Exploring flexibilities in protein nutrition for a sustainable dairy industry

Kelly Nichols, PhD

August 5th, 2025 Balchem – Real Science Lecture Series

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Acknowledgements

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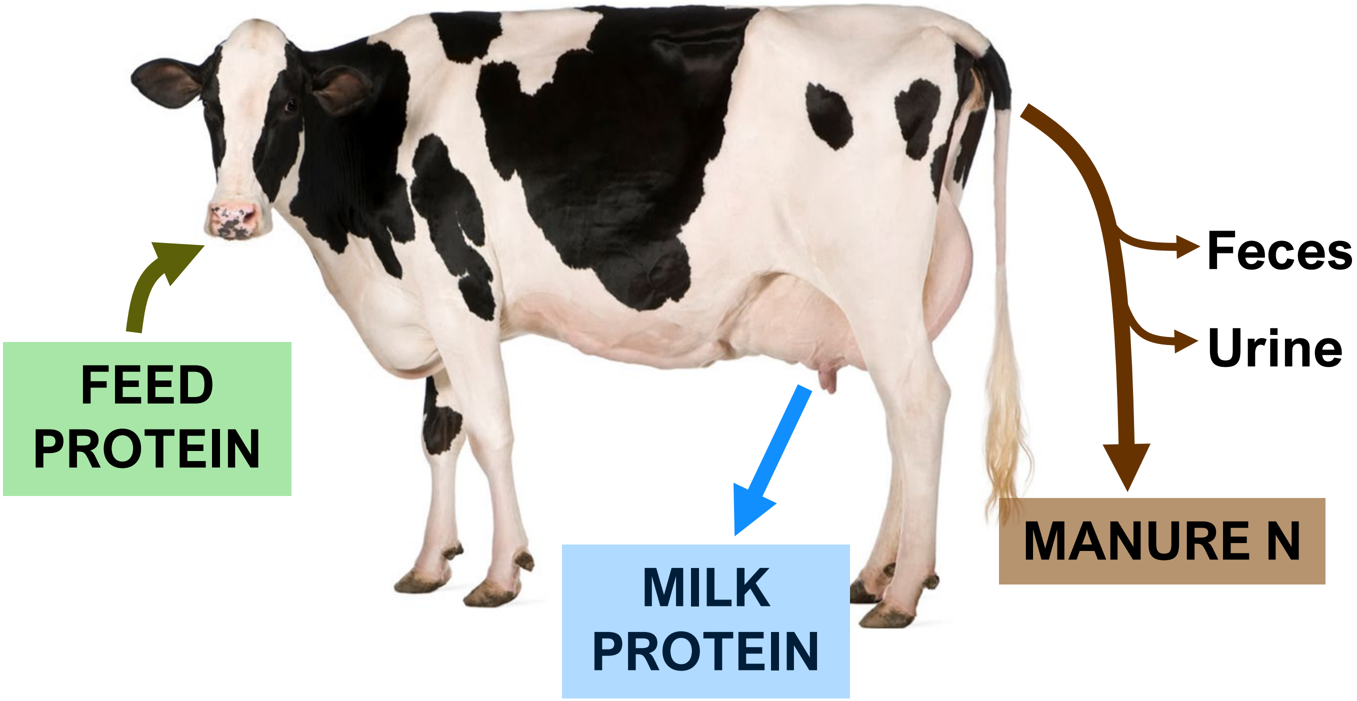
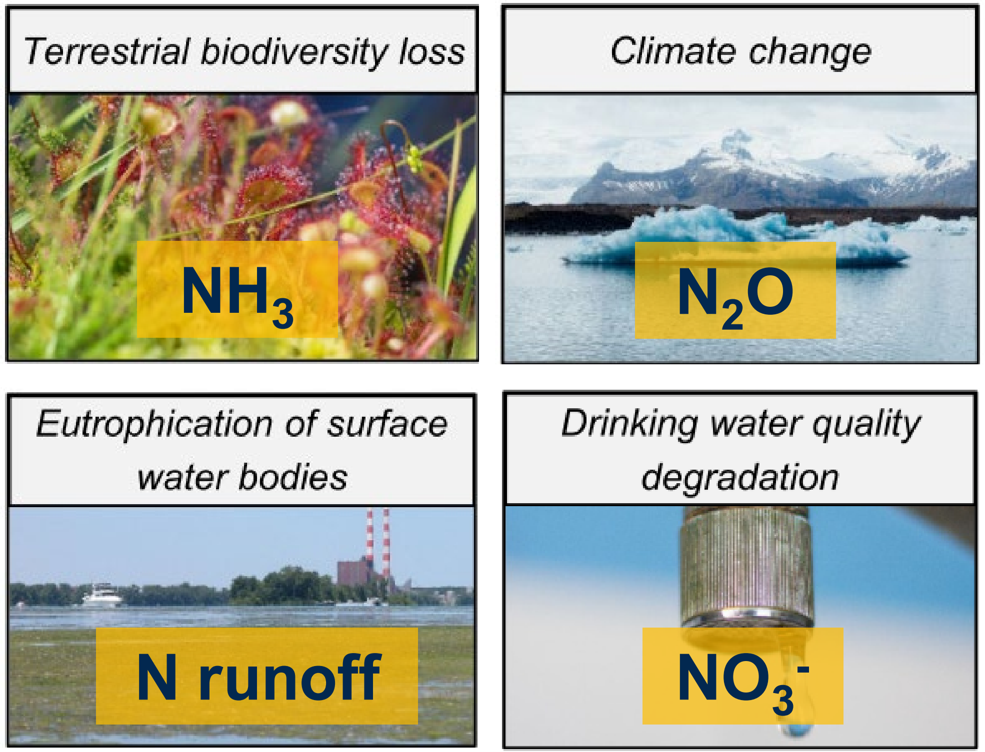
Protein nutrition intersects with sustainability concerns





- Imported feed is the largest N input to whole-farm N balance
  - Approximately 2x the volume of fertilizer N

Dutch dairies: Jarvis et al. 2011; The European Nitrogen Assessment
USA dairies: Ros et al. 2023; J. Dairy Sci. 106:3268-3286

The "Nitrogen Crisis": Not just a European problem

Nitrogen wars: the Dutch farmers' revolt that turned a nation upside-down

In 2019, a looming crisis over pollution led the Dutch government to crack down on farm emissions. The response was furious - and offers a warning to other countries about protecting the environment without losing public trust

The Guardian

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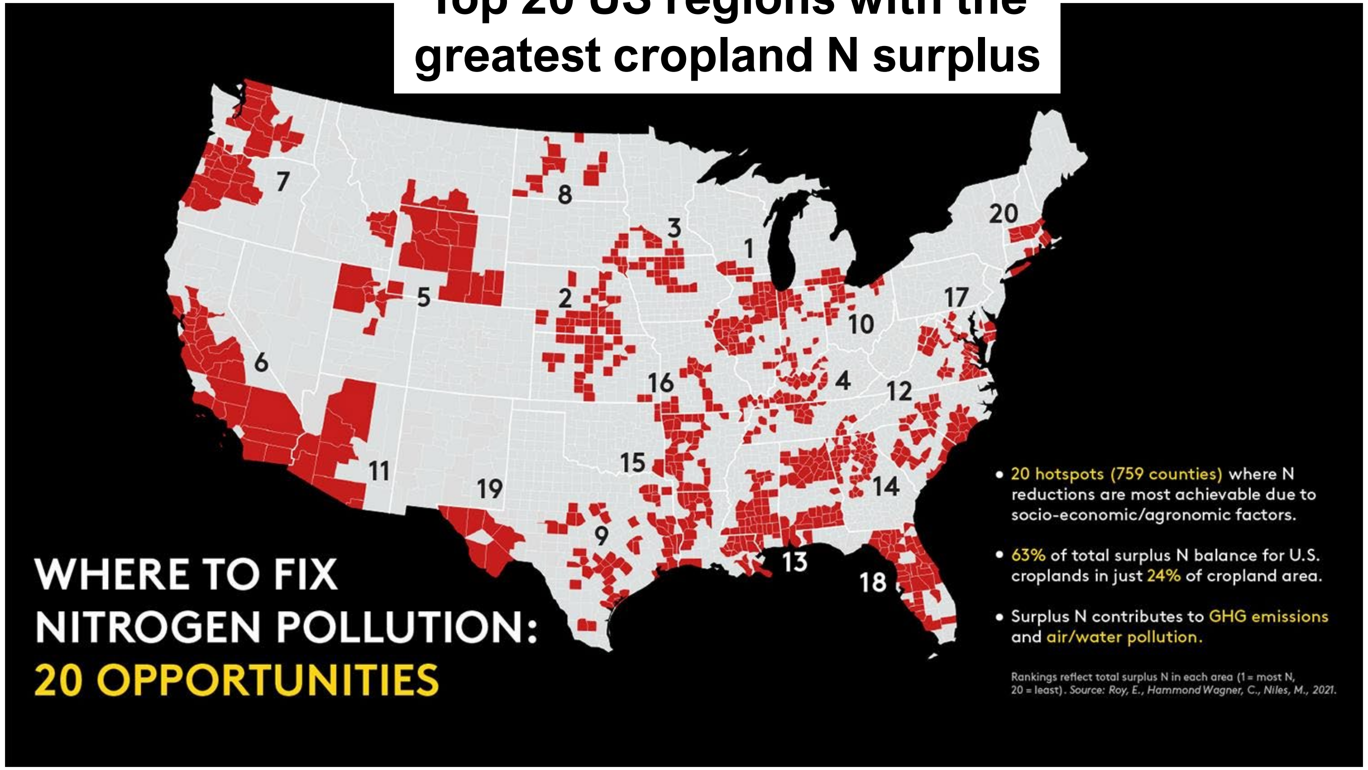
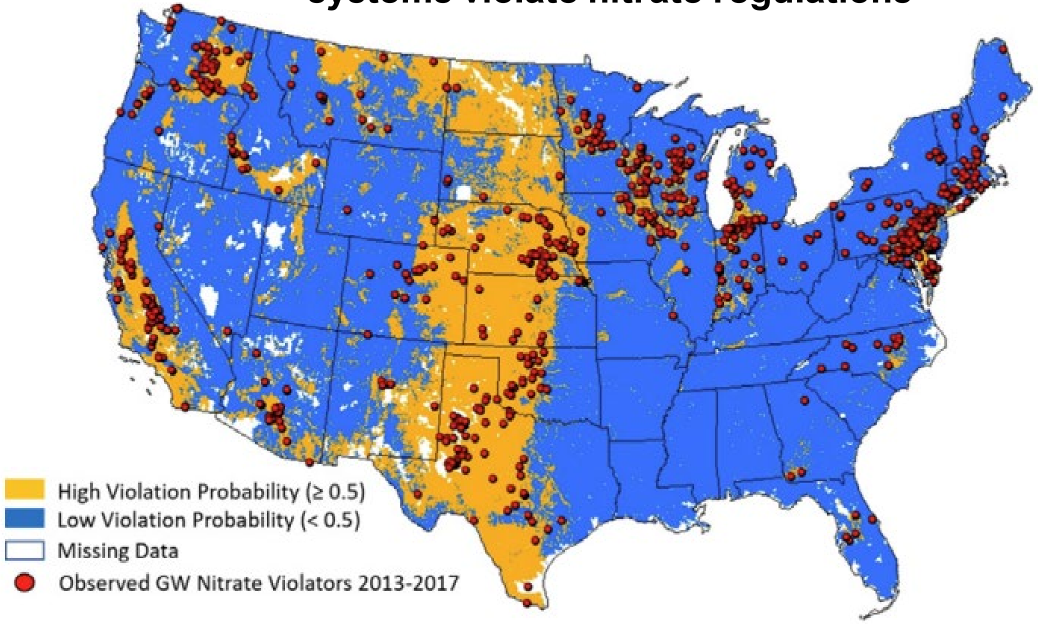
The “Nitrogen Crisis”: Not just a European problem

Top 20 US regions with the greatest cropland N surplus



Roy et al. 2021; Environ. Res. Lett. 16:035004

Probability that groundwater systems violate nitrate regulations



Pennino et al. 2020; Sci. Total Environ. 722:137661

It’s Time for California to Act on Nitrogen Pollution

This year marks a turning point in the fight to protect communities from climate and health harms.

June 12, 2025 NRDC

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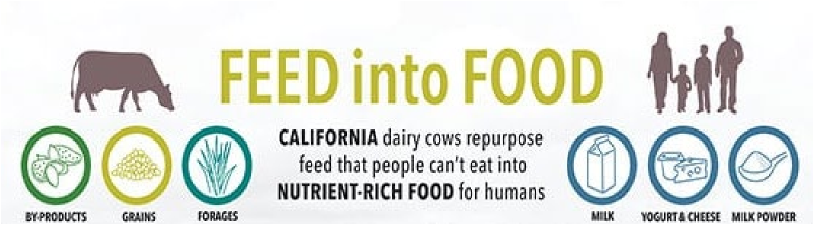
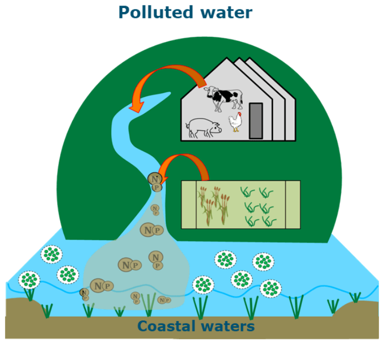
Protein nutrition intersects with sustainability concerns

- **Ruminants deliver efficiencies *and* inefficiencies with their transfer of dietary N into human-edible protein**





- Growing emphasis on N discharge regulations and N-source air pollution is likely to continue in agriculture-intensive areas of the US
  - How to deal with manure N surplus? → reduce manure N content

- Resource availability → cost of protein-rich ingredients, variable global markets, public perception (e.g., feed vs. food debate, GMO)

Understanding metabolic flexibility in ruminants → determine strategies for improved protein efficiency that align with goals and requirements of producers

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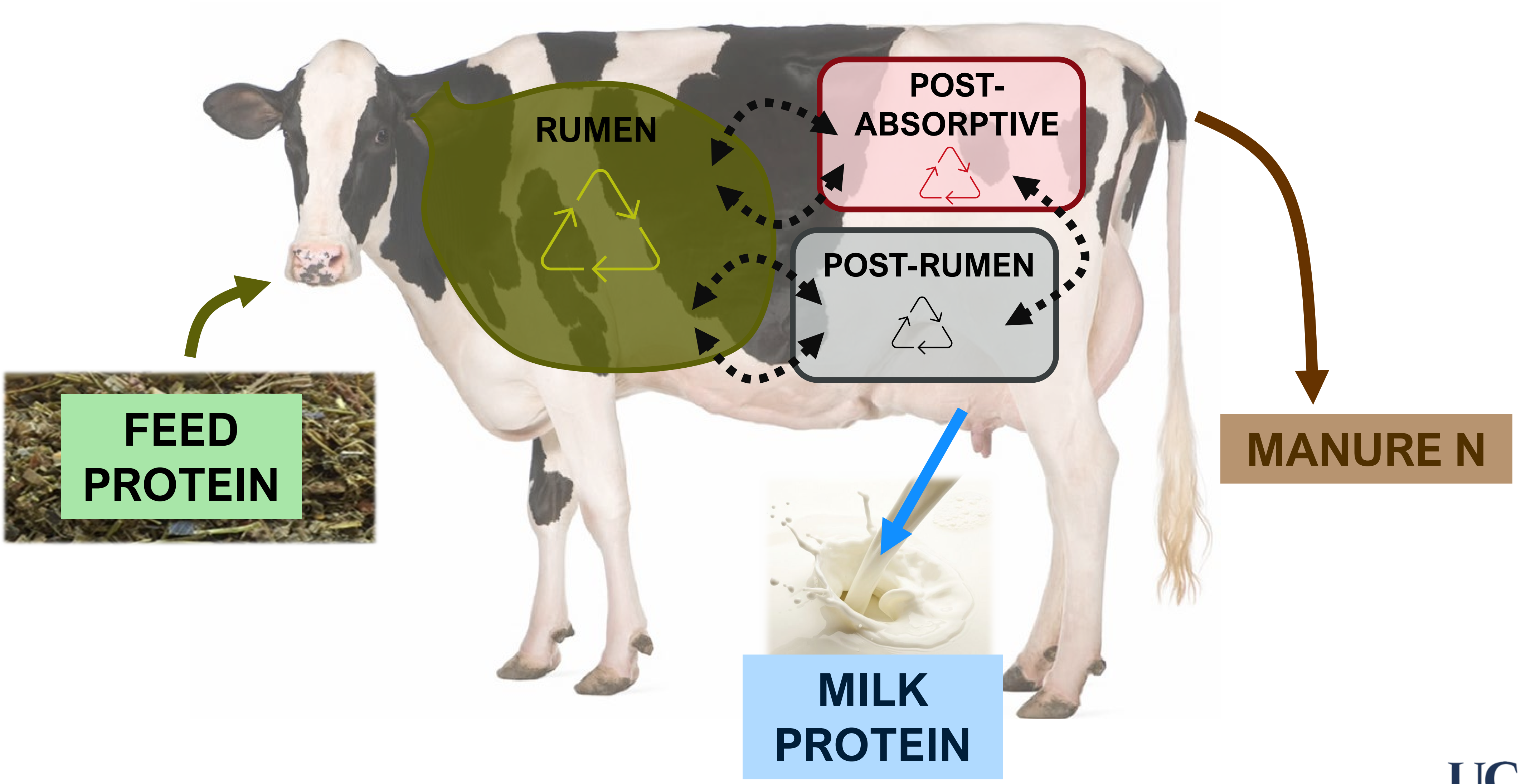
Exploring flexibilities in protein nutrition

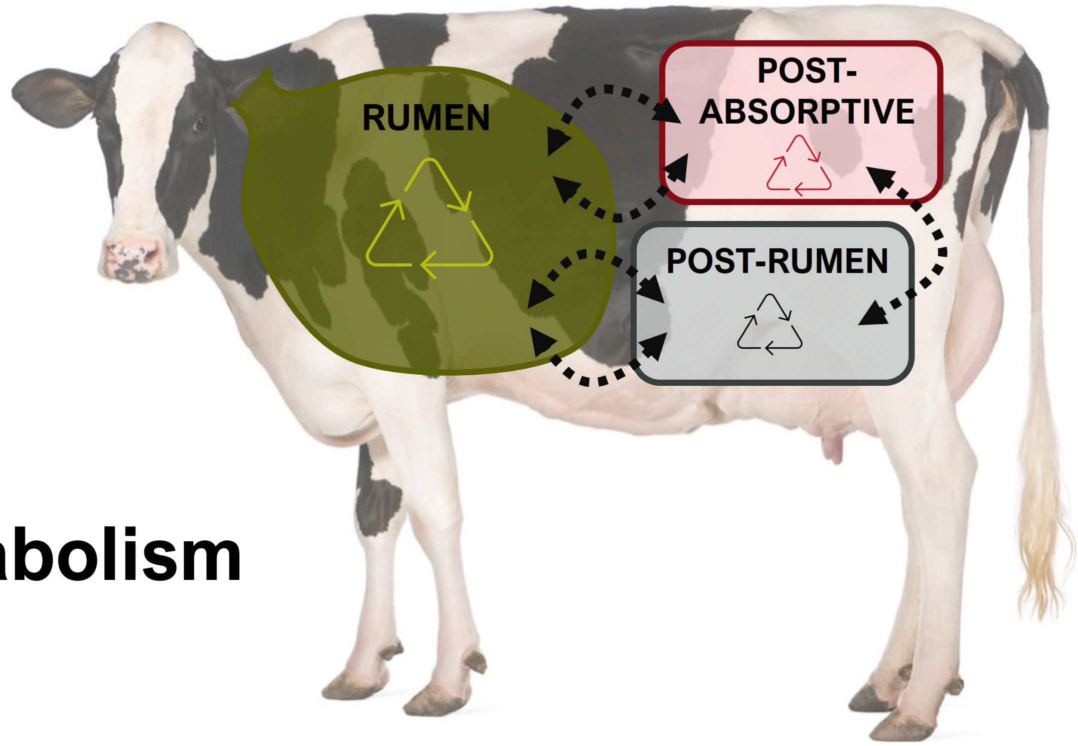


Exploring flexibilities in protein nutrition

1) **Impact of energy source**

2) **Rumen N balance**

3) **Mammary gland amino acid metabolism**



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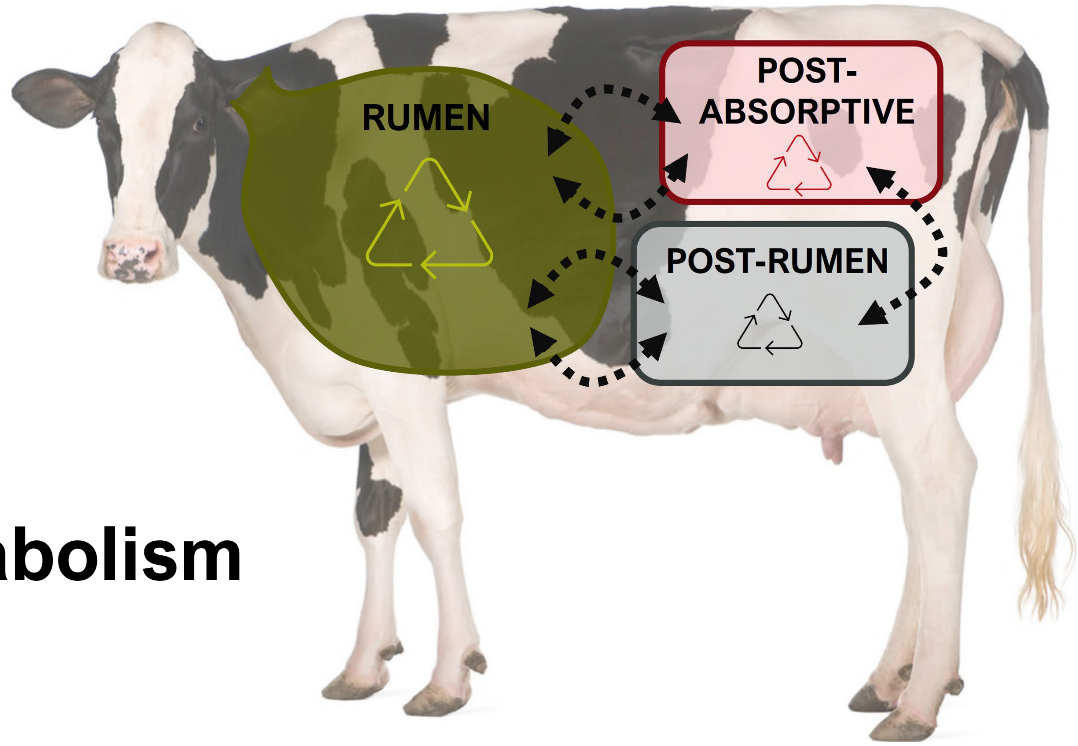

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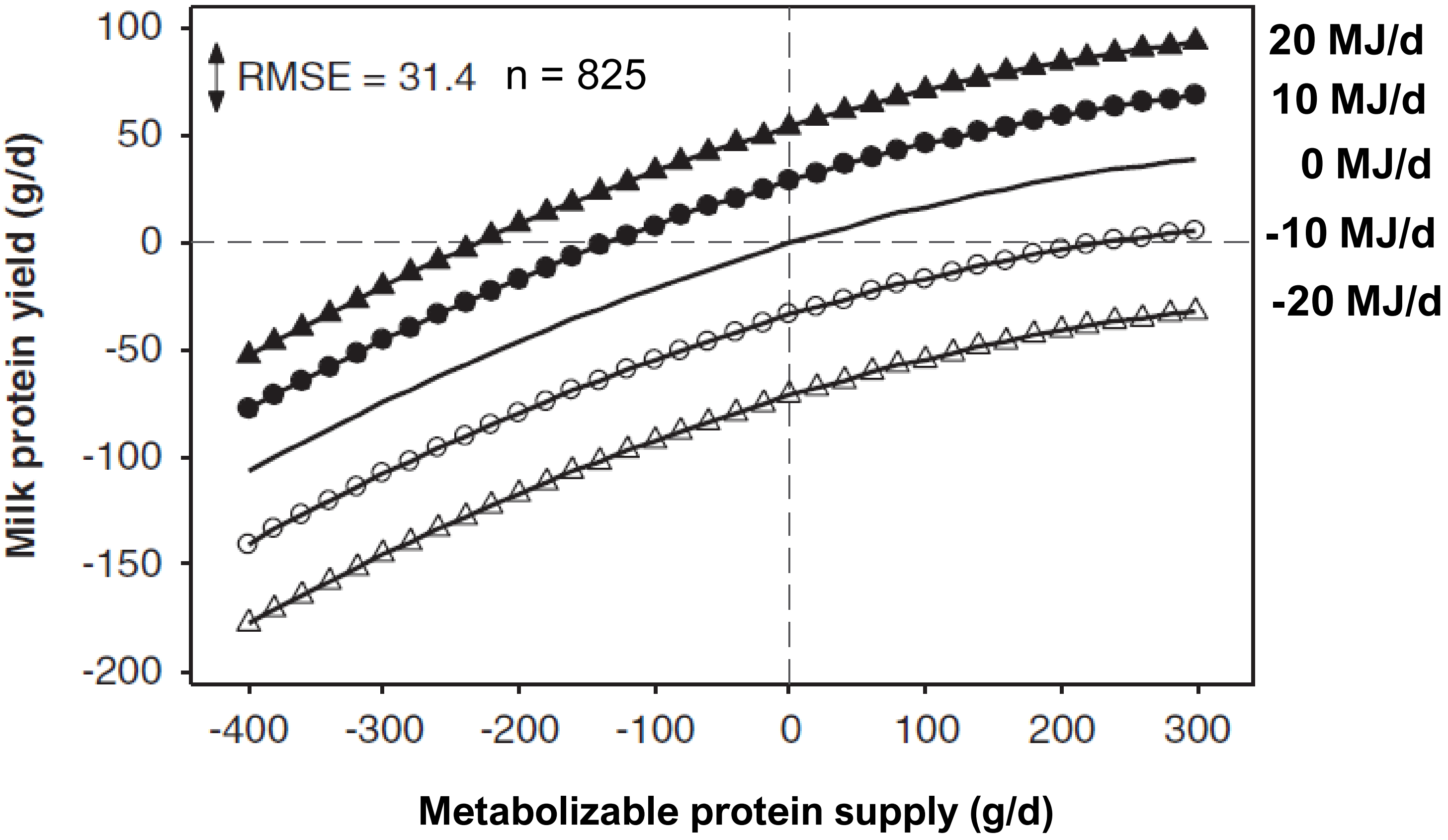
Metabolizable protein efficiency is related to energy supply



Daniel et al. 2016; Animal 10:1975-1985

- Energy-expensive protein synthesis
- Glucogenic potential of amino acids
- Energy-induced endocrine signaling regulates protein synthesis

- **What about the source of this energy?**

Energy source affects the transfer of dietary N into milk N

GLUCOGENIC

- Starch-rich feedstuffs

- Post-ruminal glucose
- Ruminal propionate

LIPOGENIC

- Rumen-inert fat supplements (Ca-salts, saturated long-chain fatty acids)
- Fiber-rich feedstuffs → acetate, butyrate

- Post-ruminal infusion of fat or fatty acids

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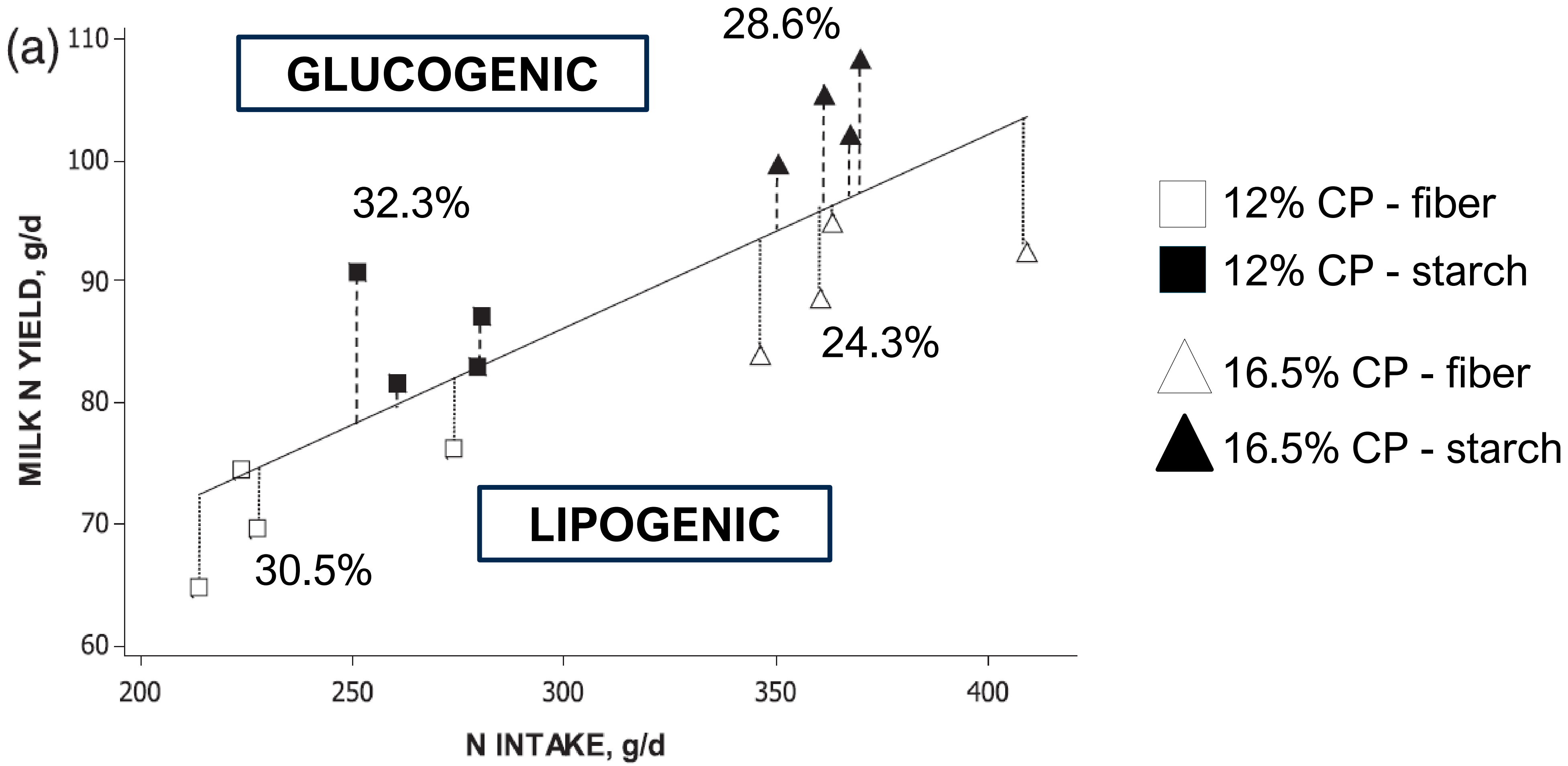
Energy source affects the transfer of dietary N into milk N



Cantalapiedra-Hijar et al. 2014; Animal 8:275-285

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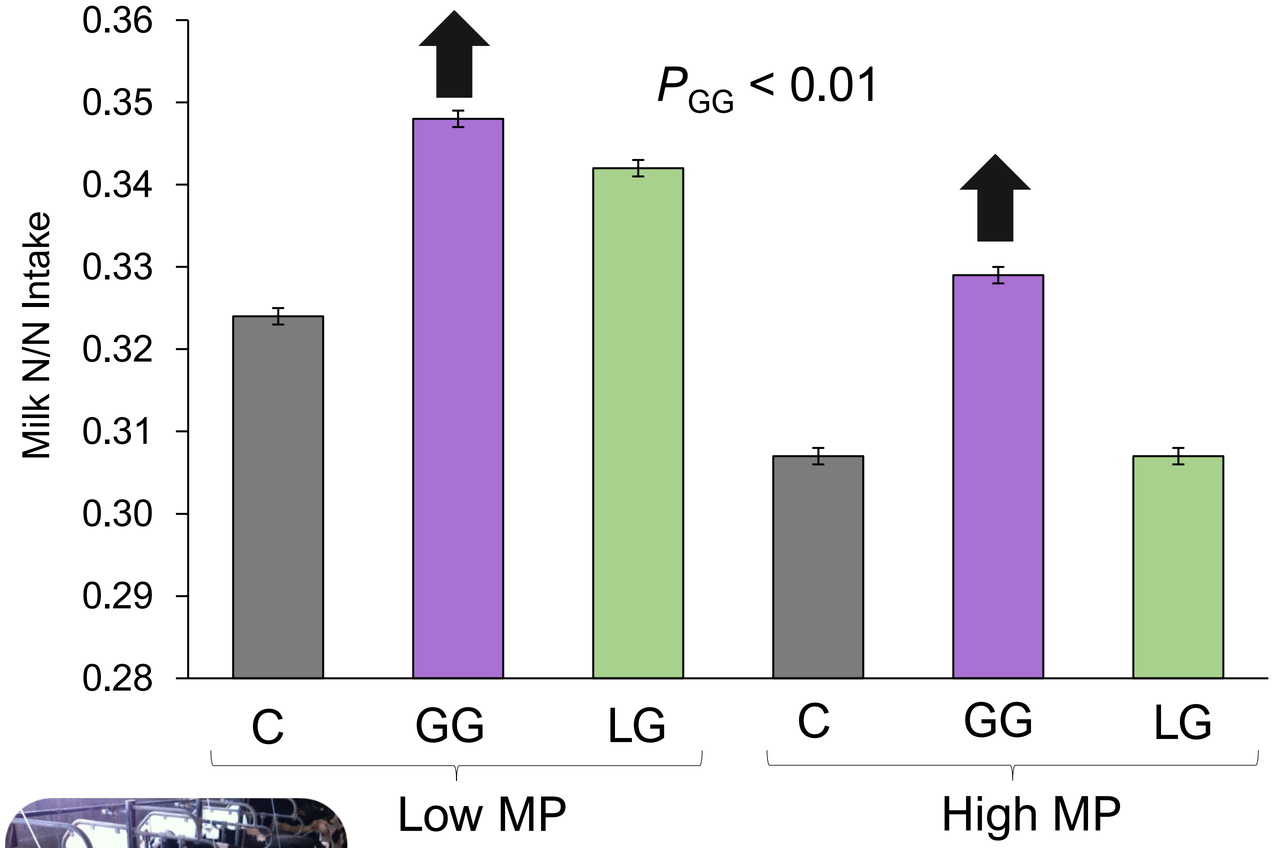
Energy source affects the transfer of dietary N into milk N

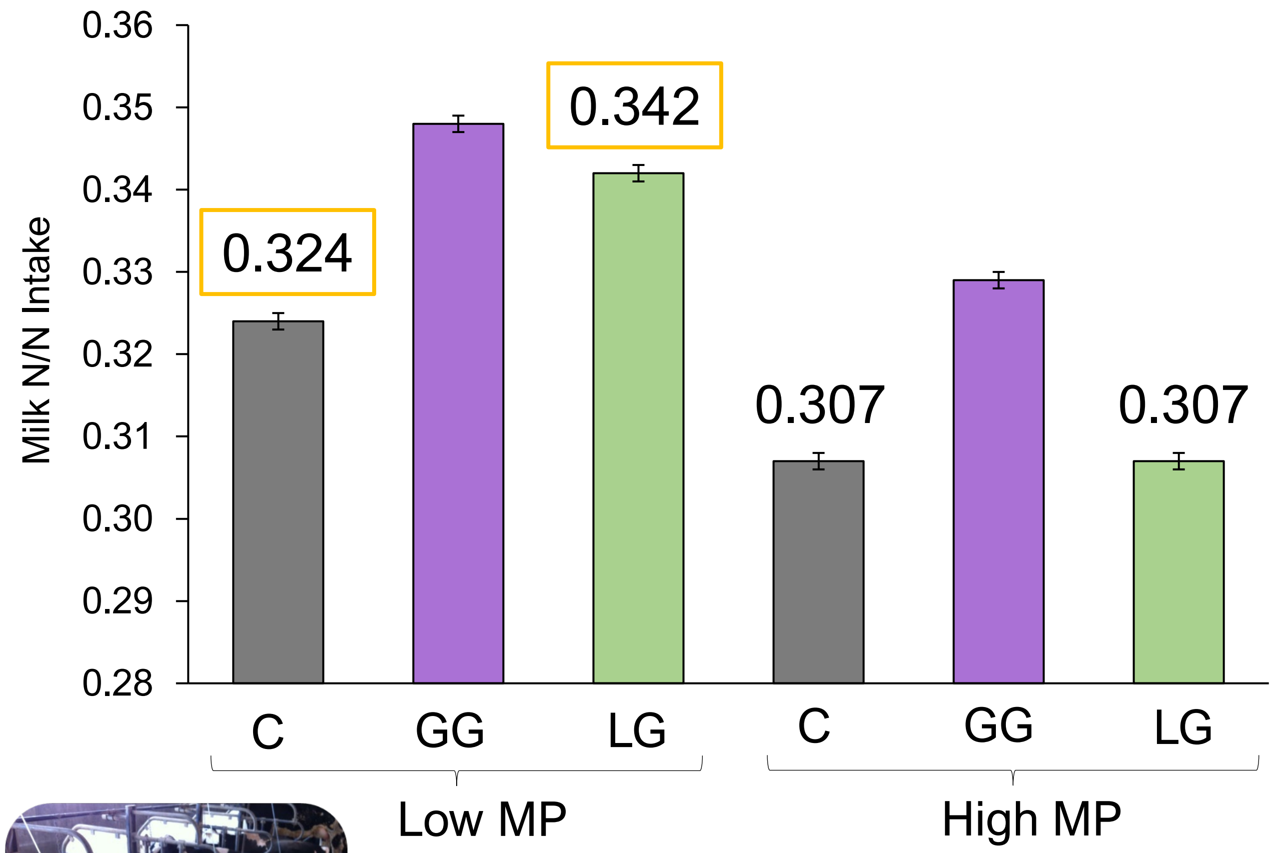
- ↑ milk N efficiency with glucogenic energy

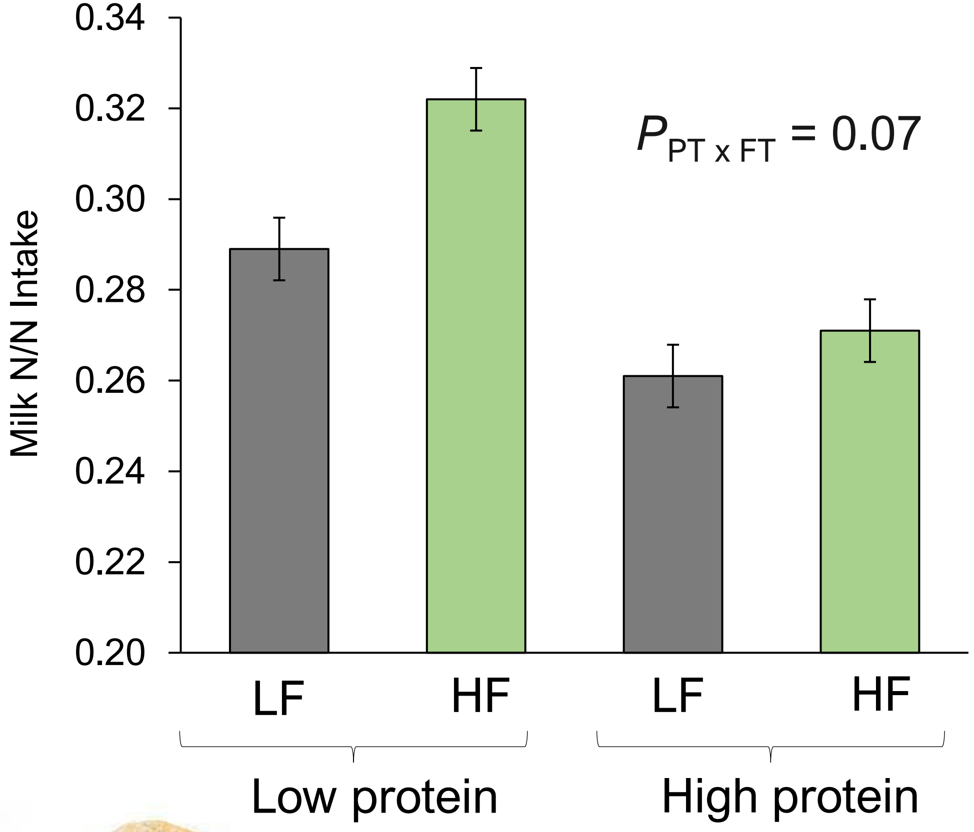


Nichols et al. 2018; J. Dairy Sci. 101:7857-7870
Nichols et al. 2019; J. Dairy Sci. 102:395-412

Energy source affects the transfer of dietary N into milk N

➢ Milk N efficiency tends to ↑ with fat supplementation at low protein levels





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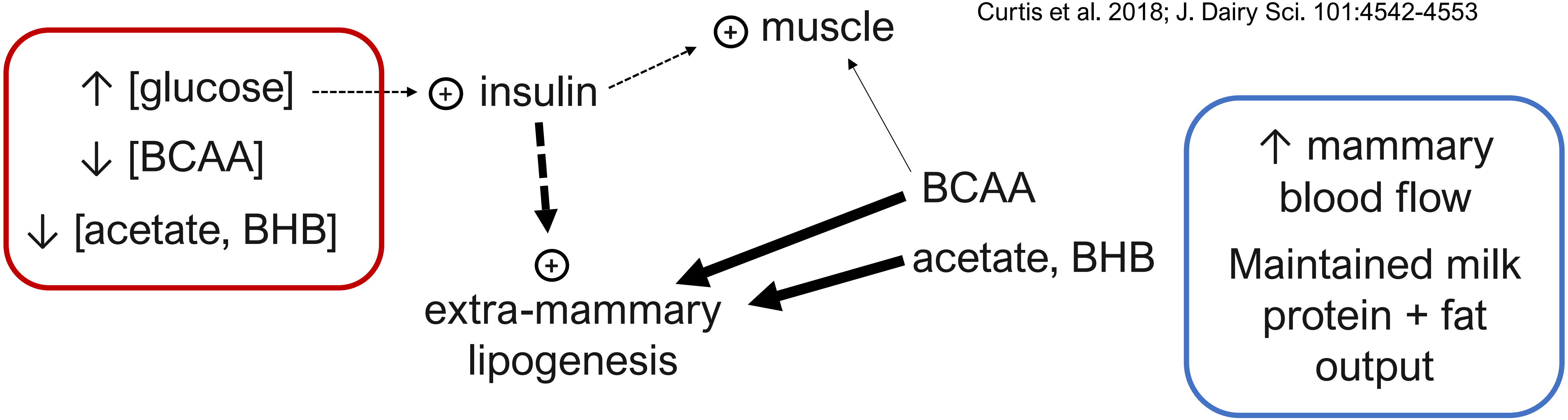
Energy type affects amino acid partitioning

- Glucogenic energy stimulates partitioning of branched-chain AA (BCAA) towards extra-mammary peripheral tissues

Lemosquet et al. 2009; J. Dairy Sci. 92:6068-6082
Nichols et al. 2016; J. Dairy Sci. 99:1145-1160
Curtis et al. 2018; J. Dairy Sci. 101:4542-4553



- Lipogenic energy (saturated LCFA) does not affect AA partitioning

Nichols et al. 2019; J. Dairy Sci. 102:1160-1175
Nichols et al. 2019; J. Dairy Sci. 102:7150-7167

Summary: Impact of energy source on protein efficiency

GLUCOGENIC

- Stimulates milk protein yield and ↑ N efficiency
- Stimulates insulin cascade → re-partitioning of BCAA and energy metabolites towards extra-mammary peripheral tissues (muscle and adipose) = ↑ mammary blood flow

LIPOGENIC

- Positive responses in milk N efficiency at low protein levels → more research needed
- No insulin response → no AA re-partitioning

➢ **Consideration for dietary ingredient inclusion, especially novel ingredients or byproducts** → does this offer more glucogenic or lipogenic energy, and what might the implication be on protein metabolism?

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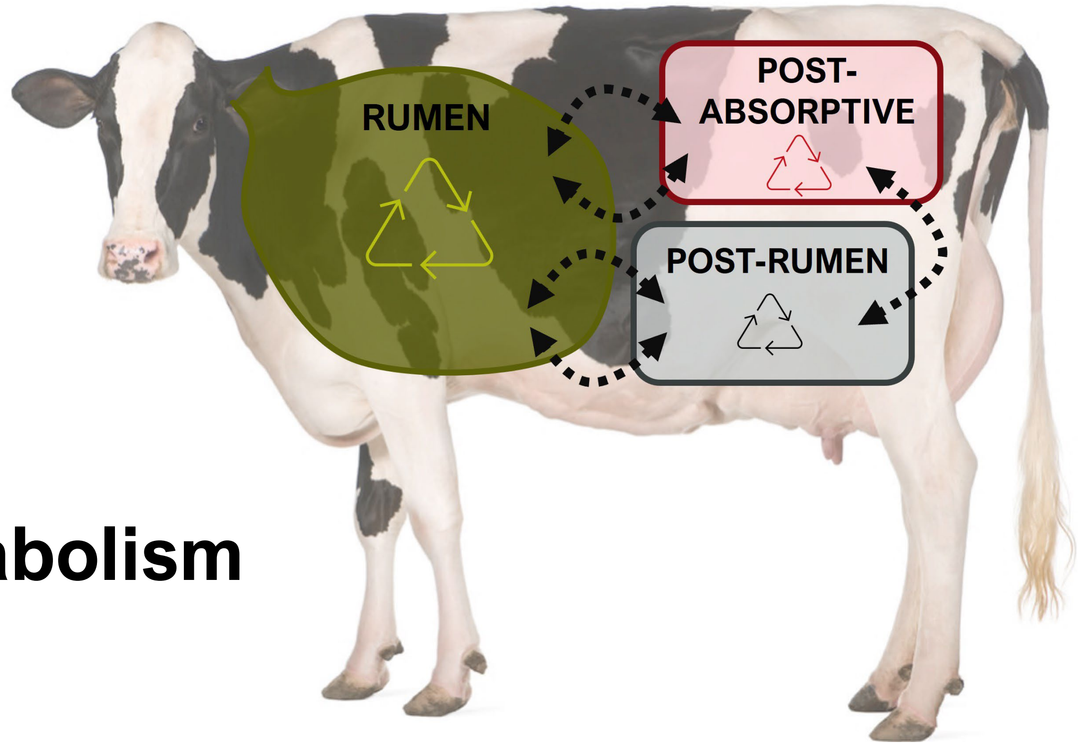
Exploring flexibilities in protein nutrition

1) Impact of energy source

2) Rumen protein balance

3) Mammary gland amino acid metabolism



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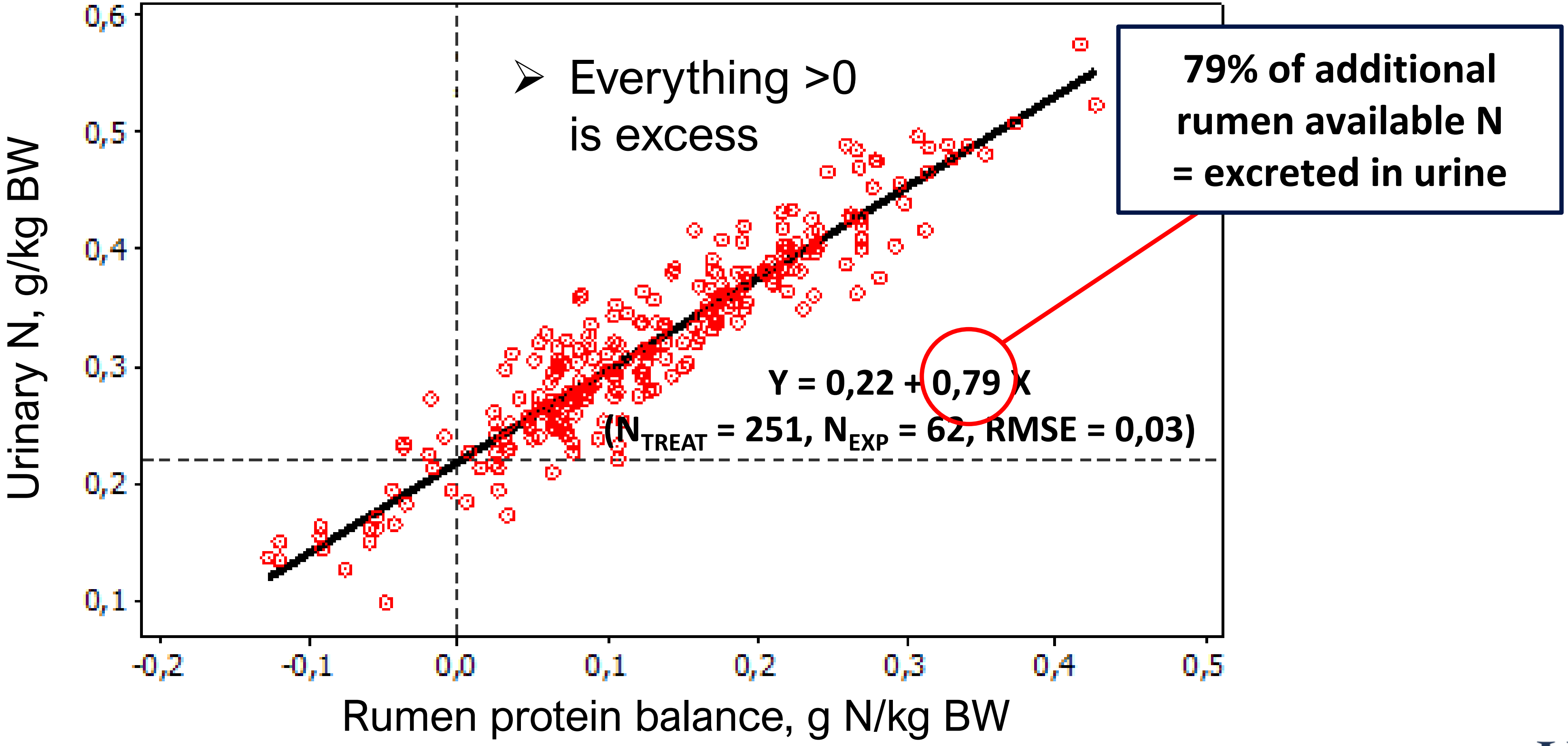
Refining rumen protein balance

- **Rumen protein balance**: difference between maximum possible microbial protein synthesis from rumen-available N and energy



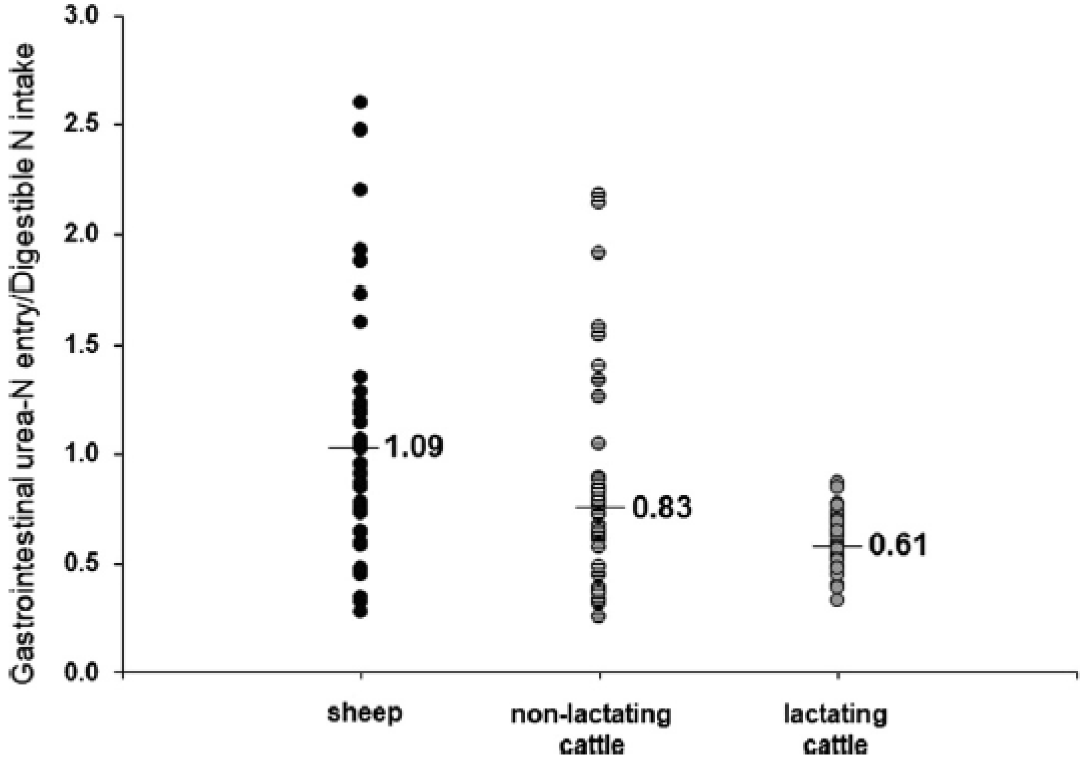
Sauvant et al. 2015; INRA Productions Animales: 347-368

Refining rumen protein balance

➢ Diet formulation parameters are dimensioned to achieve ruminal synchrony between protein and energy supply

- Assumes N metabolism, N recycling, and N utilization are constant
- Ignores contribution from endogenous N

➢ In practice, may lead to excessive safety margins for rumen N supply



Nichols et al. 2022; Animal. 16:100537

Refining rumen protein balance

	Base + Met	**Base + Met + Urea**	*P*-value
Rumen N requirement*	0.83	0.96	-
CP, g/kg DM	136	146	-

* Calculated based on bacterial growth depression % from CNCPS v7 → estimate based on ruminal nitrogen requirements given the number of bacteria that can be produced from the fermentable carbohydrate

- CNCPS v.7 → does account for endogenous urea-N recycling
- Both diets deficient in MP relative to estimated requirements

Higgs et al. 2023; J. Dairy Sci. 106:1826-1836

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Refining rumen protein balance

	Base + Met	**Base + Met + Urea**	*P*-value
Rumen N requirement*	0.83	0.96	-
CP, g/kg DM	136	146	-
DM intake, kg/d	24.1	24.7	$0.05 \leq P < 0.10$
ECM yield, kg/d	38.7	39.4	> 0.05
Milk true protein, g/kg	29.5	29.7	> 0.05
Milk true protein, kg/d	1.14	1.14	> 0.05

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Milk true protein, kg/d	1.14	1.14	> 0.05
Milk urea N, mg/dL	7.1	8.6	< 0.05
Milk N efficiency, %	35.4	32.3	-
Plasma urea N, mg/dL	5.7	8.5	< 0.05
Predicted urine N, g/d	130	170	< 0.05
NDF digestibility, %	40.1	42.4	> 0.05

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- **Balancing for estimated rumen N requirements by adding urea (likely) ↑ N excretion with no positive impact on ECM yield, milk protein content, or milk protein yield**
- **If trying to reduce N excretion, do we need to supplement extra RDP?**

Higgs et al. 2023; J. Dairy Sci. 106:1826-1836

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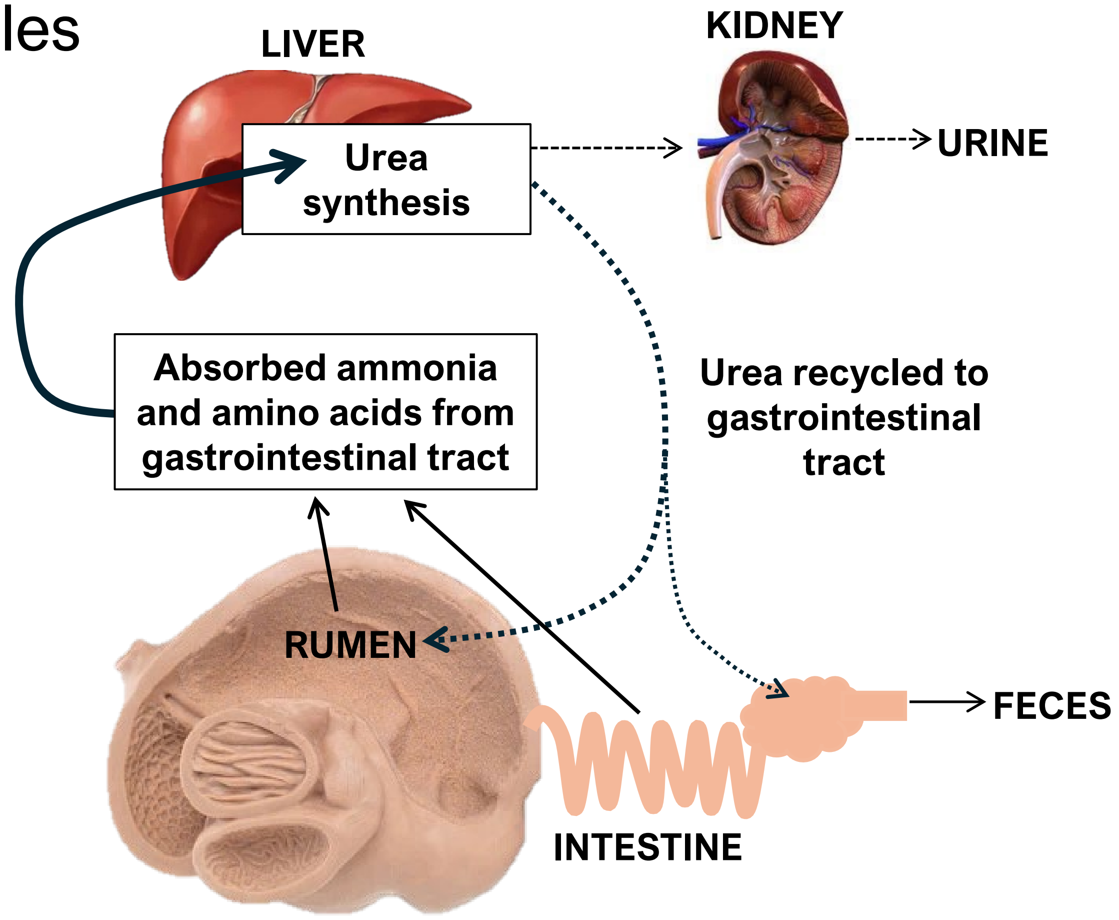
Can we rely on endogenous urea to compensate?

- Proportion of hepatic urea output that recycles to the GIT ↑ as dietary CP content ↓

  Mutsvangwa et al. 2016; J. Dairy Sci. 99:6298-6310
  Chibisa and Mutsvangwa, 2013; J. Dairy Sci. 96:6550-6563

- Source of protein supply between RUP and RDP and the balance between them matters more as dietary CP content ↓

- What are the underlying mechanisms that may be inhibiting greater return to the GI tract of endogenous urea?



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Summary: Reconsidering rumen protein balance

- Cattle can use endogenous N to support short-term periods of ruminal N insufficiency → may be able to ↓ safety margin on rumen-available N

- Lowering ruminal N supply is a route to reducing dietary CP content and N excretion
  - In practice, assess the need for excess rumen N supply (e.g., highly positive rumen protein balance) for a given diet

- Deeper understanding of urea recycling mechanism in lactating dairy cattle will enhance opportunities to rely on this mechanism to improve N efficiency

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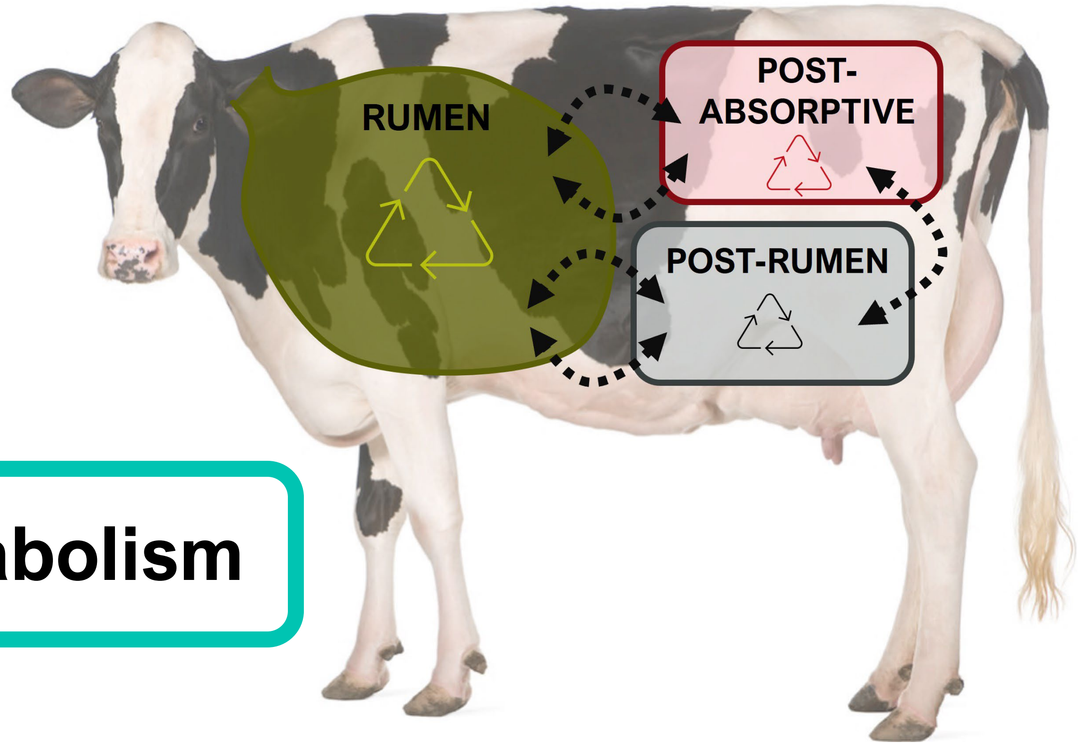

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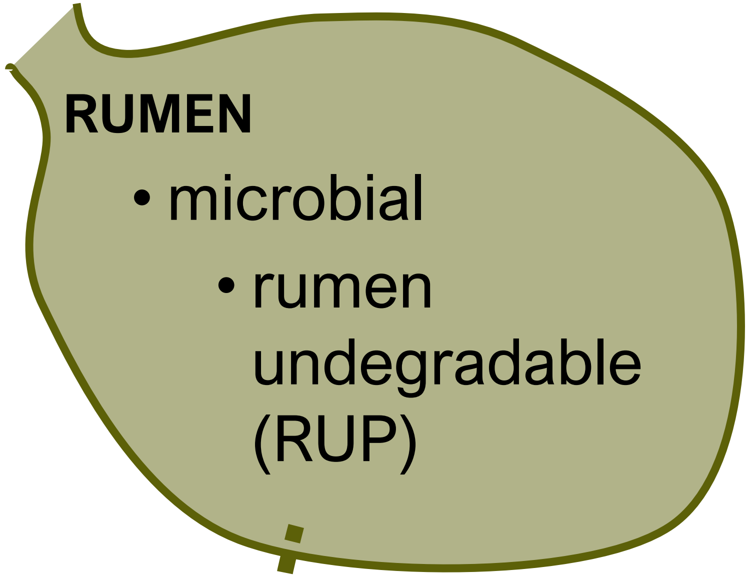
Digestible amino acid profile



- **Microbial CP** → assume a fixed AA profile
- **RUP** → this can be changed based on feed ingredients

➢ Optimizing N efficiency = aiming for RUP AA profile that complements microbial AA flow

➢ **But what is the complementary profile?**

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Absorbed amino acid profile affects marginal efficiency

Post-ruminal profile (infused or rumen-protected)	**AA dose** (g/d)	**Marginal efficiency**	Reference
Complete essential AA (EAA)	359	0.31	Doepel and Lapierre, 2010 J. Dairy Sci. 93:3264-3274
Complete non-EAA (NEAA)	356	0.03	
EAA+NEAA	715	0.25	

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Complete EAA	562	0.35	Nichols et al., 2019 J. Dairy Sci. 102:8963-8976
Group 1 AA+Ile+Leu+Val	562	0.28	
Group 1 AA+Arg+Lys+Thr	562	0.18	
Ile+Leu+Val	562	0.12	

*Group 1 = His, Met, Phe, Trp

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His+Met+Lys	101	0.67	Nichols et al., 2024 J. Dairy Sci. 107:6797-6816
soybean meal + rapeseed meal (EAA+NEAA)	101	0.17	

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Absorbed amino acid profile affects marginal efficiency

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Complete essential AA (EAA)	359	0.31	Doepel and Lapierre, 2010 ...4
Comp...			
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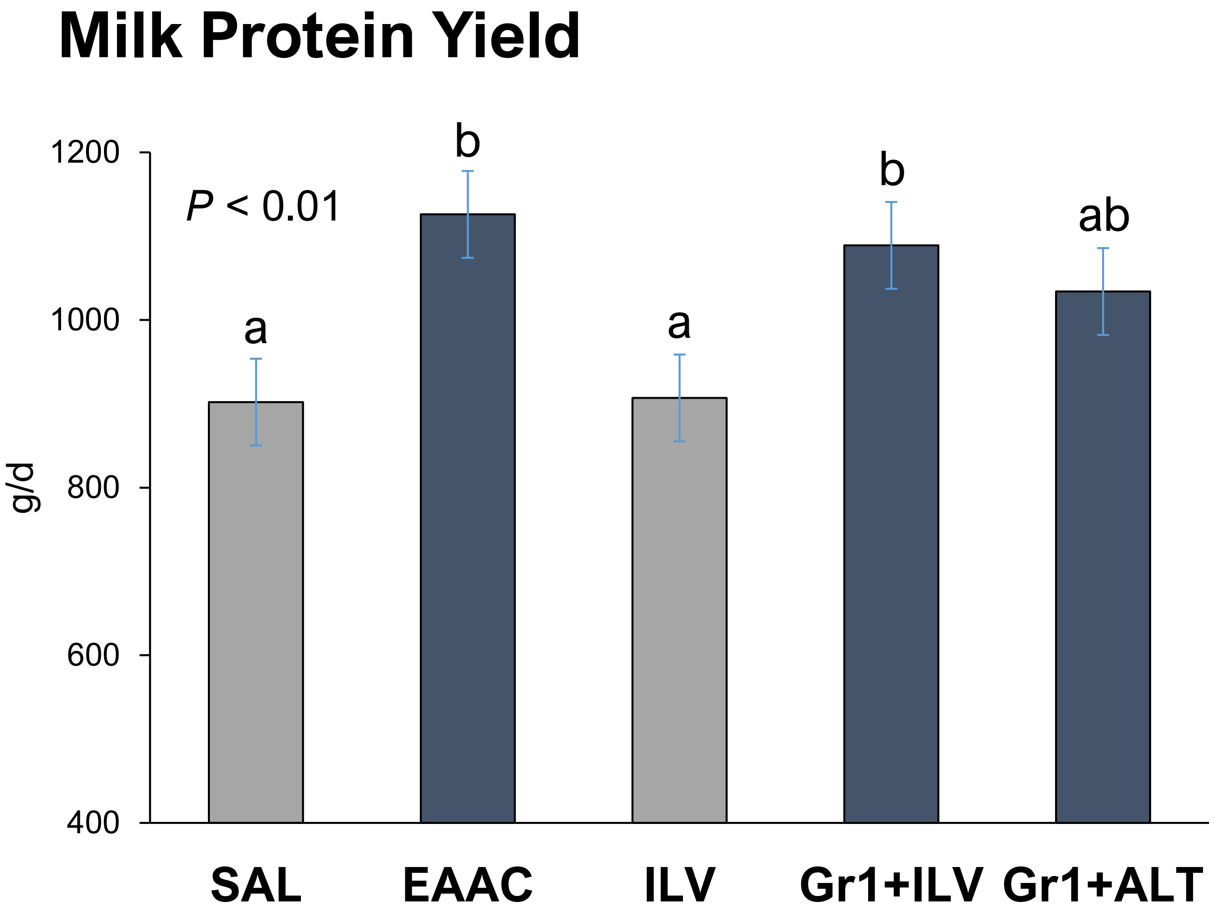
- **Marginal efficiency ↑ as digestible AA profile more closely resembles casein**
- **Greater efficiency if EAA supply is prioritized within this profile**

Flexibility in mammary gland amino acid metabolism



Nichols et al. 2019; J. Dairy Sci. 102:8963-8976

Group 1 His, Met, Phe, Trp

ILV Ile, Leu, Val

ALT Arg, Lys, Thr

↑ milk protein yield with incomplete EAA profiles when group 1 AA are present

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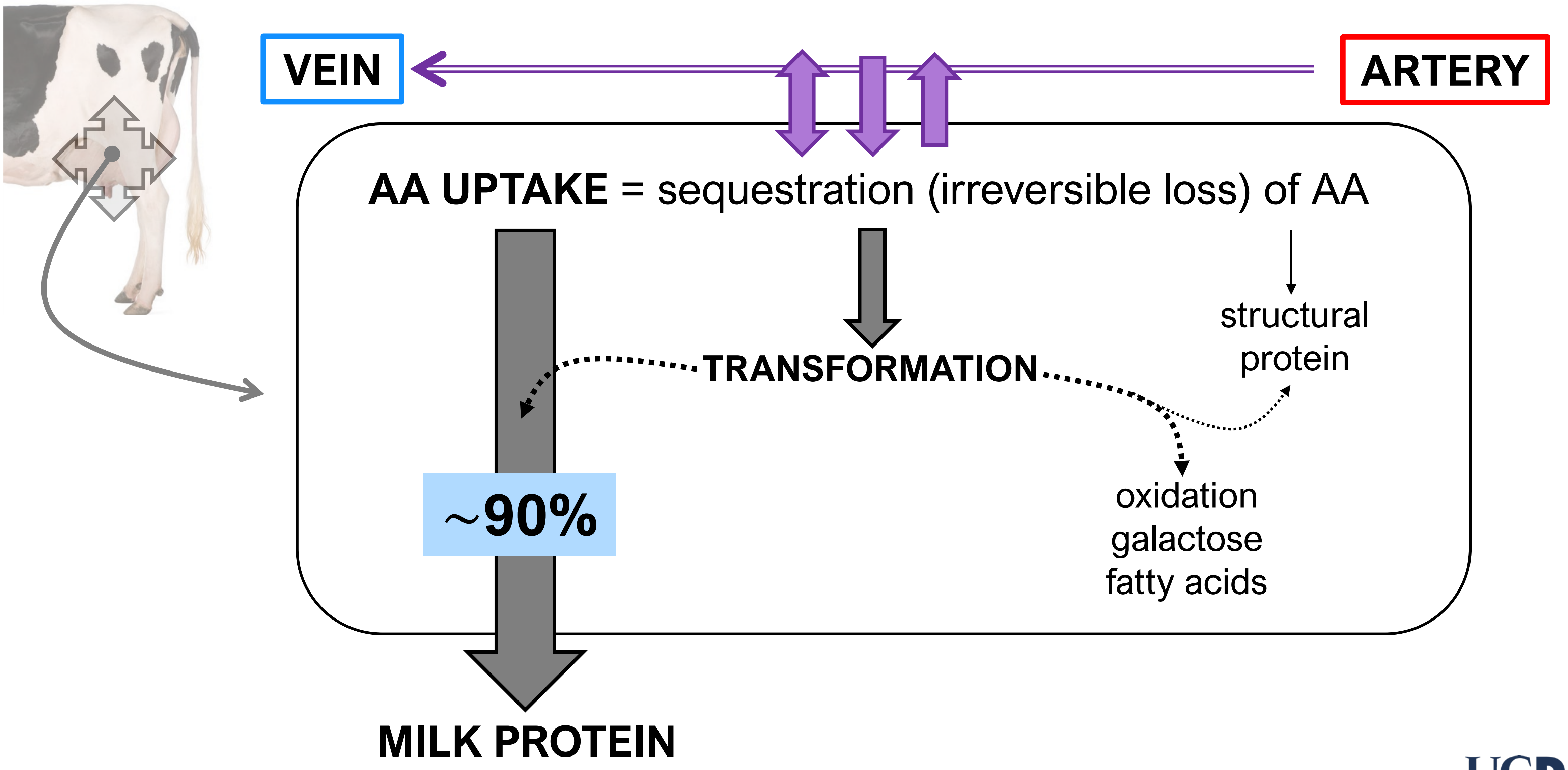
Flexibility in mammary gland amino acid metabolism



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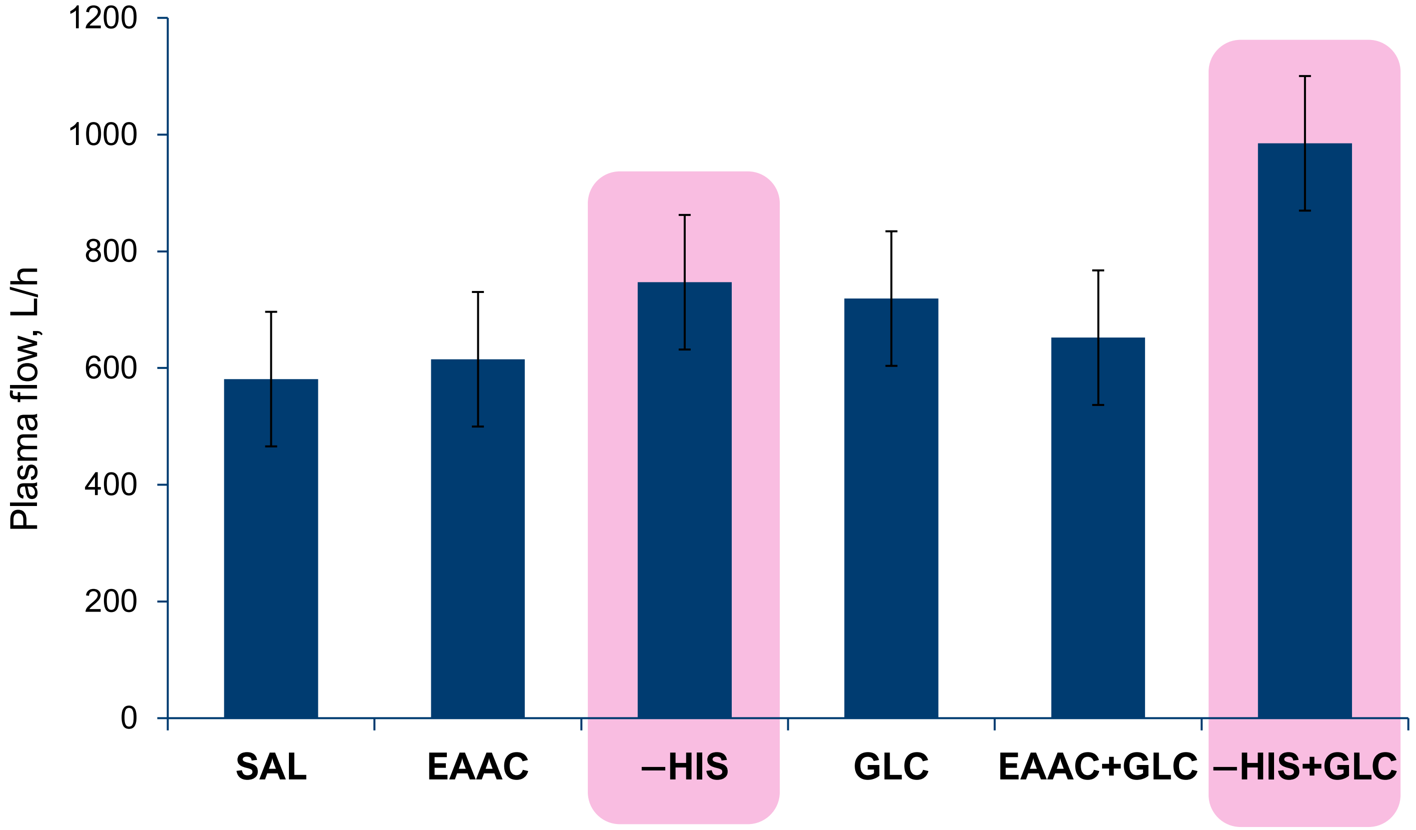
Mammary gland adaptation to essential AA profiles

- **Blood flow →** altered by changes in vasodilatory systems and intramammary metabolite and energy balance
  - AA deficiency and imbalance ↑ mammary blood flow



- His deletion ↑ mammary plasma flow

$P_{-HIS} = 0.05$

Doelman et al., in preparation

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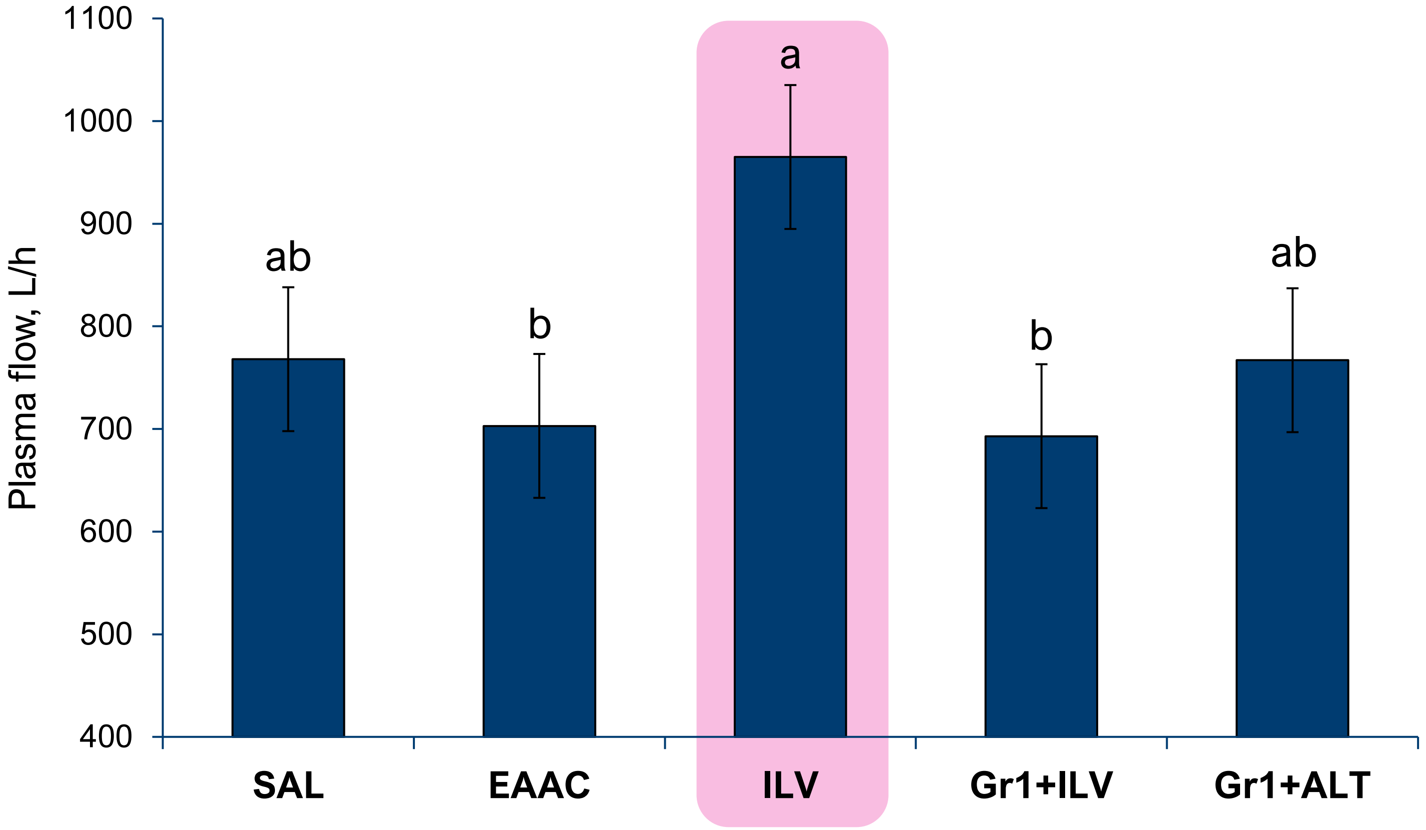

- ↑ plasma flow with greater imbalance in EAA profile

P = 0.04

Nichols et al. 2022; J. Dairy Sci. 105:7354-7372

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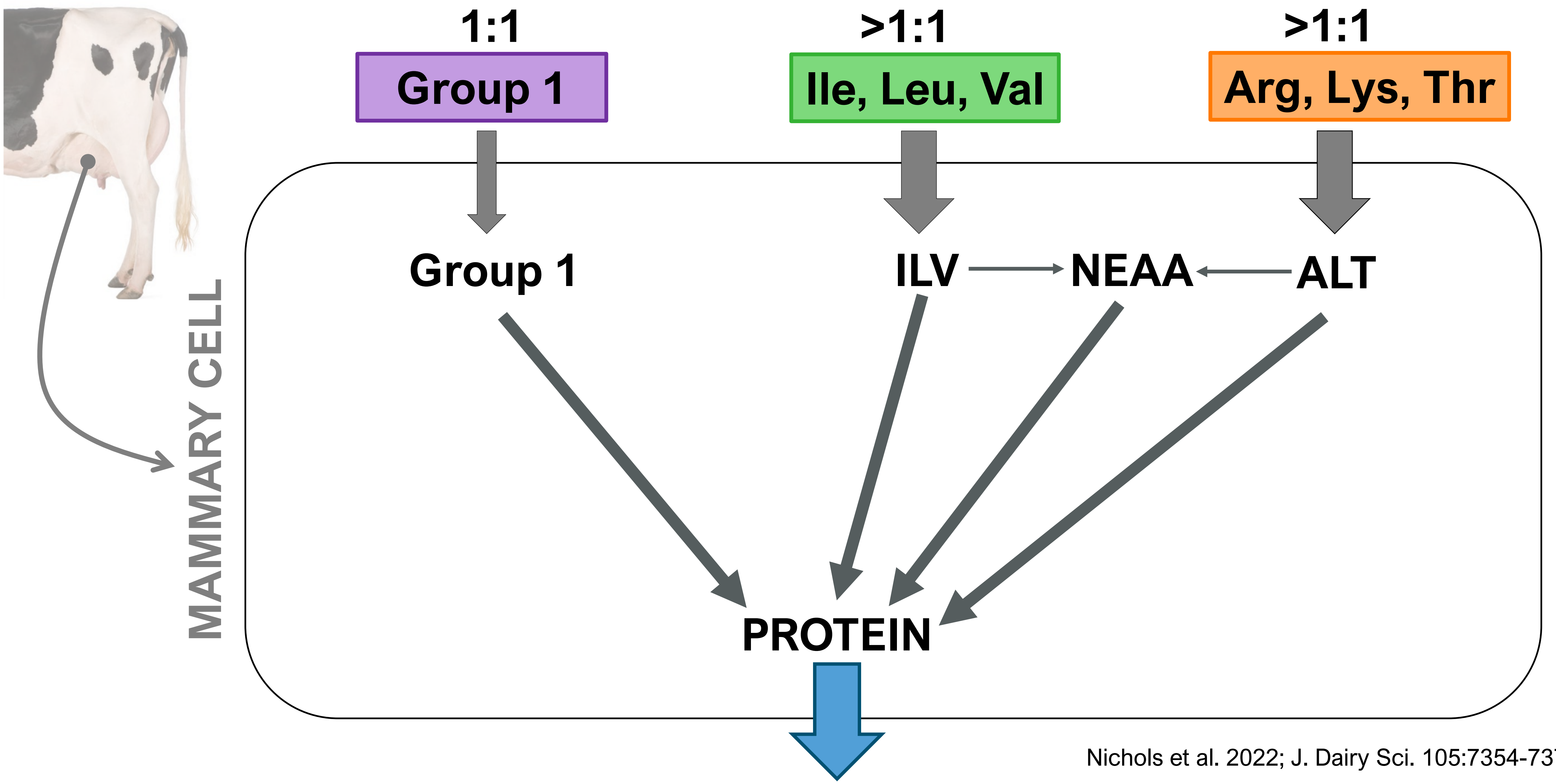
Intramammary flexibility



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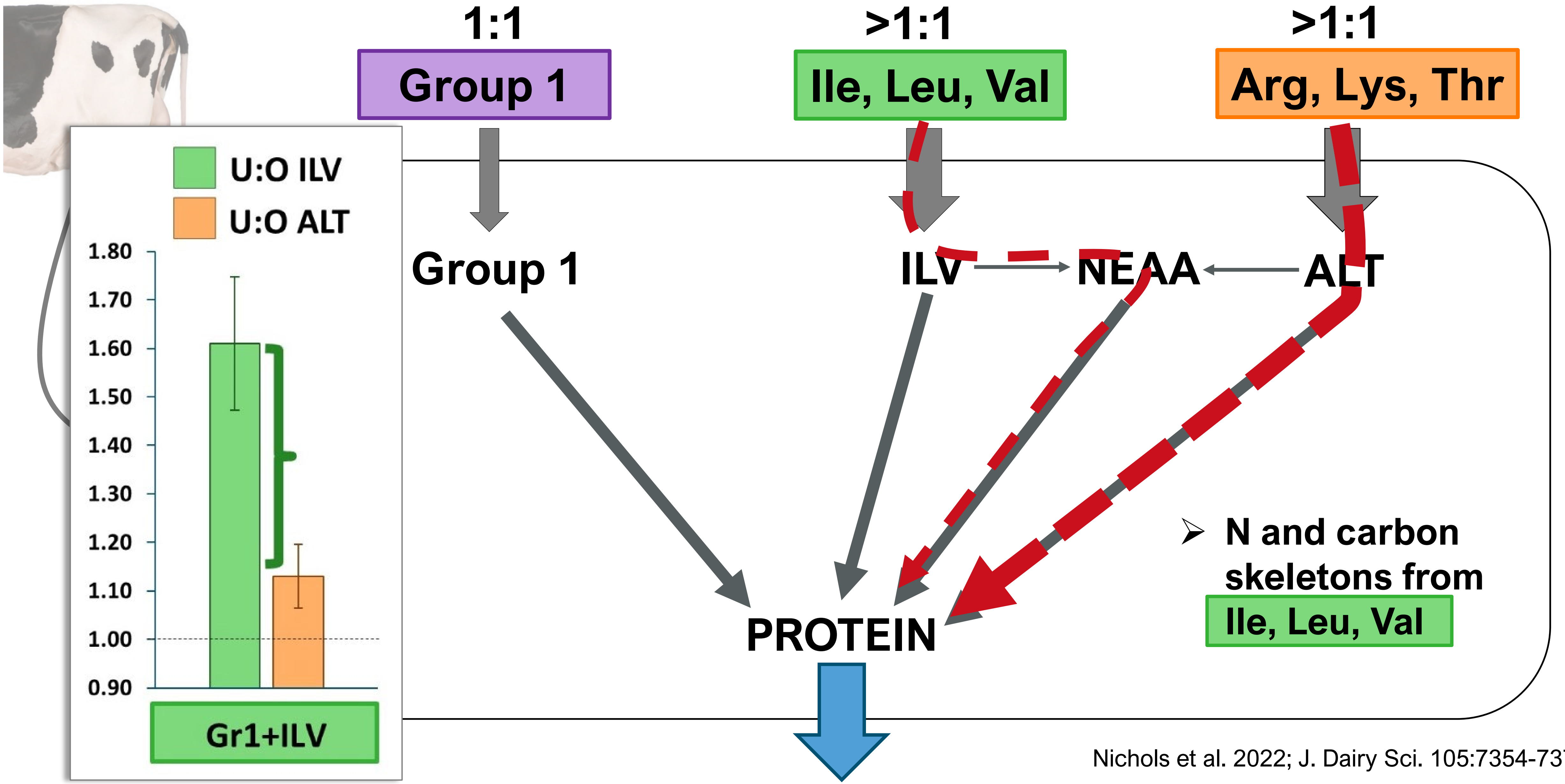

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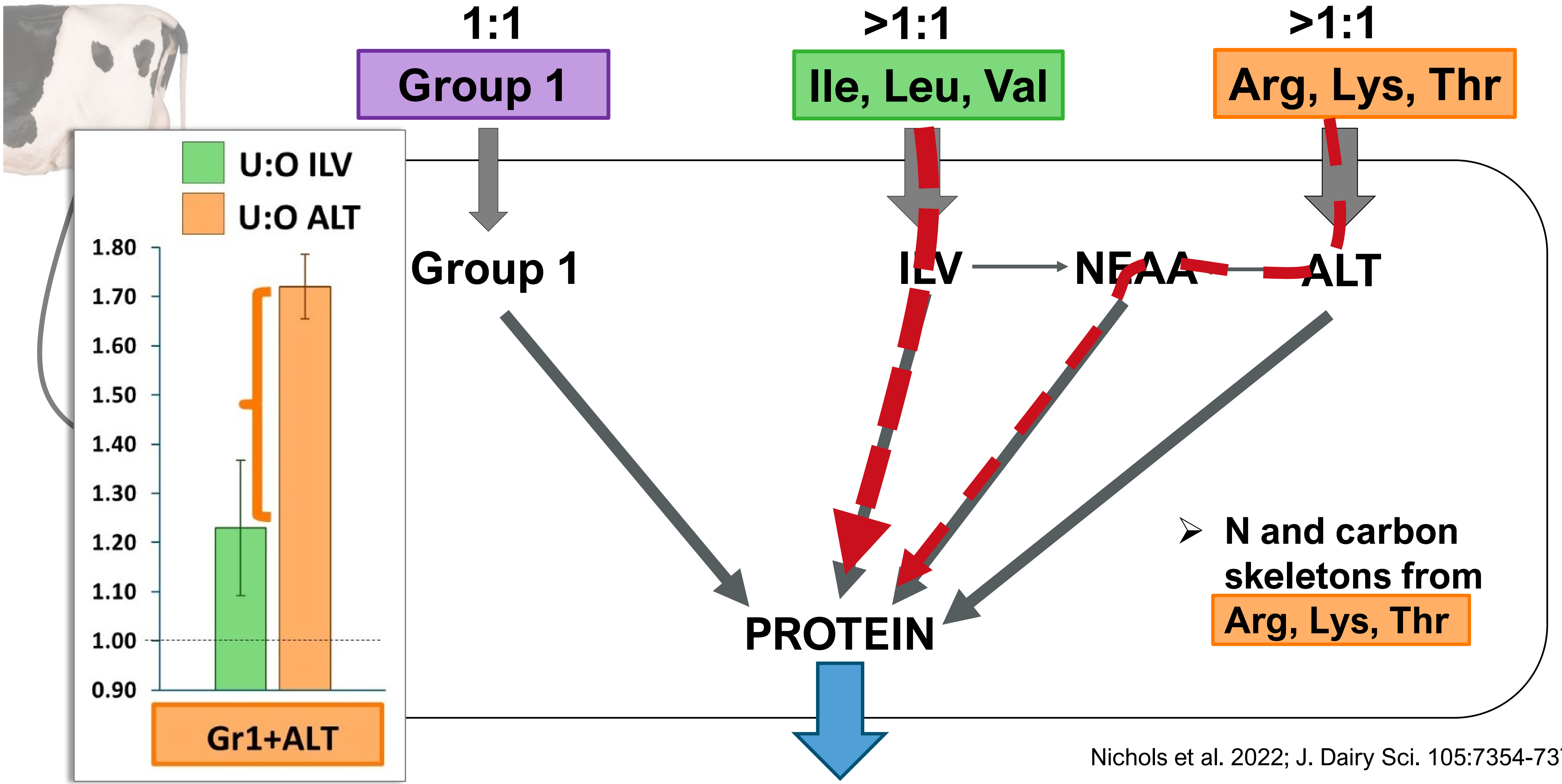

➢ N and carbon skeletons from Arg, Lys, Thr

Nichols et al. 2022; J. Dairy Sci. 105:7354-7372

Summary: Mammary amino acid metabolism

- The profile of digestible AA will impact the efficiency of use of dietary protein sources
  - Look for ingredient profiles that enrich digestible protein with EAA that more closely match the AA profile of casein
- Intramammary compensation for N and carbon between non-group 1 EAA → supports milk protein synthesis when absorbed EAA profile is incomplete
  - What is the scope of this flexibility?
- Consider the profile of EAA groups, not necessarily individuals, when supplementing rumen-undegradable protein in dairy cattle rations

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Harnessing flexibility: Take-home messages

- Energy source matters with respect to improving protein efficiency
  - Glucogenic and lipogenic energy elicit different effects on postabsorptive AA metabolism but both can improve N efficiency
- Minimize rumen degradable protein balance
  - Can achieve moderate increases in milk protein efficiency, and substantial decreases in urinary N excretion
  - To a degree, recycling of endogenous urea can compensate for periods of low rumen N supply → utility is overlooked, and the dynamics are not well understood
- The mammary gland is flexible in its use of AA
  - Digestible profile of AA groups should become a focus alongside balancing for individual AA

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