of patience by the producer with the weaning phase of the system. Calf nutrition and management experts can help producers watch over the babies on farms to ensure their welfare and economic success.

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The importance of and strategies for heat stress mitigation on dairy farms

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Abstract

One of the biggest challenges to modern dairying are increasing ambient temperatures, which will continue to be a problem into the foreseeable future. Heat stress impacts farm economics through increases in cow disease and mortality, and reduced performance of both lactating and dry cows. Marked alterations in feed intake, metabolism, immune function, and milk production have been observed in lactating heat stressed dairy cows. More recent studies have begun to uncover detrimental effects of heat stress on the dry cow, demonstrating short-term impacts on the processes of mammary involution and redevelopment, and longer-term impacts on mammary growth and function into the subsequent lactation. This review will provide a summary of some of the most prolific impacts of heat stress on both the lactating and the dry dairy cow and highlight effective on-farm strategies for mitigating the adverse effects of heat stress.

Introduction

Over the past 140 years, global temperatures have increased by 0.85°C and further increases of 1 to 2°C by the end of the century are predicted (IPCC, 2018). Elevated ambient temperature is currently one of the major environmental pressures affecting dairy cow health and production, and consequently dairy farm economics. Estimates indicate that heat stress costs the dairy industry upwards of $2 billion annually, due to declines in milk yield and increased cow morbidity and mortality (St-Pierre et al., 2003, Laporta et al., 2020). A recent projection showed that milk yield losses attributed to heat stress will increase at a rate of 174 kg/cow/decade, with the fastest rates occurring in the southeastern US (Gunn et al., 2019). However, it is estimated that within the next 3 decades, one third of the United States will have a heat index above 52°C (Wilson et al. 2022). Thus, even temperate regions of the US will experience increases in heat stress-inducing temperatures that will affect cow productivity. For example, Gunn et al., (2019) predicted that the number of heat stress days (defined as days with THI > 70) in the northeastern US by the end of the century would likely be similar to current heat stress conditions in the southeast if greenhouse gas emissions are not curtailed. Climate change is also increasing the likelihood of extreme weather events, such as wildfires and droughts, that can exacerbate the adverse effects of heat stress on the dairy cow (Cox et al., 2016, Anderson et al., 2022).

Dairy cows are highly susceptible to heat stress. The most abundant dairy breed in the US, the Holstein-Friesian, originates from northern Europe and is not adapted to a hot climate (Mansfield, 1985, Huson et al., 2020). Further, the high milk yields of the modern cow are associated with high metabolic rates and reduced thermal tolerance (Renaudeau et al., 2012). The thermoneutral zone is the ambient temperature range within which an animal's metabolism is independent of ambient temperature. Thus, within the thermoneutral zone, energy is not expended to maintain a constant body temperature of 38.0-39.3°C for cows. The thermoneutral zone for cows is between 5°C and 25°C. Ambient temperatures outside of the thermoneutral zone require an increase in metabolic rate to either generate or dissipate heat. Indicators of heat stress in the cow occur when ambient temperatures exceed the upper critical limit of the thermoneutral zone, inducing changes in cow behavior and physiology that serve to limit heat production and promote heat dissipation. Thus, cow performance is optimized when they remain within the thermoneutral zone, as critical resources and energy can be channeled towards maintenance and production, instead of thermoregulation. Beyond temperature, other environmental conditions, such as wind speed, solar radiation, and humidity, determine the heat load experienced by an animal (Collier et al., 2017). The temperature humidity index, THI, is a commonly used environmental indicator of heat stress in cattle; dairy cows exhibit signs of heat stress, including elevated body temperature and respiration rates, and reduced milk production when THI exceeds 68 (Collier et al., 2011). However, the THI threshold for heat stress will vary somewhat depending on factors such as parity, lactation stage, and productive stage (e.g., dry vs. lactating) and the animal indicator assessed (Laporta and Skibiel, 2024). For example, rumination time has been shown to drop when THI surpasses 52 (Müschner-Siemens et al., 2020)

Effects of heat stress on lactating dairy cows are well-documented and include decreased feed intake, changes in metabolism, immune suppression, greater risk of disease and metabolic disorders, and decreased fertility. One of the most economically devastating effects of heat stress is reduced milk yield. Heat stressed lactating cows can experience declines in milk yield up to around 40% depending on lactation stage (Rhoads et al., 2009, Kim et al., 2010, Baumgard et al., 2011). Impaired lactation performance is a consequence of direct effects of temperature on processes such as blood flow, metabolism, and mammary function and indirect effects through reduced feed intake (Laporta and Skibiel, 2024). Over the last decade, a number of studies have also shown both immediate and long-term effects (i.e., after calving in the subsequent lactation) of heat stress during the non-lactating dry period on dairy cow health and performance (Tao and Dahl, 2013). For example, cows heat stressed when dry have decreased immune function, altered metabolism, blunted mammary growth during late pregnancy, and reduced milk yields in the next lactation, even when heat load is managed through forced cooling after calving (Tao and Dahl, 2013, Dado-Senn et al., 2019, Skibiel et al., 2022).

Considering the substantial impacts of heat stress on the dairy enterprise, it is not surprising that an abundance of research over the past several decades has been aimed at devising innovative strategies for minimizing heat stress to promote animal health and performance. This review will provide a brief overview of some of the physiological responses of both dry and lactating dairy cows to heat stress and the production consequences. For more detailed reviews, see Tao and Dahl (2013), Dahl et al. (2020), Tao et al. (2020), and Laporta and Skibiel (2024). Several heat mitigation strategies for dairy cows are covered, including methods to modify the environment or the ambient temperature experienced by the cow, methods to enhance heat loss from the cow, and nutritional interventions, such as supplements and feed additives.

Physiological responses of dairy cows to heat stress

Immune System

The immune system is negatively affected by heat stress in both lactating and dry cows. Many aspects of the immune system, such as the complement system (part of the immune system that helps destroy pathogens and recruit migration of immune cells to areas of infection), white blood cell counts, and immune cell function and viability, are reduced in lactating cows during summer or under experimental heat stress conditions relative to cows in the thermoneutral zone (Lacetera et al., 2006, Min et al., 2016, Abeyta et al., 2023). Studies have also shown changes in production of acute phase proteins (involved in the inflammatory response) with heat stress (Saco and Bassols, 2023). Heat stress during the dry period has immediate and carry-over effects on a cow's immune system. For example, heat stress during the dry period results in immediate reductions in pro-inflammatory cytokine and antibody production in immune cells (do Amaral et al., 2010, do Amaral et al., 2011), and reduces immune cell function and proliferation in the subsequent lactation, even when cows are actively cooled postpartum (Tao and Dahl, 2013).

Heat stressed cows are at greater risk of developing diseases, such as metritis and mastitis. Both metritis and mastitis infections are more common in the warm summer months compared to cooler times of the year (Thompson and Dahl, 2012, Santos and Ribeiro, 2014, Gernand et al., 2019). The energy required for mounting an immune response can redirect resources from the mammary gland, impairing milk synthesis, thus contributing in part to reduced milk yield associated with heat stress. Furthermore, pathogen transmissibility may be elevated in hot climates. For example, one study found that shedding of a common contagious mastitis pathogen was greater when THI exceeded 60, which can increase herd risk (Hamel et al., 2021). However, as pathogen prevalence is not always linked to elevated ambient temperatures, seasonal variability in disease may also be attributed to altered host responses to pathogen exposure (Dahl et al., 2020). Altogether, these studies indicate that heat stress reduces the immune system's capacity to fight off pathogens.

Metabolism

Effects of heat stress on macronutrient metabolism in dairy cows is well-established. Lactating heat stressed cows have alterations in lipid, carbohydrate, and protein metabolism. Heat stress reduces the body's response to lipolytic hormones, despite increases in circulating concentrations of catabolic hormones, and consequently circulating non-esterified fatty acid (NEFA) concentrations are reduced (Baumgard and Rhoads, 2013). Aside from being used by the mammary gland to produce milk fats, NEFA are an important source of energy, allowing the limited glucose available to be used primarily by the mammary gland for milk synthesis (Drackley, 2001). Concentrations of beta-hydroxybutyrate, triglycerides, and glucose were also reduced in heat stressed compared to thermoneutral lactating dairy cows (Marins et al., 2017). Although heat stress increases liver production of glucose, extramammary tissues of heat stressed lactating cows appear to utilize glucose more readily, at the expense of milk synthesis (Wheelock et al., 2010, Baumgard et al., 2011). In heat stressed cows, breakdown of proteins in the body is increased as well as utilization of amino acids in peripheral tissues, such as the intestines and liver, associated with enzymatic antioxidant production, acute phase protein and heat shock protein (play a protective role in cells under a variety of stressors) production, and use of amino acids as precursors for glucose synthesis (Ríus, 2019). In addition, amino acid absorption in the small intestine is reduced with heat stress (McGuire et al., 1989).

During the dry period, heat stress does not appear to exert much influence on macronutrient metabolism, despite reductions in DMI, as circulating NEFA and glucose concentrations are similar between cooled and heat stressed cows during the dry period (do Amaral et al., 2011, Tao et al., 2012). However, dry period heat stress does impact metabolism after calving, even when cows are cooled during the lactation period. Similar to responses of cows heat stressed when lactating, there is evidence of a blunted response to lipolytic hormones, reduction in plasma NEFA concentrations, reduced fatty acid oxidation, and greater peripheral glucose use in early lactation when cows are heat stressed during the dry period (do Amaral et al., 2009, Tao et al., 2011, Skibiel et al., 2018).

Mammary function

Heat stress has numerous detrimental impacts on mammary development and function in both lactating and dry cows. Beyond the reduced DMI associated with heat stress, milk yield declines may be due to changes in metabolism (described above) and mammary nutrient availability, mammary development, and mammary function. Mammary blood flow is reduced in lactating heat stressed dairy cows (McGuire et al., 1989). Along with reduced expression of genes involved in nutrient transport within the gland, these studies suggest reduced nutrient delivery to the gland and reduced mammary nutrient uptake with heat stress. In addition, in vitro work has demonstrated stunted growth and programmed death of bovine mammary secretory cells even with short duration exposures to hyperthermic conditions (Collier et al., 2006b, Du et al., 2008).

During the dry period, heat stress affects the processes of mammary involution and redevelopment, with consequences continuing into the subsequent lactation. During involution, mammary cell death is accelerated to clear out old and defective cells. Expression of genes involved in cell death processes were reduced with dry period heat stress and resulted in a lower proportion of cells undergoing apoptosis (Dado-Senn et al., 2018, Fabris et al., 2020). Additionally, mammary growth, as measured by mammary cell proliferation, during the late dry period was impaired from heat stress (Tao et al., 2011). Changes in hormone levels, such as prolactin, estrogen, and progesterone, may contribute to stunted mammary growth during the dry period (Tao and Dahl, 2013). Impediments to the involution process lead to fewer alveoli, the functional units of the lactating mammary gland, and greater mammary connective tissue area, in the subsequent lactation, which may reduce the gland's ability to synthesize milk (Dado-Senn et al., 2019).

Mitigation strategies

In the U.S., management of the thermal environment experienced by the cow is one of the primary methods used to reduce heat stress. This can be accomplished by offering shade and shelters that reduce cow exposure to solar radiation and lower the temperature of the cow's microenvironment or by evaporative and convection systems that directly facilitate heat loss from the cow. Heat abatement practices are important for cows in buildings, on dry lots, and on pasture. Advances in nutritional and nutraceutical interventions are also contributing health and performance benefits for heat stressed cows. Table 1 provides a list of recent literature reviews and extension articles on various mitigation strategies for heat stress in dairy cows.

Shade

Provision of shade is a minimum requirement to reduce heat stress in dairy cows. Shade provides refuge from solar radiation. Structures can be natural (e.g., trees) or artificial (e.g., permanent or portable manufactured structures) and range in price depending on size and materials used. Artificial shade structures should have between 3.5 to 4.5 m^2 of space per cow, should be at least 4.3 m in height, and should be set up with ample spacing around the structure to maximize air flow (Collier et al., 2006a). Orientation of the shade is an important consideration to maximize the length of time per day under shade and ensure proper drainage under the structure.

The specific orientation recommended is dependent on wind direction and farm location in a wet or arid environment. Roofing material of the shade structure also plays a role in the heat load an animal experiences. Choosing highly reflective materials, such as aluminum, will increase shading efficacy (Renaudeau et al., 2012). Overall, temperatures under shade structures can be up to 11°C cooler than non-shaded areas. Many aspects of cow physiology and production, including body temperature, respiration rate, fertility, and milk yield, are improved by providing shade (Fournel et al., 2017).

Foggers and misters

Foggers and misters are considered indirect cooling devices, using the heat in the air to evaporate water, thereby lowering air temperature. Fine (foggers) or larger (misters) water droplets are released from nozzles that often feed into fans to enhance evaporation of the water droplets. As the air temperature drops, the temperature difference between the environment and the cow's body is increased, resulting in heat loss from the cow (McFarland, 2022). These devices are more effective in arid to semi-arid environments with relatively low humidity. In these climates, across multiple studies, fogging and misting systems successfully decreased body temperature and respiration rates and increased milk yields (Fournel et al., 2017).

Water sprinklers/soakers and fans

Effective heat exchange can be promoted using cooling devices such as fans and water sprinklers/soakers. Fans can improve ventilation and facilitate convective (movement of fluids) and evaporative (phase change of liquid water to vapor) heat transfer by increasing air flow around the cow while water sprinklers and soakers enhance evaporative cooling by wetting the hair (Renaudeau et al., 2012). These cooling devices can be placed over holding pens, free stalls, and feeding bunks. Cows may be confined to the holding pen for up to an hour prior to each milking and the close proximity of cows in these areas can impair effective heat exchange. Therefore, fans and/or water sprinklers are often recommended in holding pens. Direct cooling systems employ water sprinklers/soakers in combination with fans for greater evaporation (Collier et al., 2006a).

Generally, fans should face downward at a 20-30° angle and run continuously. One 91 cm diameter fan is recommended for each 14 m^2 or one 121 cm diameter fan for each 28 m^2 of pen space. Rows of fans should be separated by 51 to 61 cm for 91 cm diameter fans and 76 to 91 cm for 122 cm fans (Brugger, 2006). Water sprinklers typically have a flow rate of 0.75 – 2 L/min, a pressure of 20-40 psi, and an on-cycle of 1-3 min every 5-15 min (Collier et al., 2006a; Fournel et al., 2017). Sufficient time is required between on-cycles to allow for evaporation to occur. Heat loss from the cow is dependent on the volume of water applied with each on-cycle, the duration of the on-cycle, and the time interval between on-cycles (Renaudeau et al., 2012, Tresoldi et al., 2019). The on-time for each cycle will depend on the sprinkler flow rate and sprinkler spacing as well as temperature and humidity (Brugger, 2006). Sprinkler cycles may be programmed to automatically engage at a specified temperature or humidity level and cycle frequency should be increased with increasing temperatures (Collier et al., 2006a).

Despite disparate sprinkler on-cycles across studies, results are congruent with lower respiration rates and body temperatures and increased DMI and milk yields in lactating dairy cows with access to sprinklers compared to those without (Fournel et al., 2017, Safa et al., 2019). Additionally, multiple studies have shown positive effects of direct cooling of dry cows on body temperature and respiration rate and milk yield in the subsequent lactation (Tao and Dahl, 2013, Dado-Senn et al., 2019, Fabris et al., 2019). Provision of evaporative cooling devices and shade can also reduce incidence of mastitis on dairy farms (Safa et al., 2019). The cost to benefit ratio for supplying heat abatement in the form of sprinklers and forced ventilation is projected to decline across the 21st century as ambient temperatures continue to climb and more of the US experiences heat stress conditions (Gunn et al., 2019).

Feeding management

In lactating dairy cows, 35-50% of the drop in milk yield associated with heat stress is attributable to declines in DMI (Baumgard et al., 2011). Heat stress reduces DMI in dry cows as well, although to a lesser extent than during lactation due to overall lower DMI during the dry period, and declines in DMI prepartum contribute somewhat to reduced milk yields after calving (Laporta and Skibiel, 2024). Thus, in addition to environmental management, feeding management and nutritional or nutraceutical interventions can be important methods to mitigate heat-induced milk losses. To maintain DMI under heat stress conditions, it is recommended that feed bunks are filled with less feed but more frequently throughout the day to promote small meals and prevent overheating and spoilage of feed. A feed bunk space of 76 to 91 cm per cow for transition cows and 46 to 61 cm per cow for dry cows can reduce crowding and encourage feed intake (McCarville et al., 2021). Digestive heat production peaks around 3-4 hr after feeding, thus feeding in the cooler parts of the day, including early morning and late evening, can help reduce heat load and maintain feed intake (Staples, 2007).

Water. Lactating cows will consume around 68 to 151 L of water a day, equating to 4 to 4.6 kg of water per kg of milk produced, and water volume consumed is increased by almost 30% in hot environments (Kononoff and Clark, 2017). Respiration rates are greater in hot environments and water is an essential conduit for heat loss in both lactating and dry cows through panting and sweating (Collier et al., 1982). Water troughs should be kept clean and located in close proximity to feed bunks (Renaudeau et al., 2012). Shade structures over feed troughs can promote water consumption.

Nutrients and nutraceuticals. Modifications to the diet aim to maintain feed intake, improve immune function, replace nutrients lost through sweating and panting, and compensate for reduced nutrient intake during heat stress (Renaudeau et al., 2012). Rations should be adjusted before heat stress occurs, and dietary changes are important for both lactating and dry cows. Consulting a dairy nutritionist prior to altering the ration is recommended.

Dietary protein

Although declines in DMI from heat stress reduce crude protein intake at the same time amino acid demand for inflammatory responses (i.e., acute phase protein and heat shock protein production) is elevated (Ríus, 2019), overfeeding dietary protein is not recommended due to increased energy costs associated with urea production and elimination (West, 2003). In one study, feeding moderate levels of crude protein (16.1% CP) to heat stressed lactating dairy cows increased milk protein percentage, but no improvement in milk yield was detected relative to cows fed low levels of crude protein (12.5% CP) (Kaufman et al., 2020). However, reducing rumen degradable (RDP) and undegradable protein (RUP) from 10 to 8% and 8 to 6%, respectively, in a 14% CP diet reduced systemic insulin concentration, increased lipolysis, and enhanced plasma amino acid concentrations, which was associated with greater energy corrected milk and milk protein yield (Kaufman et al., 2018). Thus, feeding a roughly 50:50 ratio of RDP to RUP in a lower protein diet (14 or 16% CP) may improve amino acid and fatty acid utilization, and lactation performance in lactating heat stressed dairy cows (Kaufman, 2019). Heat stressed dairy cows may also benefit from supplementation of rumen-protected amino acids, such as arginine, cysteine, leucine, lysine, histidine and methionine (Loor et al., 2023). For example, supplementing a 14% CP diet with lysine, methionine, and histidine had positive effects on metabolism of heat stressed lactating cows (Ruiz-Gonzalez et al., 2021).

Dietary fat

Increasing the fat content of the ration increases the energy density of the feed without increasing metabolic heat production, due to the lower heat increment of fats relative to fiber and starch (Renaudeau et al., 2012). Some studies have supplemented polyunsaturated fatty acids, which also have anti-inflammatory and antioxidant properties (Kotsampasi et al., 2024). Supplementing the diet with 16.6 kg/d of whole flaxseed, rich in polyunsaturated fatty acids, resulted in higher milk yield, and milk protein and fat yields in lactating dairy cows exposed to high ambient temperatures (Caroprese et al., 2010). Moreover, adding conjugated linoleic acid to the diet improved the negative energy balance associated with heat stress (Sammad et al., 2020). However, high polyunsaturated fats in the diet can negatively impact fermentation and contribute to milk fat depression. Supplementing with saturated fatty acids such as palmitic, lipoic, and oleic acids may increase DMI, reduce oxidative stress, improve glucose utilization, and increase energy intake without the adverse effects on rumen health and biohydrogenation (Rhoads et al., 2013, de Souza and Lock, 2018, Kim et al., 2022).

Forage to concentrate ratio

Balanced forage to concentrate ratio is important during heat stress conditions. To promote feed intake and lower the heat of fermentation, neutral detergent fiber (NDF) in the ration can be slightly reduced when providing a higher energy feed from fats and grains, but reducing fiber too much can lead to acidosis and displaced abomasum (West, 2003). Heat stressed cows are already at a greater risk for ruminal acidosis because of increased respiration rate, panting, and drooling, and reduced rumination time. Saliva contains bicarbonate, an important rumen buffer, that is reduced with drooling and lower rumination time (Meneses et al., 2021). Adding sodium bicarbonate to the diet can help maintain optimal rumen pH when feeding a high grain diet (Erdman, 1988). Supplementing lactating heat stressed dairy cows on a high concentrate ration with 0.1% sodium bicarbonate increased feed intake 8.5% and milk yield by 5% relative to cows not receiving the supplement (Schneider et al., 1986).

Probiotics

Heat stress directly (through increase in rumen temperature) and indirectly (through changes in feed intake, changes in salivary bicarbonate, and reduced chewing time) affect rumen microbial populations, and their metabolism and growth (Zhao et al., 2019). Lactate producing bacterial strains and those that are more resistant to elevated temperatures typically increase in abundance whereas microbes producing acetate are often reduced in heat stressed cows (Zhao et al., 2019, Kim et al., 2020). Lactate accumulation in the rumen affects rumen pH and can impair growth of rumen microbes more sensitive to changes in pH, which can contribute to subacute ruminal acidosis (Zhao et al., 2019). Probiotics include microbial additives, such as live bacteria strains and live fungal cultures, like *Saccharomyces cerevisiae* and *Aspergillus oryzae. Saccharomyces cerevisiae* has been shown to increase abundance of microbes that are involved in fiber digestion and lactate breakdown (Li et al., 2023). *Saccharomyces cerevisiae* and *Aspergillus oryzae,* also have many other reported benefits for heat stressed cows, including improved feed efficiency and digestion, enhanced feed intake, and improved immune status. Live yeast (*Saccharomyces cerevisiae*) supplemented daily for 70 d to lactating heat stressed dairy cows increased protein and fiber digestibility, efficiency of feed conversion into energy corrected milk (ECM), and increased rumen production of acetate. In the same study, energy corrected milk yield was highest and acute phase protein production the lowest when cows were supplemented with 1g/d of yeast compared to cows fed 0 or 0.5 g/d (Perdomo et al., 2020). Feeding heat stressed cows with a yeast-containing feed additive through the dry period and the subsequent lactation decreased respiration rate and body temperature and increased milk yield compared to cows provided a bentonite placebo (Fabris et al., 2017). Likewise, feeding yeast cultures to lactating heat stressed cows increased milk yield by 1.2 kg/d compared to cows not receiving yeast cultures (Bruno et al., 2009). Feeding the same yeast-additive to lactating cows reduced serum concentrations of a positive acute phase protein, body temperature, and milk somatic cell count (Leiva et al., 2017). Additionally, *Aspergillus oryzae* fed to lactating heat stressed dairy cows reduced concentrations of circulating inflammatory markers and increased energy corrected milk (Kaufman et al., 2021). Thus, supplementation with fungal cultures has positive effects on metabolism, immune function, and performance of heat stressed cows.

Minerals and vitamins

The decreased DMI associated with heat stress reduces mineral intake at the same time electrolyte losses are accelerated through panting, sweating, and urination (Renaudeau et al., 2012). Furthermore, heat stress can induce oxidative stress through elevated production of reactive oxygen species (ROS) and impairments to antioxidant defense systems (Bernabucci et al., 2002, Skibiel et al., 2018, Chauhan et al., 2021, Skibiel et al., 2022). Imbalances between ROS production and quenching can result in oxidative damage to cells and tissues. Supplementing minerals and vitamins during heat stress conditions can help cows replenish electrolytes and prevent oxidative damage due to their antioxidant properties.

Increasing the dietary cation-anion difference (DCAD) through supplemental potassium and sodium during heat stress in lactating cows has been shown to increase essential amino acid concentrations in the blood, allocating their use for milk synthesis over maintaining acid-base balance (Wildman et al., 2007). Providing potassium and sodium above NRC recommendations to lactating heat stressed cows has also been shown to increase milk yield (Beede and Collier, 1986). When potassium is added to the diet, magnesium concentrations may need to be increased as well, as potassium reduces magnesium absorption (Amaral-Phillips, 2016). Selenium is necessary for synthesis of glutathione peroxidase, an important enzymatic antioxidant (Tappel, 1974). Supplementation of selenium, copper, and zinc prevented metabolic aberrations observed with heat stress and reduced oxidative stress in dairy steers (Son et al., 2022). Chromium is a trace mineral with roles in fat, glucose, and protein metabolism by modulating insulin signaling (Mertz, 1993). Supplementing heat stressed cows with chromium improves energy metabolism and milk yield (Soltan, 2010, Mirzaei et al., 2011).

Vitamins are important for immune function and energy production and many also function as antioxidants. The B vitamin, niacin, improves metabolism in lactating heat stressed cows and induces vasodilation, which channels heat to the skin surface for effective heat dissipation (Di Costanzo et al., 1997). Adding rumen-protected niacin to the diet also facilitates thermoregulation by increasing sweating rate (Zimbelman et al., 2013). In a recent study, Ruiz-González et al., (2023) fed lactating heat stressed dairy cows average or high concentrations of selenium and vitamin E along with either average or high concentrations of vitamin D and calcium. They found that body temperature and markers of inflammation and oxidative damage were lower in the group receiving high concentrations of vitamin D and calcium, independent of selenium and vitamin E concentrations. Supplementing vitamins and minerals may improve thermoregulation, metabolism, and milk yield and reduce oxidative stress in heat stressed cows. However, supplementation amount, duration, and productive stage all play a role in the impact of minerals and vitamins on the heat stressed cow. Depending on the particular mixture, supplementing with multiple minerals or vitamins may or may not confer additional benefits.

Phytobiotics

Phytobiotics are naturally occurring biologically active compounds from plants and include betaine, essential oils, and polyphenols. Betaine, a naturally occurring derivative of glycine, is an osmolyte, is involved in metabolism of methionine and other amino acids, and is a source of nitrogen and methyl groups (Dobrijević et al., 2023). In grazing heat stressed cows, betaine supplementation improved milk yield and fat and protein yields (Dunshea et al., 2019). Supplementing lactating cows during summer heat stress with betaine had positive effects on feed intake and milk yield, and reduced oxidative stress (Zhang et al., 2014). However, other studies did not observe an increase in milk yield with betaine supplementation, and in fact, found that water and feed intake were reduced when heat stressed dairy cows were given betaine compared to a heat stressed control group that did not receive betaine (Hall et al., 2016). Studies on benefits of essential oils to heat stressed cows are limited.

Polyphenols are phenol-containing chemical compounds that are anti-inflammatory and antioxidants (Gessner et al., 2017). Pretreating bovine mammary epithelial cells in vitro with the polyphenol, procyanidin B2, prior to heat challenge prevented cell death and suppressed the inflammatory cascade. Further, pretreatment with procyanidin B2 increased the activity of enzymatic antioxidants, activated Nrf2 signaling, a cellular antioxidant defense system, and reduced ROS production and oxidative stress (Wang et al., 2022). Another polyphenol, resveratrol, was found to alter expression of genes involved in fat metabolism and reduced malondialdehyde, a marker of oxidative stress in cultured bovine adipose cells (Kra et al., 2021). More studies at the animal level are needed to assess the potential for heat stress mitigation through polyphenol supplementation.

Conclusions

Heat stress has substantial economic, and animal health and production implications. For both dry and lactating cows, heat stress has suppressive effects on the immune system contributing to elevated disease risk, alters metabolism such that adaptive glucose sparing mechanisms are not achievable, and negatively affects mammary cell processes, impairing mammary growth and milk synthesis. Methods to modify the cow's environment and capacity for heat loss, such as providing shade and cooling devices, have been successful in at least partially recovering milk losses from heat stress. Various nutritional interventions, such as supplementing dietary fats, and use of nutraceuticals, such as phytobiotics and probiotics, have also shown some benefit to physiological and production parameters of heat stressed cows. Future work will no doubt continue to build upon, refine, and diversify our arsenal of heat mitigation tools.

Table 1. A selection of recent literature reviews and extension articles covering various methods to mitigate the adverse effects of heat stress on dairy cattle health, physiology, and performance.

Article type	Topic	Reference
Literature Reviews		
	Environmental management of heat stress	Becker and Stone, 2020
	Environmental management of heat stress	Fournel et al., 2017
	Use of plant extracts to minimize heat stress	Guo et al., 2023
	Methods to improve immune function of heat stressed dairy cattle	Gupta et al., 2023
	Environmental management of heat stress	Ji et al., 2020
	Strategies to reduce heat stress impacts on the rumen microbiome	Kim et al., 2022
	Nutritional interventions for heat stressed dairy animals	Kotsampasi et al., 2024
	Amino acid supplementation for heat stressed ruminants	Loor et al., 2023
	Nutritional and environmental management of heat stress	Negrón-Pérez et al., 2019
	Environmental management of heat stress	Polsky and von Keyserlingk, 2017
	Environmental management and feeding strategies to alleviate heat stress	Sammad et al., 2020
	Nutritional and environmental management of heat stress	Toledo et al., 2022
Extension articles		
	Management of summer rations	Akins and Schmidt, 2021
	Environmental management of heat stress	Armstrong and Janni, 2023
	Nutritional and environmental management of heat stress	Erickson, 2021
	Management of heat stress in grazing cattle	Mayerfeld et al., 2021
	Management of heat stress in dry cows	McCarville et al., 2021
	Environmental management of heat stress	McFarland, 2022
	Feeding and environmental management of heat stress	Okkema, 2023a
	Management of heat stress in grazing cattle	Okkema, 2023b
	Environmental management of heat stress	Van Os and Halbach, 2021

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Optimizing Nutritional Strategies for Dairy Calves and Post-Weaned Heifers

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Introduction

Nutritional management of dairy calves and post-weaned heifers significantly influences their development, productivity, and overall health. While pre-weaning strategies primarily focus on milk replacer formulations and starter feed intake, post-weaning diets must ensure optimal energy and protein intake to support growth and mammary development. This paper summarizes our lab's findings regarding the use of high-fat milk replacers for preweaning calves, new technology to enhance milk replacer fat content in dairy calves, and updated nutritional strategies for heifers based on our findings about the latest NASEM (2021) model.

Milk Replacers and Early Nutrition in Dairy Calves

Proper nutritional management during the early weeks of a calf's life is crucial for its growth and eventual lactation performance. The Dairy Cattle Code of Practice advises that newborn calves should consume at least 15% of their birth weight in milk or milk replacer daily, equating to about 6 liters for Holsteins. This intake should increase to 20% of birth weight (approximately 8 liters for Holsteins) between 7 and 28 days of age. Additionally, calves exposed to cold stress require greater milk intake to meet their higher energy demands (NFACC, 2023). These recommendations align with research indicating that feeding a milk replacer containing 20% crude protein and 20% fat promotes healthy growth without negatively impacting mammary development (Hill et al., 2009).

Increasing protein and energy intake during the first eight weeks has been linked to greater average daily gain (ADG) and improved feed efficiency up to weaning, potentially leading to enhanced first-lactation performance (Brown et al., 2005). However, the extent to which early growth advantages persist beyond weaning varies, depending on post-weaning nutrition and management strategies (Soberon et al., 2012). The consumption of a high-quality, nutrient-rich starter concentrate is also essential for supporting early development and optimizing future milk production (Hill et al., 2009).

Seasonal variations further underscore the importance of early nutrition. Calves born in autumn and winter generally consume more protein and energy to support growth under colder conditions (Chester-Jones et al., 2017). This increased intake helps offset higher maintenance energy needs caused by cold stress, contributing to early weight gain. However, while improved nutrition during colder months supports early growth, its direct effect on first-lactation milk production remains unclear. Chester-Jones et al. (2017) observed that while calves born in colder seasons exhibited greater early growth, they produced lower 305-day milk yields in their first lactation compared to those born in the summer. This highlights the complex relationship between early-life nutrition, environmental factors, and long-term productivity outcomes.

A well-balanced diet, combining milk replacer and starter concentrate alongside proper management, is essential for establishing a strong foundation for calf growth and future production potential. Rauba et al. (2019) found that early energy intake significantly correlated with first-lactation performance. Calves achieving an ADG above 0.80 kg/day consumed greater amounts of protein and energy, which was associated with increased milk yields in their first lactation. Although this relationship is correlational and influenced by multiple factors—including genetics, post-weaning nutrition, and overall herd management—research suggests that improved early nutrition plays a role in metabolic programming and mammary development. Specifically, for every 1 kg increase in metabolizable energy (ME) intake during the first eight weeks, milk yield increased by approximately 1.80 kg/day. However, further research is needed to fully understand the direct causal mechanisms behind these associations and refine feeding strategies to maximize long-term lactation performance.

Whole milk contains approximately 28-30% fat, whereas conventional milk replacers often contain 18-22% fat. Increasing fat levels in milk replacers has been proposed as a strategy to enhance energy intake, particularly in cold climates where thermoregulation is a concern (Hill et al., 2009; Leite et al., 2024). However, while high-fat milk replacers improve energy density, their isolated impact on ADG is minimal, emphasizing the need for balanced nutrient composition (Marcondes et al., 2025).

Fat composition in milk replacers (MR) is a critical factor influencing the growth, health, and metabolic development of pre-weaning calves. The use of appropriate fat sources enhances digestibility, impacts energy utilization and gut development, and supports immune function. Different fat sources vary in their fatty acid (FA) profiles and triglyceride (TG) structures, which directly affect absorption and utilization in calves (Castro et al., 2023).

One of the primary differences between whole milk (WM) and conventional MR is the reduced levels of short-chain fatty acids (SCFA) such as butyric (C4:0) and caproic (C6:0) acids. These SCFA play a vital role in gut health, metabolism, and immune modulation

(Leite, 2024). Castro et al. (2023) investigated the effects of supplementing MR with tributyrin (TB) and tricaproin (TC) to restore physiological levels of C4:0 and C6:0, similar to those found in bovine milk fat. Their findings suggest that incorporating these compounds improves fecal consistency and reduces the incidence of diarrhea in pre-weaning calves. Additionally, TB and TC supplementation were associated with a lower need for drinking assistance in newborns, indicating better palatability and acceptance (Castro et al., 2023).

Another key aspect of MR formulation is the balance between saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA). According to Leite (2024), different fat sources such as lard, palm, and rapeseed oil contribute varying FA profiles, influencing lipid metabolism and plasma cholesterol levels. While rapeseed-based MR was associated with higher plasma cholesterol, the study found no significant differences in growth rates among calves fed different fat sources. This suggests that although alternative fats can provide adequate energy, their long-term metabolic implications require further investigation (Leite et al., 2024).

In summary, selecting the right fat sources for MR is essential for optimizing calf growth and health. Incorporating SCFA such as TB and TC can enhance gut health and metabolic efficiency, while careful balancing of SFA, MUFA, and PUFA helps ensure proper lipid metabolism. Future research should continue to explore the long-term effects of different MR fat compositions on lactation performance and metabolic programming in dairy calves.

Recents studies revealed that feeding calves with high-fat milk replacers influence lipid metabolism, insulin sensitivity, and gut microbiota. The presence of medium-chain fatty acids (MCFA), such as lauric and butyric acid, has been linked to improved intestinal integrity and reduced diarrhea incidence (Miragoli et al., 2021). Furthermore, fat-soluble vitamins A, D, E, and K are more efficiently absorbed in the presence of dietary fat, contributing to immune development and overall health (Herdt & Stowe, 1991).

Aiming to better understand the consequences of feeding high-fat milk replacers for calves our group ran a study with pre-weaned Holstein calves, focusing on muscle and liver lipidomics. Fifty calves were divided into high- and low-fat MR groups, harvested at 30, 60, and 90 days of age. Lipid profiling was conducted using multiple reaction monitoring mass spectrometry to assess metabolic differences between the groups. The lipidomic analysis at 30 days revealed that calves fed a high-fat MR had increased phosphatidylcholines (PC), triglycerides (TG), and glycerophospholipids in muscle tissue. These lipids play a crucial role in membrane remodeling, mitochondrial function, and energy storage. The high-fat group exhibited elevated levels of PC(40:5) and PC(38:3), indicating enhanced membrane fluidity and lipid transport, which are essential for muscle development and function. Additionally, higher triglyceride accumulation suggests improved energy storage, likely supporting muscle endurance and resilience. Conversely, calves on a low-fat MR had increased sphingomyelins (SM) and cholesteryl esters, which may influence membrane integrity and cholesterol metabolism. These changes suggest that while a low-fat diet supports stress resilience, it may also increase oxidative stress and alter muscle lipid composition, potentially impacting long-term metabolic health.

In liver tissue, the high-fat group showed increased carnitines (CAR 18:1) and phosphatidylcholines, indicative of enhanced fatty acid oxidation and lipid transport. The upregulation of specific triglycerides, including TG C18:1 and C16:0, suggests more efficient lipid turnover and utilization, supporting overall metabolic efficiency. The high-fat MR also promoted increased lipid droplet formation, facilitating better energy storage and reducing metabolic stress. In contrast, the low-fat group exhibited elevated levels of cholesteryl esters, ceramides, and triglycerides, suggesting higher hepatic lipid accumulation and reduced lipid export. These findings indicate a potential risk for fatty liver development and altered cholesterol metabolism, which could negatively affect long-term liver function. The lower carnitine levels in this group further suggest reduced fatty acid oxidation, reinforcing the metabolic advantages of a high-fat diet.

Feeding high-fat milk replacers (MR) provided several health benefits for dairy calves, particularly in improving energy utilization, gut health, and metabolic stability. Compared to conventional MR formulations, high-fat MR more closely resembles the macronutrient composition of whole milk, ensuring a more efficient energy supply during the pre-weaning period (Leite, 2024). Proper fat composition in MR enhances intestinal development, reduces gut permeability, and supports immune function by promoting a healthier gut microbiome (Castro & Ghaffari et al., 2024). Additionally, the inclusion of short-chain fatty acids (SCFA) such as butyric (C4:0) and caproic (C6:0) acids in MR through tributyrin (TB) and tricaproin (TC) supplementation has been shown to improve fecal consistency, reducing the incidence of diarrhea—a major cause of early-life morbidity in calves (Castro et al., 2023). Moreover, calves fed high-fat MR demonstrate improved lipid metabolism, as seen in altered hepatic metabolomic profiles that favor better nutrient absorption and energy efficiency (Castro & Ghaffari et al., 2024). While different fat sources contribute varying metabolic responses, high-fat MR formulations that balance saturated (SFA) and unsaturated fatty acids (MUFA, PUFA) ensure optimal growth and immune resilience without compromising metabolic health (Leite, 2024). A high-fat MR supported improved muscle energy reserves, enhanced fatty acid metabolism, and reduced metabolic stress in pre-weaned calves. The increased presence of phospholipids and triglycerides in muscle tissue promotes better muscle repair and endurance, while greater lipid oxidation in the liver enhances metabolic flexibility. Additionally, maintaining phospholipid balance may contribute to a stronger gut-liver axis, reducing gut inflammation and improving nutrient absorption. These findings emphasize the importance of strategic fat selection in MR to enhance calf health, reduce disease susceptibility, and promote long-term productivity.

Optimal early-life nutrition, particularly through the strategic use of milk replacers, plays a vital role in shaping the health, development, and long-term productivity of dairy calves. Evidence supports that feeding high-fat milk replacers—especially those supplemented with key short-chain fatty acids and balanced fatty acid profiles—can enhance growth, improve gut integrity, support immune development, and promote favorable metabolic programming. Lipidomic insights further suggest that these nutritional strategies positively influence muscle and liver function, reinforcing the benefits of high-fat formulations. While early gains in performance are promising, continued research is needed to refine milk replacer composition and better understand the long-term implications for lactation efficiency and herd sustainability.

Nutritional Management of Post-Weaned Heifers

Dry matter intake

The NASEM (2021) model introduces updated equations for predicting dry matter intake (DMI), energy utilization, and protein requirements in dairy heifers. Compared to NRC (2001), the new model offers greater precision by incorporating factors such as compensatory gain, breed differences, metabolic efficiency adjustments, and revised feed passage rates. A key improvement is the model's emphasis on metabolizable energy (ME) efficiency for both maintenance and growth, including breed-specific corrections (VandeHaar, 2021).

However, despite these advancements, several limitations remain. Notably, the model does not explicitly incorporate heifer performance data into its predictive framework. Although heifer development systems in the U.S. are relatively standardized, average daily gain (ADG) can range widely—from 700 to 1,500 g/day—depending on the breeding strategy and target age at first calving. This variability calls for more performance-responsive modeling approaches.

Another concern lies in the model's linear assumptions for body composition changes. Most literature on energy and protein requirements indicates that tissue accretion follows an allometric, rather than linear, relationship. A linear approach implies that body composition remains constant across different body weights or growth rates, which is inaccurate. In reality, heavier animals or those growing at higher rates require disproportionately more energy due to increased fat deposition. Thus, applying a fixed ME efficiency factor can lead to under- or overestimation of nutrient requirements, compromising predictions of feed conversion and growth outcomes.

Moreover, energy and protein requirements are interdependent. As energy intake increases and lean tissue deposition is prioritized, protein requirements must also rise accordingly. Fox et al. (2004) emphasized that energy retention efficiency varies with growth stage: early growth favors lean mass, while later growth shifts toward fat deposition. To support optimal lean gain in heifers, the metabolizable protein (MP) to metabolizable energy (ME) ratio should reach at least 43 g/Mcal (Albino et al., 2015).

Modern models have also improved the estimation of nutrient requirements in pregnant heifers. Previous models, such as CNCPS v5, CPM, and NRC 2001, overestimated maintenance and growth requirements by including conceptus weight as part of the heifer's total body weight. This oversight led to inflated nutrient estimates for bred heifers. CNCPS v6+ addressed this by implementing a correction in which the weight of the conceptus is subtracted from total body weight, thus improving accuracy. This same principle has been applied in recent studies estimating protein and mineral requirements for pregnant cows, where weight gain calculations exclude conceptus weight (Marcondes et al., 2023; Camisa Nova et al., 2025). Activating the SCALE WEIGHT = TRUE setting in modern models ensures accurate nutritional planning for pregnant heifers, avoiding overfeeding and enhancing feed efficiency.

To assess the predictive performance of the NASEM (2021) model, we used a comprehensive dataset generated by the MarcondesLab (N = 924). This dataset included Holstein and Holstein × Gyr heifers raised under both confinement and grazing conditions. For confined heifers, the model demonstrated moderate predictive ability, with concordance correlation coefficients (CCC) ranging from 0.55 to 0.71, accuracy from 0.82 to 0.97, and precision from 0.63 to 0.76. As expected, results were slightly lower for grazing animals, likely due to the model's reliance on a predominantly confinement-based dataset.

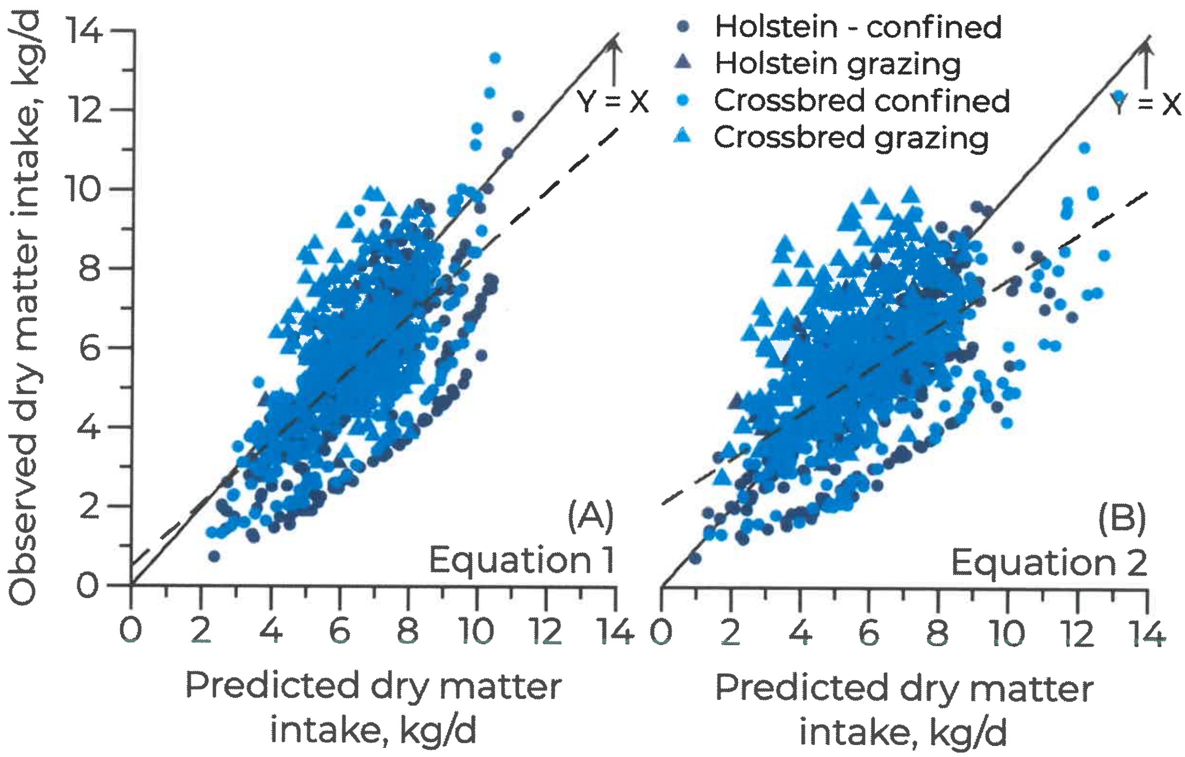

Figure 1 – Observed and predicted DMI of heifers using NASEM (2021) from MarcondesLab database of Holstein and Crossbred in confined and grazing systems

Thus, while the NASEM (2021) model represents a notable improvement over its predecessors, further refinements are needed to address nonlinear body composition changes, integrate performance variability, and better accommodate pregnant heifers. Incorporating more diverse datasets and dynamic modeling approaches will enhance prediction accuracy and practical relevance for modern dairy heifer management systems.

Rumen Degradable Protein (RDP) to Rumen Undegradable Protein (RUP) Ratio in Dairy Heifer Nutrition

Balancing RDP and RUP is essential for optimizing microbial protein synthesis, nitrogen utilization, and overall growth efficiency in dairy heifers. The NASEM (2021) model refines previous recommendations by emphasizing the need for a dynamic approach to protein utilization rather than fixed ratios. Unlike traditional models that assumed fixed requirements, new research highlights the importance of adjusting the RDP:RUP ratio based on heifer age, physiological stage, and dietary composition (Silva et al., 2018a,b).

The relationship between rumen-degradable protein (RDP) and rumen-undegradable protein (RUP) in the diets of post weaned heifers has not been thoroughly evaluated and remains complex due to the variability in heifer responses to a protein source, inclusion level, and overall diet composition. The current NRC (2001), NASEM (2021), and CNCPS models recommend a protein profile with RDP varying between 60 and 70%. However, recent and past studies challenge this paradigm, suggesting that higher RUP proportions (>50%) may be more beneficial for achieving optimal growth, especially in heifers with high average daily gain (ADG) targets exceeding 1.0 kg/d.

A consistent observation across studies is that the response to increased RUP is highly dependent on the RUP source (Table 1). For instance, Tomlinson et al. (1997) demonstrated that increasing RUP from 31% to 55% significantly improved feed efficiency and BW gain in heifers, but also showed a clear depression in dry matter intake (DMI) as RUP increased, particularly with the use of blood meal. Similar intake suppression was observed by Garthwaite (1997a), who used xylose-treated soybean meal (Soy Pass®), showing improved ADG and DMI efficiency during early growth phases. However, in later stages (>100 kg BW), additional RUP had minimal benefits. These results suggest that some RUP sources may limit intake due to palatability or metabolic feedback, masking potential performance improvements.

Table 1 – Collection of studies evaluating RDP:RUP relationships for dairy heifers

Reference	Treatments	Main Results
Cummins et al. (1982)	RUP levels (40, 55, 70% of CP) with soybean meal, corn gluten, cottonseed, or alfalfa meal in different diet forms	No differences in DMI; 55% RUP (cottonseed + alfalfa meal) resulted in lower N retention than 40% or 70% RUP
Zerbini and Polan (1985)	Bull calves supplemented with fish meal vs. corn gluten or cottonseed meals	Fish meal supplementation improved ADG compared to corn gluten or cottonseed meals
Amos (1986)	Heifers (120 kg) fed 30% and 70% RUP diets with distillers dried grains and alfalfa meal replacing soybean meal	Higher RUP increased ADG
Thonney & Hogue (1986)	Comparing the feeding value of fish meal vs. cottonseed meal	No significant difference between fish meal and cottonseed meal in feeding value
Mantysaari et al. (1989)	Supplementing RUP from fish meal, meat and bone meal, or animal protein blend vs. soybean meal	No significant response to RUP supplementation from animal-based sources

Swartz et al. (1991)	100-kg calves fed diets with blood meal, soybean meal, and corn proteins at 30, 34, and 38% RUP	Higher RUP improved feed efficiency by lowering DMI, but ADG was unchanged; no differences in body composition
Steen et al. (1992)	Heifers fed 40% RUP diet with cottonseed meal and animal protein vs. low RUP control	Slight increase in empty-body protein with 40% RUP; no significant differences in skeletal dimensions
James (1993)	Heifers (193 kg) fed factorial combinations of RUP (blood meal replacing soybean meal) and fermentable carbohydrates (barley and corn)	Carbohydrates had a greater influence on ADG than RUP; wither height increased with RUP; increased RUP improved digestible energy efficiency and tended to increase body fat
Tomlinson et al. (1997)	Holstein heifers (213-231 kg BW) fed diets with 31, 43, 50, or 55% RUP for 50 days	Increasing RUP improved feed efficiency and BW gain. DMI, digestible energy intake, and feed efficiency differed with treatment. There were no differences in waist height, heart girth, or empty body fat percentage.
Bethard et al. (1997)	2x2 factorial: Holstein heifers fed diets with low (30% CP) or high (50% CP) RUP and low (0.6 kg ADG) or high (0.9 kg ADG) energy levels	Higher DMI and ADG in high-energy diets. High-energy and high-RUP improved dry matter efficiency. High RUP increased total digestible nutrient efficiency. No overall ADG difference as slow growth in phase 1 was compensated by faster growth in phase 2.
Garthwaite (1997a)	2x2 factorial: Low (5.8% RUP) vs. High (8.8% RUP) with or without rumen-stable Lys and Met for Holstein heifers (6 wk to 175 kg BW)	High RUP in Phase 1 improved ADG (758 vs. 700 g/d), DMI efficiency, and reduced days on feed; increased serum urea N. In Phase 2, high RUP increased pin width but had no effect on heifers >100 kg. Rumen-stable Lys and Met increased frame size in Phase 2.
Garthwaite (1997b)	2x2 factorial: Low (5.0-4.3% RUP) vs. High (8.0-7.38% RUP) with or without rumen-stable Lys and Met for heifers (175-410 kg BW)	No significant growth responses observed in either phase. Heifers >175 kg BW consuming ad libitum diets may not benefit from additional RUP.
Ribeiro et al. (2005)	Holstein-Gyr heifers (211 kg BW) on pasture supplemented with 40% or 60% RUP	Intake of forage and total diet affected by pasture quality and nutrient supply. No significant differences in weight gain between RUP levels or supplement vs. pasture alone (average 509 g/d).
Zanton et al. (2007)	Postpubertal Holstein heifers (455 kg BW) fed diets with low/high soluble protein (SP) and low/high RUP in a 4x4 Latin square	No differences in DM, OM, or NDF digestibility. Higher SP increased rumen ammonia concentrations. Urinary N excretion was highest in low SP/low RUP and high SP/high RUP diets, making them least efficient in N retention. Nitrogen retention responses depended on diet composition.
Oliveira et al. (2008)	Brown Swiss heifers on Brachiaria brizantha pasture supplemented with high, medium, or low RUP levels	No effect of supplements on forage intake. Diets with high RUP had lower DM, OM, and CP digestibility. NDF digestibility decreased over time for high/medium RUP and increased for low RUP. Plasma urea N concentration was lower in high RUP diets.
Silva et al. (2018b)	4x4 Latin square: Holstein heifers (276 kg BW) fed diets with 38, 44, 51, or 57% RUP of total dietary protein	No effect on intake or nutrient digestibility. Increasing RUP tended to reduce ruminal and intestinal CP digestibility. Urinary N excretion decreased, while retained N, metabolizable protein flow, and RUP increased, with highest values in 51% and 57% RUP.

		Microbial protein synthesis and efficiency decreased with increasing RUP.
Silva et al. (2018a)	4x2 factorial: Heifers at prepubertal (106 kg BW) or pubertal (224 kg BW) stage-fed diets with 38, 44, 51, or 57% RUP of dietary CP	51% RUP increased BW, ADG, feed efficiency, and N retention regardless of physiological stage. PRE heifers had lower intake, digestibility, and N retention but more fat in mammary glands. PUB heifers had greater ADG and N retention. No effect on mammary gland composition. Serum progesterone and IGF-I were higher in PRE, while insulin increased at 51% RUP.

In contrast, studies that used a broader array of RUP sources or adjusted energy intake showed more consistent benefits. Bethard et al. (1997) found that high RUP diets improved nutrient utilization efficiency, particularly when paired with high-energy diets that support ADG > 0.9 kg/d. Likewise, Silva et al. (2018a) found that RUP levels of around 51% maximized BW gain, feed efficiency, and nitrogen retention in both pre-and postpubertal heifers, supporting the idea that high-RUP diets promote lean tissue accretion when energy is adequate. Zanton et al. (2007) further emphasized that nitrogen retention and utilization efficiency vary depending on RUP and soluble protein levels, reinforcing the importance of protein source and degradability characteristics. Although some studies, such as Ribeiro et al. (2005) and Oliveira et al. (2008), observed minimal performance differences with varying RUP levels, these were often under pasture-based systems with moderate growth rates, suggesting that the benefit of high RUP may be more apparent under intensive systems targeting higher gains.

Collectively, these findings challenge current model recommendations by showing that higher RUP levels—when derived from appropriate sources—can enhance performance in postweaned heifers, particularly when aiming for rapid growth. Future formulations should prioritize both RUP level and quality, rather than adhering strictly to static RDP:RUP ratios.

Starch/Fiber Levels in Heifer Diets

With the new farmer aiming to get heifers calving earlier (20-22 months) and with the full understanding that heifers should weight around 85% of their mature size (NASEM, 2021) right after calving (not before), nutritionist around the world are formulating diets aiming higher weights gains (1 - 1.45 kg/d), there is a need to increase dietary starch to supply that extra energy. Additionally a common practice in the Us is to feed heifers with cows leftovers, which usually contains high levels of starch. Thus understanding the best starch levels in diets for heifers is a new concern in the industry. Starch provides fermentable carbohydrates for energy, but excessive levels increase the risk of ruminal acidosis and metabolic imbalances. Also, unnecessary starch levels can lead to excessive body weight gain and accumulation of fat in the mammary gland during the heifers' development (Albino et al., 2017). Thus, combining carbohydrate (starch or fiver) with. Protein supplementation is of utmost importance during this stage.

When compiling data from studies that evaluated varying starch levels in diets for post-weaned heifers, we observed substantial variation and a notable lack of studies specifically designed to isolate the effects of starch while keeping dietary forage levels constant (Table 2). In most cases, studies either altered the forage-to-concentrate ratio or evaluated the inclusion of by-products without maintaining standardized diets. This lack of consistency makes it challenging to draw definitive conclusions about the independent effects of dietary starch on heifer performance and development.

Table 2 - Collection of studies evaluating starch:fiber relationships for dairy heifers

Reference	Description of Animals and Treatments	Major Results
Bailey (1989)	Holstein steers fed diets of: (1) 85% hay + 15% concentrate, (2) same as 1 + rumen undegradable protein, or (3) 85% concentrate + 15% hay; diets fed post-weaning until ~500 kg BW.	High-concentrate diet increased empty body weight gain by 42% and energy gain efficiency by 50%. Group 2 (supplemented hay) increased lean tissue gains. Performance gains largely due to increased fat (group 3) or protein (group 2).
Slavick et al. (2024)	Replacement heifers limit-fed either high-concentrate (high-starch) or high-forage diets during gestation.	High-concentrate diet influenced oxygen consumption and mitochondrial function in liver and jejunum; indicative of altered energy metabolism in high-starch fed heifers.
Kim et al. (2003)	18 Hereford—Friesian steers fed grass silage only or silage + concentrate (60:40 ME basis); slaughtered at 250, 350, or 500 kg BW.	Supplementing silage with concentrate improved live weight and carcass fat and protein gain, reducing time to slaughter by 57 days; carcass protein gain was consistent across diets.
Scollan et al. (2003)	92 Hereford—Friesian steers (140-550 kg) fed grass silage alone, silage + fish meal, or silage + concentrate at 30% or 70% of DM; slaughtered at intervals from 250 to 550 kg.	Concentrate diets increased live-weight gains (up to 34%), carcass fat, and visceral fat; protein deposition increased with moderate concentrate or fish meal. Fat partitioning shifted to more visceral fat with high concentrate.
Sejrsen and Foldager (1992)	Red Danish heifers fed isoenergetic high- or low-energy density diets from 3 months old; slaughtered at different BWs (139-383 kg).	No significant differences in mammary development or milk yield between diets. Mammary tissue increased with body weight. Growth hormone correlated with parenchyma tissue weight.
Zanton and Heinrichs (2007)	Dairy heifers fed high- or low-starch diets 60 days pre-breeding; target ADG = 0.9 kg/d.	High-starch diets induced estrus 22-24 days earlier than low-starch. Performance targeted at controlled ADG.

Lascano et al. (2012)	Dairy heifers fed 28% (high) or 17% (low) starch diets; Saccharomyces cerevisiae doses: 0, 10, 30, 50 g/day.	Yeast improved NDF digestibility with high starch; high starch increased plasma urea N, suggesting greater protein degradation. Nutrient digestibility improved overall.
Pino and Heinrichs (2016)	Dairy heifers fed high-starch diets.	High-starch diets reduced rumen pH and fiber digestion by harming fibrolytic microbes. Risk to rumen health highlighted.
Haisan et al. (2019)	Dairy calves post-weaning fed high- or low-starch diets.	No significant differences in body weight between treatments; suggests starch level had limited effect on growth in early post-weaning period.
Williams et al. (2021)	Post-bred dairy heifers with high and low genomic RFI; fed high-energy (15% starch) or low-energy (11% starch) diets.	Low RFI heifers were more efficient on low-energy diets. Highlights potential for genetic selection to enhance efficiency on lower-starch rations.
Satoh et al. (2023)	27 Holstein calves fed high (41.8%), medium (31.9%), or low (22.0%) starch calf starters under high milk replacer feeding; growth tracked to 13 weeks.	High-starch starter increased ADG post-weaning and starter intake without affecting fecal starch, pH, or diarrhea; suggests enhanced rumen development and energy utilization.
Gelsinger et al. (2020)	Ten Holstein bull calves weaned at 8 weeks; fed calf starters designed to induce (42.7% starch, pelleted) or blunt (35.3% starch, texturized) ruminal acidosis; evaluated through 17 weeks.	Post-weaning, calves on high-starch (AC) diet had lower DMI, BW gain, and starter intake rate; greater ruminal lesion scores and lower hemoglobin/hematocrit. Calves on lower-starch (BL) diet had better intake and growth, and healthier rumen epithelium.
Hill et al. (2008)	48 Holstein steer calves (58-60 d old); fed textured starters with either 5% or 15% chopped hay from day 56 to 84.	Calves fed 15% hay had lower ADG (0.90 vs. 1.03 kg/d), and starter intake vs. 5% hay. Feed efficiency was similar. Excess roughage reduced growth without efficiency gains.
Hill et al. (2008b)	48 Holstein bull calves (8-9 weeks old); fed textured starters with 0%, 14%, 28%, or 42% soyhulls for 28 days.	ADG declined linearly by 14% as soyhulls replaced corn in starter (1.33 to 1.14 kg/d). Feed efficiency decreased as soyhull levels increased. No difference in starter intake. Higher soyhull levels diluted energy density and reduced performance.
Hill et al. (2016)	Two 56-d trials with Holstein calves (58â€"60 d old; ~72 kg BW); Trial 1: high (52%) vs. low (20%) starch diets with different MP levels; Trial 2: pelleted diets based on soyhulls, middlings, or corn (13â€"42% starch).	High-starch diets improved ADG (1.08 vs. 1.00 kg/d), hip width change, feed efficiency, and digestibility of OM and CP. Corn-fed calves (Trial 2) had greater ADG and nutrient digestibility than those fed soyhulls or middlings. MP level had no effect.
Laarman et al. (2012)	42 Holstein bull calves weaned at 8 weeks; fed starter with dry ground corn (35.3% starch), beet pulp (33.4%), or DDGS (31.4%) during the weaning transition. Calves limited to 2.5 kg/d starter.	No differences in overall ADG or growth measurements. DDGS group had faster starter intake increase and greater severity of rumen acidosis (longer time pH <5.2, more AUC). Beet pulp group showed reduced intake increase but similar growth. Rumen pH not improved by reduced starch.

Stamey et al. (2012)	Holstein calves (n=89) assigned to low (20% CP) or high (28.5% CP) milk replacer regimens; within high MR group, calves received conventional (19.6% CP) or high-CP (25.5%) starter; tracked through 10 weeks.	Post-weaning BW and starter intake were greater in high-MR + high-CP starter group. Final BW (wk 10) was 88.0, 94.9, and 99.9 kg for low MR + conv. starter, high MR + conv. starter, and high MR + high-CP starter, respectively. Greater starter CP enhanced intake and reduced slump in ADG post-weaning.
Suarez et al. (2007)	64 male Holstein-Friesian — Dutch Friesian veal calves (10 days old); fed milk replacer + diets with various roughage types (straw, grass, corn silage) and concentrate ratios (100% to 40:60) for 10 weeks.	ADG ranged from 688 to 779 g/d. Straw reduced DMI and ADG vs. grass or corn silage. Roughage source and level did not affect final BW or feed efficiency in restricted-fed calves but reduced rumen plaque incidence and improved rumen wall appearance. Ad libitum feeding increased DMI and empty rumen weight but not growth efficiency.

Across multiple studies, increasing dietary starch or concentrate levels generally led to improved growth performance and feed efficiency in post-weaned heifers. Diets with moderate to high concentrate inclusion increased average daily gain (ADG), enhanced carcass development, and improved nutrient utilization. For instance, Bailey (1989), Kim et al. (2003), and Scollan et al. (2003) reported that supplementing forage-based diets with starch-rich concentrates enhanced live-weight gains and energy efficiency. Slavick et al. (2024) also observed increased oxygen consumption in heifers fed high-concentrate diets, suggesting possible shifts in metabolic intensity. However, Sejrsen and Foldager (1992) found no significant effects on mammary development when isoenergetic diets varied in starch content, indicating that total energy intake may play a more crucial role than starch specifically in some developmental outcomes. Importantly, across these trials, the dietary starch levels used typically ranged from 15% to 30% of dry matter, which are considered moderate for growing heifers. As such, ruminal acidosis was rarely a concern, especially given the high forage inclusion and gradual adaptation protocols used in most studies. This reinforces that moderate starch levels can be safely incorporated into heifer diets to promote growth without compromising rumen health, provided that effective fiber and total dietary structure are maintained. Several studies also explored the partial replacement of starch-rich concentrates with fibrous byproducts such as beet pulp, wheat middlings, and soybean hulls. These ingredients provided fermentable fiber and digestible energy without excessive starch load, often leading to comparable or improved growth rates while reducing the risk of acidosis. For example, replacing part of the grain with beet pulp or soyhulls supported similar ADG while improving rumen fill and possibly enhancing gut health. These byproducts can therefore serve as valuable tools in formulating balanced heifer diets, particularly when managing dietary starch levels, promoting rumen development, or addressing feed cost constraints.

In summary, moderate increases in dietary starch levels (typically 15–22% of DM) can effectively support growth and feed efficiency in post-weaned heifers without raising significant concerns about ruminal acidosis. The use of fibrous byproducts such as beet pulp, wheat middlings, and soyhulls offers a practical alternative to high-starch concentrates, allowing for energy-dense diets that promote performance while supporting rumen health. These findings support flexible ration formulation strategies that optimize growth while minimizing metabolic risks and feed costs in replacement heifer programs.

Conclusions

Optimizing calf and heifer nutrition is fundamental for improving dairy productivity and economic returns. High-fat milk replacers provide advantages in thermoregulation and early energy intake, but must be balanced with adequate protein to prevent excessive fat deposition.

Post-weaned heifers require precision-formulated energy and protein intake to maximize lean growth while ensuring long-term lactation performance. By applying the latest nutritional models, advanced feed analysis techniques, and strategic feeding strategies, dairy producers can enhance efficiency, sustainability, and long-term profitability in heifer management.

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Balancing dietary amino acids for optimum milk fat synthesis and implications of dietary fatty acid supply and profile – a modeling exercise

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With the implementation of genomic selection, the genetic capacity for milk fat and protein synthesis has dramatically increased. The rate of change for milk fat is nearly exponential, given the selection pressure on genes and alleles such as SCD1 and DGAT1, and the rate of change for milk protein yield is similar. These changes suggest, at least in Holsteins, that the potential content and yield of milk fat and protein is extraordinarily high with reports of first lactation Holstein cattle with milk fat contents of >6.5% and true protein contents >4.0%, and combined component yields approaching 9 pounds per day. These changes are analogous to creating a new genotype, similar to reevaluating new generations of growing swine to match the essential amino acid (EAA) supply to the protein accretion rate of the animal (https://webconnect.uscdcb.com/#/summary-stats/genetic-trend).

Dietary strategies that allow for increases in the yields of milk and milk components are important to increase profitability for dairy producers, the dairy industry's sustainability, and to meet the ever-increasing genetic capacity. In previous studies conducted in our lab, the focus has been on formulating diets that optimize milk component synthesis by providing adequate dietary aNDFom content and digestibility, starch, sugar, fatty acids (FA), nitrogen, and amino acids (AA), among other essential nutrients. LaPierre et al. (2020) and Higgs et al. (2023) evaluated the relationship between metabolizable energy (ME; Mcal/d) and AA (g/d) supply to determine the AA requirements of histidine (His), methionine (Met), and lysine (Lys) to be 1.19g His/Mcal ME, 1.19g Met/Mcal ME, and ~3.20g Lys/Mcal ME (or 2.7 times Met) as modeled in CNCPS v6.55 and 6.56. After balancing the supply for these AA, it is important to recognize that there may be limitations in the supply of other EAA, such as Leucine (Leu) and Isoleucine (Iso) (NASEM, 2021), and possibly non-essential AA (NEAA) such as proline (Pro) or alanine (Ala). The BCAA are essential for biological functions and have been reported to be important upregulation signaling molecules for mammalian target of rapamycin (mTOR) and other downstream cascades involved in milk component synthesis (Arriola Apelo et al., 2014; Pszczolkowski et al., 2020). Casein protein is a three-dimensional molecule comprised of ~20% BCAA, and contains many Pro molecules which, due to the three-side chain structure, allows for adequate turning and folding of the side chains in an energetically unfavorable configuration (Kumosinski et al., 1993). Accordingly, the Pro content of casein is about 10%, making it one of the most used AA in the structure of the protein. In high-producing dairy cattle that might be resource-limited, it is possible that NEAA-like Pro can become limiting, especially in early lactation. In diets where the supply of EAA are limited compared to their requirements, biological function and milk production are constrained to the most-limiting AA even as the supply of non-limiting AA increases. Thus, it is crucial to meet the requirements of all AA to sustain many biological processes while maximizing productive functions such as growth, reproduction, and lactation.

It is also critical to recognize other end-products of metabolism that can confound our estimations of N utilization, mainly when we apply a reductionist approach to N metabolism where the utilization of N appears intuitive but might not produce a direct outcome. For example, when considering the EAA requirements of lactation in cattle, many calculations are made solely based on the EAA requirements for milk protein synthesis and yield (NASEM, 2021; Lapierre et al., 2005). This is partially true, as EAA, although essential and contributing to the production of milk protein, is functional in the mammary gland outside of milk protein synthesis. Lactose and fat synthesis are EAA-intensive processes that also involve metabolic regulation through protein and enzyme synthesis. When discussing EAA requirements, all metabolic processes in the mammary gland for the yields of milk and milk components are protein synthetic pathways (Bionaz and Loor, 2008; Mu et al., 2021; Osario et al., 2016; Palmquist and Harvatine, 2020) and calculating efficiencies of use for EAA must incorporate all uses of the EAA integrated with diet energy allowable productivity – from a CNCPS perspective this is ME. The study of Higgs et al. (2023) and review by Reed et al. (2014) suggested the concept of relating N efficiency to the ME supply and energy status of the animal and expands on many of the approaches previously used to improve N efficiency. When considering available ME, all available energy sources, including carbohydrates, lipids, and proteins, should be well described. In the context of nitrogenous compounds, such as AA, many EAA and NEAA are glucogenic, providing necessary precursors for cellular energetics and metabolism. Discrete predictions for EAA supplies have been commonplace in our diet formulation systems, yet, until discrete NEAA supply is fully described, MP will still be used as a proxy of total AA sufficiency, for both protein synthesis and energy metabolism.

The requirements of FA for lactation are not as well defined as the requirements of AA or other nutrients, although there is a biological requirement of FA for many productive functions. Additionally, improving our understanding of the extent of ruminal biohydrogenation of unsaturated FA and the quantification of bacterial and protozoal FA may lead to more precise predictions of the post-ruminal FA supply and profile. Milk fat is comprised primarily of FA that originates from three main sources: de novo, mixed, and preformed FA. De novo FA are short and medium-chain FA (<16 carbons) that are synthesized in the mammary gland, preformed FA are long-chain FA (>16 carbons) that originate from dietary sources, and mixed FA (16-carbon) can be synthesized de novo or absorbed from the diet. Gresti et al. (1993) quantified the most prevalent FA combinations found in milk triglycerides (TG) and determined TG containing a C4:0, C16:0, and *cis*-9 C18:1 had the greatest molar frequency compared to other combinations of three FA suggesting a balance of FA from all sources may be important to optimize milk fat synthesis. Similarly, balancing the intake or supply of dietary FA to maintain a ratio of 1.5:1:1 for C16:0, *cis*-9 C18:1, and C18:0 may improve the balance of preformed FA supply and optimize the conversion process of C18:0 to *cis*-9 C18:1 in the mammary gland. In addition, there are interactions between the amount and profile of FA being supplied to the cow. The general recommendation is to feed moderate levels of total FA and a balanced ratio of individual FA, similar to balancing for EAA. Overall, more research is warranted to understand the requirements of FA, thus allowing for more refined diet formulation to optimize FA supply for milk component synthesis and other productive functions.

In previous studies, we observed that optimizing AA supply to meet the requirements increased milk fat and protein content. Benoit et al. (2021) fed treatment diets comprised of 15% CP, 32% aNDFom, 25% starch, 5.75% sugar, and 3.63% total FA that supplied 1.19g Met/Mcal ME, 1.24g Met/Mcal ME, and 3.09g Lys/Mcal ME to mid to late lactation dairy cows. Although the study was designed to test the effect of increasing the dietary supply of monensin, the average production across all treatments was 39.6 kg/d milk yield, 46.6 kg/d energy-corrected milk (ECM), 4.67% milk fat, 3.37% milk true protein, and 4.63% milk lactose. Interestingly, the increase in milk fat was achieved by synthesizing higher levels of de novo and mixed FA with the average FA content (g/100g milk) across treatments being 1.16% de novo FA, 1.89% mixed FA, and 1.35% preformed FA which was similar to the milk fat composition of Jersey dairy cows (Barbano et al., 2019). Additionally, Danese et al. (2024) evaluated the effect of increasing the supply of Met, while maintaining equivalent levels of His and Lys, on milk, milk components, and milk FA. The authors observed that increasing Met from 0.86g/Mcal ME to 1.19g/Mcal ME increased ECM yield, the contents of milk fat, true protein, de novo FA, and mixed FA, suggesting that optimizing the supply of Met is essential to optimize milk component synthesis and ECM yield (Tables 1 and 2). The data from these studies suggest that supplying optimal levels of Lys, His, and Met that meet the requirements for lactation increases milk fat production by increasing de novo FA synthesis. Thus, AA may play a role in enzyme activity or signaling cascades that are essential for milk FA synthesis. Interestingly, balancing for AA improves energy efficiency by overcoming limiting resources and allowing increased nutrient utilization in the mammary gland, thus increasing milk component production and ECM yield.

Many studies have evaluated the mechanistic role of AA and FA in milk synthetic pathways by assessing their effects on mTOR and sterol regulatory element-binding protein (SREBP), as well as essential enzymes for milk fat synthesis, such as acetyl-CoA carboxylase (ACC), FA synthase (FAS), stearyl-CoA desaturase (SCD), and diacylglycerol acyltransferase (DGAT). Li et al. (2019) supplemented bovine mammary epithelial cells in vitro with Lys and a FA mix containing C16:0 and *cis*-9 C18:1 and observed that cells treated with both Lys and FA increased the expression of SREBP-1 and secretion of triglycerides (TG) compared to supplementation of only one treatment. Lys has been shown to facilitate the upregulation of FA binding protein (FABP) and SREBP, which in turn, upregulate enzymes such as acetyl CoA synthase (ACS), ACC, and FAS, enhancing de novo FA synthesis. Further, Ding et al. (2022) observed that infusing arginine (Arg) increased de novo and mixed FA yield and increased the expression of ACC, SCD, and DGAT compared to the control. Met and Leu have also been shown to be involved in upregulating SREBP(Li et al., 2018). Elongation of the FA carbon chain requires FAS and data has demonstrated the role of His, Lys, serine (Ser) and cysteine (Cys) in the expression and activity of the enzyme system, also suggesting that FAS requires both EAA and NEAA. In addition, there are interactions the amount and profile of FA supplied to the cow. To achieve increased milk FA synthesis, the requirements of EAA at a metabolizable level are generally much greater than historically supplied. Using the approach of

Higgs et al. (2023), the grams per Mcal of ME provides a more precise approach for achieving the supplies required to increase the expression of these enzymes. Additionally, the level of AA supply for these processes and protein synthetic pathways reflects the increased genetic capacity of the mammary gland to achieve higher milk fat and protein production. For example, supplying at least 1.19 g metabolizable Met and His/Mcal ME, and 3.2g metabolizable Lys/Mcal ME provides adequate levels of those EAA to achieve increased milk fat synthesis. It is also important to consider dietary sources of substrates that enhance ruminal butyrate production, as butyrate is used in significant quantities to synthesize FA and triglycerides on a molar basis.

These data suggest AA are required to optimize milk FA synthesis by providing substrate for enzyme activity or acting as signaling molecules for protein synthetic cascades. Protein synthetic pathways and cascades are regulated by the amount of nutrients available for the synthesis of the end-product of interest and the signaling molecules that dictate the action of these nutrients to form a specific end-product. Mackle et al. (2000) utilized the hyperinsulinemia-euglycemic clamp technique to evaluate the effect of increased insulin supply with and without the infusion of casein and BCAA. The authors observed that insulin independently increased the yields of milk and milk protein compared to the control, whereas insulin and AA infusion further increased the yields of milk and milk protein compared to the treatments

Table 1. Body weight, dry matter intake, milk and energy corrected milk yield and milk components in lactating dairy cows fed three levels of rumen protected methionine where lysine and histidine were formulated at 3.2 and 1.19 grams per Mcal ME using CNCPS v6.5. Danese et al. 2024. Rows with different superscripts differ P < 0.05.

	Diet, g Metabolizable Met/Mcal ME				
Parameter	0.86	1.05	1.19	SEM	*P*-value
Body Weight, kg	698	705	701	3.3	0.30
Delta BW, kg	16.4	23.9	9.80	6.8	0.35
Dry Matter Intake, kg	26.4	26.5	26.1	0.30	0.59
Milk Yield, kg	44.6	45.3	44.8	0.40	0.38
ECM, kg	48.8^{a}	50.2^{b}	50.4^{b}	0.44	0.02
ECM/DMI, kg/kg	1.87	1.88	1.92	0.02	0.21
Milk True Protein, g/100g	3.09^{a}	3.24^{b}	3.34^{c}	0.01	<0.01
Milk True Protein, kg	1.38^{a}	1.46^{b}	1.49^{b}	0.01	<0.01
Milk Fat, g/100g Milk	4.21^{a}	4.25^{a}	4.36^{b}	0.03	<0.01
Milk Fat, kg	1.88	1.92	1.94	0.02	0.16
MUN, mg/dL	11.20	11.44	11.09	0.12	0.12

Table 2. De novo, mixed and preformed fatty acid content in lactating dairy cows fed three levels of rumen protected methionine where lysine and histidine were formulated at 3.2 and 1.19 grams per Mcal ME using CNCPS v6.5. Rows with different superscripts differ P < 0.05.

	Diet, g Metabolizable Met/Mcal ME				
Parameter, g/100g milk	0.86	1.05	1.19	SEM	*P*-value
Denovo	1.14[a]	1.17[b]	1.20[b]	0.010	<0.01
Mixed	1.65[x]	1.67[xy]	1.70[y]	0.015	0.07
Preformed	1.16	1.15	1.19	0.013	0.20
Relative Concentration, g/100g FA					
Denovo	28.79[a]	29.33[b]	29.34[b]	0.09	<0.01
Mixed	41.83	41.61	41.56	0.15	0.40
Preformed	29.33	29.08	29.07	0.17	0.43

independently. This data suggests insulin may be an essential regulator of the partitioning of nutrients in the mammary gland for milk component synthesis. Insulin-induced genes (INSIG) are responsive to insulin changes and affect the translocation and activation of SREBP, affecting the downstream actions of genes involved in milk fat and protein synthesis (Bionaz and Loor, 2008).

Nutrient supplies need to increase concomitantly with the change in capacity to realize the genetic capabilities of high-producing dairy cattle. This requires a more integrated approach where both the AA and FA are described together as a function of the ME and MP supply, to better meet the mammary capacity for milk fat and protein synthesis and yield. This also requires that our nutrient requirements and supply models are more precise in describing the supplies of these nutrients to optimize productivity while reducing the environmental impact of dairy production.

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2025 CANC SCHOLARSHIP WINNER - CONOR MCCABE

Methane emission measurement via head chambers impacts dairy cattle performance in days following measurement events

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The objective of this research was to determine the impact of head chamber (HC) measurement duration and frequency on Holstein dairy cattle production and behavior. Two experiments evaluated separate rumen modifiers that did not result in CH_4 emission reductions from October-December 2018 and October 2022-January 2023. Prior to the experiment starting, cows were trained to be restrained in HC equipment. During Experiment 1, dairy cows were restrained to the HC for measurements between 0600 and 1800 h at four separate timepoints and spent the overnight period in a freestall pen. In Experiment 2, dairy cows were restrained to the HC at five separate timepoints from 0700-0900, 1300-1500, 1900-2100, and 0100-0300 h. In between measurement periods, dairy cows were released to a freestall pen. Disruptions to dairy cows' normal daily routine were assessed via milk yield (MY) and dry matter intake (DMI) on the day of and each of the three days following a HC measurement. Due to nonsignificant results in CH_4 reductions ($P > 0.05$) both control and treatment cows were utilized in statistical analyses. A linear mixed model using the fixed effect of Experiment Number (1 or 2), Day Relative to HC (0-3), Timepoint (1-5), and the random effect of cow nested within treatment was performed in R v. 4.4.1. In Experiment 1, DMI was lower on Day 1 post HC measurement compared to the HC day (24.6 vs. 25.7 kg/d; $P < 0.05$), whereas in Experiment 2, there was no difference in DMI between the HC day and any of the days following a HC measurement ($P > 0.05$). In Experiment 1, there was a tendency for reduced MY on Day 2 post HC measurement compared to the HC day (35.4 vs. 34.4 kg/d; $P = 0.06$), while in Experiment 2, there was a tendency for reduced MY on Day 1 following a HC day, (38.3 vs. 37.5 kg/d; $P = 0.09$). In both experiments, MY rebounded to previously recorded levels by Day 3. The duration and frequency at which dairy cow enteric emissions are sampled via HC impacts performance in days following measurement, demonstrating tradeoffs associated with this tool.

Keywords: Cow behavior, Methane, Methodology

BIAS ASSESSMENT OF CREATININE AS A MARKER TO PREDICT URINARY VOLUME IN NON-PREGNANT, NON-LACTATING COWS

ABSTRACT

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Accurate estimation of urine output is essential for assessing nutrient utilization, particularly for markedly excreted urinary minerals and protein-derived metabolites. In lactating dairy cows, an equation based on creatinine and BW has been developed: Urine volume = [29 × BW (kg)] / [urinary creatinine (mg/L)]. However, its applicability to non-pregnant, non-lactating cows remains unknown. Data from a prior study evaluating the relative availability of different Mg sources were used. Briefly, the study was a duplicated 6 × 6 Latin square with cows (n = 12) assigned to the square based on low (square 1) or high (square 2) BW with 6 periods. Cows were of second (n = 8) or ≥third (n = 4) parity, and BW ranged from 590 to 831 kg. Data on total urine collection and creatinine concentration from 24 h before treatment administration was used in this study. To assess the agreement between estimated urinary daily volume (EUV) and centered observed urinary daily volume (OUV), we built two mixed-effects models. The first model assessed slope bias (slope ≠ 1), while the second evaluated mean bias (intercept ≠ 0) between EUV and OUV. Results indicated a slope bias with an estimated slope of 0.86 ± 0.06 (P = 0.03) and mean bias with the intercept significantly different from 0 (P = 0.01). Additionally, when assessing bias variation across BW quartiles, cows in the lowest quartile showed 10% less bias compared to higher BW groups, suggesting greater accuracy at lower BW levels. Our results suggest further research is needed to refine the predictive equation using creatinine and BW for non-pregnant, non-lactating Holstein dairy cows.

Keywords: Urinary volume, creatinine, body weight.

Assessment of Transfer of Passive Immunity (TPI) in Crossbreed Calves at 2 and 7 Days of Age

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Calves are born immunologically naïve and rely on TPI from colostrum to protect against infections. A group of experts recently proposed a 4-level TPI classification system, based on immunoglobulin G (IgG) and serum total protein (STP) concentrations, applicable to samples collected in dairy calves from 24 hours to 7 d of age. This system has the potential to guide colostrum management and reduce morbidity and mortality at the herd level; however, it has not yet been applied to crossbred calves. The objectives of this study were to (1) evaluate the agreement between IgG- and STP-based TPI categories and (2) investigate changes in classifications from 2 to 7 d. Calves were enrolled from a California calf-raising facility and sampled for IgG (radial immunodiffusion assay) and STP (digital refractometry) at 2 and 7 d of age. IgG and STP were categorized as follows: IgG-based categories [excellent (≥ 25 g/L), good (18–24.9 g/L), fair (10–17.9 g/L), and poor (< 10 g/L)] and STP-based categories [excellent (≥ 6.2 g/dL), good (5.8–6.1 g/dL), fair (5.1–5.7 g/dL), and poor (< 5.1 g/dL)]. Agreement between TPI categories was assessed using Cohen's Kappa, and changes over time were evaluated with Bowker's tests. The study included 198 calves (49% female, 51% male; 44.4% HO × beef, 55.6% JE × beef) sourced from seven dairies. TPI distribution is presented in Table 1. Cohen's Kappa indicated moderate agreement between IgG- and STP-based TPI categories on day 2 ($\kappa = 0.57$; 95% CI [0.46, 0.66]; $p < 0.001$) and fair agreement on day 7 ($\kappa = 0.41$; 95% CI [0.30, 0.53]; $p < 0.001$). Bowker's test showed significant shifts in TPI classification from day 2 to 7 for IgG-based ($\chi^2 = 40.2$; $p < 0.001$) and STP-based ($\chi^2 = 31.0$; $p < 0.001$) categories. This study provides insights into changes in TPI classification at two different time points (2 and 7 days of age). As TPI classifications appear to change with age, the age at sampling should be considered when interpreting TPI results. Further research is needed to determine if the current 4-level TPI classification, designed for dairy calves, is applicable to crossbred calves.

Keywords: TPI, IgG, STP, crossbred calves

Table 1. Distribution of TPI categories based on IgG and STP concentration in crossbreed calves at 2 and 7 days of age (n = 198)

	IgG		STP	
TPI Category	Distribution (%)	Median (IQR) [g/L]	Distribution (%)	Median (IQR) [g/dL]
Day 2				
Excellent	30.3%	28.5 (26.8–33.6)	20.2%	6.5 (6.3–6.7)
Good	28.3%	22.3 (19.6–23.5)	14.1%	6.0 (5.8–6.0)
Fair	17.7%	14.9 (13.0–16.6)	27.8%	5.4 (5.3–5.6)
Poor	23.7%	6.0 (5.0–7.2)	37.9%	4.6 (4.4–4.8)
Day 7				
Excellent	17.7%	28.6 (26.4–33.9)	7.6%	6.5 (6.5–6.7)
Good	23.7%	21.0 (19.2–22.5)	10.1%	6.0 (5.8–6.0)
Fair	30.3%	14.3 (12.9–15.9)	40.4%	5.4 (5.3–5.6)
Poor	28.3%	5.0 (4.3–6.5)	41.9%	4.7 (4.4–4.9)

Effect of probiotic fed in milk and starter grain during the pre-wean period on gut development, fecal score, and gut microbiome in Holstein x Angus calves

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Administering probiotics can improve gut development and delay the onset of diarrhea in pre-weaned calves. This study evaluates the effectiveness of feeding a Lactobacillus acidophilus and Lactobacillus casei probiotic supplement (PS: 1×10^9 CFU) in milk and starter grain 1x /d on blood beta-hydroxybutyrate (BHB) and glucose (GL) concentrations, fecal scores, and gut microbiome. Pre-weaned Holstein x Angus cross calves age < 48 h with serum total proteins ≥ 5.2 g/dL were randomly enrolled into two treatment groups: 1) Control (CON: n=149), and 2) Probiotic (PRO: n=150). Fifty mg/calf/d of PS were added to individual milk bottles in the am feeding, and 50 mg/calf/d were top dressed in starter grain until weaning at 60 d of age. Blood samples were collected from approximately 50 calves per treatment at 7, 21, 35, 49, and 56 d via jugular venipuncture to determine gut development represented by BHB and GL. Fecal consistency was evaluated daily using a 1-3 scale, with 1 representing normal, and 3 indicating watery manure. Fecal samples were collected at 42 d from 10 calves per treatment to perform metagenomic analysis. Blood metabolite results were analyzed using general linear models (SAS v. 9.4, 2024) with backwards elimination of independent variables ($P > 0.1$). Independent variables included sex, serum total protein and age. A Kaplan-Meier analysis was used to compare the treatment groups' median days to first heightened fecal score (MedCalc v. 23.1.3). Variables BHB and GL were not different among groups at any time point. The median time to heightened fecal score was 14 d and did not differ among groups. Gut community structure and α-diversity did not differ between control and treatment groups. Probiotic feeding did not appear to affect gut or microbiome development under the conditions of this study.

Keywords: Calves, Probiotics, Fecal Score

Effect of probiotic fed in milk and starter feed to pre-weaned Holstein Angus calves on Health

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Feeding probiotics to pre-weaned calves can reduce gastrointestinal related health challenges. The objective of this study was to determine the effects of feeding a lactobacillus probiotic supplement (PS; 1 x 10^9CFU) in milk and starter grain on Holstein x Angus cross calves health from 24-48 h to weaning at 60 d of age. Calves were randomly enrolled into 4 treatment groups: 1. Control with serum total proteins (STP) < 5.2 g/dL (n = 65), 2. Control with STP ≥ 5.2 g/dL (n = 149), 3. Treated with 50 mg/calf/d PS added to milk, 50 mg/calf/d added to grain and STP < 5.2 g/dL (n = 65) and 4. Treated with 50 mg/calf/d PS added to milk, 50 mg/calf/d added to grain and STP ≥ 5.2 g/dL (n = 150). Calves were weighed at enrollment and at weaning to determine total gain. Calves were scored daily with Fecal scoring (FS) on a scale from 1-3 with 1 being normal and 3 being scours, respiratory score (RS) and general appearance scores (GA) were recorded on a scale of 1-5 with 1 being normal. Data was analyzed using general linear models (SAS v. 9.4, 2024). Difference was determined by $P < 0.05$. There were no differences between treatments for total gain, ADG, cause of death as determined by necropsy, number of days of FS of 3, number of days with RS ≥ 4, number of days with GA ≥ 4 (GA). Total gain was affected by initial body weight and GA. Average daily gain was affected by total proteins, initial bodyweight, days on treatment, FS and GA. Of the total number of calves necropsied (n=8), the cause was predominantly pneumonia (n = 7) and was affected by hutch, days on treatment, RS and GA. Fecal scores were affected by hutch. Although treatment did not affect the outcome of the calf, days on treatment may have increased ADG, but higher incidence of higher FS decreased it. Fecal scores affected by hutch number implies that calves could have spread scour causing pathogens across the hutches.

Blood concentrations of energy and nitrogenous metabolites as affected by breed (Holstein vs. Jersey), parity, and serum TNFα concentrations through the transition period

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Requirements for glucose, energy, and amino acids increase greatly as cows move from late pregnancy to early lactation and the degree to which cows experience negative nutrient balance may be reflected in blood concentrations of selected metabolites. Also, there is increasing interest in the role of the inflammatory response in the partitioning of these nutrients. Therefore, we evaluated blood concentrations of glucose, beta-hydroxybutyrate (BHB), non-esterified fatty acids (NEFA), total free AA, urea N, and tumor necrosis factor-alpha (TNFα; assayed by a bovine specific ELISA) in cows throughout the transition period. Sixty-three cows (32 Jersey and 31 Holstein) at the Cal Poly dairy unit of 1^{st} (n = 16), 2^{nd} (n = 16), 3^{rd} (n = 15), and ≥ 4^{th} (n = 16) parity were enrolled in a longitudinal study with frequent blood samples obtained from 28 d prior to expected parturition to 30 d postpartum (i.e., target days relative to parturition were -28, -21, -14, -7, -3, -2, -1, 0, 1, 2, 3, 7, 14, 21, 28). Metabolite concentrations were evaluated using mixed linear models including the effects of breed, parity group, day, and their interactions, with day as a repeated factor. Also, serum TNFα values were evaluated as a covariate for other metabolites. All metabolites were affected ($P < 0.001$) by day of sampling. Concentrations of BHB rose steadily across time whereas NEFA concentrations peaked at day of parturition and then declined towards prepartum values. Both BHB and NEFA were affected ($P \leq 0.02$) by an interaction of breed with day. Glucose concentrations increased sharply on day of parturition and also were affected ($P < 0.001$) by the interaction of day with breed. For nitrogenous metabolites, plasma concentrations of both total free AA and urea N decreased as cows approached parturition and subsequently increased; nadir values were obtained at day of parturition (total free AA) or day 1 post-partum (urea N). There was also an interaction ($P = 0.02$) of parity group with day for total free AA; nadir values were much lower for multiparous vs. primiparous cows, potentially reflecting AA limitation. Either the main effect or interactions involving TNFα were significant ($P \leq 0.02$) covariates for each metabolite, possibly reflecting a role for TNFα in nutrient partitioning.

Keywords: dairy cows, hypocalcemia, inflammation

Dietary supplementation of blends of organic acids and monoglycerides alleviated diarrhea and systemic inflammation of weaned pigs infected with enterotoxigenic *Escherichia coli* F18

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This study aimed to investigate the effects of dietary supplementation of organic acids (OA), monoglycerides (MG), and a combination of both (OA+MG) on diarrhea and immune responses of weaned pigs experimentally infected with a pathogenic *Escherichia coli* (*E. coli*) F18. Forty pigs (body weight = 7.81 ± 0.84 kg) were individually housed and randomly assigned to one of four treatment groups (10 replicates/treatment): basal diet (CON), basal diet supplemented with OA blend at 0.3%, MG blend at 0.3%, or combination of both the OA blend at 0.2% and the MG blend at 0.2%. The experiment lasted 28 days, with 7 days before and 21 days after the first inoculation (d 0). All pigs were orally inoculated with *E. coli* F18 (10^{10} CFU/3 mL) for 3 consecutive days from d 0. Daily fecal score was recorded throughout the experiment from 1 to 5 (1 = normal feces, 5 = watery diarrhea). The frequency of diarrhea was calculated as the percentage of the pig days with a fecal score 3 or greater. Whole blood samples were collected on d 0, 5, and 14 PI to perform a complete blood count analysis. Porcine Cytokine/Chemokine13-Plex Discovery Assay (Eve Technology, Canada) was also conducted with serum samples from d 0, 5, and 14 PI. All data were analyzed by ANOVA using the PROC MIXED of SAS with a pig as the experimental unit. The frequency of diarrhea was calculated and analyzed by using Chi-square test. Supplementation of OA, MG, or OA+MG significantly reduced ($P < 0.05$) the frequency of diarrhea (25.5 to 29.8%) compared with CON (39.3%). *E. coli* F18 infection increased ($P < 0.05$) counts of total white blood cells on d 5 and 14 PI, compared with d 0. Supplementation of the OA+MG reduced ($P < 0.05$) the counts of total white blood cells and lymphocytes compared with CON. Pigs fed with MG had higher ($P < 0.05$) neutrophil counts than pigs in the CON on d 14 PI. In conclusion, dietary supplementation of OA, MG, and OA+MG may alleviate diarrhea or systemic inflammation of weaned pigs during *E. coli* F18 infection by modulating related cytokines.

Keywords: *Escherichia coli* infection, monoglycerides, systemic immunity, weaned pig

Effects of short chain fatty acids derivatives on diarrhea and growth performance of weanling pigs challenged with F4 and F18 enterotoxigenic Escherichia coli

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The objective of this study was to investigate the effects of short-chain fatty acid derivatives, specifically monobutyrin (MB) and monovalerin (MV), on diarrhea and growth performance of weanling pigs experimentally infected with F4 and F18 enterotoxigenic Escherichia coli (ETEC). A total of 176 pigs (7.14 ± 1.12 kg BW) were housed individually and randomly allotted into 11 treatment groups (n = 16). The treatments included a negative control without ETEC infection, a positive control (PC) with ETEC, and 9 additional groups supplemented with 0.005% carbadox, 0.25% zinc oxide (ZnO), 0.10% sodium butyrate, 0.10% or 0.15% MB, 0.10% or 0.15% MV, a combination of 0.05% MB and 0.05% MV, and a combination of 0.075% MB and 0.075% MV, respectively. All percentages indicate the amount of additives supplemented in percentage of diet composition. The experiment lasted for 28 days, including 7 days of adaptation and 21 days of post inoculation (PI). After the adaptation, piglets in treatment groups were inoculated with 1010 CFU/3 mL oral dose containing equal amount of F4 and F18 ETEC on day 0, 1, 2 PI. Body weight was measured on day -7, 0, 5, 14, and 21 PI. Diarrhea score (DS; 1, normal, to 5, watery) was recorded twice daily. Data were analyzed by ANOVA using PROC MIXED of SAS with a randomized complete block design. Supplementation of high dose ZnO or carbadox yielded the lowest frequency of diarrhea (DS ≥ 3 and DS ≥ 4), followed by sodium butyrate, MB (0.10 and 0.15%), and 0.15% MV. The combination of low dose MB and MV also reduced the severity of diarrhea ($P < 0.05$) compared with the PC. Inclusion of ZnO, carbadox, 0.15% MB and the combination of low dose MB and MV yielded higher ($P = 0.054$) body weight on d 5 PI compared with the PC group. In conclusion, dietary supplementation of MB or MV can reduce the severity of diarrhea and enhance the growth rate of weaning pigs infected with ETEC F4 and F18.

Keywords: monobutyrin, monovalerin, weaned pigs

Peripheral blood mononuclear cell mitochondrial enzyme activity associations with embryo transfer success in dairy cattle recipients

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Mitochondria produce energy vital for health, reproduction, and metabolism and have their own maternally inherited DNA. The objective was to determine if mitochondrial enzyme activities (MEA) of Complex I (CI), Complex IV (CIV), and Complex V (CV) in peripheral blood mononuclear cells (PBMC) were associated with pregnancy outcomes in embryo transfer (ET) recipients, hematological, management, and genomic variables. Whole blood was collected from 40 Holstein cows from June to Sept 2024. Recipients were randomly assigned either Embryo A (Donor 1/Sire 1, n=20) or Embryo B (Donor 2/Sire 2, n=20). Crude mitochondrial extracts were isolated from PBMC and analyzed for MEA of CI, CIV, and CV (Abcam, Cambridge, UK). Pregnancy outcomes were checked at approximately 32 days carried calf (DCC) and confirmed at 45 and 90 DCC. Management, genomic, and pregnancy outcome data were collected from DC305 (VAS, Tulare, CA). Enzyme activity was regressed on pregnancy outcome, embryo, DIM at enrollment (DIMT), MEA (CI, CIV, CV), red blood cell (RBC) count, hemoglobin (HB), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), age at first calving (AGEFC), weight at first calving (WGTFC), week 4 and 8 daily milk yield, and genomic daughter pregnancy rate using the GLM procedure of SAS (SAS 9.4, SAS Institute Inc., Cary, NC, USA). Of the 40 cows, 12 conceived, 6 from Embryo A, and 6 from Embryo B. Complex I, IV and V activities of recipients were not associated with pregnancy outcome up to 90 DCC. However, the activities of CI, CIV, and CV were associated with RBC, MCHC, DIMT, AGEFC, and WGTFC, in addition to HB and MCH solely for CIV and CV. This is consistent with the role of RBC and HB in oxygen transport, which is important to mitochondrial function. The association of recipient MEA with AGEFC, WGTFC, and DIMT show that metabolic state influences MEA. Associations with live birth or ET calf survivability remain to be determined.

Keywords: mitochondria, enzyme activity, embryo transfer

Inducing trans-10-Shifted Biohydrogenation Pathways Improves Feed Conversion Efficiency and Carcass Quality in Feedlot Lambs

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We previously found a negative association between the backfat concentrations of trans-10 biohydrogenation intermediates, trans(t)10-18:1, and the USDA yield grade in feedlot lambs. This study aimed to evaluate the causal effects of inducing t10-shifted biohydrogenation pathways by feeding a grain-based diet supplemented with high linoleic acid corn oil on growth performance and carcass characteristics. Twelve Dorper (BW=37.57±17.04 kg) and 12 Black faced Suffolk x White Face/Rambouillet (BW=41.82±18.97 kg) lambs were used in a completely randomized block design with breed as the block. Within each block, lambs were randomly assigned to one of three diets: a control diet (CTL, no fat supplement), a grain-based diet (GBD) containing 6% palm oil-based saturated fat supplement (PAL), or a GBD containing 6% high-linoleic corn oil (COR) for 35 days. Individual feed intake was recorded daily, and body weight (BW) measured weekly. Plasma samples were obtained on days 0, 18, and 35 for fatty acid analysis. Backfat thickness(BFT) was measured on days 0 and 35 using ultrasound. The lambs were processed at the Superior Farms plant and graded with a USDA-inspected camera grading system. Data were analyzed using the PROC MIXED procedure in SAS. Plasma concentration of t10-18:1 was higher ($P < 0.05$) in COR (5.61%) compared to CTL (1.40%) and PAL (2.18%). The t10:18-1/t11:18-1 was lower ($P < 0.05$) in CTL (0.79) than both PAL (2.84) and COR (3.97). Final BW (50.35±5.76kg) and BW gain (10.73±1.92kg) did not differ among treatments ($P > 0.05$). COR had lower ($P = 0.0311$) average daily dry matter intake than PAL but was not different from CTL (1.35±0.44 kg, 1.53±0.51 kg, 1.50±0.37 kg, respectively). The feed-to-gain ratio was lower ($P = 0.0108$) in COR (1.90) compared to CTL (2.32) and PAL (2.34), indicating superior feed efficiency in COR. PAL diet resulted in increased ($P = 0.0472$) BFT compared to CTL (10.11±2.08 mm and 7.37±2.43mm, respectively), but no increase ($P > 0.10$) was observed in the COR (8.32±1.98 mm). Moreover, hot carcass weight was significantly greater in COR (26.72kg) compared to CTL (25.15kg) but was not different from PAL (26.93kg). Overall, our data suggest that inducing trans-10-shifted pathways can improve feed efficiency and carcass quality in feedlot lambs. Long-term studies with a larger sample size are needed to verify these findings.

Keywords: feed efficiency, high linoleic acid, lamb

The effect of feeding Bacillus subtilis on fecal microbiota and antimicrobial resistance gene composition of weaned pigs

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Our previous research found that supplementing Bacillus subtilis reduced diarrhea frequency and improved growth in weaned pigs infected with pathogenic Escherichia coli (E. coli). This study further investigated the effects of dietary Bacillus subtilis or carbadox on antimicrobial resistance gene (AMR) composition and microbial community in fecal samples from weaned pigs. The four experimental treatments were: 1) negative control, pigs fed a control diet without E. coli challenge, 2) positive control, pigs fed a control diet with E. coli challenge, 3) antibiotic group, pigs fed a diet supplemented with 50 mg/kg of carbadox with E. coli challenge, and 4) probiotics group, pig fed a diet supplemented with 2.56×10^9 CFU/kg of Bacillus subtilis with E. coli challenge. 32 fecal samples were collected from pigs' rectum on day 21 after the first E. coli inoculation. Total microbial DNA was extracted from feces and submitted for WGS Sequencing (Illumina NovaSeq). Microbiota analysis was conducted using Sourmash. AMR gene analysis was performed using RGI. At the phylum level, supplementation of antibiotic reduced ($P < 0.05$) the relative abundance of Bacillota but increased ($P < 0.10$) the relative abundance of Bacteroidota in feces of pigs compared with those in other groups. At the genus level, antibiotic group had the lowest ($P < 0.05$) relative abundance of Lactobacillus, Streptococcaceae, Bifidobacterium among all treatments, while it led to the highest ($P < 0.05$) relative abundance of Clostridium. A total of 148 AMR genes were identified while 57 genes were shared by all groups. AMR genes like Mel, tet(Q) were highly abundant regardless of treatment while genes like tet(A), lsaE were only predominant in antibiotic group and negative control. In conclusion, dietary Bacillus subtilis and carbadox have different impacts on microbiota community and AMR gene profile in feces of weaned pigs.

Keywords: Bacillus subtilis, metagenomic analysis, weaned pigs

CANC 2025 UNDERGRADUATE ABSTRACTS

Evaluation of Excell® supplementation on growth performance in weaning lambs

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Abstract

Weaning is one of the most stressful periods in a lamb's life, often leading to reduced feed intake, slowed growth, and increased susceptibility to illness. Without proper rumen development, lambs struggle to efficiently transition from a milk-based diet to solid feed, impacting their overall health and performance. Previous research in calves showed that Excell®, a probiotic supplement containing *Lactobacillus*, increased butyric acid production and improved rumen development, but its effects in lambs have not been studied. If Excell® could enhance digestive development and feed efficiency in lambs, it would provide producers with a practical tool to improve growth performance and reduce weaning-related setbacks. The objective of this study was to evaluate the effects of Excell® on rumen development, morbidity, and post-weaning growth performance in lambs, with the hypothesis that supplementation would reduce morbidity and improve post-weaning average daily gain (ADG). This study utilized a randomized controlled design at the university Sheep Unit. A total of 41 ewes were used, with their lambs randomly assigned to one of two treatment groups: Excell® (n = 24 ewes, 30 lambs; standard creep feed with Excell® mixed in, ad libitum) or Control (n = 17 ewes, 26 lambs; standard creep feed only, ad libitum). Creep feeding was implemented using a creep feeder to ensure lambs had exclusive access to grain before weaning at 65 days of age. Supplementation continued for 17 days post-weaning. Feed intake was monitored daily, and individual lamb body weights were recorded weekly. Growth performance was assessed by calculating ADG pre-weaning (30 and 60 days), post-weaning (30 days post-weaning), and adjusted weaning weights at 60 and 90 days. Feed efficiency was calculated as the ratio of total weight gain to total feed intake over the post-weaning period. Raw data suggests that Excell supplementation resulted in greater ADG post-weaning compared to the control group. Our first statistical analysis was conducted using SAS software with a PROC GLM model, treating treatment as a fixed effect. It indicates that Excell may enhance feed efficiency and promote growth in weaning lambs. Our initial results suggest that Excell supplementation could be a viable nutritional strategy to support lambs through weaning and is reason to replicate the study in the fall.

Comparison of the Effects of Palm Oil-Based and Animal Fat-Based Lipid Supplements on Milk Fatty Acid Composition and Milk Fat Thermal Properties in Dairy Goats

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Palm oil-based (PBS) and animal fat-based (ABS) lipid supplements are commonly fed to dairy cows, but there is limited data on their effects on dairy goats. Our hypothesis was that compared to ABS, feeding PBS would increase C16:0 in goat milk fat and increase energy needed to melt milk fat at room temperature. Eight goats were paired and assigned randomly to either PBS or ABS at 100g per day for 18 d. The goats had free access to alfalfa hay and water and were fed 700g of concentrate mixed with 100g of lipid supplement at milking (5 PM). Concentrate intake and milk yield were recorded daily, and milk fat and protein content were analyzed using a LactoScope FT-A. FA profile was analyzed using gas chromatography and melting properties using differential scanning calorimetry. Data was analyzed using paired t-tests in GraphPad Prism. Milk yield, fat content, protein content, fat yield, and protein yield were not different ($P > 0.05$) between PBS and ABS after 18 d on test. After 18 d, the PBS goats had a higher ($P < 0.05$) milk C16:0 content than the ABS goats (41.9% & 31.6%, respectively). The ABS group had a higher milk C18:0 content than the PBS group on day 18 (7.8% & 3.2%, respectively). Other major milk FAs did not differ ($P > 0.05$) between PBS and ABS. Thermal analysis of milk fat showed that of the total energy needed to melt the sample, the ABS group absorbed a larger percent than PBS when heated from 5°C to 22°C (74.3% & 45.0%, respectively). In conclusion, compared to ABS, feeding PBS to goats increases milk fat content of C16:0 and the energy needed to melt milk fat, which may have negative effects on butter healthiness due to the atherogenic properties of C16:0, as well as reduced butter spreadability due to change in thermal properties.

Key Words: Dairy Goat, Fat Supplements, Milk Fatty Acids, Butter

Technical Symposium
Speaker Biographies

Rafael Neves, Ph.D., grew up in the Southeast region of Brazil and received his DVM degree from Pontificia Universidade Catolica de Minas Gerais. Following graduation, he completed a master's degree in Epidemiology and Dairy Health Management at University of Guelph, Canada; a clinical residency in the Ambulatory and Production Medicine Clinic at Cornell University, and a PhD in Comparative Biomedical Sciences at Cornell University. He was on faculty for 18 months in the Department of Veterinary Sciences, Texas Tech University. Currently, he is an Assistant Professor of Food Animal Ambulatory at Purdue University.

Heather White, Ph.D., is originally from southern Indiana and earned her BS from St. Mary's College, Notre Dame, Indiana. She then earned her MS and PhD at Purdue University and subsequently did a postdoctoral fellowship at the Indiana University School of Medicine. Heather went to the University of Connecticut as an Assistant Professor before joining the University of Wisconsin-Madison as faculty in 2013. Heather is now a Professor at the University of Wisconsin-Madison in the area of dairy cattle nutritional physiology. Dr. White's research strives to determine the mechanism of nutrient partitioning, feed efficiency, and metabolic health in order to provide science-based solutions and interventions to improve dairy cow health and productivity. Within the transition to lactation period, Dr. White's research program focuses on the individual animal variation and nutritional interventions that support successful transition with hepatic and whole-animal nutrient partitioning and metabolism.

Ashley Niesen, Ph.D., is a Dairy Technical Service Manager with Phibro Animal Health. She received her M.S. and Ph.D. degrees from the University of California Davis where she studied ruminant nutrition and metabolism on California commercial dairies. She is a Central Valley native with experience in developing Ag technologies and dairy innovations. When not wrangling cows or data, she enjoys road trips and outdoor adventures with friends and family.

Stephanie Hansen, Ph.D., is a professor of animal science at Iowa State University, where her laboratory pursues a better understanding of the critical roles of trace minerals and vitamins in cattle. She has won awards for research, teaching and advising, and published more than 100 papers to date. In her free time she loves hiking and writing fiction, usually not at the same time.

CANC Speaker Biographies

Brady Brewer, Ph.D., is an assistant professor in the Department of Agricultural Economics at Kansas State University. His research agenda includes the broader topics of agribusiness and profitability, agricultural finance, and production/supply chain issues at the farm level. His extension work includes educating farmers on credit concerns and lending, as well as working with the agricultural banks across the state. Courses that he has previously taught include agribusiness management and agricultural finance courses at both the and graduate levels. Before joining the faculty at KSU, Brady was an associate professor of agricultural economics at Purdue University and the director of the MSMBA in Food and Agribusiness. Before Purdue, he spent three years in the Department of Agricultural and Applied Economics at the University of Georgia. Brady grew up on a family farm in Oklahoma that raised wheat, soybeans, alfalfa, an cattle. He received a B.S. in economics and accounting from Oklahoma State University and later earned both his M.S. and Ph.D. from Kansas State University in agricultural economics.

Keynote Speaker, Kevin Good, is Vice President of Industry Relations at CattleFax. He grew up on a purebred cow/calf operation and graduated from Kansas State University with a bachelor's degree in animal science. While at Kansas State, he was a member of both the meats and the livestock judging teams. Kevin began working with CattleFax in 1982.

James K. Drackley, Ph.D. is Professor Emeritus of Animal Sciences at the University of Illinois Urbana-Champaign. His research program focused on nutrition and metabolism of dairy cows during the transition from pregnancy to lactation, fat utilization and metabolism, and aspects of calf nutrition and management. Dr. Drackley has published extensively, supervised more than 45 graduate students to MS or PhD degrees, and received numerous professional awards. Drackley is widely sought by the global dairy industry for speaking and consulting services. He served on the National Academies of Science, Engineering, and Medicine committee to prepare the 8th edition of Nutrient Requirements of Dairy Cattle.

Eduardo Rico, Ph.D., is the Assistant Professor of Population Medicine, Sustainable, and Food Security in the Department of Clinical Studies – New Bolton Center. Following his work as an applied nutritionist in Colombia, Eduardo came to the US to pursue his Master's and Doctoral studies. Prior to joining UPenn, Dr. Rico completed postdoctoral training at Cornell University and held a Professorial appointment at the University of Maryland. Leveraging observational and randomized controlled approaches, his research aims to identify primary causes of metabolic dysfunction, particularly during the transition from gestation to lactation. Current areas of focus include the effects of hyperketonemia and hyperlipidemia on immune function and health, the investigation of the i fatty NAD+metabolome in relation to energy utilization efficiency, as well as the impact of dietary omega-3 fatty acids on dairy cow health and bovine milk quality. Dr. Rico received a BS degree in Animal Science from the National University of Colombia, Bogota, Colombia, MS Animal Science, Michigan State University and Ph.D. Nutritional Biochemistry, West Virginia University, Morgantown, West Virginia.

Amy Skibiel, Ph.D., is an Associate Professor of Lactation Physiology in the Department of Animal, Veterinary and Food Sciences at the University of Idaho. Previously, Amy held postdoctoral fellowships in the Department of Animal Sciences at the University of Florida and the Department of Human Evolutionary Biology at Harvard University. Dr. Skibiel earned her B.S. in Biology at Juniata College and M.S. and Ph.D. degrees in Biological Sciences at Auburn University. Currently, Dr. Skibiel teaches undergraduate and graduate-level courses in Lactation Biology and Environmental Physiology. Her research program focuses on cellular metabolism during the transition period in dairy cows and responses of dairy cattle to environmental stressors, including heat stress and wildfire smoke exposure. Dr. Skibiel also serves as the Chair of the Production Division of the American Dairy Science Association.

Marcos Marcondes, Ph.D., completed his Bachelor's in Animal Science at the Federal University of Vicosa-Brazil, where he earned his Master's (2007) and Doctorate (2010) at the same institution. He then conducted postdoctoral research at the University of Florida from 2018-2019. From 2010-2021, he served as a Dairy Cattle Management and Nutrition professor at the Federal University of Vicosa. In 2021 he joined the Washington State University faculty as a Dairy Cattle Nutrition professor. In October 2024 he joined the William H Miner Institute as a dairy research scientist. At Marcondes Lab, he focuses on researching feed evaluation nutrient requirements, and the economics of dairy operations. Dr. Marcondes also researches additives for mitigating methane production in cattle and the impact of nutrition on the performance and mammary gland development of calves and heifers. He takes a collaborative approach, integrating research on dairy cattle nutrition, reproduction, and behavior.

Ralph Ward is the founder and director of Cumberland Valley Analytical Services (CVAS), a laboratory providing forage and feed evaluation services in the U.S. and globally for the past 30 years. With a background in dairy production and nutritional services, Mr. Ward has focused on developing analytical systems for forage and feed quality determination and modeling in dairy rations. He has worked to develop and expand the use of an extensive set of NIR equations and to multiple partner labs in the U.S. and globally. His current focus is implementation of a new NDFD system and implementation of recently developes amino acid NIR equations for forage and dairy feed ingredients. As well, a long term focus is on development of improved methods for starch digestibility characterization and general nutrient modeling.

Mike Van Amburgh, Ph.D., is a Professor in the Department of Animal Science and a Stephen H. Weiss Presidential Fellow at Cornell University where he has a dual appointment in teaching and research.

Faculty experience

1995-2002: Assistant Professor, Dept. of Animal Science, Cornell University
2002-2013: Associate Professor, Dept. of Animal Science, Cornell University
2013- Present: Full Professor, Dept. of Animal Science, Cornell University

Teaching experience

1995-2023: Professor, Cornell University. AnSc 1160 – Lead instructor for 3 years; AnSc 2500 – Lead instructor for 5 years, co-instructor for 4 years; AnSc 2550 – Lead instructor for 28 years; AnSc 3511 – Lead instructor for 8 years, co- instructor for 3 years; AnSc 3560 – lead instructor for 18 years; AnSc 4110 – Lead instructor for 29 years; AnSc 4120- Co-instructor for 17 years; AnSc 4510 – Lead instructor for 10 years, co-instructor for 10 years; AnSc 4560 – Lead instructor for 9 years, co-instructor for 12 years. AnSc 6130 – Lead instructor for 2 years.

His undergraduate degree is from The Ohio State University and his Ph.D. is from Cornell University. He leads the Cornell Dairy Fellows Program, advises approximately 30 undergraduate students, and is the Cornell University Dairy Science Club advisor. Mike currently leads the development of the Cornell Net Carbohydrate and Protein System (CNCPS/CPM Dairy), a nutrition evaluation and formulation model used worldwide. Through licensing, the CNCPS is used to formulate diets for approximately 70% of the dairy cows in North America. Through the modeling effort, he focuses on enhancing the efficiency of nutrient use by ruminants to improve the environmental impact of animal food production. A significant component of his current work is to understand whole animal and ruminal nitrogen metabolism and amino acid supply and requirements to enhance the productivity of high-producing lactating dairy cattle and use that information in the further development of the Cornell Net Carbohydrate and Protein System. Further, his group is active in developing methods to better describe the interaction between forage and feed chemistry, rumen function and post-ruminal digestion to complement the model. He has authored and co-authored over 100 journal articles and many conference proceedings. He is the recipient of several awards, including the American Dairy Science Foundation Scholar Award, the Land O'Lakes Teaching and Mentoring Award from ADSA, the American Feed Ingredient Association Award for Research, Journal of Dairy Science Most Cited Award, the CALS Professor of Merit Award, and the CALS Distinguished Advisor Award. In 2016, he was named a Stephen H. Weiss Presidential Fellow, the highest teaching award given by Cornell University.

California Animal Nutrition Conference
2025 Steering Committee

Chairperson: Carlyn Peterson, Ph.D., P.A.S., Selko USA
Carlyn Peterson is a Dairy Technical Manager for Selko USA (formerly Micronutrients) primarily covering the Western region of the US. Carlyn specializes in sustainable dairy systems and their interaction with dairy nutrition. Prior to joining Selko in 2022, Carlyn provided technical support for the Smartline category with Adisseo for two years. Between 2013 to 2020 she worked with Dr. Frank Mitloehner at the University of California, Davis, to complete a Master's degree and PhD in Animal Biology with a focus on Sustainability and Ruminant Nutrition. Carlyn is passionate about improving sustainability in the dairy sector. The title of her dissertation is "Effects of Feed and Waste Additives on Dairy Cattle's Impact on Greenhouse Gasses and Air Quality." Her research focused on reducing the environmental impacts of dairy while maintaining production. Carlyn also holds a Bachelor's degree in Animal Science, emphasis in Livestock and Dairy, from UC Davis. She is originally from San Diego County where she got her start in agriculture through participating in the FFA.

Vice Chairperson: Tricia Wood, Ph.D., Lallemand Animal Nutrition
Tricia Wood was raised on a farrow-to-finish hog operation and was active in 4-H in her youth. Her bachelor, masters, and Ph.D. degrees were all awarded from the Iowa State University focusing on animal physiology. Her graduate school research all centered around calf immune system development and nutritional supplements that can affect development and efficiency of the immune system (pre/probiotics). She has over 15 years of experience in the dairy feed additive and feed industries where she has formulated milk replacer and provided sales and technical support for dairy calf and feed additive products. She is a member of the Ruminant Technical Services team with Lallemand Animal Nutrition, North America. In her current role, she provides technical support, product expertise and industry knowledge alongside the Lallemand territory business managers for the western United States. She has consulted on numerous calf ranches in the Western half of the country, as well as in the Midwest. Tricia resides in Caldwell, Idaho, with her husband and two sons on a small farm where they raise horses and chickens.

Ex-Officio: Kyle Thompson, Ph.D., College of the Sequoias
Kyle Thompson teaches in the Agriculture Department at the College of the Sequoias. He received his B.S. degree in animal science from Fresno State (2006) and his master's and Ph.D. degrees in animal science from Oklahoma State (2011/2015). While at OSU, he was attending classes and teaching from January 2007-June 2016 and served as the graduate student assistant manager of the campus dairy cattle center. His research included dairy nutrition research trials and lactating cow probiotics. He also assisted in research for bovine respiratory disease, rumen temperature bolus, milk production by weigh-suckle-weigh, and swine antimicrobial replacements. Recently, Dr. Thompson served as the Assistant Professor of Dairy Science and Dairy Unit manager at Fresno State from 2016 to 2023. He owns and operates Wild Acre Ranch, which raises registered Brown Swiss and beef Shorthorns and produces grasses and winter forage for hay production. As a Fresno State student, he worked in the sheep unit for three years, served

as a campus farm tour guide, and dairy unit herdsman and feed/hospital technician. He also worked as an exotic animal nutrition intern (2009) and a global nutrition fellow at the San Diego Zoo (2013).

Committee Members:

Leslie Jacobsen, M.S., P.A.S., Phibro Animal Health Corporation
Leslie Jacobsen is an Account Manager with Phibro covering the Southern California region. In 2022 she completed her Master's degree in Animal Biology with a focus on Ruminant Nutrition with Dr. Heidi Rossow at University of California, Davis. After obtaining her Master's degree, she worked as a Nutrition Consultant for Nutri-Systems INC. from 2022 – 2023. She is also on the board of the American Registry for Professional Animal Scientists as Director at Large. Leslie also holds a Bachelor's degree from Fresno State, with an emphasis in Dairy Production.

Samantha Pearle, M.S., PAS
Samantha has been in the feed and nutrition industry for 12 years and currently serves the California dairy industry providing bypass fat solutions from Energy Feeds International.

Brian Rainey, M.S., MBA, P.A.S., Pine Creek Nutrition Service, Inc.
Upon graduating from Kansas State University, Brian made a gradual progression west seeking career fulfillment in working hands-on with livestock producers. Brian joined Pine Creek Nutrition Service, Inc. in May 2010 and brings a science, business, and industry portfolio to the consulting staff. Brian received a Bachelor of Science degree in Animal Science in 2001 from Kanas State University, Manhattan, KS, a Master of Science in Ruminant Nutrition in 2004 from Montana State University, Bozeman, and a Master of Business Administration, with Distinction, Phi Kappa Phi, May 2010 California State University, Fresno.

Tanner Schmidt, M.S., Zinpro Corporation
Tanner Schmidt is an account manager for Zinpro Corporation. His role involves providing mineral and nutrition support for beef producers in California, Oregon, Idaho, Nevada, and Washington. He earned his bachelor's degree in Animal Science and Agricultural Economics from Oklahoma State University and a master's degree in Ruminant Nutrition. covering dairy and equine in California.

Noelia Silva-del Rio, Ph.D., University of California, Davis Veterinary Medicine School
Noelia Silva del Rio is the UC Davis Cooperative Extension Dairy Specialist at the veterinary medicine school. She is located at the Veterinary Medicine Teaching and Research Center in Tulare. She earned her veterinary degree from the University of Santiago de Compostela in Spain in 1998. She practiced for two years in the northwest region of Spain by supporting dairy producers with the implementation of reproduction, nutrition, and herd health programs. In 2007, she obtained her Ph.D. in Dairy Science from the University of Wisconsin with focus on nutrition and reproduction. Soon after graduation, she joined UCCE as a Tulare Dairy Advisor, a position she held for over three years before joining the UC Davis SVM as a Specialist in 2012.

Her extension program aims to improve herd health through management from feeding to treatment decisions, with special focus on finding management solutions to mitigate transition cow disorders and calf health issues.

John Traini, Kemin Animal Health and Nutrition
John Traini grew up in Oakdale, California, where he was involved in 4-H and FFA programs. He graduated from Fresno State University in 2016 with a degree in Animal Science. Upon completing his degree, John joined Veterinary Service Inc. (VSI), where he was a sales representative for four years. In the Fall of 2021, John joined KEMIN Animal Health and Nutrition as a Key Account Manager covering California and Arizona.

CANC Chairperson History

YEAR	CHAIRPERSON	COMPANY AFFILIATION
2025	Dr. Carlyn Peterson	Selko
2024	Dr. Kyle Thompson	College of the Sequoias
2023	Mr. Ruben Almada	Turlock Dairy & Refrigeration
2022	Mr. Zachery Meyer	Rock River Laboratory, Inc.
2021	Jennifer Heguy, M.S., P.A.S.	University of California, Coop. Ext.
2020	NO CANC CONFERENCE	
2019	David Ledgerwood, M.S., P.A.S.	Chr-Hansen
2018	Jason Brixey, M.S., P.A.S.	Pine Creek Nutrition Service
2017	Dr. Phillip Jardon, DVM, MPVM	Elanco Animal Health
2016	Dr. Phillip Jardon, DVM, MPVM	Elanco Animal Health
2015	Mr. Ben Tarr	Adisseo USA Inc.
2014	Dr. Jeffrey M. DeFrain	Zinpro Performance Minerals
2013	Mr. Doug DeGroff	Diversified Dairy Solutions, LLC
2012	Mr. Eduardo Galo	Novus International, Inc.
2011	Dr. Michael A. DeGroot	DeGroot Dairy Consulting
2010	Dr. Jim Tully	Pine Creek Nutrition Service, Inc.
2009	Mr. Michael Braun	Phibro Animal Health
2008	Dr. Luis Rodriguez	Zinpro Corporation
2007	Dr. Marit Arana	A.L. Gilbert Company
2006	Mr. Dennis Ervin P.A.S.	Prince Agri Products, Inc.
2005	Dr. Lawson Spicer	Nutri Management Inc.
2004	Dr. Luis Solorzano	Purina Mills, Inc.
2003	Dr. Alfonso Mireles, Jr.	Foster Farms
2002	Mr. Edmund Vieira	Pine Creek Nutrition Service, Inc.
2001	Dr. Melinda Burrill	California State Polytechnic University - Pomona
2000	Mr. Dave Fischer	Foster Farms
1999	Dr. M. Steven Daugherty	California State Polytechnic University - SLO
1998	Dr. Doug Dildey	Alltech, Inc.
1997	Ms. Carla Price	Nutritionist
1996	Dr. H.John Kuhl, Jr.	Nest Egg Nutrition
1995	Mr. Dennis Ralston	M. Rinus Boer Co., Inc.
1994	Dr. Doug Dildey	Alltech, Inc.
1993	Dr. Mark Aseltine	ConsultingAnimal Nutritionist
1992	Dr. Carl Old	MacGowan-Smith Ltd.
1991	Mr. Nick Ohanesian	Ohanesian & Associates
1990	Mr. Rod Johnson	M. Rinus Boer Co., Inc.
1989	Mr. Timothy Riordan	Nutri-Systems, Inc.
1988	Dr. Russ W. Van Hellen	Great West Analytical
1987	Dr. John E. Trei	California State Polytechnic University, Pomona
1986	Dr. A.A. Jimenez	Ancon, Inc.
1985	Dr. Wm. A. Dudley-Cash	Foster Farms
1984	Dr. Joel Kemper	Penny-Newman Co.

CANC Chairperson History Continued

YEAR	CHAIRPERSON	COMPANY AFFILIATION
1983	Dr. Alex J. Kutches	O.H. Kruse Grain & Milling Co.
1982	Dr. Howard Waterhouse	Bell Grain & Milling
1981	Mr. Don Ulrich	Diamond Shamrock Chemical Co.
1980	Mr. Tom Geary	PMS-West, Inc.
1979	Dr. Frank Parks	Kemlin Industries
1978	Mr. Fred Pfaff	Zacky Farms
1977	Mr. Rene Lastreto	Diamond Shamrock Chemical Co.
1976	Mr. Rene Lastreto	Diamond Shamrock Chemical Co.
1975	Dr. R.D. Hendershott	Nulaid Foods
1974	Dr. R.D. Hendershott	Nulaid Foods
1973	Dr. Leland Larsen	Nutri-Systems, Inc.
1972	Dr. Leland Larsen	Nutri-Systems, Inc.
1971	Mr. Rene Lastreto	Diamond Shamrock Chemical Co.
1970	Mr. Fred Pfaff	Balfour Guthrie
1969	Mr. Fred Pfaff	Balfour Guthrie
1968	Mr. Fred Pfaff	Balfour Guthrie
1967*	Mr. Gary L. Frame	J.G. Boswell Co.
1966*	Mr. Gary L. Frame	J.G. Boswell Co.
1965*	Mr. Arne Jalonen	Topper Feed Mills
1964*	Mr. Arne Jalonen	Topper Feed Mills
1963*	Dr. W.P. Lehrer	Albers Milling Co.
1962*	Dr. H.J. Almquist	The Grange Co.
1961*	Dr. H.S. Wilgus	The Ray Ewing Co.
1960*	Mr. Bert Maxwell	Nulaid Foods
1959*	Mr. Bert Maxwell	Nulaid Foods
1958*	Mr. Robert Caldwell	Anderson Smith Milling Co.
1957*	Mr. Emery Johnson	P.C.A., Los Angeles
1956*	Mr. Emery Johnson	P.C.A., Los Angeles
1955*	Dr. H.J. Almquist	The Grange Co.
1954*	Dr. H.J. Almquist	The Grange Co.
1953*	Mr. Clifford Capps	California Milling Co.
1951*	Mr. Dolph Hill	Golden Eagle Milling Co.
1950*	Dr. H.J. Almquist	The Grange Co.
1949*	Dr. H.J. Almquist	The Grange Co.
1948*	Dr. H.J. Almquist	The Grange Co.

* California Animal Industry Conference

History of the California Animal Nutrition Conference

The California Animal Nutrition Conference (CANC) originated in the 1940s as the California Animal Industry Conference, sponsored by the California Grain & Feed Association (CGFA). CGFA wanted to expand the continuing education program into a forum encompassing animal health, nutrition, and management. The expectations were that communications between (nutritionists) industry, educational institutions, and regulatory agencies would be improved. In 1972, CGFA discontinued sponsoring the Animal Industry Conference.

After the conference was discontinued, a small group of nutritionists began meeting annually in Fresno. Two or three invited speakers from industry or the universities presented information on nutrition, especially poultry.

In 1975 a set of organizational bylaws were developed by the steering committee. CANC was established and was provided support by CGFA. The CGFA Board of Directors appointed a chairperson annually and approved the steering committee. In 1978, Dr. Frank Parks, the Chairperson, requested that CANC be granted independent status and be established as a self-governing committee of CGFA. This request was granted.

For a few years, meetings were held in Fresno and Corona, California. For a couple of years starting in 1978, CANC published "Nutri-Facts," a "newsletter" consisting of articles on animal production.

In 1979, donations were requested from industry companies to help keep registration fees low. During the 1980s and through the 1990s the attendance at CANC continued to grow as the quality of the conference improved and the conference became known nationwide. In the 1990s a pre-symposium was added. The pre-symposium is sponsored by a company selected by the CANC Steering Committee and this process allows the selected company to showcase its research and products. In the year 2000, posters on research by students were included.

Attendance at the conference has grown from 50 in the 1970s to over 300 attendees. To encourage attendance, different activities have been tried such as keynote speakers, skiing expeditions, and a very successful barbeque dinner put on by the Animal Science Department at California State University, Fresno.

The California Grain & Feed Association has supported and allowed CANC to work and grow. The premise of the CGFA and CANC relationship is to work together to educate the feed industry with information for problem-solving and to disseminate valuable research information. CANC is not an industry, university, or government entity, but a committee collectively working together for the good of agriculture in California.